Radiology in Global Health

Strategies, Implementation, and Applications

Daniel J. Mollura
Melissa P. Culp
Matthew P. Lungren
Editors

Second Edition

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Dedicated to the loving memory of my mother, Gina Mollura, and my daughter, Nicole. To my wife, Laura, and our children, Anna and Daniela, whose love brings inspiration and hope. To all the RAD-AID members, supporters, and volunteers who teach me the example of self-sacrifice and vision for a better world.

–Daniel J. Mollura

With love to Edmund, Ian, and Nathaniel;
With gratitude to my family, friends, and colleagues.

–Melissa P. Culp

"Hope is the thing with feathers" by Emily Dickenson
"Hope" is the thing with feathers
That perches in the soul
And sings the tune without the words
And never stops at all
And sweetest in the Gale is heard
And sore must be the storm
That could abash the little Bird
That kept so many warm
I've heard it in the chillest land
And on the strangest Sea
Yet never in Extremity,
It asked a crumb of me.

–Matthew P. Lungren

Foreword

I am honored to write the Foreword to the second edition of *Radiology in Global Health: Strategies, Implementation, and Applications*. As amazing as it sounds, so much has occurred in both medical imaging and in the state of the world's health during the 4 years since the book's original publication that a new edition is warranted. Most importantly, co-editor Dan Mollura's vision in founding RAD-AID has grown at a remarkable pace. RAD-AID and its partner institutions now provide previously unavailable medical imaging services to 53 sites in 27 countries. As a result, an estimated 40 million people residing in medically underdeveloped regions around the globe have new access to the same life-saving diagnostic imaging and image-guided treatment technologies that over the past four decades have revolutionized medical care in more prosperous countries. As a result of RAD-AID's efforts, people residing in these regions enjoy safer, more effective care than previously.

The covers of this book house the fruits of these labors. *Radiology in Global Health* is a comprehensive "how-to" as well as a guide to imaging diagnosis. What RAD-AID has accomplished and its promise of future work are a precious gift not only to the people that directly benefit from RAD-AID's work but to all of us. The world grows ever smaller. Jet travel and 24-h news cycles link all of us, one to another. An outbreak of infectious disease in one locale bears with it a greater risk of dissemination to our corner of the globe than ever before. War, famine, and rapidly morphing vectors of disease threaten to spread annihilation to populations that previously thought themselves immune.

Better access to modern medical imaging, in and of itself, does not proffer protection. Imaging technology alone cannot surmount these deadly problems. The third world scourges of drug-resistant tuberculosis, malaria, AIDS, and unpredictable infectious epidemics continue to claim hundreds of millions of lives annually and will continue to do so until every human on the planet enjoys better sanitation, reliable access to clean water, and improvements in nutrition, and education. However, RAD-AID's enabling the application of cross-sectional imaging technologies like ultrasound, CT, and magnetic resonance imaging will lead to earlier disease detection, improved diagnosis and treatment, and reduced suffering and death.

This book is a look backward, a reflection of what RAD-AID has already achieved and guidance for the future. RAD-AID has accomplished much, often working on a metaphorical shoestring. There is a great deal more to do.

An estimated three to four billion people still have no access to modern medical imaging. Many of these people live so remotely or are dispersed over such wide geographic areas that conventional fixed imaging facilities would be ineffective. Working with corporate partners, RAD-AID is beginning to address these populations with novel movable approaches that may soon further progress toward the overriding goal of providing access to the benefits of diagnostic imaging and image-guided therapy to every person, regardless of where they reside.

To the editors and authors of this book go my heartiest congratulations. The publication of this second edition of *Radiology in Global Health* is a sentinel event. May its contents help power the light of modern medical imaging to shine on those corners of the world that still remain in darkness.

January, 2018

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Preface

Welcome to this second edition of *Radiology in Global Health*. We are pleased that the success and impact of our first edition in 2014 warranted this updated text for discussing the role of radiology in international health and underserved regions.

As over half the world has little or no access to medical imaging and radiology, this text focuses on the questions of *why this disparity is important and what we can do to address it*. To begin that discussion, it is first essential to envision what the absence of radiology at the global level really means at the local and individual human level:

A little boy is carried into an emergency room in urban Africa after suffering serious injuries in a car accident. Physicians see a likely leg fracture on physical exam, but an x-ray machine is not available to image the leg and determine whether surgery is needed. A pregnant woman in rural South America is in labor that fails to progress after 24 h and there is unexplained bleeding, but there is no ultrasound available to diagnose the problem. A refugee camp in the Middle East shows signs of a spreading respiratory illness defined by increasing cough and fever, but no chest radiography is available to diagnose possible pneumonia or tuberculosis. A woman in India is losing weight and has a lump in her left breast, but she does not have access to mammography or ultrasound in her community for further evaluation.

These are just a few examples of the worldwide need for medical imaging, and the failures in medical care that result from radiology's scarcity. These vignettes also highlight radiology as a fundamental infrastructure component in health care systems containing interdependent and interlocking parts, including (i) screening, (ii) diagnosis, (iii) treatment, and (iv) long-term disease management, all of which have interfaces with radiology. The central implication is that radiology's absence interrupts patient-referral networks and treatment pipelines, such that individual patients are unable to access definitive care.

Radiologic services common to the industrialized economies of the world are scarce in the impoverished and low-resource regions of the world. Among the wealthier health care systems, medical imaging plays a vital role in patient care. When a patient sees a physician or health care provider in a high-resource health care system, it is widely acknowledged by both patient and provider that imaging plays a significant role in the diagnostic work-up: women routinely undergo breast cancer screening via mammography; patients with heart disease receive angiography and CT; trauma patients are evaluated by CT and radiography; the patient's response to cancer therapy is monitored by CT, MRI, and PET; expecting mothers are monitored by fetal ultrasound; and the list goes on and on. In underserved areas, particularly in low and middle-income countries (LMICs), these medical imaging services may be absent or inaccessible due to remote location, wait-time, personnel-shortages, equipment failure or inoperability, thereby leaving patients with few or no options for diagnosis and care.

In addition to the patient-care clinical impact of radiology scarcity across the world, the radiology divide has technological and economic development impacts, interwoven as a strong theme throughout this text, because radiology has consistently been the entrance gateway for advanced health technology adoption at the facility and regional levels. Hospitals that adopted digital imaging in radiology in well-resourced contexts over the last decade also rapidly adopted other health information technologies, such as electronic medical records (EMR), radiology information systems (RIS), picture archiving and communications systems (PACS), health information systems (HIS). Since imaging is now digital in the high-income countries, radiology is at the forefront of hospitals advancing these other data management systems that are now also driving the arrival of artificial intelligence in automated data processing, simulated human learning, and cognitive computing in medicine. However, the radiology divide between wealthier and low-resource regions, therefore, reinforces an information technology chasm that ripples not just within the radiology departments, but to the entire health care systems of low and middle-income countries unable to join this advancing edge of imaging informatics and information technologies.

Who is the intended audience of this book? This is an important question because solution development requires dialogue with the correct audience and professional participants. This book is intended for a broad audience of health care providers (such as physicians, nurses, technologists, and sonographers), hardware/software engineers, policy-makers, business leaders, researchers, and public health specialists, at all levels who utilize or implement health care services for underserved populations. This encompasses the medical imaging community, including radiologists, radiology residents, radiology technologists, and radiology nurses. Moreover, as health care providers utilize radiology in the process of clinical decision-making, this text is also designed for clinical physicians, nurses, nurse-practitioners, physician assistants, and paramedical personnel who recognize and utilize the strong role of imaging in patient care. Administrators and public health personnel are important constituencies in this dialogue and text, as the planning of radiology services for health care systems at both the facility level and at the population level requires a clear understanding of the technological challenges and management opportunities.

Perhaps you are a medical volunteer aiming to use, implement, or improve a clinical service using radiology. Perhaps you are a humanitarian aid specialist trying to implement, manage, or evaluate an existing screening service in a refugee camp or other low-resource facility. Perhaps you are a radiology resident, trainee, or a resident in any related field of medicine, pediatrics, surgery, and Ob-Gyn, needing adequate background for international health rotations and global health training. Perhaps you are a radiology technologist, radiation therapist, medical physicist, or sonographer, aiming to teach the best-practice imaging techniques, protocols, and procedures for low-resource hospitals trying to take better care of patients. All of these perspectives are encompassed in this text to bridge the vital components of medical imaging and radiologic work for patient care in underserved regions.

With such a broad audience in mind, this text has an interdisciplinary format based on RAD-AID's 10 years of work (2008–2018) serving indigent communities around the world, mixing approaches and perspectives to analyze solutions for radiology in global health efforts. Such an interdisciplinary approach entails the synthesis of business management, government policy formulation, clinical methods, and engineering, in order to integrate economic development, technology innovation, clinical model planning, educational strategies, and public health.

This multidisciplinary approach is also intended in this text to address a diverse set of global health contexts including acute emergency care, communicable (infectious) outbreaks, disaster response, chronic health services, community screening, and long-term care of cancer and cardiovascular diseases. As radiology is a strong component of all these contexts, this text delivers a multidisciplinary perspective for radiology's role across this wide range of settings and applications. Since the expertise required to assess, plan, implement, and monitor these radiology programs is also multifactorial, this text aims to comprehensively cover this planning process from diverse vantage points.

We welcome you to the exciting adventure of radiology in global health covered in the chapters that follow. It is our hope that this text will give you new tools, ideas, and strategies for bringing vital radiology to low-resource areas and underserved populations. This text hopefully can empower you to think of tomorrow's solutions in radiology serving the world.

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Part I

Global Health Radiology Strategies and Implementation

Introduction

1

Daniel J. Mollura, Melissa P. Culp, and Matthew P. Lungren

This textbook is designed to give you the tools for how to assess, plan, implement, and support medical imaging and radiology services in low-resource settings for underserved populations. The ultimate objective of these efforts is to reduce global healthcare disparities particularly where radiology is scarce, absent, or inaccessible.

The premise for this work is based on long-standing estimates from the World Health Organization (WHO) that approximately half to two-thirds of the world's population has non-existent, sparse, or inadequate radiology [1–3]. This profound disparity motivates this text in addressing the diversity of the world's health-care systems, the multifactorial contributors to radiology scarcity, and the complexity of radiologic services via a thorough approach that can be methodically adapted to diverse conditions at the facility, regional, and national levels.

It is important to begin by first introducing the concept of *global health*. Occasionally, this term's meaning is vague among different sources due to definitional overlaps with the terms *public health*, *international health*, and *tropical medicine*, which all have some aspects in common with *global health*. As the aim of this textbook is to give you tools for optimizing radiology in global health, an upfront definition is warranted. *The Lancet* published the following definition of *global health*:

> Global health is an area for study, research and practice that places a priority on improving health and achieving equity in health for all people worldwide. Global health emphasizes transnational health issues, determinants, and solutions; involves many disciplines within and beyond the health sciences and promotes interdisciplinary collaboration; and is a synthesis of population-based prevention with individual level care [4].

To introduce this textbook and frame the chapters that follow, we adapt this definition to include radiology, based on a definition of *global health radiology* that we published in the *Journal of the American College of Radiology* (JACR) in 2014 [5]:

- Study, research, and practice of radiology, radiological sciences, and medical imaging for improving health and achieving worldwide health equity
- Application of radiology to transnational health issues for identifying determinants and solutions

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- Multidisciplinary collaboration promoted across radiologic and nonradiologic medical specialities as well as outside the health sciences (such as economics, technology, engineering, business management, and social science disciplines)
- Synthesis of population-based preventions with individual-level clinical radiologic services

Therefore, there are several key concepts that differentiate this text from other clinical radiology textbooks. First is the emphasis on using radiology outreach to improve world *health equity*, so that health outcomes across populations can converge by attempting to equalize radiology access. For example, the 5-year survival rate for breast cancer among women in the United States is approximately 89%, while the 5-year survival rate of breast cancer patients in South Africa is 53% [6]. Although the causes of this mortality difference are multifactorial and are addressed later in detail in this book, differential levels of mammography screening and early detection are considered to be strong contributors to these breast cancer outcomes [3, 7–10]. Consequently, this textbook examines the questions of how disparate access to radiology impacts such health outcomes and how the optimization of radiology can help converge health outcomes for health equity across regions and populations.

Second, integral to the definition of *global health radiology*, this text emphasizes the *transnational character* of radiology outreach, which implies that the challenge of radiology healthcare disparity transcends national boundaries. This transnational element refers to the global burden of disease that afflicts far-ranging populations in similar ways, thereby requiring similar approaches for prevention, containment, and treatment. These diseases may include the communicable pathogens such as influenza, tuberculosis, and human immunodeficiency virus (HIV), which interface regularly with radiological services for diagnosis, treatment, and long-term surveillance. The global disease burden also includes the noncommunicable conditions, among which cancer and heart disease are leading killers of men and women in high-, middle-, and low-income countries. For example, WHO's International Agency for Research on Cancer (IARC) projects cancer incidence to double in Africa by 2030, and the Union for International Cancer Control (UICC) has advocated for more international cooperation on data sharing and healthcare capacity-building to stem the rise of cancer among countries that currently have under-resourced oncology sectors [11]. As cancer and cardiovascular diseases entail medical and surgical services that are highly radiology-dependent for diagnosis, staging, treatment, and monitoring response to therapy, this disease burden shared across nations and regions necessitates a radiology strategy that operates internationally.

Another element of radiology's transnational scope is the global market for imaging technologies and equipment through international trade and finance. The large scale of radiology equipment-makers across mature and emerging markets raises opportunities for these products and services to reach the underserved. This may entail synchronization of regulatory structures across countries for the safe management of medical and radiological equipment. As radiology has predominantly become digital in high-income countries, the archiving of radiology data in cloud architectures for low- and middle-income countries (LMICs) raises international questions about patient privacy and data transit across borders. Some nations prohibit the storage of health data in cloud archives when the data is considered to be exported outside national boundaries, and many of the cloud storage service providers are multinational corporations. Some countries have already migrated health data to cloud architectures with web-based interfaces for medical data retrieval. Moreover, telemedicine and teleradiology may be moving the imaging data across national borders for image interpretation and clinical reporting. Therefore, radiology's role in global health means interfacing with these transnational elements in the technological, public health, policy, and international market spaces.

From the perspective of the global health radiology practitioner, this transnational element entails overcoming the biases and practice patterns of one's own healthcare system to communicate with and enter into the other contexts that may have very different practice patterns, clinical outcomes, cultural frameworks, resource constraints, and medical workflows. Assumptions about medical training, roles of personnel, hospital organization, and government regulations have to be reassessed in the global context for sharing ideas, transferring knowledge, and adapting radiology to local parameters. Data sharing, teaching, and knowledge exchange in the global context become paramount as a means of communicating best-practice methods to new adopters of radiologic methods. Medical and radiologic data sharing may also be an important strategy for combatting international health crises, such as epidemics and natural disasters. For these reasons, this textbook emphasizes the role of communications, cultural competence, ethics, stakeholder relations, and educational strategies for empowering you in the field of radiology global health.

Third, an essential component of radiology in defining global health is the *multidisciplinary character* of study, research, and practice in this field. Multidisciplinary assessment and planning constitute strong themes throughout this textbook as the chapter authors and content draw from fields of engineering, medical physics, economics, communications, clinical medicine (across medical, radiological, and surgical specialities), nursing, public health, and business management. The interprofessional and multidisciplinary nature of global health radiology is derived significantly in this text from the models and methods of RAD-AID International, a nonprofit organization managing diverse outreach teams of medical professionals and volunteers having diversified expertise in efforts to help radiology development in low-resource and underserved settings. Ideally, an international outreach team can be a microcosm of a radiology department by including the vast sets of personnel skills among team members to deliver integrated radiology solutions and healthcare capacity expansion. The World Health Organization emphasizes *Interprofessional Education and Collaborative* Practice models, which apply to global health radiology and are discussed in Chap. 11.

In addition to teambuilding for combining multidisciplinary skillsets, RAD-AID's Radiology-Readiness Assessment tool is fundamentally premised on the priority of multidisciplinary data collection as the first step in outreach program planning. Covered in more detail later in this textbook, the RAD-AID Radiology-Readiness Assessment is a due-diligence data collection tool for analyzing radiology in low-resource settings and then proposing specific solutions to optimize imaging for concrete patient-centered goals based on available coexisting resources. This tool is named "Radiology-Readiness" because it raises the questions of whether and how a low-resource institution is ready for radiology. Is it effective to donate a mammography unit to a location that cannot care for breast cancer patients? Is it sensible to donate a computed tomography (CT) unit if a facility does not have a stable electrical grid? Can a picture archiving and communication system (PACS) be effectively implemented given a facility's current data management systems, computers, and networks? Are referral systems sufficiently developed to run patient screenings or implement imaging for trauma and infections? Some components of the Radiology-Readiness Assessment entail the following types of information:

1. Infrastructure of the community, such as roads and telecommunication
2. Availability, reliability, and technical parameters of energy for powering imaging equipment
3. Staffing availability of clinical care providers, nurses, and technicians with full assessment of referral systems and communication systems among general healthcare providers and specialists
4. Availability of antibiotics for treating diagnosed infections and vaccinations for preventing infections
5. Availability of resources for biopsy/surgery or referral to outside institutions for diagnostic pathology and treatment
6. Availability of laboratory testing that complements imaging findings

By integrating this vast information at the assessment stage, a multidisciplinary approach can be applied to radiology outreach in which a solution specifically tailored to the location's disease patterns, patient population, medical personnel, infrastructure, and equipment can be implemented, while the outreach strategy fills in the highest-yield gaps to achieve the best outcomes. This approach argues against a uniform solution because an approach that works for one community or country may not work for another due to differences among these contexts that must be first analyzed in a robust assessment stage. This strategy of first-stage assessment for tailored solutions also requires that practitioners of global health radiology learn first and act second, which is inherently nonpaternalistic toward international partners and concretely data-driven.

Fourth, the synthesis of population-based methods and individual-level clinical strategies as tenets of the global health definition are interwoven into this textbook as we discuss the micro and macro scales of radiology healthcare capacity-building. At the micro and individual scale, the radiology approaches in this text may address specific clinical scenarios, such as imaging of trauma, infection, cardiovascular disease, and cancer. These topics may entail best-practice methods for imaging of diseases, particularly when resources are very limited. At the broader population level, radiology's role in global health may strategize policy at the national and international scales, ranging from a regional or national screening program or a transgovernmental scale at the United Nations and World Health Organization for global health policy. This textbook draws from experiences within RAD-AID and other nonprofit and nongovernmental organizations at the provider-to-patient level in discussing ways to teach and deliver medical imaging in underserved areas. More broadly at the macro and population scale, RAD-AID has served as a nonstate actor in *official relations* with the World Health Organization since 2015, in which RAD-AID specifically supports the WHO's health policy efforts in radiology advancement. By viewing radiology in global health from the individual and population-based vantage points, it is possible to better synthesize how radiologic technologies and services best fit the needs of patients and populations for preventing and treating illnesses.

To accomplish these objectives in this textbook, we begin in Part I (Global Health Radiology Strategies and Implementation) by describing the radiology enterprise and the relevant stakeholders for radiology capacity-building (Chap. 2). This chapter emphasizes the dynamics of healthcare enterprises and the radiology department within healthcare entities so that collaborations and resource investments can be sustainable. This leads to an in-depth discussion of how to define *access to care*, so that the right radiology capacity-building in low-resource areas can target high-yield gaps in those access points (Chap. 3).

In order to build and support radiology in low-resource areas along lines that are most respectful and understanding of the local context's clinical patterns and cultural frameworks, Chaps. 4 and 5 address the roles of medical ethics and cultural competency, respectively. Chapter 6 is a detailed discussion of the RAD-AID Radiology-Readiness Assessment, which is introduced above, as a fundamental cornerstone of radiology global health program development. This data collection tool conducts an analysis of what resources exist at a local institution, what gaps must be addressed, what are the highest-yield clinical goals that the institution can address with radiology for an underserved area, and then offers approaches for how radiology strategies can sustainably accomplish those objectives.

Given the capital-intensive, knowledge-intensive, and complex costs of radiology equipment and services, Chap. 7 discusses the economics of radiology in global health projects, and Chap. 8 presents strategies for hardware procurement, installation, and maintenance. Since the acquisition of imaging hardware brings on patient-safety responsibilities, the concepts of medical imaging safety are then presented afterward in Chap. 9. To discuss the software side of radiology healthcare capacity-building, Chap. 10 presents the goals of supporting health information technology (IT) networks and imaging platforms. As mentioned earlier, radiology is an important gateway and the first step for institutions to adopt health IT and can introduce a learning curve for institutions in underserved regions to progressively adopt a wider array of IT architectures (such as electronic medical records and health information systems). Therefore, radiology outreach has the potential to be a spearhead for broader health IT objectives in LMICs, emerging markets, and areas of radiology scarcity, along with introducing foundations for the future arrival of artificial intelligence and cognitive computing.

Ultrasound imaging capacity-building is presented in Chap. 12, which is rapidly changing trends due to innovations in hand-held designs, increasing portability, and lower costs. Ultrasound is proliferating in access and use among some LMICs and underserved zones and represents a leading edge for how to consider incorporating an imaging modality into point-of-service and diagnostic care clinical models. To complete this first section of the book, we present Chap. 13 on educational strategies so that the content of Chaps. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12 can fit into an educational program that supports best-practice utilization of imaging in the global health context.

In Part II of the textbook, Global Health Radiology Clinical Applications, we review clinical aspects of patient care in low-resource regions, beginning with a focused examination of radiology in global health and the United Nations Sustainable Development Goals (Chap. 14) spanning 2016–2030. We then turn to a review of public health and international epidemiology (Chap. 15) so that we can study disease patterns and potential solutions offered by radiology. Next, we address specific clinical topics that are pertinent to low-resource areas of the world, such as radiology for infectious diseases (Chap. 16), cardiovascular conditions (Chap. 17), pediatrics (Chap. 18), maternal-infant care (Chap. 19), and women's health (Chap. 20). Given the high importance of cancer within radiology outreach, oncologic care and the roles of imaging are included in these chapters as well as radiation oncology in Chap. 25.

The strong need for radiology in remote areas, which have scarce radiology and lack reliable transportation infrastructure, is addressed in Chap. 21 where we discuss mobile strategies for bringing radiology to marginalized populations. This chapter reviews mobile radiology over the last century, including imaging services aboard trucks, boats, and aircraft. The topic of mobile outreach then segways into a discussion of disaster response in Chap. 22, in which radiology outreach can bring services to isolated and traumatized populations and radiology teams can assess and repair damage to fixed sites that incurred outages from natural catastrophes. Historically, radiology has not typically been included in disaster responses and crisis zone interventions. However, the high cost of radiology equipment and the large contribution of imaging to clinical operations infer that protection and preservation of such equipment at facilities in natural disasters is a priority that radiology global health practitioners can carry out. Along those lines, clinical imaging of trauma is then addressed in Chap. 23. Finally, interventional radiology for the role of image-guided procedures in low-resource areas is discussed in Chap. 24. Interventional radiology is vital across many areas of healthcare such as cardiovascular, oncology, pediatrics, women's health, and infectious disease specialities, with large demand for interventional radiology arising from low-resource institutions in LMICs. The textbook concludes with examples in our Appendices containing cases of radiology education systems, educational collaboration design, and discussion questions that can help readers to further review and digest this textbook's content.

Conclusion

We remind our readers that this text cannot present all solutions to this widely daunting task in our global health system. Out of respect for the diversity of healthcare systems worldwide and their respective specific challenges and needs, we avoid any paternalistic overgeneralizations. Instead, this text is a starting point for global health work by covering rapidly advancing imaging technologies and presenting novel ways to implement these tools in diagnosing and treating disease. This text is primarily aimed to empower the reader by offering tools that enable analysis and thoughtful planning of radiology in global health collaborations. Through careful assessment, planning, and management, with steadfast dedication to our patients' well-being, this text can be another step toward improving global health.

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2 Radiology Overview: Defining Radiology and Stakeholders in the Radiology Enterprise

Garshasb P. Soroosh, William W. Mayo-Smith, and Daniel J. Mollura

Introduction

As a practicing radiologist, healthcare provider, resident, or health service planner, it is easy to overlook the many complex, interlocking parts that make a radiology organization function smoothly in the delivery of medical imaging services. Standards for image quality, communication, and patient safety apply to all radiology enterprises, regardless of the technologies, cultural context, or economic environment. For example, mobile services for rural outreach still must obey the same organizational principles of larger stationary radiology departments inside tertiary care centers.

Lack of sufficient attention to radiology organizational structure has been commonly cited as a main factor contributing to the failure of international radiology service deployment [1–4]. For example, donating a piece of equipment, such as an x-ray machine or ultrasound unit, to a hospital does not substitute for all the other organizational features that will enable the successful use of that equipment. Integrating a new piece of imaging equipment into a medical care facility requires an understanding of how best managed radiology organizations operate. Practicing radiologists and residents within these organizational structures often take for granted the complexity of the departmental dynamics because interpreting radiology scans is only a small part of what a radiology enterprise delivers [1–4]. Therefore, it is important to understand not only the different players but also the process that makes up a radiology enterprise in order for healthcare providers to best offer radiology services in limited-resource settings.

Defining the Radiology Enterprise

The radiology enterprise can be defined as an organization, either independent or within a larger medical facility, specialized for the delivery of medical imaging services, including diagnostic imaging and image-guided procedures and treatments [3, 5, 6]. The primary diagnostic imaging modalities included in the radiology enterprise include radiography, ultrasound, mammography, computed tomography (CT), nuclear medicine, magnetic resonance imaging (MRI), and fluoroscopy. Interventional image-guided treatments include biopsy, drainage, embolization, ablation,

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and others. Overall, the radiology enterprise has many defined personnel specialized for the different components of medical imaging, as well as the equipment (i.e., the imaging hardware, servers, workstations) and software (computer-based applications). In the context of this text, the radiology enterprise may consist of a few staff operating a single piece of imaging equipment, which is in stark contrast to some tertiary care centers that have hundreds of staff managing multiple imaging units encompassing several modalities. Even a single portable x-ray unit in a refugee camp must be regarded as a radiology enterprise so that the components of this service can be fully analyzed and optimized to fit the needs of appropriate diagnosis, patient safety, and equipment maintenance. Regardless of the scale or type of imaging within the medical imaging department, there are key structural similarities that will aid an assessment of how these services are being delivered and standards that must be maintained to ensure patient safety and effective treatment.

Defining the Processes

As described above, the diagnostic radiology enterprise can vary in scope from a single operator of an x-ray unit to a complex multidisciplinary organization spanning many hospital networks and countries. Despite variations in scale and scope, there are multiple processes common to all radiology enterprises that are critical to establishing appropriate delivery systems [6–8]. A breakdown in any one of these processes in the complex imaging chain will defeat the desired outcome. The common processes include the following (each will be discussed in depth throughout the text):

1. Scheduling of the patient for the appropriate test/procedure
2. Proper equipment to perform the test/procedure (this includes stable reliable electricity, shielded room, imaging equipment, etc.)
3. Appropriately trained personnel to operate the equipment
4. System to transmit and store imaging data and reports (either via printed film or digitally)
5. System to visualize the imaging data
6. Radiologist (or other trained medical professional) to interpret imaging data
7. System to generate a report of the findings and recommendations from the imaging data
8. System to transmit the report to the referring healthcare provider
9. Equipment maintenance program (*all equipment requires maintenance!*)
10. System of continuing education and quality assurance to ensure all equipment is properly maintained and personnel are appropriately trained
11. Financial method of reimbursement to make the system economically viable and sustainable

Defining the Stakeholders (Personnel)

A radiology imaging service unit cannot operate well without a well-organized, highly trained group of staff. In advanced healthcare institutions, the roles listed in Table 2.1 are generally involved in the workflow of delivering imaging services. This set of interlocking personnel and variables has changed greatly in the last several decades as radiologic technology has progressed in the digital age. Several decades ago, the workflow of radiology was mainly centered on the printing and storage of images as film. Similar to the transition from film to digital photography, radiology in advanced healthcare systems has become mainly digital with virtually all interpretations occurring from a computer workstation enabling advanced manipulation of images, which requires new staff, responsibilities, and skill sets [7]. In settings with limited technical, staffing, or economic resources, the roles outlined are often performed by fewer, less specialized personnel. For example, it is possible that the technologist may also service in administrative and information technology (IT) capacities. Some radiologists will do their own nursing procedures (starting

Table 2.1 Stakeholders and their responsibilities

Stakeholder	Responsibilities
Administrators	Schedule patients Document payments, insurance Manage human resources Manage quality inspections Monitor care outcomes for potential points of improvement Run the business economic aspects of the unit
Nurses	Manage patient safety Perform procedures on patients that require imaging exam
Technologists	Operate imaging hardware Transmit images (print or electronic) to radiologists
Physicists	Manage safety (radiation dose) of imaging hardware Manage quality (resolution, calibrations) of imaging hardware and software Monitor continuing safety and quality of all equipment
Information Technology	Manage saving/sending of imaging studies Use formats like DICOM Manage specialized servers (PACS) to conduct high-volume traffic from technologist to radiologist
Radiologists	Interpret images for patient care Perform procedures under image guidance

IVs, evaluating patient prior to imaging, performing imaging procedures, etc.). It is important to recognize, however, that these roles must be represented in some way, either by specialized personnel or by multi-tasked individuals, because these capacities are all vital for effective and safe imaging [6–8].

Technologies and Equipment

The equipment in a radiology enterprise varies by size and specialized resources of the department. Table 2.2 lists the possible types of equipment potentially present in an imaging organization, along with its relative expense. This wide variety of possible modalities, and the associated high cost, requires that each department must choose and optimize imaging equipment to meet the clinical needs of its community and patient population. For example, some hospitals without a breast cancer screening program will not have mammography equipment; a rural outreach clinic lacking reliable electricity may only use portable modalities, such as ultrasound. This topic of optimizing equipment for the resources of an institution and the epidemiological needs of a community is covered in greater depth in the *Radiology Readiness* chapter of this text.

Table 2.2 Equipment and relative expense

Modality	Relative expense
Radiography (x-ray) plain film	$–$$$
Ultrasound	$–$$
Mammography	$$–$$$
Computed tomography (CT)	$$$–$$$$
MRI	$$$–$$$$$
Nuclear medicine	$$$–$$$$$
Fluoroscopy for interventional procedures	$$–$$$$
Radiation therapy units	$$$$$
Dual-energy x-ray absorptiometry (DXA)	$$–$$$

Aside from choosing the best modality and the accompanying capital expense, imaging equipment must be managed for patient safety and diagnostic quality by a physicist. In limited-resource settings where a physicist may not be present, this can be quite challenging, as physicists are highly trained individuals understanding the physics, engineering, safety, and quality measures that keep equipment running. The absence of a physicist and appropriate quality assurance measures can lead to an accidental breach of regulations or safety [7]. It is important to recognize radiation exposure as one of the major safety concerns for a radiology enterprise, and that this problem often goes unseen and can be easily neglected without the presence of qualified personnel who are actively monitoring risk prevention. Only by scaling up the number of physicists, or by delegating the role to another trained professional, can we make progress toward the goal of matching the quality of services in resource-limited regions to that of large radiology departments.

Daily operation of the equipment for patient care and periodic testing for quality control are performed by technologists. In some countries where technologists are in short supply and/or with inadequate training, the technologist's role may overlap significantly with the radiologist's role. Technologists acquiring the images of patients on the imaging equipment will then either format the images digitally for transmission into electronic servers, termed "picture archiving and communications system" (PACS), or develop the printed film using analog film development techniques. PACS have largely replaced printed film in developed countries, but printed film is still present in many resource-limited regions of the world. This topic is covered in greater detail elsewhere in the text.

Relationships Among Stakeholders for Service Delivery

The organized relationships among stakeholders in radiology service implementation are critical [2, 3]. Communication is vital so that these human and technical elements can work in synchrony. Each part must understand the respective role and specialized contribution with appropriate boundaries for handoff and communication. For example, once an image is interpreted by the radiologist, accurate and timely communication of the results to the referring clinician is essential.

In developed healthcare settings, this may involve a phone call or a page indicating the results. In low- and middle-income countries (LMICs) or rural areas, the lack of reliable communications may impair this dialog. In one model offered by Imaging the World, SMS messaging of results has been deployed for communicating results [1, 4]; the proliferation of cell phone technologies in LMICs has made this mode of communication among the most stable for a communication structure among healthcare providers. Moreover, widespread utilization of tablet devices with useful applications ("apps") has made portable devices more relevant in the communication across stakeholders and may play a significant role in next-generation models of medical imaging implementation. For example, radiology images can be viewed on tablets with communication based either on cell phone data or Wi-Fi to streamline these interconnections between radiology and other care providers [4].

Personnel Education and Training

All personnel in a medical setting that are involved in the delivery of patient care (i.e., radiologists, nurses, technologists) must engage in continuing education activities. These programs, which can range from pre-recorded video lectures to published journal articles to one-on-one didactic activities, provide a structured means for maintaining professional competencies and developing workforce education. Multiple studies have shown that continuing education measures improve professional practice and healthcare outcomes for patients [9]. In larger radiology departments, administrators organize opportunities for personnel to earn continuing education credits, keep a record of credits earned by each individual, and set benchmarks for annual credit requirements in compliance with requirements set by governing bodies. In resource-limited regions, the onus may rest on the radiologist and/or technologist to seek out such educational resources as part of their professional activities.

Establishing educational infrastructure requires setting aside time and monetary resources, designing a curriculum and teaching methods, and measuring student performance outcomes [10, 11]. Of note is the need for radiology residents, technologists, and others seeking specialized training to have access to mentorship support, be it locally at their home institution or remotely through communications with institutional partners. The topic of personnel education is discussed more fully in other parts of this text.

Radiology Planning

In briefly reviewing the previously discussed structural components of a medical imaging organization, we can now turn to the role of integrating these components in planning or improving imaging services in resource-limited regions. The integration of these parts is essential for (a) providing adequate care and then (b) communicating with the rest of the clinic or medical service so that imaging can be optimized for patient care. For example, if an abnormal finding is discovered upon imaging, that result must be included with all other clinical information in order to arrive at the best action plan for the specific patient. Diagnosis of a breast tumor on mammography will not achieve optimal results unless communicated to the breast surgeons and oncologists, who will then act on that finding to implement a patient care plan. This involves prime attention to how radiology fits into the complex referral system of triaging and diagnosing patients so that they can receive follow-up care; these and other medical imaging project planning considerations are discussed in greater detail in the text.

Conclusion

This chapter presented a brief overview of the radiology enterprise, which can be as simple as a single piece of equipment with few staff or as complex as hundreds of personnel operating many scanners for thousands of images and patients per year. As a vital component of public health infrastructure, addressing numerous diagnostic needs in medical and surgical care, radiology services can have a great impact on healthcare disparities worldwide when properly organized and delivered. In the chapters that follow, this text aims to show how the stakeholders and their relationships develop to form operational entities for delivering medical imaging services. Moreover, how these stakeholders and resources interact forms the crucial nexus of how to plan outreach in areas that have limited or no existing radiological care.

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3 Access to Imaging Technology in Global Health

Michael A. Morris and Babak Saboury

Introduction and Background

Healthcare technology is one of the six building blocks identified by the World Health Organization (WHO) as essential for all health systems [1, 2]. Missing even one of the six impedes a health system from functioning at a level necessary to improve the health of individuals and populations [1, 2]. Diagnostic imaging plays a key role in identifying pathology and tracking the progression of a disease in the practice of modern medicine. Imaging allows earlier accurate diagnosis, which can shorten the time to proper management. The efficiency of patient management provided by diagnostic imaging can lower downstream healthcare costs [3]. Diagnostic imaging also plays a role in early detection or prevention of disease via screening. Diagnostic imaging is a core healthcare technology.

The evaluation of access to medical imaging services is complex and difficult to understand fully. The WHO made initial attempts to characterize access to medical imaging from the late 1970s to the early 1980s [4–9]. According to the WHO reports, one-half to two-thirds of people in the world lack adequate access to basic imaging technology, such as X-ray and ultrasound [7, 10–12]. In order to better understand how to develop a strategy to improve access to imaging services, one must first delve deeper into the subject of access assessment, which is a modern and evolving area of public health and sociology. A review of the development of the scientific approach to the study of access can help one to better understand access in the context of healthcare systems and more specifically as it relates to diagnostic imaging.

Historical Perspective: Etymology and Early Scientific Study

The Oxford English Dictionary (OED) defines access as "the right or opportunity to benefit from or use a system or service," and suggests its first use in this context was by Bairdy in 1681: "The one has access to the legal maintenance; the other is cast upon." Even this historical reference suggests the imperative of access and its equality. Before its use in the English language, access stems from the fourteenth-century French use of "acces," which means "onslaught, attack; onset (of an illness)." This term comes from the Latin

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word "accessus" and was used to mean "a coming to, an approach; way of approach, entrance." The past participle is "accedere" meaning "to approach," from the assimilated form of ad, meaning "to," combined with "cedere," meaning to "go, move, withdraw," and comes from the proto-Indo-European (PIE) root *ked- "to go, yield." Other related terms originating from "cedere" and its PIE root include abscess, excess, recess, ancestor, success, decease, necessary, secession, concession, and intercede.

Initial scientific study of access began in the domains of geographic and spatial sciences [13]. Early studies of access emphasized the distribution of natural resources relative to various communities of people. The initial scientific evaluation of access relied on quantification of spatial distribution. For instance, the distance of a community to a resource, such as water, could be easily measured and visualized using geographic techniques. The visual representation of resources in geographic sciences provides population-level information as a heatmap in a spatial distribution [14]. Efforts are continuing to improve measurement and understanding of accessibility in the information age [15]. Geographic analysis of resource access provided a framework to measure, compare, and graphically report on access with a bird's-eye-view perspective (Fig. 3.1). Quantifying access in this way has led to improvements in policy and planning for resource management throughout the world [16–18].

Emerging Concepts and Theory

More recently and increasingly, the idea of measuring access is applied in terms of sociological resources in addition to natural resources. When population health is reported in a geospatial fashion, the outcome is viewing patient health with a macroscopic lens focusing on multiple patients in a community setting—medical imaging in the sociological context, for example (Fig. 3.2). Initially, measurement of healthcare access was performed similarly to natural resource distribution by measuring the distance of a community to a healthcare resource. This approach is simple and easy to compute [19]. In this fashion, distance is a surrogate marker for accessibility and availability, presuming that increasing distance is proportional to decreased ability for a patient to obtain care.

The discussion of access will begin with application of the traditional geospatial methods to evaluate availability of imaging technology. Then, the modern understanding of the complexity of access beyond availability will be considered. The modern definition of medical imaging access must also consider need, infrastructure factors, quality, economic factors, and psychosocial factors. Each component of the modern definition of access will be evaluated in terms of the key contributing factors as described in highly cited literature references. Finally, the authors will discuss theories for the modern assessment of access and propose an evaluation mechanism that includes each of the contributing factors as described in the modern literature.

Essential Imaging Technologies in the Developing World

The first step in understanding "access to medical imaging" is understanding "availability." The Needs Assessment for Medical Devices is a technical review series report published by the WHO in 2011 that outlines exactly how a country's Ministry of Health can calculate the gaps in access to medical device technology [20]. In its simplest form, it is meant to assist a nation in comparing what is available in terms of imaging technology with what should be available to better define their gap in care. More specifically, it offers a seven-step approach that can be used at the local up to the national level. Continuing to build upon prior surveys, this WHO model takes into account financial, human resource, and infrastructure constraints, as well as data on the unique disease burden of a nation to best assess need. As mentioned in the last step, this allows a nation to prioritize need in hopes of maximizing the utility of every intervention [20]. RAD-AID Radiology Readiness™ is another tool endorsed by the Pan American Health Organization

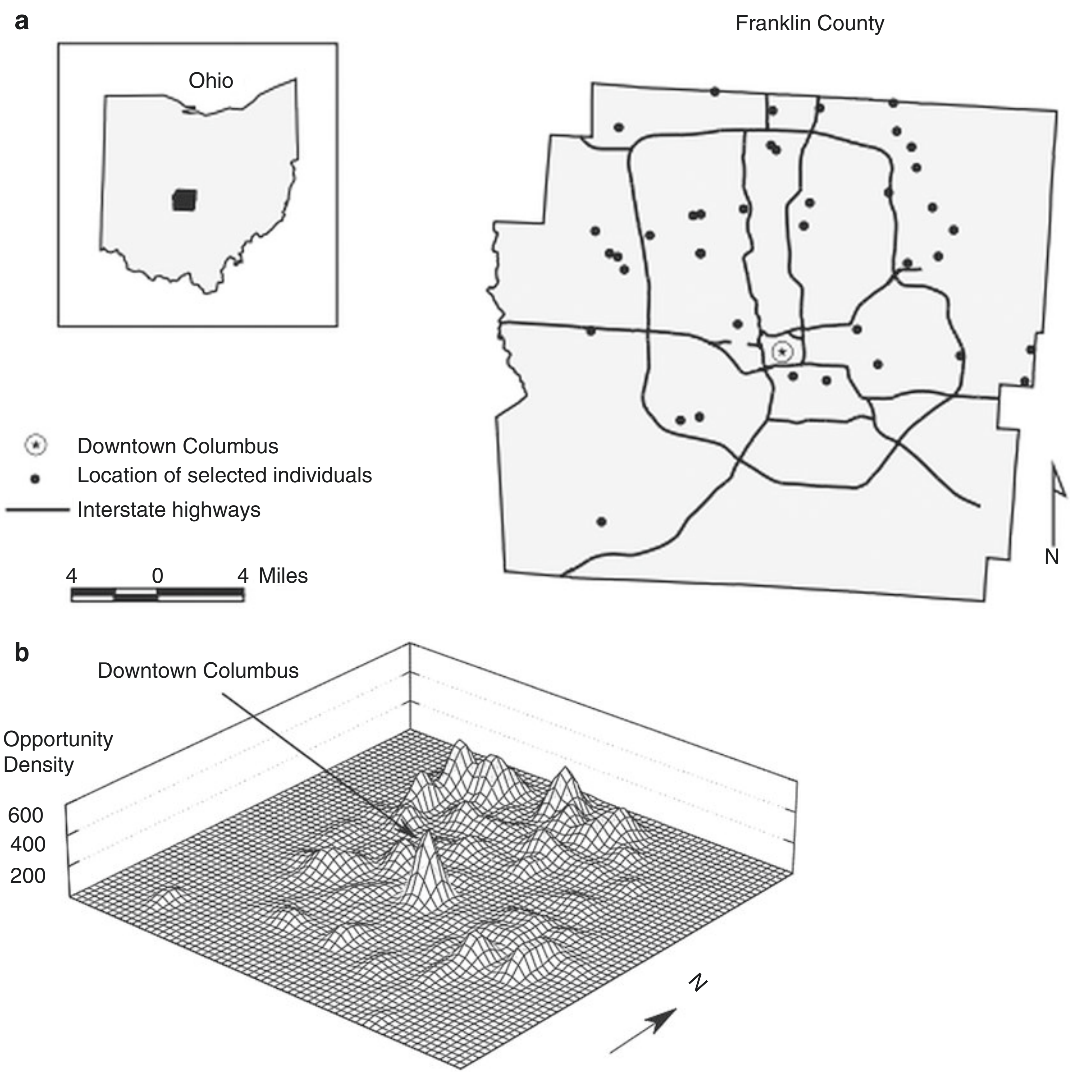

Fig. 3.1 Early example of geospatial representation of access to opportunities in the greater Columbus, Ohio, metropolitan area in the United States displayed with indicators of transportation infrastructure (**a**) and by opportunity density (**b**) [14]. (Reprinted from Kwan [14], (C) 1999, Vol. 51, pp. 210–227, by permission of Taylor & Francis Ltd., http://www.tandfonline.com)

(PAHO)/WHO since 2012 to address the need by specifically evaluating available medical imaging technologies as well as potential areas of need.

It has been suggested that 80–90% of the imaging need in low- and middle-income countries (LMICs) can be met by X-ray and ultrasound alone [11, 21, 22]. X-rays are essential in the diagnosis and treatment for the large proportion of patients in LMICs presenting with pulmonary or orthopedic conditions, among other things [21]. This is true for acute conditions, such as pneumonia, pleural effusion, hemothorax, fractures, and osteomyelitis, as well as chronic ones, such as tuberculosis (TB), asthma, chronic obstructive pulmonary disease (COPD), and occupational lung disease [21]. Ultrasound has an established role in obstetric imaging. From gestational dating of a fetus and assessing fetal well-being to identifying placental abruption and placenta previa, ultrasound is important in the

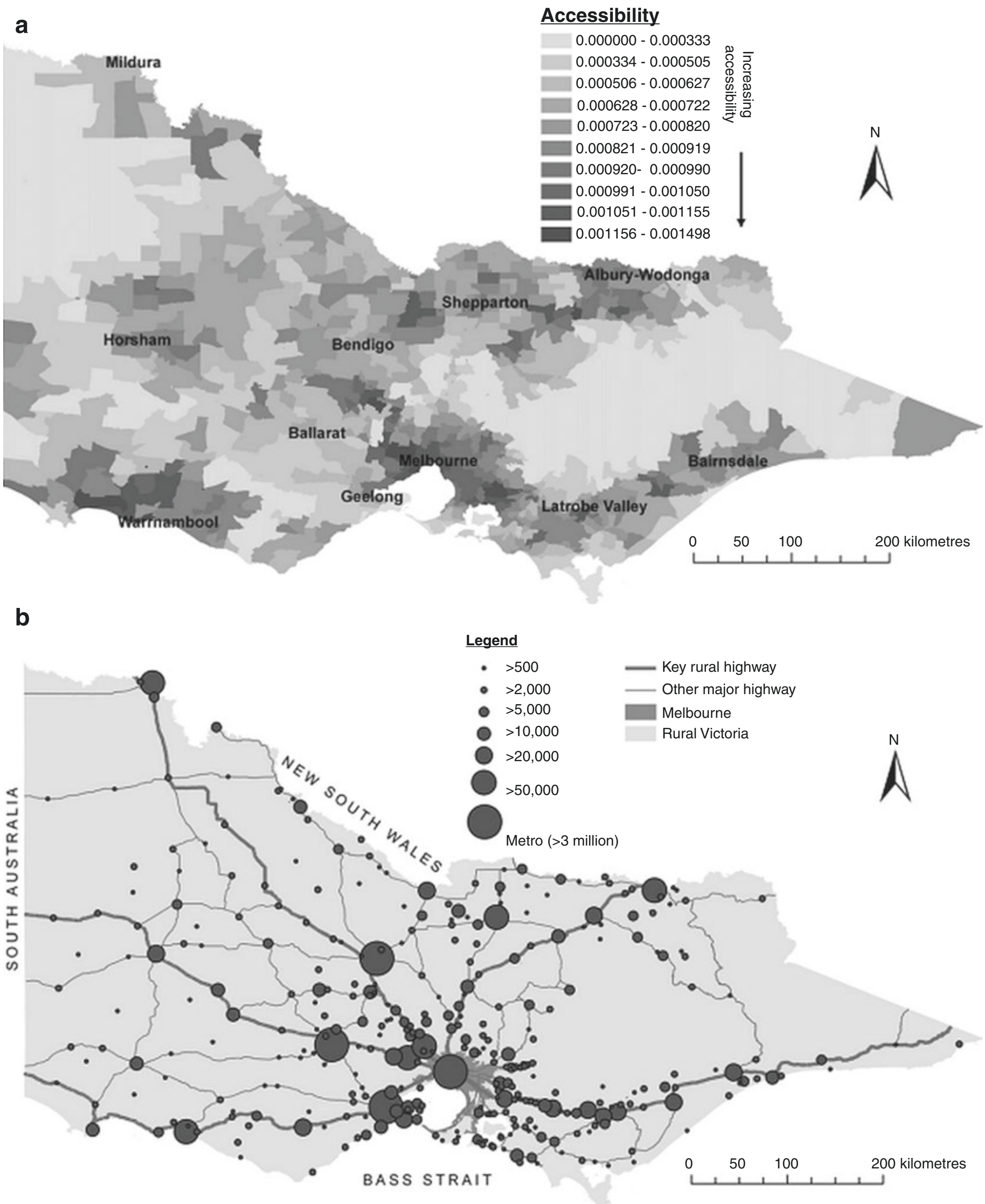

Fig. 3.2 (**a**) Geospatial heatmap of accessibility to primary care in Victoria, Australia, using the two-step floating catchment area (2SFCA) method according to travel distance with maximum travel time of 60 min. (**b**) Comparison is made to distribution of population and transportation infrastructure in Victoria, Australia [19]. (Reprinted from McGrail and Humphreys [19], (C) 2009, with permission from Elsevier)

screening and diagnosis of disease [21]. Additional conditions for which ultrasound has a critical role in resource-poor settings include deep vein thrombosis, cardiac valvular disease, cardiomyopathy, abdominal trauma, abdominal masses, abdominal sequelae of patients suffering from human immunodeficiency virus (HIV), ascites, neonatal cerebral hemorrhage or infection, and procedural guidance, such as for any type of fluid drainage, intravenous (IV) access, and difficult lumbar punctures [21, 23].

Simply having these technologies available does not necessarily mean they are being used or making an effective impact on patient care. It is imperative to decipher the impact of available imaging technologies on clinical management and patient outcomes. A review of studies on ultrasound by Sippel et al. found that ultrasound either changed patient management, increased detection of disease compared to baseline physical exam, narrowed the differential diagnosis, or pinpointed the definitive diagnosis in a range of conditions studied in numerous LMICs around the world [23]. A benefit of ultrasound technology is that it is highly portable and can be utilized in real time at the point of care to rapidly characterize diverse pathology and guide direct management including image-guided intervention, procedures, surgery, or medical therapy [24].

As per the "Global Burden of Disease" report by the WHO, lower respiratory tract infections (mainly pneumonia) are the leading cause of disability-associated life years (DALYs) lost in the world and in low-income countries [25]. In addition, they rank fourth in terms of projected causes of death globally in 2030, with the top three being cardiovascular disease, cerebrovascular disease (stroke), and COPD [25]. Accurate interpretation of a simple chest radiograph can rapidly direct diagnosis and management of these diseases. Furthermore, the burden of maternal conditions, while almost entirely confined to LMICs, is so great that they, alone, make up one-fifth of the leading causes of disease among women aged 15–44. Almost all of this loss of healthy life years is avoidable [25]. Properly applied medical imaging technologies in these disease processes, even the most basic use of X-ray and ultrasound technology, significantly affect the overall healthcare delivery system. It is clear that medical imaging technologies have a vital role in the practice of medicine throughout the world. What remains is achieving adequate access.

Assessing Availability of Imaging Technology

Since the late 1970s, the WHO has aggregated world data on medical imaging. In 1979, the Radiation Medicine Unit of the WHO conducted a survey to assess radiological services in countries from around the world. They received responses from 89 countries of varying income levels. A key estimate extrapolated from the data was that out of 3.8 billion people in the world, radiological services were acceptable or good for 1.2 billion, poor for 1.1 billion, and that there was no access to radiological services for 1.4–1.5 billion [4]. This finding led to the publication of numerous diagnostic manuals detailing various imaging modalities, such as X-ray and ultrasound, as well as how to use them in LMICs after taking into account various infrastructure factors [12, 26].

The WHO continued to publish manuals with the goal of disseminating educational resources, but it was not until 2007 that they, again, started focusing on assessing access to medical imaging in LMICs [20]. Their work led to creation of the Baseline Country Survey on Medical Devices in 2010, a two-page survey that covers the availability of specific imaging technology, national policies on health technology, guidelines on procurement of medical devices, regulatory bodies, and healthcare infrastructure [27, 28]. It was administered to the Ministries of Health in 145 WHO member countries. The questionnaire builds upon the 1979 survey to allow one to understand the various factors that make up "availability" of medical imaging technologies. For example, LMICs, as defined in the World Health Statistics report from the WHO, had fewer than 1 mammography unit per million people compared to 23 per million in high-income countries [29]. In terms of computed tomography (CT) imaging, 1 unit per million people was found in low- and lower middle-income countries, while slightly higher than 44 units per million were seen in high-income countries who participated in the survey [27]. This disparity between the high-, middle-, and low-income nations is the same, if not worse, when looking at access to magnetic resonance imaging (MRI), positron emission tomography (PET), and nuclear imaging devices as per the baseline survey. Advanced imaging modalities are particularly important in the management of cancer, which is becoming increasingly important in global health. Already, 70% of cancer deaths occur in the LMICs, and there is an increasing trend largely due to delayed diagnosis from lack of access to medical imaging technologies [30–36].

The report on the baseline survey breaks data down by nation. The annual World Health Statistics report and Global Health Observatory Data Repository compiled by the WHO separate the questionnaire data based on imaging device, regulation standards, and hospital infrastructure among other things. This can further be categorized by a nation's income level [29, 37]. For example, since national policy and regulations also influence access, the questionnaire found that of the low-income countries who participated, only 33% have a national policy for health technology. In addition, 40% of low-income countries do not have an authority responsible for implementing and enforcing medical device regulations which ensures the safety of the device for the practitioner and the patient [1]. Regarding infrastructure, one key statistic was the discrepancy in available hospital beds: 16.5 per 10,000 people in low- and lower middle-income countries compared to more than three times that number in high-income countries. It is evident from the data collected that disparity exists between high-, middle-, and low-income nations.

A thoughtful understanding of the term "access" has paved the way for numerous reports and a compilation of technical series on medical devices that serve as resources for nations as they construct, among other things, a needs-based assessment of medical imaging technology. Nonetheless, at the core, a definition of need has to be compared with a definition of adequate access. For example, a WHO manual on diagnostic imaging in communities cites that there should be at least 1 diagnostic imaging system, 1 X-ray, and 1 ultrasound unit, per 50,000 people [12]. Using this barometer, many LMICs may still fall short in the capacity to provide appropriate access to both X-ray and ultrasound technology [4–6, 24]; however, utilization and interpretive services are considered separately or may not even be considered in current assessments at all. There is no similarly accepted guideline for how many radiologists are needed. What remains to be seen are other benchmarks to aid nations in understanding adequate access.

Access Beyond Availability, a Public Health Perspective

In order to better understand the meaning of "access" to radiology services, one may consider the public health literature. An initial framework for understanding health service access relied on utilization as a surrogate measure of access, which is then divided into several components [18]. In 1978, Andersen and Aday first proposed a distinction between "potential access" and "realized access" by studying the interconnected issues of *health need*, *service availability*, and realized access [38–40]. Andersen and Aday encourage an approach that investigates each interconnected factor affecting realized access [38–40].

In 1981, Penchansky and Thomas suggest five concepts to help understand "realized access" from a population survey model including *availability*, *affordability*, *accessibility*, *appropriateness*, and *acceptability* [41]. These models of understanding access are summarized by Halfon et al. as indicators of potential access to care versus those of realized access to care (Table 3.1) [42]. In 1993, Weissman and Epstein suggested that *service quality* is also an important component of access and proposed a modified definition as "the attainment of timely, sufficient, and appropriate health care of adequate quality such that health outcomes are maximized" [43]. Khan and Bhardwaj nicely elaborate on the concept of barriers, proposed originally by Lewis, by integrating the inversely related concepts of barriers and facilitators—which others have referred to similarly as enablers—in terms of potential

Table 3.1 Health care access key considerations and markers

	Personal characteristics	System characteristics
Potential access markers		
Predisposing	Age Gender Education Occupation Ethnic background Family organization/values	
Healthcare need	Baseline health measures Perception of need Acute health risk	
Enablers	Insurance coverage, Income Transportation Time to appointment Regular provider, source of care Attitudes and beliefs Residential location Convenience of services	Care models Service capacity Funding availability, healthcare benefits Provider availability, training, attitudes Geographic distribution, location of sites of care Collaborative relationships, co-localization Service and system integration
Realized access markers		
Utilization	Care point of entry Care services volume Care services types	Utilization expenditure patterns
Outcomes	Patient satisfaction Health outcome measures	Preventable patient morbidity and mortality Population overall mortality and morbidity

Adapted and modified from Halfon et al. [42], Andersen et al. [39], Penchansky and Thomas [41], and Weissman and Epstein [43]

access versus realized access [44]. They refer to spatial (geographic access) and aspatial (social access) in terms of potential and realized opportunities and costs.

The WHO defines access broadly as an interaction of different factors melding the "five As" of Penchansky and Thomas with Weissman and Epstein's emphasis on quality [45]. Thus, it is not enough for individuals to be geographically within reach of healthcare facilities that house imaging technologies as might be explained by "availability." A medical device or imaging technology must be scientifically valid, address local need, and be utilized in a manner that a country and patients can afford. The incorporation of cultural beliefs and individuals' attitudes regarding the use of various medical devices and imaging modalities is termed "acceptability." Acceptability is more fluid as it varies with education, need, and cultural/community beliefs. On the other hand, "quality" refers to the national regulatory standards that are in place to assure safe and effective use of all health technologies [45, 46]. A proper understanding of the term "access" is necessary to provide both effective and equitable solutions for assessing global radiology services.

In order to measure the impact of diagnostic imaging on healthcare outcomes, there must be appropriate emphasis on service delivery in addition to availability of appropriate healthcare technologies. As Frost and Reich summarize, "Just because a good health technology exists does not mean that it will be delivered, used, or achieve its potential to bring good health, especially for poor people in poor countries." Inequalities in access to radiology services despite available technology are often even present within a country. One example is comparing private sector to public sector services. While the private sector often has the technology and the resources to offer needed imaging services, they are inaccessible to many people due to cost and centralization near urban areas. Medical facilities in the public sector, on the other hand, aim to provide for all, but are overburdened due to the volume of demand and a lack of sufficient resources both in trained staff and imaging devices. For public sector facilities in more rural areas, the challenge lies in having the resources to house, maintain, and repair the most basic imaging services as well as entice trained staff to stay in the area to offer services [6, 21, 47]. A paradox is created potentially skewing data to show services that are technically, however not practically available.

The concept of equity in access is explored by Outka who evaluates criteria of social justice as they relate to equal access to healthcare. Outka suggests it is difficult to apply traditional market principles such as merit, societal contributions, or supply and demand to a just allocation of healthcare resources. Instead, essential needs and similar treatment for similar cases are more appropriate measures of equity [48]. O'Donnell points out that the Demographic Health Surveys (DHS) provides some of the strongest data on the distribution of child and reproductive health services comparing the index of household assets to healthcare access. Sub-Saharan Africa has some of the highest availability of coverage among developing regions. Counterintuitively, it also has the highest inequality in coverage, although inequalities remain high throughout the world [49]. A modern definition of access is offered by Levesque, "the opportunity to identify healthcare needs, to seek healthcare services, to reach, to obtain or use healthcare services and to actually have the need for services fulfilled" [49].

Infrastructure

Infrastructure is an important component of healthcare access. For instance, a study in rural Nepal compared access in terms of accessibility and quality using structural metrics and found that accessible infrastructure such as proximity to a major road was a greater indicator of available services than traveling time [50]. Additionally, the study found that poor-quality facilities were underutilized and concluded that investments to improve the quality of facilities were more important than the number of facilities.

Investments in radiology infrastructure can serve as a foundation on which further healthcare technology improvements can take place. As film becomes more costly [51], digital imaging systems are increasingly being implemented around the world. Access to computed tomography has encouraged interpretation of images in real time on the computer. Exposure to digital imaging technologies has grown excitement throughout the world for the adoption of a digital diagnostic imaging workflow incorporating a picture archiving and communications system (PACS) [52]. The most recent revision of the RAD-AID Radiology Readiness™ in 2016 incorporated the PACS Readiness Assessment in order to evaluate the available infrastructure and needs prior to PACS implementation.

Investments in technology that otherwise might be deemed a luxury for healthcare systems in LMICs are justified in order to provide basic diagnostic imaging services. Through attracting patients who might otherwise seek suboptimal care or who might delay care entirely, improved technology increases realized access. Patients prefer care centers with better infrastructure, such as hospitals, compared to community clinics due to cost, accessibility, and higher service technical quality [53]. In order for healthcare facilities to adopt a complete digital imaging workflow with PACS replacing cumbersome and costly film technologies, there must be access to computers and a high-speed internal network. Fortunately, the availability of powerful computing hardware at affordable prices as well as open source medical software continues to grow. In the discussion of access, organizers should consider elements of the local communities themselves, which may promote or discourage adoption of radiological services. Indeed, from a community planning and geographical/social economic perspective, the issue of access to radiological services and the methods to address key infrastructure components such as power and network/Internet capacity could impact not only the public health but the growth and development of healthy communities.

Radiology is a unique area of medicine that relies on access to technology in its modern practice. The infrastructure required for successful adoption of modern radiological services provides a public health initiative for infrastructure development that has the potential to promote access to Internet and reliable power [54]. Through this mechanism, promoting access to essential basic radiology services fosters socioeconomic and infrastructure development more broadly. The impact of these community resources on access is termed "livelihood assets" and is identified by Obrist et al. as an enabler that is often overlooked [55]. Reid et al. found unstable housing and economic standing were associated with poor access to healthcare. They found a higher likelihood of not having insurance, delaying needed care and medications, and increased hospitalization rates among affected patients [56]. Delayed care and hospitalizations are examples of access inequality that might not be appreciated in an account of utilization alone. Temporal utilization is also important, and increased utilization of hospital services might represent inadequate access rather than increased access, for instance. A corollary in radiology might be radiography or ultrasound utilization versus computed tomography utilization. Increased CT utilization might indicate decreased access to simpler diagnostic tests or to early diagnosis in general among a population.

Acquisition and Maintenance

The bare minimum standard for availability is access to imaging equipment. However, the presence of equipment alone does not guarantee its quality or adequate utilization. Equipment must be properly maintained and in good operational and functional status with proper power and network resources. There must be trained individuals capable of using the equipment to obtain reproducible studies, i.e., radiographers and sonographers. The images obtained using imaging equipment must be able to be converted into a format, either hardcopy (film) or softcopy (digital), that is available for interpretation by the radiologist.

Access to Interpretive Services

Access to imaging technological equipment itself is just the first step. The equation for access is multifactorial, nuanced, and affected by different aspects spanning beyond technological resources to human resources and health policy. An accurate definition of access must also account for equipment utilization and the availability of skilled medical image interpretive services. In many regions, there are not enough physicians with specialized training in diagnostic radiology in the public sector to generate reports to detail and record the salient findings for the majority of studies (plain radiographs and ultrasound). Without skilled interpretive services, although imaging technology may be present, the patients may not have realized access to a health outcome benefit. Findings may be left undocumented or missed entirely.

There are current efforts throughout the world to address the issue of access to diagnostic imaging interpretive skills. As physicians are already in short supply, physicians with specialized training in diagnostic radiology can be scarce to nonexistent in some parts of the world. A mature diagnostic imaging program is required to train diagnostic radiologists, yet many regions are only recently obtaining basic radiography or ultrasound equipment. Even in areas of the world with long-term access, reliable quality access can mean an abundance of examinations compared to the available interpretive services. For instance, in Haiti, a hospital with a CT scanner performs head CT examinations without radiology or neuroradiology interpretation. No report is generated, and instead clinicians without formal training in imaging adjust management decisions based on their personal experience. In South Africa, radiography is the most commonly performed study in the public healthcare sector; however, it is the least likely to be reported. Only examinations flagged for interpretation are reported, and the turn-around time can exceed 4 weeks. Primarily, three models to improve interpretive skills access are utilized in resource-challenged settings.

The first approach is to train skilled healthcare workers directly involved in imaging services such as sonographers and radiographers who are in relatively larger supply than physicians and are required to operate the equipment, which can decrease added cost for interpretive services. In some regions, sonographers are provided interpretive training as part of their educational curriculum and are licensed to generate reports for ultrasound studies [23, 57]. Radiographs that are deemed suspicious by skilled technologists or other healthcare providers may be referred for consultation by a radiologist, decreasing the overall workload.

Another approach takes advantage of the advent of portable imaging technologies. Today, radiography, ultrasound, mammography, CT, MRI, and PET can be fitted into a mobile unit. Mobile imaging technologies have the added advantage of being able to bring the necessary equipment directly to those in need [58–62]. These technologies include carrier, automobile, train, and more recently the proposal of an airship-based approach to bringing medical diagnostic imaging to where it is needed. Importantly, mobile units can still be cost-prohibitive if provided as an out-of-pocket service on the private market. In some regions of the world, medical transports will even take patients from the point of care to an imaging facility and return the patient after a test is complete in order to obtain a key diagnostic imaging test such as a CT in an urgent situation.

An approach to improving access to interpretive services that is increasingly emerging is through increasing adoption of digital imaging technologies. In the United States, the adoption of a PACS-based workflow is cited to have increased the productivity of radiologists by over 70%. Similar efficiencies could be obtained through adoption of technology in LMICs with the added advantage of decreasing reliance on costly and increasingly less available film technologies. With digital imaging, telemedicine solutions have the potential to redefine the regional care model of care services in radiology. Imaging equipment could be physically located where the patients are in need and interpreted by radiologists throughout the country [63].

Psychosocial and Other Non-insurance, Non-technical Factors

After building on an established infrastructure for radiology services by providing access to examinations and interpretive services, one must consider the more nuanced aspects of access. Will patients actually use these services? Do they know what they are for? Do they feel comfortable? The capital city of the United States of America has the highest breast cancer mortality in the country despite having access to exceptional breast cancer care. Although all women with "Medicaid"—the public healthcare system covering individuals with low income—in Washington, D.C. have perceived access to breast cancer screening by skilled centers that will perform the preventative study, one in five women presents with advanced stage 3 or 4 disease, and one in five women has not had a mammogram within the past 2 years [64]. One must consider the social and cultural factors of the local population in addition to perceived access to care in evaluating realized access. Levesque et al. identify five psychosocial/socioeconomic aspects of healthcare access as ability to perceive, ability to seek, ability to reach, ability to pay, and ability to engage [49].

Patients with socioeconomic challenges have increased barriers to healthcare [65]. One of the key barriers is access to information, which was previously demonstrated by phone ownership; however, a more modern example could be Internet access (which is now often synonymous with phone ownership in the era of mobile devices). Non-working poor patients are more likely to report transportation as an important factor in access to care. Disadvantaged patients also are more likely to report the healthcare system as "cold, unfriendly, and insensitive to their culture needs" [66]. Ahmed et al. conclude that "barriers to access are multiple, and having insurance mitigates but does not eliminate access problems" [65]. Effective efforts to improve access to underserved populations may need to address adequate communication, transportation, family issues, financial issues, and patient perceptions that trigger avoidance of available services.

In healthcare, the community perceptions of access and quality must also be taken into account. Thomas and Penchansky adapt their model of access and utilization in terms of patient satisfaction [67]. Perceived access can affect realized access by increasing the amount of patients who choose to delay or forego care. Kruk et al. describe village social interaction as a significant factor in women's choice of obstetrical care in rural Tanzania: "If local health centers and providers have a reputation for poor quality of care—particularly in the context of better opinions of traditional providers—women may be less likely to use them" [68]. Their findings indicated that proximity to a health clinic was not associated with delivery at the facility. The implication is that models of access that use time to care as a key measure could be inaccurate without taking social perceptions into proper account. Kruk et al. suggest this is not unique to women's care, but consistent with a commonly published phenomenon regarding community confidence and trust where "interactions are a key source of information about the ability of the health system to meet individual's needs" [68]. In assessing access to radiology services, one must consider the opinion of the service provider among both patients and also referring providers. Both groups may assess quality of equipment and interpretive services and have the potential to change utilization patterns based on these perceptions.

Halfon et al. focus primarily on identifying factors affecting access for children besides availability of insurance coverage [42]. They cite studies demonstrating empirical evidence that important factors include economic factors, educational factors, cultural factors, and infrastructure factors. Important economic factors include poverty, income, community mean income, residence, and family size. Cultural factors include ethnicity, birth order, mother's age, mother's education, parental use of healthcare, and family structure. Infrastructure factors include residential location, physician supply, and travel time to care. The effect of these socioeconomic factors has largely been studied on the basis of utilization. Utilization may be a better measure for accounting for access to service than availability alone because it accounts for these socioeconomic factors. Utilization, however, is still not the ideal measure for assessing access to imaging services because it is often the case that equipment is utilized despite lack of interpretative/reporting services. This is a difference between clinical medical care and diagnostic imaging. When clinical medical care is utilized, this indicates the care of a skilled provider for the patient. In diagnostic imaging, utilization of care does not necessarily indicate the consultation of a skilled provider. A similar paradox exists when medical care is provided in the absence of available pharmaceuticals. Halfon et al. echo that "much of the data and analyses currently available on access to care has examined utilization of physician services without reference to physician type or site of care" [42]. Children are a particularly vulnerable population because they do not often seek care individually and must rely on caregivers, which emphasizes the importance of socioeconomic factors in access to care for children. In radiology, it is important to consider the type of imaging service and the local experience with regard to pediatric imaging protocols and modality choices in order to understand the complete picture of access.

O'Donnell provides several examples of the realities of effective coverage and unrealized access [69]. Treatable diseases such as pneumonia, malaria, and diarrhea make up 52% of child deaths worldwide. In South Asia, fewer than one-half of women receive obstetrical care, and only one-fifth of children are born with medical supervision. In low- and middle-income countries, treatment for AIDS can be as low as 5%. It is estimated that child mortality could decrease by 63% worldwide if 99% of children had access to preventative services and treatment. Similarly increasing maternal care to the 99% level is estimated to decrease maternal mortality by 75%. Deficient seeking of available care is attested to be a factor in unrealized care in up to 70% of child deaths. The authors cite a study in Bolivia where 60% of fatal illness events occurred in children who never presented for available medical care. Similarly, in rural India there is little use of the public health system despite free access, which the authors attribute to perceived quality, noting that "the private sector alternatives are also of dubious quality." An important part of these deficiencies in care relates to access to information and local cultural factors. This might not be entirely unfounded as the authors point out that there is mixed evidence on the impact of primary care clinics on population health. An opportunity provided by access to diagnostic imaging services may be to boost the quality of point of care interventions through providing increased speed and accuracy of diagnoses. Access to interpretive services is essential to achieving the highest quality impact on healthcare outcomes through radiological services.

Derose and Varda provide perhaps the most inclusive review of the impact of communities and socioeconomic circumstances on healthcare access [70]. They investigate the concept of "social capital," defined as "generally tangible and intangible resources accrued to members of a social group as a result of social interactions." The concept of social capital has origins in sociology literature and ultimately has been compared to economic advantage of a community or a sort of collective capital or mutual benefit. There are also negative aspects of social capital that could be considered as side effects. Negative consequences of social capital include exclusion of unfamiliarity, excess claims, demand for conformity and restrictions on independent thought, and pressures restricting upward mobility of an individual. Implications for health policy must consider social capital because policy can influence whether social capital results in gains or losses in access to care. For instance, if the respected community leaders support efforts to improve access to imaging services, they are more likely to be successful. The first step to achieving access might therefore be understanding the goals and perceived needs of local policy makers. At the same time, access to information can help to shift individual views and augment outside influences.

Economics of Access

In order to achieve reliable long-term service over time, an economic model must be available that provides self-sustaining financial security to account for the cost of service. Examples of ongoing costs of radiological services provided to patients include use and maintenance of equipment and retaining necessary staff. Adequate remuneration either through direct fee for service by the patient, adequate health insurance, public health coverage, or a sustainable charitable model in order to assure continued availability of skilled technical services is essential. A previous study in Uganda, for instance, found that after eliminating patient fees, catastrophic healthcare costs did not decrease even though utilization increased. This was felt to be associated with the inability of free clinics to stock medications in the absence of fees. A similar phenomenon can occur in diagnostic imaging if a facility is not operational, even though it has equipment, or if an important finding was not recognized because no interpretive services were able to be provided for a study performed [71].

Suggestions for fee structures are offered by Russell and Gilson [72]. They suggest care centers retain decentralized control of fees in order to retain and use revenue to improve service quality; however, acknowledging this can create further inequalities if not paired with well-managed subsidies. Policies must encourage revenue translation into improvements that benefit the underserved. The goals of this measure are to increase perceived value of care and maintain utilization despite fees. It is also important to include exemptions where appropriate for those unable to pay. This aspect can be challenging, especially in developing regions where the majority may not be able to pay. There is also the challenge of the burden of proof for not being able to pay. One way to solve this is by allowing a separate local authority to make decisions regarding who qualifies for exemptions. It has been suggested that one way to quantify subsistence difficulty is housing quality and instability. Another method is to favor essential services such as maternal and child health for exemptions. However, there may be varying local and cultural views regarding what is considered essential. Local authorities could also be tasked with decisions regarding essential services. In their survey of 26 countries, the authors found the objectives of user fees reported in order of most to least common include to raise revenue, to improve service quality, to extend service coverage, to discourage unnecessary visits, and to encourage appropriate use of referral systems. Priorities for expenditures in order from most to least common include medical care, maintenance, equipment, staff incentives, additional staff, local community subsidy, and subsidy for poor patients. Traditionally, medical care would be pharmaceuticals or other treatments; however, in the case of radiologic services, the analogous key intervention is interpretive services. Key stakeholders to prepare and audit expenditures should include the hospital management team, executive expenditure committee, district accountant, and district health management board. A careful transparency structure is suggested in order to assure appropriate remuneration and expenses.

It would be difficult for individual outreach efforts or charitable funding to provide long-term reliable coverage of costs. Outreach efforts and philanthropy are difficult to scale at the pace of growing need [73, 74]. Therefore, it is inevitable that sustainable models for global access to radiology must acknowledge and consider remuneration within the public and private sector. Early and accurate diagnosis through diagnostic imaging provides more effective and targeted treatment of disease, which can decrease wasted healthcare dollars. Due to the intermittent and sometimes transient nature of charitable funds, these may be better utilized for intermittent costs such as procurement of new equipment or establishment of new services rather than maintenance of routine recurrent costs.

Approaches to the Access Equation

One of the early modern measurable definitions of access to public medical services is from experience during early adoption of public medical care insurance in Canada—the inverse of the proportion of families of a given economic class who have not received physician services in a given year [75]. The two-step floating catchment area method (2SFCA) is a geographic approach to quantifying spatial access through distance to a care center, which was recently demonstrated through application to the rural population of Victoria Australia [19]. Geographical analysis of spatial availability is also helpful for public health planning in urban areas which have similar challenges to rural areas in terms of resources per patient and typically have greater social inequalities [76]. Differences in methods influence results and should be carefully applied when using geographical analysis to the proper circumstances. Factors to consider may include the distance type (such as Euclidean distance, Manhattan distance, shortest network distance, or shortest time), measure of accessibility (such as immediate proximity, availability within one area unit, availability provided by immediate surroundings, average cost to reach all destinations, and average cost to reach diversity), aggregation methods and spatial unit of reference (such as residential census tracts or census blocks). Thinking about variables in this way quickly highlights why infrastructure improvements might decrease travel time even to more distant care centers.

A progressive definition of access is offered by leaders at the United States Department of Veteran's Affairs based on the work of Penchansky and Thomas, "as a set of specific dimensions that characterize the fit between the patient and the healthcare system" [41, 77]. This definition provides a mechanism to integrate various dimensions of access and account for emerging components over time. It is suggested that assessment of access in modern healthcare should consider both actual and perceived access and incorporate geographical, temporal, financial, cultural, and digital factors.

The WHO suggests a definition for the access problem as "effective coverage," which they define as "the fraction of maximum possible health gain an individual with a health care need can expect to receive from the health system." They suggest that factors involved in assessment of effective coverage include human capital, economics, physical planning of infrastructure, and quality assurance, among others. One of the key indicators they identify for quality is making the correct diagnosis when the patient presents, enabling the proper intervention strategy and application of appropriate clinical standards [78]. Finally, a forward-looking, termed "ex ante," view of coverage is perceived to increase effectiveness of overall public health planning because it evaluates the potential health gain of the system for those who may become in need. This is as opposed to the "ex post" view which is a retrospective lens. Shengelia et al. propose to quantify effective coverage (EC) for patients (i) by an intervention (j) in terms of quality (Q) of the care for the patient (i) by the intervention (j) and utilization (U) as the probability of a patient (i) receiving a care (j) from any available providers and the patient's (i) need (N) for the care (Eq. 3.1) [78].

Equation 3.1

$$\mathrm{EC}_{i,j} = U\left(i, j|N\right).Q\left(i,j\right)$$

$$i = \text{Patient}_{id}$$

$$j = \text{Intiervention}_{id}$$

$$N_{\text{Pt,Intervention}} = \begin{array}{l}\text{Need of Patient}_{id}\\ \text{to have Intervention}_{id}\\ \text{at this encounter}\end{array}$$

$$N_{\text{Pt,Intervention}} \in \left[0,1\right]$$

$$\begin{array}{l}U\left(\text{Patient, Intervention}|\text{Necessity}\right)\\ = \text{Probability of recieving Intervention}_{id}\\ \text{by Patient}_{id} \text{ given the necessity of } N_{\text{Pt,Intervention}}\end{array}$$

$$U\left(\text{Patient, Intervention}|\text{Necessity}\right) \in \left[0,1\right]$$

$$\begin{array}{l}Q\left(\text{Patient,Intervention}\right)\\ = \text{Quality of specific service}\left(\text{Intervention}_{id}\right)\\ \text{recived by specific patient}\left(\text{Patient}_{id}\right)\end{array}$$

$$Q\left(\text{Patient,Intervention}\right) \in \left[0,1\right]$$

Much of the public health literature acknowledges the measurement of quality of care is perhaps the most challenging critical factor of effective access [78]. In the absence of an accurate measure of responsibility for patients by providers, interpersonal relations known as "responsiveness" of providers may be used as a proxy for quality by communities [78–82]. Therefore, WHO also provides us with a formal equation for quality as the "health gain" (HG) for a patient (i) having intervention (j) from provider (k) and the probability that the person will choose a particular provider for an intervention (U_{ijk}) based on perceived need. Provider behavior is further subdivided into diagnostic ability, choice of management, and the management effect itself (Eq. 3.2). Their work can be extrapolated to a population of individuals and also to the maximum potential health gain for a system (Eq. 3.3a, b). Radiology fits into the equation by improving objective provider quality through improving accuracy and time of diagnosis and helping to ensure effective and efficient management through skilled consultation. The effect on diagnosis depends on the effectiveness of the test (theoretical accuracy), the skill of the interpreter (actual accuracy), the receipt of a consultation (typically in the form of a report), and the ability to understand and act on the consultation appropriately. Organizations interested in the public health applications of diagnostic imaging should become familiar with methods in which to measure and distinguish potential access from realized access.

Equation 3.2 Optimal health gain assuming quality is 100%

$$Q_{i,j} = \frac{\sum_{k=1}^{n} \mathrm{HG}_{i,j,k}.U_{i,j,k}}{\left(\sum_{k=1}^{n} \mathrm{H.G}_{i,j,k}.U_{i,j,k}|P_k = P_k^{\max}\right)}$$

Equation 3.3 (a) Effective health gain for an individual. EC = effective coverage.

$$\mathrm{EC}_j = \frac{\sum_{i=1}^{n} \mathrm{EC}_{i,j} \mathrm{HG}_{i,j} \Pr\left(N_{i,j} = 1\right)}{\sum_{i=1}^{n} \mathrm{HG}_{i,j} \Pr\left(N_{i,j} = 1\right)}$$

(b) Effective health gain at the system level.

$$\mathrm{EC} = \frac{\left(\sum_{j=1}^{n} \mathrm{EC}_j \mathrm{HG}_j | P_k = P_k^{\max}\right), \forall k \in \{1, 2, \ldots, n\}}{\left(\sum_{j=1}^{n} \mathrm{HG}_j | P_k = P_k^{\max}\right), \forall k \in \{1, 2, \ldots, n\}}$$

Equations 3.1, 3.2, and 3.3 reproduced from [78]. Reprinted from *Social Science & Medicine*, Vol 61/Issue 1, Shengelia B, Tandon A, Adams OB, Murray CJ, Access, utilization, quality, and effective coverage: an integrated conceptual framework and measurement strategy, p. 97–109, Copyright (2005), with permission from Elsevier.

Discussion and Conclusion

In the emerging modern understanding of access, several factors have been identified that contribute to realized access in addition to the traditional evaluation of availability in terms of *distance* to a resource. *Transportation* infrastructure can result in a patient who is traveling by car, bus, or train having easier accessibility to a more distant health service than the patient traveling on foot has to a closer health service. The *time from the request* for a healthcare service until the service is available and the *value/urgency* of the need for service are other important factors in regard to accessibility and availability.

Affordability can be thought of as the economics of access. Affordability is a function of *out-of-pocket expenses*, *income after essential expenses*, and *time consumption* in obtaining care. Out-of-pocket expenses are the direct cost to the patient for services. Income available after necessary costs such as housing and food provides a measure of the burden of the out-of-pocket costs. Time consumption is the time that it takes for a patient to arrange for services including scheduling requests, travel time, and time spent to receive the service. Time consumption reduces the patient's ability to perform other work on personal tasks and therefore represents an additional cost.

Acceptability is the psychosocial aspect of access. Acceptability is a function of *social capital*, *emotional cost*, and the *value perception*. Social capital costs reflect the acceptance of a healthcare service by a community. For instance, concerns regarding radiation safety have led some patients to avoid medical imaging services involving X-rays. It is important to point out that this measure reflects the community's perception rather than a ground truth. Some communities might not realize that ultrasound does not involve X-rays and therefore avoid prenatal screening for mothers. Educational resources may help to normalize the acceptability of healthcare technology across communities; however, there will likely always be some distinct cultural differences. Emotional cost factors in the mental costs of the experience of healthcare delivery. A patient may not seek available healthcare services if they feel they will be mistreated. Value perception is affected by both the patient's perception of quality of service and also the perception of urgency for a given healthcare need.

The ten factors discussed above encompass the core measures for evaluating healthcare accessibility as defined in the modern literature. These factors can be considered a cost index. In review, these ten factors include distance, time available, transportation, time optimal/urgency, time consumption, out-of-pocket costs, monthly income minus necessary food and housing expenses, emotional cost, community/social cost, and value perception (urgency perception/quality perception). In addition to the cost index, a measure of service quality also factors into the healthcare access equation. If the quality of service is poor, then even services with a low overall cost index will not provide realized access. The quality measure can be thought of as a service index that depends on the components of a healthcare service. The service index for diagnostic imaging encompasses image acquisition and image interpretation. Both the cost index and the service index can be combined to form an overall equation for access. (Eq. 3.4).

Equation 3.4

$$\text{Access} \cong \text{Accessibility} \otimes \text{Service\_quality}$$

$$\text{Accessibility} \cong \text{Availability} \otimes \frac{\text{Purchase Power}\left(\propto \text{Surplas Income}\right)}{\text{Cost}}$$

$$\text{Availability} \approx \frac{\text{Time}_{\text{optimal}} : \text{optimal time to recieve the service given specific medical condition urgency}}{\text{Time}_{\text{poc}} : \text{estimated time to reach Point\_of\_Care}}$$

$$\text{Time}_{\text{poc}} \cong \frac{1}{\text{Distance}} \odot \frac{1}{\text{Quality}_{\text{transportation}} : \text{efficiency and quality of the transportation infrastructure}} \text{Cost}$$

$$\cong \text{cos t}_{\text{economic}} \oplus \text{cos t}_{\text{psychologic}} \begin{cases} \text{cos t}_{\text{economic}} : \text{out of pocket cost to reach the center and recieve the service and go back} \\ \text{cos t}_{\text{psychologic}} : \dfrac{\text{Emotional cost and social cost to recive the service}\left(\text{e.g., social acceptance, shame, } \ldots\right)}{\text{Percived Value : How much patient believes there is utility for this procedure}} \end{cases}$$

In light of the pervasive presence of imaging technology in the healthcare system in more privileged parts of the world, it is easy to take for granted a technology that remains so difficult to provide in much of the world. The first step in attacking this problem is looking at the various surveys conducted by the WHO. A clear disparity exists in the access to medical imaging technology, among all modalities, between the developed and the developing world. This needs-based assessment is the foundation for uncovering the overall gap in available imaging technology. The next step is to understand the various factors that contribute to a more complete definition of "access." With this information, all parties involved, whether radiologists, radiologic technologists, sonographers, nongovernmental organizations (NGOs), ministries of health, or LMICs, will be able to join forces to close this gap.

Imaging technology, technological resources, reliability, utilization, interpretative services, reporting services, and communication services should all be considered in assessing access to diagnostic imaging services. As access to medical care demands more than access to a laboratory test, access to medical imaging relies heavily on adequate human resources in addition to adequate technology. As medical imaging technology is becoming more ubiquitous, human resource demands are an important and often overlooked bottleneck to achieving adequate access. Appropriate infrastructure investments and new decentralized and asynchronous medical services ("telemedicine" and "teleradiology" services) made available by the expanding presence of the Internet throughout the world are key emerging solutions to the human resource problem. While there has been much effort by the international community, WHO, and public health research to better understand access qualitatively and quantitatively, Halfon suggests, "The essential challenge is not obtaining the knowledge or tools necessary to achieve these objectives, but developing the policies and political will that can accomplish the task" [42]. Perhaps the best recipe for improving access to the full spectrum of medical imaging is simply collaborative concerted effort together edging closer toward this goal [83, 84].

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4 Medical Ethics in Global Health Radiology

Sarah L. Averill, Farouk Dako, and Janet H. Pollard

Introduction

> Ethics demands that we are explicit about our moral frameworks and our choices, and that we explicitly explore the consequences that arise from these [1]. —James Orbinski
>
> Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control.
>
> —UN Declaration of Human Rights, Article 25 1948

If you are reading this book, chances are you recognize and are deeply troubled by the enormous economic disparity across the world and its impact on health. To give just one example of this fact, life expectancy in Canada is 80 years and still rising, while in parts of Africa it is as low as 40 years and declining [2]. Many determinants of health are a function of socioeconomic factors including income and social status, education, physical environment, social support networks, and health services [3]. Even now, 70 years after the UN Declaration of Human Rights, we are still grappling with an ever-widening gap between rich and poor and healthy and unhealthy. As the global economy continues to grow, and while medicine and technology continue to improve, it is impossible to engage in radiology outreach efforts without immediately confronting the larger social and geopolitical theatre of social and economic inequality; we must begin asking questions about the origins of these inequalities. Global health advocacy must persevere if there is any hope of closing this divide.

Outreach efforts are naturally beset by difficulties and can face ethical dilemmas that stymie progress. No individual or group is immune, no matter how well intentioned or prepared. Anticipating issues and their solutions can make for a better experience, but many situations cannot be predicted and rarely have simple correct answers. This chapter seeks to introduce concepts of medical ethics and useful resources to help with recognizing ethical dilemmas and understanding the ethical underpinnings of various courses of action [4]. Several case scenarios from our own and others' experiences are presented and discussed with respect to ethical principles and resources. Inasmuch as none of the chapter authors have specialized ethics training

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beyond self-motivated inquiry, we offer this chapter not as a definitive guide but as an acknowledgment of the importance of ethics in the reflective, appropriate care of patients in global radiology outreach.

Classical Medical Ethics

Ethical frameworks, though limited, can help us understand norms of practice in clinical and educational work. The four principles of *autonomy*, *beneficence*, *nonmaleficence*, and *justice* are widely taught in Western medical education. In addition to these principles, there are other principles and norms of practice such as *informed consent* and *truth telling*.

Autonomy refers to self-governance and freedom of choice. This is a central concept to obtaining informed consent for clinical procedures and research studies which supports the principles of truth telling, patient decision-making, respect for privacy, and protecting confidential information. Informed consent for procedures and research requires adequate information and understanding; otherwise, consent is not truly autonomous [5]. However, unyielding insistence on autonomy has its criticisms, even from within Western culture, where there is recognition that placing the full burden of medical decisions on the patient can be frightening and isolating. There is growing advocacy for the patient's right to choose whom they prefer to make decisions on their behalf [5, 6].

The principle elements of formal informed consent are competence, disclosure, understanding, voluntariness, and consent itself [5, 7]. For research purposes it is thorough and ideally documented in writing. In the clinical setting, informed consent is applied with varying degrees of rigor depending on the circumstances. When performing a physical exam or very minor procedures, consent is obtained almost without notice. In the United States, consent for complex and risky procedures mirrors the rigor of the consent process used in research, owing to the medicolegal situation. Standards of practice in low- and middle-income countries (LMICs) for such procedures are not uniform and do not always entail written documentation. That being said, whether they *should* is an unsettled matter. In resource-rich settings, written consent is easily achieved but can be unreasonably burdensome in LMICs with limited resources. In addition, patients may be skeptical of lengthy documents, seeing them as potentially deceptive or coercive. Bhutta in *Beyond Informed Consent* advocates that processes for informed consent should be adapted to a health-care environment's resource level and population's cultural practices [7].

Autonomy is counterbalanced by other ethical principles such as beneficence and nonmaleficence, because unbridled autonomy and personal choice can sometimes adversely affect others [5]. Beneficence refers to doing good, whereas nonmaleficence and the principle of primum non nocere ("first do no harm") come into play with unintended adverse consequences of well-intentioned actions. Justice or fairness informs much of the work of global health in its attempt to redress inequity.

Whether these classical principles can apply globally in all cultural and geopolitical settings is debated. Universalist views of ethical theory contend that these principles should hold up everywhere, whereas the relativist view contends that there is no universal ethical principle that all humans must follow [8]. Increasingly, voices from various nations and cultures have emerged to challenge the notion of universal applicability of classical ethical principles. Alora and Lumitao in *Beyond a Western Bioethics* argue that autonomy as conceived in the West is not adaptable to their home country of the Philippines and by extension cannot be adapted for general applicability in other parts of the non-Western world. For the Philippines, they propose a culturally informed framework of medical ethics that values family and community more than the autonomous individual as well as strong extended family ties, deep religious faith, and respect for authority [9]. For some cultures, truth telling and full disclosure, such as revealing a grave diagnosis to a patient or discussing the risks of a procedure, are at odds with social norms. Traditional Navajo tribespeople in North America, for example, believe that language has the power to shape reality, and negative information such as the risks of a procedure (even if low probability) carries with it the potential to cause true harm [5]. Some scholars caution that the notion of cultural incompatibility of truth telling, such as holding back grave diagnostic information, leads to paternalism. Tulga Guven, in her article on truth telling to cancer patients in Turkey, argues that sensitivity to cultural differences does *not* exempt providers from reflecting critically on patient's wishes to receive or not to receive information [10].

The dispute between universal and relative moral values can be accounted for at least in part by the differences between descriptive and normative ethics [2]. *Descriptive ethics* pertains to observed differences in how people actually behave which determines acceptable moral behavior in various communities [2, 8]. *Normative ethics*, rather than observing and describing, critically reviews moral norms of conduct and considers what we *should* accept [2, 5, 8].

What Is Global Health?

Global health in general terms is a field that seeks to address health problems across national borders. Others define it more specifically as a field that addresses the health of marginalized populations across the world and engages with the social, economic, and political determinants of health that lead to inequalities in resource distribution and health [11]. One of the distinctive features of global health is a commitment to entering into "true" partnerships with poor countries [12]. The Universal Declaration of Human Rights and the Declaration of Alma Ata view healthcare as a human right. Health as a human right is what rights theorists call a *claim right*. By the widely agreed-upon structure of rights, any claim right has a *correlative duty* that is assigned to at least one other party [5, 13]. On the subject of the interrelationship of rights and duties, Benatar expresses concern that there has been "inadequate attention" to the intimate connection between rights and duties and that our "ability to enjoy rights is...determined by our willingness to accept our responsibilities" [2]. A focus on duties and responsibilities could expose the responsibilities of both wealthy nations (and individuals) and poor nations alike and elucidate the ways in which they undermine the potential flourishing of people in LMICs [2].

Global Health Ethics

Global health ethics offers a rationale for the beneficence and mutual caring that underpins the work of organizations seeking to reduce health and resource inequity for marginalized people. Global health ethics modulates the familiar principles of medical ethics for cross-cultural use [8]. In addition to classic medical ethical principles, a framework of global health ethical principles includes: (1) *respect for all human life;* (2) *human rights, duties, and needs;* (3) *social justice;* (4) *equity;* (5) *freedom* to do and *freedom from* want*;* (6) *participatory democracy;* (7) *environmental ethics;* (8) *solidarity;* (9) *humility;* and (10) *introspection* [8, 14]. Pinto and Upsher frame global health practice as a learning cycle that engages all participants at every level of experience. The cycle begins with an individual's *orientation* to a subject or problem and involves questioning and information gathering. This is followed by the *visceral experience* of being present in the field. The challenges of the experience inspire *humility* and stimulate *introspection* and *self-reflection* which in turn lead to the *continual learning* and relearning of global health [15].

Solidarity is one of the most important global health ethical concepts. Solidarity is rooted in social democracy and linked to notions of common interest and mutual support through working with others [2]. This contrasts sharply with *individualism*, a concept central to individual and political rights [2, 16]. Solidarity among individuals develops through increasing empathy and humility. In global health, solidarity begins with the interpersonal physician-patient relationship and extends more broadly to engage socially and politically at local, state, and international levels [2].

The growing worldwide gap between the rich and poor has led some to advocate for greater *distributive justice,* that is, the legal and economic framework by which a society distributes its social services, economic goods, rights, and responsibilities [8]. Theories of distributive justice—such as utilitarianism, egalitarianism, cosmopolitanism, libertarianism, among others—describe distribution of resources based on material principles such as need, effort, contribution, merit, and free market exchange [5, 8]. *Social justice* is a related concept and in global health refers to the goal of equal distribution of determinants of good health while upholding human rights [8].

Global outreach efforts can create unintended consequences that may subvert the good intentions of a project. The ethical principles of *nonmaleficence*, *humility*, and *introspection* come into play while analyzing these situations and learning from them. A large body of literature exists with respect to unintended consequences at the individual, institutional, and organizational level and the potential population-level harms that can result from the diversion of resources from basic population care. For example, rationing a limited resource risks reinforcing the historical unjust patterns of distribution, maintaining the status quo that serves the elite rather than the impoverished in a host country. Another example is diversion of limited resources from one health need to another without weighing the relative importance of one need over the other. The diversion of resources on a smaller scale as in short-term medical missions and clinical electives is also an important ethical consideration. Host country clinicians have limited time for patient care and for the supervision of trainees and medical teams not familiar with patterns of disease in the host country; this can unduly burden clinic resources [16]. Robert Merton theorized that unintended consequences of purpose-driven social action arise from at least three sources: knowledge asymmetries (such as when doctors might misunderstand a language dialect or cultural nuance), rigid habits (such as failing to embrace or recognize the merits of local health-care practices and customs), and "imperious immediacy" (emergency responses that by their nature have moral urgency but which due to their inherently unpredictable nature can have long-lasting and unforeseeable consequences) [17].

Global Health Ethics in the Research Setting

Research is a key component to closing the international health-care gap and developing sustainable health services across the world. Data-driven projects span the gamut from quality improvement activities to well-funded transnational clinical trials. Essential elements of ethical research are (1) value (to health and science), (2) scientific validity, (3) fairness of subject selection, (4) favorable risk-benefit ratio, (5) independent review, (6) informed consent, and (7) respect for enrolled subjects [18]. The Council for International Organizations of Medical Sciences (CIOMS) and the WHO have jointly produced a useful manual for ethical research with the aim of protecting the welfare of individuals, communities, and vulnerable populations [19].

Independent scientific and ethical review should be conducted by boards in both sponsoring and hosting countries [6, 19]. However, the resources for this review vary considerably across the world due to scarcity of funding and trained personnel. A 2002 study revealed that out of 203 low-income country (LIC) and low- to middle-income country (LMIC) researchers who responded to a survey, 44% reported that their projects were not reviewed by any review board or ministry of health [20]. Barriers to seeking independent review also include lack of familiarity with the host country's health and regulatory system, language barriers, and the perception that a review could be overly time-consuming [21].

Projects should be sensitive to a community's culture and health needs and should honor subject privacy [19, 22]. As discussed previously, informed consent is essential to all human subject research, though the process of obtaining consent varies across cultural settings [21]. Informed consent is intended to minimize risk of coercion. Economic and health disparities encountered by researchers in resource-poor countries can transform what seems to be routine financial and health-care incentives into coercive forces. Language and cultural barriers also hamper true informed consent [23].

Not all forms of health-related investigation constitute research that requires ethical and scientific review. Quality improvement (QI) activities, although data-driven, do not require this same oversight due to the fact that these activities are generally very low risk and are a normal part of health-care operations [24, 25]. The CIOMS-WHO's *International Ethical Guidelines for Health-Related Research Involving Humans* (2016) defines research as "activities designed to develop or contribute to generalizable health knowledge within the more classic realm of research with humans, such as observational research, clinical trials, biobanking and epidemiological studies. Generalizable health knowledge consists of theories, principles or relationships, or the accumulation of information on which they are based related to health, which can be corroborated by accepted scientific methods of observation and inference." QI activities on the other hand are "not intended to generalize knowledge but to improve care for a specific population, usually in a limited application. It is a process of self-monitoring and self-assessment. Results are applied in an effort to improve a process or practice. Trends are monitored with process improvement tools" [26]. QI methodology such as the plan-do-study-act (PDSA) cycle produces knowledge but not with the same rigor required of academic research [27]. Some projects at the interface between research and QI are difficult to categorize.

Confidentiality is an important part of health-related investigation due to potential harm, stigma, or distress that misuse of data could cause [19]. As such, there is growing consensus worldwide that patients and research subjects have a right to privacy and confidentiality. Legal and regulatory protections, however, vary around the world and across jurisdictions. Even in the absence of laws and regulations, the norms of patient confidentiality are often observed [28].

Global Health Ethics in Radiology

Efforts over the last 50 years have focused largely on primary care initiatives based on cost-effectiveness and the preferences of leaders in the aid enterprise [29]. Involvement of radiologists in global health outreach is a relatively new phenomenon. Widespread uptake of radiology in LMICs has been hampered by unreliable infrastructure, the high cost of implementing and maintaining imaging systems, the lack of personnel trained in safe operation of these systems, and the lack of competent personnel to interpret studies generated by the systems. Projects aimed at bringing expensive, sophisticated diagnostic and therapeutic tools to resource-limited settings must also recognize the reality of diverting limited economic resources toward medical tools which will benefit a small number of the population. Given the severely constrained access to radiology in most of these settings, questions of allocation, priority setting, and rationing are nearly universal across radiology outreach initiatives. These reservations notwithstanding the severe shortage of radiology services and other highly technical health-care services in the developing world represent one of the largest and most challenging gaps between the rich and poor around the world. This enormous disparity underlies the moral imperative that drives outreach efforts of organizations such as Imaging the World, Federation for Ultrasound in Medicine and Biology, and RAD-AID International.

Another unique and important consideration in radiology outreach is the safe use of radiation, ultrasound, and MRI. Although radiation protection across the globe is guided by recommendations from the International Commission on Radiation Protection (ICRP), in practice the application of these recommendations rests with the operators themselves where local and national regulations and their enforcement may be nonexistent. Relatively little scholarship has been done in the ethics of radiation protection. Malone and Zolzer suggest that this may be due to relatively low recognition of radiation protection as an issue in the wider medical world and that even where recognized, there persists a misconception that the mere existence of the ICRP's international standards and the presence of a handful of radiation protection specialists around the globe are sufficient to protect patients [30]. The radiation protection principles, including justification for exams, optimization of exams, and limitation of radiation dose when possible, are underpinned by several ethical concepts which Malone and Zolzer propose as a framework for approaching ethical dilemmas in the clinical radiology setting that adds *prudence*, *precaution*, *honesty*, *transparency*, and *openness* to the classical medical ethical principles [30].

Case Scenarios, Questions, and Discussion

Case Scenario 1

Louisa, a US radiology resident, traveled to Nicaragua for a 2-week elective with a faculty radiologist from her institution. Over multiple trips, the US team developed good rapport with the Nicaraguan medical staff at a nonprofit women's health clinic. The team's objective was to improve early breast cancer diagnosis by teaching local general practitioners the skills necessary to image and biopsy suspicious palpable breast lesions using ultrasound.

The training was conducted using equipment that had been previously donated to the clinic including a laptop-sized ultrasound unit with a damaged transducer that produced artifacts at the edge of images, biopsy needles, and other supplies. The visiting team brought gelatin breast models with embedded objects. They closely monitored trainees as they learned to handle the transducer and target "lesions" with a biopsy needle. The team taught clinical breast exam and imaging techniques on live patients as they presented to the clinic with breast complaints. Toward the end of the visit a patient with a suspicious breast mass presented, the first person in 2 weeks that seemed to have an indication for biopsy. The mass was large and it was immediately apparent that it was cancer, due to findings on exam and ultrasound imaging which showed cancerous features, chest wall invasion, and regional lymphadenopathy.

The group agreed that biopsy was certainly feasible. The local health infrastructure included pathology and surgical services, but chemoradiotherapy was not available locally and would require travel and long-term lodging in the distant capital city. The conversation switched to Spanish as one of the local physicians discussed the possibility of biopsy with the patient and her two adult daughters. Louisa could understand Spanish and squirmed at the prospect of biopsy which was presented as an "opportunity" while a "health brigade" (the US team) was on site and that it could lead to treatment. Louisa knew that the advanced state of disease and its grave prognosis as well as the risks of biopsy had not been discussed, as she was accustomed to in the US. Louisa felt uncomfortable voicing her concerns about the potential risks and futility of care.

Consent was given and the trainees eagerly set up for a live biopsy. The skin was prepared with antiseptic cleanser. An unfolded paper envelope from a set of sterile gloves served as a makeshift field for needles and a biopsy device. A condom substituted for a sterile probe cover. The skin was numbed with lidocaine from a multiuse vial. Then someone asked for sterile gel. There was a pause, then a scramble, and sadly none was found anywhere in the clinic.

The team resorted to non-sterile gel and chose a far-lateral needle approach so as to minimize contamination. Unfortunately, in the midday heat, the gel slid toward the needle entry site threatening the sterile field. The condom cover also slipped down the neck of the transducer breaking the sterility of the trainee's gloved hand. Louisa watched all this, gut churning. Finally, biopsy tissue samples were obtained.

Discussion

This scenario illustrates a short-term clinical project including education and training, a common way for health-care professionals to engage in global health.

1. What technical standards should be applied in settings where resources are limited? Do the benefits of biopsy outweigh the risks? Does the risk of contamination justify aborting the procedure? Would the answer differ depending on the setting?

In resource-poor settings, creative repurposing of available resources serves as a reminder that much can be done with little, which underscores the ongoing enormous waste present in resource-rich countries. Be that as it may, this scenario demonstrates that when resource limitations are greater than anticipated, the risk of harm increases, potentially violating the principle of nonmaleficence. In this case, the risk of bacterial infection increased when the sterile field was broken. Moreover, the patient's presumptive diagnosis carried a dismal prognosis further complicated by issues relating to accessing oncologic care in a distant city.

Some may argue that the biopsy should not have been offered given the prognosis. Others may argue that the team should have aborted the procedure given the risk of infection. Stepping back further, the argument that the visiting team should not have offered training using suboptimal equipment such as a damaged transducer could also be made.

On the other hand, some could counter that the risk of infection from a superficial biopsy is low and likely treatable, and to do nothing until the clinic's equipment and supplies matched that of high-income countries would compound the injustice of existing health-care disparities. An open discussion of a presumptive cancer diagnosis and short life expectancy could violate cultural norms. In addition, rescheduling the procedure so as to procure sterile gel could result in no biopsy at all. Prolonged time off work, long travel, and overnight lodging, for example, could overwhelm a patient's meager financial resources. Lastly, some may argue more broadly that an opportunity for teaching biopsy skills contributes to the greater good of making biopsy available to more people.

Detailed advance preparation such as preliminary site visits for assessment of resources or preparing a checklist of baseline necessities for a procedure can address some situations. In reality, circumstances can change rapidly, so this approach is naturally imperfect.

2. Was informed consent adequate in this case? What are the essential elements of consent? How should the team approach consent and truth telling with patients in different cultural settings? Should friends and family be involved or should the decision rest solely on the patient?

Based on the cultural norms in the United States which are driven by medicolegal risk, informed consent must include a thorough discussion of risks and benefits and be documented in writing. In this scenario, verbal consent was obtained from the patient with input from her daughters, which is within the norms present in Nicaragua. However, Louisa was worried about the adequacy of the information shared during the consent process and if the patient's decision was truly "informed" and autonomous. As discussed earlier in the chapter, consent practices are not uniform in clinical practice across cultures. Knowledge of social and institutional norms can be helpful to allay anxiety about appropriate times to speak up on a patient's behalf. However, one must also be careful that what is accepted as standard practice in one clinic may not actually be normative for that country. Speaking up in such cases may prove even more challenging and seeking expert opinion can be helpful.

Consideration should be given to the following questions about standards of informed consent before traveling in order to clarify and appropriately involve patients, family, and clinic staff in the consent process and to avoid misunderstandings: (1) What is the local process for obtaining informed consent? (2) Who is allowed to give consent? (3) Are there social or cultural obligations that need to be respected, such as involvement of family members, or even community and religious leaders? (4) How much medical information is acceptable to share directly with the patient and/or participants in the consent process?

3. What are the ethical obligations of the visiting radiology outreach team with respect to

addressing the lack of sterile gel and other essential resources in the clinic? Does recognition of resource limitations impose a duty to assist by ameliorating the lack of resources at the clinic, regional, or national level? If so, are the duties of a health-care provider the same or different than that of an ordinary citizen?

Broadly speaking, Western medicine has been reluctant to engage with these difficult questions, which are often regarded as too political [8]. In her essay, *Bioethics, Philosophy and Global Health*, Maria Merrit asks us to consider that we are "routinely accepting, participating in, and benefiting from the institutions that regulate global trade, labor, finance and other features in the background of severe chronic poverty" and that by embracing this system, we are neglecting our *duty to give assistance* and are thereby harming the poor [13].

On the local clinical level, these questions are equally important. This matters for radiology outreach teams because of the difficulty in providing adequate radiology services in the absence of basic necessities (e.g., sterile gel, soap, reliable electricity, etc.). Radiology teams must also be aware of the interconnectedness of the health-care delivery system which may be forced to divert resources away from basic services to advanced technological services. Rather than leaning on duties of benevolence and charity, Ashford in her article "*The Duties Imposed by the Human Right to Basic Necessities,*" as explicated by Merrit, argues that access to basic necessities is a human right that has correlative duties which can be imposed not only on institutions, such as governments, but also on *all* affluent individuals "because the condition of affluence itself puts one in a causal position to help alleviate severe chronic poverty" [13]. The arguments are laid out in greater detail in the remainder of Merrit's essay, which concludes there is a moral duty to take action [13].

If we accept a duty as ordinary citizens of a global world, what practical actions should we take? Giving money to organizations is one way to meet this obligation and has been discussed at length by Peter Singer in *The Most Good You Can Do* [31]. Ford argues for engagement in global advocacy and provides a framework drawing on policy analysis and case studies of several effective campaigns [32]. With respect to donations of medical/surgical devices and medication, there are guidelines available from the WHO as well as a chapter within the current textbook which can serve as a reference when planning volunteer efforts and soliciting donations of necessary equipment to safely teach and practice [33].

In this case scenario, we propose that the team's mission to teach ultrasound-guided biopsy entails procurement of all related basic necessities including gel if none are available. In this case, lack of sterile gel caught the team by surprise. Whether this represented a momentary or chronic shortage for this clinic is uncertain. Advanced preparation by making a detailed supply list and traveling with basic necessities where practicable can be helpful in dealing with such uncertain conditions. Using the Radiology Readiness Assessment tool as a preliminary site assessment tool can also help identify these deficits.

Case Scenario 2

An interventional radiologist, sonographer, and senior radiology resident from a US academic radiology program conducted a week-long workshop on ultrasound-guided interventional procedures for radiology residents at a hospital in Nigeria. The workshop consisted of phantom-based simulations of superficial biopsies, central vein access, thoracentesis, and paracentesis. Until this point at the hospital, thoracentesis had been a two-person job, relying heavily upon the radiologist handling the ultrasound transducer and identifying a fluid pocket and a surgeon placing a chest tube. The procedure drew heavily upon human resources, so the trainees were interested in learning how to place the needle themselves without the involvement of surgeons.

At the end of the workshop, a Nigerian resident trainee and local radiology faculty member decided to call for a patient they knew of with a pleural effusion so as to practice the thoracentesis technique. The resident had not yet tried the procedure on a phantom. The US team was alarmed, questioning the trainee's readiness to practice on a live person, and tried unsuccessfully to stop the procedure. Their home institution had stipulated that the lectures and trainings should not involve live patients. At this point, they felt they had two options: either to leave the room so as to avoid witnessing the procedure or to stay and help supervise. They chose to stay. When the patient arrived, there was no medical chart or recent lab values (such as international normalized ratio [INR] or platelets). Someone noted the patient had had a recent thoracentesis without complications, so the labs were assumed to be acceptable. To the visiting team, it was unclear if the procedure was clinically necessary or purely for training. The local physicians and the patient communicated in a local language without translation, and the patient apparently agreed to the procedure.

Discussion

1. How can visiting teams set boundaries during their training workshops while respecting local physician autonomy and regional differences in acceptable medical practices? To what extent is the team responsible for local patient safety and safe conduct of the procedures they taught during the workshop?

Institutions sponsoring outreach programs have a responsibility to ensure that benefits are maximized and harms minimized for all stakeholders [34]. The timeframe for this responsibility is not clearly established.

In this scenario, the visiting team's contribution of time, skills, simulation exercise, and supervision was therefore likely welcomed as a great benefit but one that would be available for only a short time. Despite the visiting team's alarm, the local trainees and their local supervisor chose to pursue a new skill on a live patient. In a setting with few resources and limited time with visiting instructors, their eagerness to seize the learning opportunity is understandable. The visiting team's reaction is also understandable. In high-resource settings, the transfer of procedural skills is more involved than merely "see one, do one, teach one" and requires observation of procedures followed by progressive practice under supervision. In some high-resource settings, simulations are utilized before procedures are performed on patients, but establishment of a formal skills training lab with procedure simulators is costly and beyond reach throughout most of the world.

The time constraints imposed by short-term outreach trips for skills training pose an ethical dilemma across specialties. A growing number of voices in the humanitarian outreach community call for more sustained involvement as well as teaching and transferring skills rather than supplanting and undermining local practitioners [35–37]. This process requires needs-based assessment, collaboration, and relationship-building which take time and commitment over repeated trips [36]. Regardless of the approach, relationship-building with local stakeholders is important to prevent the perception of "dumping" when complications occur as a result of procedures being performed in the hands of trainees not accustomed to doing them [35].

Averting the awkward and frightening situation in this scenario in the heat of the moment may not be possible. Local physician faculty are accustomed to making decisions; visitor interference could seem arrogant and could damage the relationship. Tactful management strategies for future encounters might make this scenario less likely to occur again. Laying out the goals and methods for assessing competency ahead of the encounter will serve to bring expectations into alignment between the two teams [38]. Assuring the safe and thorough training of local practitioners beyond the short-term visit may not be possible without continuity of training either with other local providers who possess those skills (the surgeons in this case) or through regular follow-up visits from the visiting team of trainers. Development of a formalized competency-based program of instruction for outreach in low-resource countries has also been described [39].

2. After trying to prevent the impending procedure, what are the ethical implications of supervising or declining to supervise the procedure?

It is not surprising that the visiting team did not anticipate this scenario, as cross-cultural work is full of surprises. As one seasoned outreach physician puts it, “before you come the second time, you must have the first time” [38].

In situations such as this, the patient must remain at the center of the decision. After the training team in this scenario voiced their concern, they ultimately supervised the procedure, a far safer solution than the alternative of adhering to institutional stipulations and declining to supervise. In these settings, patient safety should be the strongest guiding principle. Humility and respect for local norms and practice conditions are also critical for maintaining a good relationship with local providers.

Case Scenario 3

A US team of radiology and pediatric residents and sonographers were conducting an ultrasound workshop for a residency program in a Haitian hospital. In between workshop sessions, the US residents and senior sonographer accompanied a local clinician on daily rounds. In one of the units, a particularly ill 6-month-old baby showed signs of a possible cardiovascular abnormality. A US pediatric resident pressed the sonographer repeatedly to perform a cardiac ultrasound. The equipment at the hospital was suboptimal, consisting of only an adult abdominal 3.5 mHz curvilinear transducer with directional power Doppler but no color Doppler. Although seasoned from many years of experience including pediatric cardiovascular ultrasound, the sonographer had never performed a cardiac exam without the backup of an attending cardiologist—let alone an exam with the kind of equipment limitations she was now faced with. The sonographer voiced her reservations to the US team of residents. The pediatric resident continued to press her, while the radiology residents told her it was all her decision and the outcome was “on her.” After a couple days the pediatric resident eventually convinced her to at least give it a try. Working through the poor quality of the abdominal probe applied to an infant’s heart and the physics of the directional power Doppler versus color Doppler issue, she was able to identify a ventricular septal defect with right-to-left shunting suggesting pulmonary hypertension. Later in the week pulmonary hypertension was also confirmed by other testing, supporting her ultrasound findings.

Discussion

1. Should outreach teams always be led by an attending physician, given that US sonographers and residents do not routinely practice independently? Should a provider visiting another country act within their US scope of practice or mirror the scope of practice of their local counterparts, even if that extends beyond what they are used to?

Medical roles and practice limitations and responsibilities are not universal across the world. For example, sonographers in some countries perform studies independently of a physician and can give reports to clinicians and patients. In some countries sonographers may have very little training. This may be driven by financial incentive and/or response to scarcity of radiologists in these regions. The scope of practice for visiting health practitioners should respect local regulations [14]. For visiting practitioners and trainees, local host institutions and supervisors should engage trainees at their appropriate level of training, not beyond it [14]. Home institutions carry the responsibility of practitioners’ and trainees’ actions while away and, as such, carry the responsibility of assuring that they are sending well-prepared trainees [14].

In this case scenario, a highly trained and experienced sonographer was faced with a dilemma of lending diagnostic expertise without the supervision of faculty. Under pressure, the sonographer strove to practice at the top of her skill level even with suboptimal equipment in an unaccustomed practice environment. Appropriate review of the regulatory standards of the local hospital and a detailed risk-benefit analysis cannot be performed with such short notice. Keeping the patient at the forefront of the decision and with the knowledge of local sonography "businesses" where practitioners with minimal training give out ultrasound reports, the sonographer in this scenario was persuaded to proceed.

Inherent to outreach efforts in low-resource settings is the challenge of finding workarounds that get the job done despite limitations. Anticipating equipment needs is helpful, but imperfect. With experience comes resourcefulness, so in austere environments well-selected personnel are critical.

The ramifications of a medical diagnosis in a low-resource setting are different from those in a high-resource setting. (1) After a diagnosis with poor prognosis is made, what would the next steps for care be? (2) Are specialists available for referral? (3) Would the patient or family be stigmatized or placed under undue stress from such a diagnosis? (4) Is the patient or family choosing the investigation autonomously? (5) Although in this situation a seasoned sonographer was able to arrive at the diagnosis, what if in a similar situation a wrong diagnosis was given? (6) What liability if any does a practitioner carry for mistakes made in another country?

Case Scenario 4

Radiologists went on a global outreach trip to a women's health clinic in a central African country. The visiting medical team taught fetal ultrasound skills for detection of high-risk pregnancies with the goal of reducing maternal and infant mortality. Information was used to determine whether a woman met high-risk criteria and whether she should deliver her baby in a hospital rather than in a rural setting. No information was shared regarding birth defects or gender due to differences in legal and cultural practices. Another goal of the team's trip was to raise awareness and increase referral of pregnant women to the clinic. To collect information about the referral patterns reflected in the women arriving at the clinic, the team began collecting a database of demographic and clinical data similar to the information collected locally on paper records. The database was backed up through the Internet to "the cloud" using a free online software program. No consent was obtained. Data collected included patient name, age, home community, distance traveled, fetal ultrasound findings, and information about how the woman learned about the ultrasound screening service. The radiologists anonymized and presented the data at a national conference in their home country but had lingering questions as to whether their project met ethical standards for scholarly activity.

Discussion

1. Did the data gathering constitute scientific research and should formal consent have been obtained? Was regulatory oversight by an institutional review board (IRB) or governmental agency necessary either in the host or in the home country?

Although the primary purpose of the project was to transfer clinical sonography skills to local providers with the goal of reducing maternal and infant mortality, at the same time, the team wished to maximize their impact by improving local referral patterns. Systematic collection of clinic data was necessary to identify patterns and strategize program improvement. The data set was eventually formally shared at a meeting in an anonymized format. Per the definitions presented in this chapter, the project falls under QI and as such does not require IRB oversight or formal consent. While research projects do require ethical and scientific review and formalized informed consent, QI projects do not. One could argue that although the team was not required to obtain consent due to the QI nature of the project, they were remiss in not prospectively posing the question as to whether their actions constituted research and required a formal consent process. Others could argue that individual countries might not distinguish between QI and research, and in the face of uncertainty, the appropriate steps would include submission of the project for formal research ethics committee review. The WHO recommends independent board or ministry of health review of research in both home country and hosting country. Readers are referred to the CIOMS-WHO's International Ethical Guidelines for Health-Related Research Involving Humans (2016) [19] and the Hastings Institute's Ethics of Using QI Methods to Improve Healthcare Quality and Safety (2006) [25] for further information.

2. Was there adequate consideration of privacy and safety of personal health information?

Collecting private patient information such as name, hometown, and exam findings in a cloud-based database would not have met standard practice at the team's home institution. Given the uncertainty of the safety and privacy measures in place on the third-party software, anonymized data collection would have been preferable in this case. Some might argue that for routine clinic data collection, following local standards for collection and storage of data would be preferable and would likely meet local data safety standards.

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5 Cultural Competency in Global Health

Lourens du Pisanie and Christie Caldwell

Introduction: A Stepwise Approach to Forming Strong Cross-Cultural Medical Partnerships

Culture varies widely across populations and influences all aspects of life. Some societal realms are generally considered cultural neutral space. Medical science, in particular, has its own unique culture which is often felt to be immune to most outside influences; however, this assertion does not hold true [1].

An illustration of just how powerful cultural influence can be upon the practice of medicine is found in Anne Fadiman's 1997 book: *The Spirit Catches You and You Fall Down: A Hmong Child, Her American Doctors, and the Collision of Two Cultures.* This book chronicles the struggles of a Hmong refugee family from Sainyabuli Province, Laos, and their interactions with the healthcare system in Merced, California [2]. The book tells the story of the family's daughter, Lia Lee, who was diagnosed with severe epilepsy, and the cultural conflict that obstructs her treatment. Her family believed in "a little medicine and a little neeb (their traditional healing method)," but worried that too much medicine could limit the effectiveness of the spiritual healing [2].

The dichotomy between the Hmong cultural belief that epilepsy is a rare spiritual gift and western medicine's assertive understanding and treatment of her epilepsy as a neurological disorder, highlights the need for the medical community to bridge multiple culturally embedded understandings in order to heal. As the tragic story unfolds, due to cultural misunderstanding, lack of interpreters, and poor compliance, Lia's condition worsened. Sadly, despite eventual proper communication and care, Lia fell into a vegetative state [2]. While most medical professionals practice aspects of bridging cultural gaps and cultural self-awareness on a daily basis, establishing a successful cross-cultural medical partnership is a more involved process. Along with raising awareness, this chapter will address the centrality of cultural competency in the partnership forming process.

When parties with differing cultural backgrounds meet, a spectrum of outcomes are possible; however, when it comes to forming partnerships, over time either a working relationship is formed or not [3]. The following stepwise approach attempts to outline a framework for forming a robust cross-cultural partnership which is a key to the success of international medical work [4].

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1. *Cultural self-awareness*. The first step toward the co-construction of a new working culture begins with one or multiple parties recognizing and then having the willingness to bridge cultural differences or gaps which are hindering the relationship; this process is facilitated by *cultural self-awareness*. In this setting, cultural self-awareness is the action of recognizing how one's own approach to medicine and healing is a product of acculturated values and beliefs. If properly practiced, it allows parties to shed cultural bias and to more objectively view and understand the cultural forces which influence interaction [5].
2. *Assimilation and bridging cultural gaps*. The second step requires the culturally self-aware party or parties to observe and experience the operative differences in the cultural dimensions governing interaction. Understanding differences in cultural dimensions will help parties garner and use tools to facilitate their cultural assimilation by bridging cultural gaps inherent to the identified cultural dimensions at play. For example, individualism/communitarianism, achievement/ascription, affectivity/neutrality, and universalism/particularism [6]. Tools for bridging cultural differences which are critical to assimilation are outlined in the following sections; these tools rely on mutual respect and understanding to function making site selection an important part of the process [6].
3. *Cultivating mutual reflexive cultural self-awareness*. After assimilation has taken place, the culturally self-aware party or parties should begin to help cultivate cultural self-awareness in those without. This is achieved through behavioral example, open discussion, and by tactfully introducing aspects of their own culture(s) into the relationship. This may take time, but as this awareness starts to be shared, all parties can begin to transcend the classic, individualistic form of cultural self-awareness and move toward reflexive cultural self-awareness discussed in the next section.
4. *Compromise and cultural co-construction*. Reflexive cultural self-awareness in all parties involved helps foster compromise. Compromise allows parties to start the co-construction of their new working culture built from a set of mutually-agreed-upon, workable aspects of all cultures involved, which maintains respect for all parties' cultures. The practice of two key behaviors by all parties is essential to this process: (1) the ability *to invite the unexpected*, which involves taking on a learning posture in order to create space for views and behaviors which might exist completely outside of one's normal frame of reference, and (2) the ability to *frame-shift ideas*, which requires one to adapt behavior to be more effective in a different environment [7]. These two behaviors, as described in the book by Gundling et al. *What Is Global Leadership? 10 Key Behaviors That Define Great Global Leaders*, are crucial to the successful navigation of the inherent complexities of global medical partnerships [7].

Reflexive cultural self-awareness, assimilation, the above two behaviors, and tools for bridging cultural gaps all work in harmony to encourage the co-construction of a new working culture between parties. As the reader has likely noted, this is a complex process which will require willingness, compromise, patience, strong longitudinal cooperation, and hard work by all parties involved. Undertaking or completing this stepwise process is not required for a functioning cross-cultural relationship, but taking these steps can help form stronger, longer-lasting relationships. First-hand accounts by practitioners detailing their navigation of cultural differences while working abroad will supplement our further detailed discussion of this stepwise process and its central aspects.

Classical Cultural Self-Awareness and Beyond

Cultivating cross-cultural partnerships rests upon the principle of cultural self-awareness. One's understanding of other cultures is largely an amalgamation of media influences, familial influences, education, and environmental/societal interactions; one's own culture is learned and imparted by these same forces [8]. When medical practitioners or trainers do not notice and adequately address cultural differences during collaborative efforts, what can easily result is wasted time, effort, and money [4]. The first step toward navigating cultural differences includes the realization that work styles and approaches to certain tasks, such as knowledge transfer, teaching, training, or healing, are shaped by our cultural environment. The ability to see oneself and one's own practice style as the product of particular cultural influences will naturally enable self-examination of one's actions and assumptions. Anticipating how one's cultural differences may impact a cross-cultural outreach effort is the next step. These steps successfully fulfill the criteria of the classical view of cultural self-awareness, however some argue that this view is one-sided, individualistic, and limited. The article, *Rethinking self-awareness in cultural competence: Toward a dialogic self in cross-cultural social work,* states that the classical view makes the strong assumption that humans are "objects of culture" who employ the concept of self-awareness as a means of overcoming their own cultural biases to maintain professional objectivity when interacting with others. They argue that this view is flawed in assuming that relationships operate in a subject-object or worker-client dichotomy where clients are viewed as "passive objects that can be understood, classified, objectified, stigmatized, and finally helped," who lack their own cultural self-awareness. They propose a new "conceptualization of a dialogic self for cross-cultural … work" where the "respective selves of the worker and client are not fixed, individual cultural entities." They propose that, optimally, the respective selves should be in an "ongoing process of co-construction" and that self-awareness should be viewed as reflexive self-awareness. This is a process where both parties are "cognizant of how their self may contribute to their perception and experience of interaction [with the other] as well as the behavior [of others]." Furthermore, reflexive cultural self-awareness allows parties to grow through being open to the inclusion of other worldviews into their own as they begin to understand each other. It allows parties from different cultures to negotiate, communicate, and co-create new cultural meanings and understandings [9]. Practice of this new form of cultural self-awareness, although more difficult as multiple parties have to be involved, can be achieved using what we outline in this chapter as a guide.

As discussed in the introduction, the ultimate goal of cultural competency and international medical partnerships is the co-construction of a new working culture facilitated by all parties practicing reflexive cultural self-awareness. This new culture can help foster the success of international medical work by promoting a cultural environment that is understanding and supportive, and which promotes compromise among all parties. For this to occur, first, differences in cultural dimensions need to be identified, addressed, and bridged by the culturally self-aware to promote understanding and assimilation. Bridging cultural differences and awareness gaps requires willingness, experience, and observation. Through extensive research, the discipline of intercultural studies has identified a framework made up of dozens of dimensions of cultural difference. One work in particular, *Riding the Waves Culture: Understanding Cultural Diversity in Business* by Trompenaars et al. [10], aggregated data from around 9000 business managers in 43 different countries to define 7 main cultural dimensions. They also provided "tools" for bridging any cultural differences inherent to these dimensions which may impede cross-cultural work. Acknowledgement of these dimensions among parties and the use of these tools may help to facilitate better cross-cultural collaboration/self-awareness, mutual understanding, assimilation, and the avoidance of any unintended misunderstanding of actions as malicious [10]. This environment can then serve as the starting point for the cultivation of reflexive self-awareness in those who may not be practicing it and the eventual co-construction of a new working culture.

Our chapter discusses the four cultural dimensions deemed most pertinent to international medical partnerships: individualism/communitarianism, achievement/ascription, affectivity/neutrality, and universalism/particularism. The following sections define these dimensions, outline how they can affect medical partnerships, and present tools which may be helpful in bridging cultural differences as outlined in Trompenaars et al.'s work [10]. The following dimensions serve as helpful generalizations which can be used to assess situations, but one must always consider other factors beyond national culture which may be influencing the situation and that these dimensions exist on a broad spectrum. As the following four cultural dimensions are discussed and first-hand accounts given, one should keep in mind the concept of cultural self-awareness, the ultimate goal of the project, and how one would use these tools to bridge cultural gaps.

Bridging the Individualism/Communitarianism Cultural Dimension

The dimension of cultural dependence speaks to how individuals define themselves. In individualistic cultures, the emphasis is on the individual. People tend to define themselves as independent actors, comfortable with standing out from the group, valuing diverse thought, and making decisions based on what is best for the individual. The ultimate value is placed on individual freedom over group conformity. In contrast, individuals of communitarian cultures identify themselves more as part of a larger group: a family, a clan, a religious group, or a team. Individuals' wants or desires are less important and are expected to be sacrificed for the greater good of the group. The emphasis is often on maintaining harmony and conforming to positions which fit the broader needs of the group [10, 11].

In medical partnerships, this dimension can show up in different approaches to medical confidentiality or patient privacy. The concepts of confidentiality and privacy are more rooted in individualistic cultures, which see the individual as the ultimate agent and owner of information about his or her health. Privacy and confidentiality are often not as strongly rooted or valued in communitarian cultures, where individuals and information about their health are seen as belonging to the family group. Families may expect and be given access to patient data, invited into consulting rooms, and allowed in treatment areas. Treatment areas may be much more public in communitarian cultures and data may be shared more freely. Decisions about medical treatment are also made very differently as a result of these differences, with families in communitarian cultures making decisions about a patient's health that would only be made by an individual in a more independent society [10, 11].

When people from more individualistic cultures are working or bridging gaps with people from more communitarian cultures, some helpful tools to be conscious of are [10]:

- Show an appreciation for social customs, take note of them, and make it a point to be a part of these activities.
- Be patient when starting a new project as rushing can be viewed as conceited no matter the intent. Wait for group consensus and seek permission when trying to introduce new ideas or projects.
- If managing, avoid showing favoritism in the group. Praise and reprimand the group as a whole.
- Allow yourself and individuals to involve others in decision-making; this may take more time but will help with the ultimate realization of goals.
- Seek to build lasting relationships with those in the partnership as this will build trust. Colleagues may also seek to help you in making your decisions, try not to take offence to this.

When people from more communitarian cultures are working or bridging gaps with people from more individualistic cultures, some helpful tools to be conscious of are [10]:

- Be prepared for quick decisions, sudden offers, and a reluctance to go back on these.
- Be prepared to do work on your own and to take the initiative in forming relationships. Keep up with what the team is doing during meetings on your own.

- If managing, do not micromanage, as decisional autonomy is valued in individualistic cultures and it also contributes to job satisfaction.
- Praise individuals for a job well done and expect the same to be done to you.

Bridging the Achievement/ Ascription Cultural Dimension

Achievement or hierarchical cultures emphasize an individual's role in society, or in a workplace, and the behaviors appropriate to that role. Each role affords a corresponding level of respect, and individuals must constantly gauge their place relative to the other and modify their behavior accordingly. To enable correct appraisal of a person's status, hierarchical cultures often rely on many outward symbols of status or rank. In these societies, outward symbolic displays of status, such as accent, title, name card, manners, clothing, and luxury items, become increasingly important as they often determine how one is treated and one's access to certain privileges [10, 12].

Ascription or egalitarian cultures are often very uncomfortable with any *hierarchy* and believe that all individuals should be treated with equal respect no matter their title or position in society. These cultures are often uneasy with titles or with any open display of one's status or wealth. Respect is garnered through performance and merit [10, 12].

In the context of medical collaboration, gaps along this cultural dimension can appear as different expectations around individual initiative and accountability. Consider the following example:

> Following the 2010 earthquake in Haiti, a medical team of radiologists traveled to Haiti in order to train local technologists how to operate newly-donated radiology equipment and to increase their capacity to deal with the expanded needs of the population. One of the visiting radiologists from the United States noted the impact of Haiti's more hierarchical culture on the training environment: "The Haitian technologists seemed so eager to please me, and they would agree with everything I said. I wished that they would ask me more questions, but instead I felt that they would just follow whatever I said, even if I was wrong. They seemed to be so dependent on me and didn't meet me, or what I was telling them, with any disagreement and abstained from any divergent thinking."

Hierarchical cultures have more centralized decision-making, and subordinates often are not empowered to independently make decisions or solve problems. The ownership for the project or solution often rests solely on the designated leader, and the role of the subordinate is to carry out the leader's specific instructions without questioning the logic of the approach. Since the leader often controls the information, subordinates tend to avoid questioning authority or formulating their own approach to solving an issue [10, 12]. To many of the radiologist volunteer trainers coming from the more egalitarian culture of the United States, the behavior of the Haitian technologist trainees was very surprising.

> "One volunteer notes that compared to most US technicians, who after taking the required pictures, will often take additional pictures in order to be helpful to the radiologist, the Haitian technologists do exactly what they are told and do not include other pictures even if, for instance, they see a low quality image due to the patient coughing. If they were provided with a piece of equipment and no one came to explain its use, the technicians would not explore the machine to learn how to use it. One radiologist notes, "when we were trying to train the technicians on the anatomy factors that impact a good scan, for example, what happens if the patient does not take a deep breath, they showed no interest in learning these details, which they perceived to be outside their responsibilities. They just wanted to know the technical tasks they needed to complete. Whether the X-ray was good or bad, this was perceived to be the doctor's responsibility."

When people from more egalitarian cultures are working with or bridging gaps with people from more hierarchical oriented cultures some helpful social tools to be conscious of are [10]:

- Be cognizant of ways people express their status and be aware of how others in your hierarchy level interact with and address/greet those of different status levels. Try to mirror their

behavior. It is often better to assume someone is of higher status when unsure.
- Avoid actively "showing-up" those with higher status and avoid openly contesting their ideas. Expect your subordinates to avoid doing the same to you even if invited to do so.
- Try to use the title given to you as this reflects your degree of influence in the society.
- Give subordinates direct tasks to complete and do not expect them to pursue work not directly assigned to them. Expect the same to be done to you. When introducing your subordinates to a more egalitarian management style, do it slowly, but do not expect them to want more autonomy.
- You may need to go to the top of the hierarchy to get answers or projects approved before initiating them no matter their complexity. Remember to do so with respect and follow protocol.

When people from more hierarchical cultures are working with or bridging gaps with people from more egalitarian cultures some helpful social tools to be conscious of are [10]:

- Do not be afraid to show your skills and knowledge level even among your superiors as this will garner you respect. Avoid being boastful.
- Avoid taking offence as anyone can and may challenge your decisions and ideas on technical and functional grounds no matter their position in the hierarchy.
- Mirror how those on a similar level use their title. Avoid using it in social situations. Don't expect subordinates to use your title.
- Give your subordinates autonomy and delegate tasks as this helps foster job satisfaction.
- Be prepared to operate freely with little direction from those above. Make sure you know the final goal of the task and be prepared to navigate your own route to completion. Do not be afraid to ask for help, but gauge this appropriately as asking for too much help may be viewed as incompetence.
- Try to involve all those effected by a decision in the decision-making process, not just those of higher status. This will foster better cooperation.

Bridging the Affectivity/Neutrality Cultural Dimension

This cultural dimension addresses how information is communicated. An affective communication style is often found in hierarchical cultures, where one has to take note of how information is conveyed based on the status of one's counterpart. An effective communication style places emphasis on how a message is delivered, often more than the actual content of the message itself. Silence, nonverbal cues, tone of voice, eye contact, "flowery" speech, and stories are often used to get a point across in a way that will not offend the listener. Neutral communicators are often task-oriented and prefer to get to the point across quickly in order to save time and energy, and most importantly, accomplish the goal. They emphasize clarity and believe that being completely transparent shows respect and builds trust with the listener [10, 13].

Visiting medical teams from more neutral cultures sometimes encounter communication differences in the consulting room. One medical volunteer describes an example of the interplay between these two forms of communication during a diagnostic consultation:

> When I asked a general question, the patient tiptoed around the issue. Instead of saying, 'I have a headache', he started telling a long story. In my mind, what was a simple 'yes' or 'no' answer would take ten minutes to get through. He never directly stated that he had a headache. I felt as though I was supposed to infer his problem from his story.

Those involved in international medical work quickly realize the degree to which seemingly objective information is interlinked with cultural nuance and culturally determined patterns of communication. Medical partners from more affective cultures are often frustrated that seemingly obvious messages are not understood by their more neutral counterparts. They are sometimes surprised and offended by the manner in which their more neutral partners convey information [10, 13]. In traditionally affective cultures, such as India and China, it is considered extremely rude to respond to a question with a direct "no," especially when that response is directed to someone of higher status. Indian and Chinese medical staff often say that, for them, it is almost impossible to use the word "no" directly. In order to ensure understanding and clear communication, awareness of these communication differences is critical for cross-cultural medical collaborators [10, 13].

When people from more neutral cultures are working with or bridging gaps with people from more affective cultures some helpful social tools to be conscious of are [10]:

- Try to open up to people about things happening in your life, attempt to connect outside of work as this build trust and rapport.
- Be cognizant of your body language, use positive body language (do not fold your arms, have an open posture, be more expressive when talking) as this will get your point across better and avoid you being seen as unreceptive and cold. This may take practice.
- Do not be put off by strong language, touching, dramatic gestures, or strong facial expressions.
- Do not only listen to what a person is saying but pay attention to their body language as this can convey how receptive they are to your ideas or their emotion at the time.
- Be active in your response to goodwill, respond warmly and make this known through expression. Avoid a constant cool neutral demeanor as this can foster social distance between you and others.
- Do not expect that opinions are final based on the initial reception of an idea. Continue to seek their opinion.
- You may have to talk about some non-work-related points of conversation before getting to your intended points.
- Try to avoid saying no or yes directly; wait for people to fully express themselves before interrupting. Try to convey your point through expressing your feelings that accompany your no or yes answer.
- Be patient as it may take more time for groups to come to a consensus as it may take them longer to fully express their points.

When people from more affective cultures are working with or bridging gaps with people from more neutral cultures some helpful social tools of which to be conscious are [10]:

- Stick to the point; avoid verbosity and flowery speech. Prepare for meetings by have talking points written down; this could be helpful to keeping you on track when presenting ideas.
- Do not be afraid to just say yes or no when asked a simple question.
- Do not take direct speech, a calm demeanor, or lack of emotional tone as the person being uncaring. These traits are usually respected and it will be of value to at least somewhat mimic this during your social interactions.
- Find appropriate settings in which to fully express your emotions. Practice self-reflection and take time off if you need to regroup.
- Do not immediately concede when you meet resistance; restate why your points are valid and address theirs. Expect to be interrupted during your speech, do not take offence to this.
- Watch for people's reactions carefully, and be even more careful to listen to what they have to say as this may be the only way to gauge their opinion.

Bridging the Universalist/Particularist Cultural Dimension

The universalist/particularist dimension concerns priorities around what needs to happen in order for a task to be completed. In particularist cultures, a personal relationship is often requisite before engaging in collaboration. In more universalist cultures, relationships are often built through working together on a shared task. Many universalist cultures rely on processes or systems that are equally accessible to all and which do not require dependence on others. In particularist cultures, getting things done is often contingent upon knowing the right person [10, 14]. A member of a medical team describes the differences in recruiting new operators for the medical equipment:

> Our partners would just choose an operator that they knew instead of one that is well-qualified. It was not based on qualifications but rather on a

> personal connection. They are taught that radiography is just pressing buttons so they bring in cousins to press those buttons. Trust is the piece that they hold in high regard. They do not have access to as many measures of competency so they rely more on personal trust.

Medical teams from universalist cultures often arrive with a set of very ambitious targets that they hope to accomplish during a relatively brief stay. They are often surprised when their local partners do not share their sense of urgency and can become frustrated when they are unable to accomplish all that they have set out to do. The receiving partners (particularly of more particularist cultures) may be equally surprised that the visiting team expects to accomplish such a long list of tasks without first building a relationship of trust. Understanding cultural differences in this context is critical to cross-cultural collaboration, and in particular, can often be identified as the most commonly encountered area of cultural conflict [10, 14].

When people from more universalist cultures are working with or bridging gaps with people from more particularist cultures, some helpful social tools to be conscious of are [10]:

- Be active in forming relationships with those you intend to work with. You may need to meet up outside of work for people to begin to trust you and for you to fully understand their needs.
- Create relationships with many different people as information may only go to those whom are in the right networks.
- Find shared relationships when meeting new people as this may help you establish rapport with them.
- Respect others' needs when you make decisions and be flexible for others.

When people from more particularist cultures are working with or bridging gaps with people from more universalist cultures some helpful social tools to be conscious of are [10]:

- Establish trust and gain rapport through honoring your word and contracts.
- In social (outside work) settings it may be inappropriate to discuss business matters. Gauge this by listening to others before doing so.
- Use objective means to make decisions so that you can explain it to others clearly no matter their relationship to you. Do not base decisions solely on your relationship, keep in mind what is best for the whole team.
- Be cognizant of the rules and follow them, do not break them for friends.
- Provide clear instructions and be objective in your decisions and obey the rules. Be prepared to explain these decisions to those it effects in an objective logical way.

Invite the Unexpected

Cultural self-awareness among members from different cultures helps them to operate with an understanding of the "why" behind their counterpart's behavior. Without this understanding, it is natural to judge another's different behavior as bad or nonsensical. This negative judgment usually builds on both sides which can lead to mistrust and disesteem. However, when the roots of both one's own and another's behavior are understood, it creates a foundation for respect and trust, which are essential in any medical partnership [9, 10, 14]. The above-described tools can help foster cultural assimilation and understanding after which the culturally self-aware parties can begin cultivating cultural self-awareness in others through behavioral example, through open discussion, and by tactfully introducing aspects of their own culture(s) into the relationship. This will also help all parties move toward compromise and the practice of reflexive cultural self-awareness. The behaviors of inviting the unexpected and frame-shifting can then help facilitate the co-construction of a new working cultural relationship [7].

The first behavior of i*nviting the unexpected* is the ability to position oneself in a learning posture that is open to new information and experiences that exist outside of one's natural frame of reference. It is also the ability to work through unexpected events that result from cultural differences rather than letting them stifle the relationship [7, 15]. In many ways, this posture of open-mindedness is a natural by-product of *Cultural Self-Awareness*. After reflecting on one's own cultural norms and expectations, it is natural to be curious about other approaches and realities. Successful cross-cultural collaboration requires that medical staff learn a new approach to everyday interactions [7, 15].

Beyond an attitude of proactive inquiry, medical personnel working in a global context must also learn to consciously correct for the fact that human beings tend to view the world through a "default" cultural lens, and that discipline and training are required to broaden that perception. Our minds tend to incorporate mental models based upon past experiences that help us to quickly filter out superfluous information and hone in on the most important facts. This tendency can lead to missing important cues from an alternative cultural perspective, and ultimately run the risk of arriving at inappropriate conclusions [7]. An example of inviting the unexpected is supported by a practitioner's experience in western China.

> In a small city in Western China, the local hospital was gifted a state-of-the-art CT scanner to serve the local population. The donation came from a global medical devices corporation and was designed to meet the exacting standards of European medical professionals and their clientele. The Chinese medical staff and imaging technicians were provided with good training on how to effectively use the technology. They used the new machine according to the specifications laid out for them, however, the new machine soon broke and the hospital was again without any CT capabilities. The engineers who arrived to repair the machine questioned the local technicians to determine the source of the breakdown, but they found no error in the technicians' approach. As the engineers began to carry out the repairs, one of them casually asked the technician, "Out of curiosity, how many patients do you typically scan every day?" The Chinese technician answered quickly, "About a hundred and twenty." The engineer stopped his work and looked at the technician. In Europe, the average number of patients scanned by the machine in a day was closer to thirty.

In this example the equipment and protocols were designed for a European workflow but the priority of this Chinese hospital was primarily volume and capacity beyond which the machine was designed to accommodate. The supplier did not even consider the possibility that the scanner could be used on such a large scale. The difference in the market need and the corresponding approach of the Chinese medical personnel were completely outside the mental maps of the European supplier and engineers. They did not expect these differences and as a result they were predisposed not to see them.

Notable examples of the unexpected which one could face in the international medical collaboration context include [7]:

- Different needs and expectations within patient populations.
- Different understandings of illness and the body based on cultural philosophies (e.g., traditional Chinese medicine and Ayurveda, which approach illness, diagnosis, and treatment primarily from a philosophical view of energy flow).
- Religious approaches to healing and diagnosis (consider the previous example from the Hmong community with cultural interpretation of epilepsy as a visitation of the divine, impacting this community's willingness to medically cure the condition).
- Different descriptions of medical symptoms (i.e., some South Asians describe what in the West we would call "depression," as having a "heavy head").
- Stigmatization of certain health issues.
- Differences in the roles and standing of medical practitioners in the community; expectations of doctors or medical practitioners are very different in more egalitarian cultures, where they are often in the role of a consultant, offering advice or information. In these cultures, the patient often takes ultimate responsibility for determining the applicability or appropriateness of this advice. In more hierarchical societies, the doctor is in more of an expert position and can be in a role to dictate behavior. Their opinion is often unquestioned and ultimate responsibility for the outcome is totally in their hands. In these cases, the patient sometimes abdicates responsibility for their own role in recovery.

When embarking on international collaborative medical efforts, learning to position oneself to learn about critical, unexpected aspects of the culture is essential in formulating an effective plan. The difficulty of perceiving the unexpected is often compounded in many countries by the tendency to place foreign medical staff on a pedestal, and to follow their directions regardless of whether their decisions are seen as the best course of action. This happens in part due to respect for hierarchy as well as a desire to absolve those in subordinate or trainee positions from being accountable. Medical staff who are working in a new culture to transfer knowledge about the use of medical equipment or procedures must find ways to step aside from their status and accumulated expertise to understand the different perspectives at play in the culture. The above research, social tools, good longitudinal relationships, and keen observational skill can help one anticipate the unexpected to a degree; however, the unexpected must be invited and scheduling time and resources into your overall plan for these situations is advised.

Frame-Shifting

Frame-shifting is the ability to change one's perspective and behavioral approach in order to be effective in different cultural situations [7]. This willingness to change is critical to transcending the classical view of cultural self-awareness and moving toward a more reflexive mutual cultural self-awareness. Observing and learning from one's own and another's experience is key in determining which cultural dimensions are at play before one can implement the use of the above-described "tools" as well as frame-shifting.

One medical volunteer working in Haiti recognized the more communitarianism cultural dimension of their Haitian patients and realized that they had to change their normal approach to better meet the needs.

> The patients who came in for radiology treatment would always come with a group of people, mostly extended family, including children. They had a very connected way of dealing with or experiencing tragedy. I spent a lot more time speaking with the patient's whole family. When I was taking X-rays, I had to go through a careful explanation of why they could not be in the room with the patient. But they all wanted to be in the room. So, I had to make a point to explain the reasons not only to the patient, but to the entire family. I had to say "I don't want to hurt you, so you need to not be in the X-ray room." I had to make them feel okay with this decision. I had to ask them and negotiate with them to wait outside. I had to comfort them and ease their fears. I realized that they also held this fear of leaving the hospital because they believed that people go to the hospital to die and they did not want to leave their family member. I had to explain that the pictures we were taking were not like a photograph, but that we have to go through the skin and look inside the body. I could not be dismissive because they would then feel stupid. Instead, I told them that we want them to play their role, but I am asking them for the opportunity to play our role as well. They responded positively to this. The family would all sit there until I came back to give them news. So, I had to remind myself to actually come back and talk with them, to tell them that everything was okay.

Medical practitioners often face difficulty in coping with the frame-shifting required to address cultural differences in pace and timing. Often their own pace of work does not match that of their partners in another country, and their definition of what is urgent is often not aligned with how urgency is defined in their host country.

> Maybe in the United States, a certain task would take you a week to complete. In Haiti, this same task will take six months. When we go into a different culture, everything that we planned, we have to expect that those plans will come undone. There is sometimes no rush for or sense of urgency. The concept of urgency is very foreign. Time seems to stand still. I have to repeat things to convey the sense of urgency. If I only say something once, they get the message that it could wait.

Partnering with a medical institution in a different country or from a different cultural environment typically requires a new frame of reference and approach. Successful medical collaborations require team members to distance themselves from deep-rooted patterns—including those associated with past successes—on multiple levels: communication style, work style, and timing approach [7].

Conclusion

Medicine is understood through a kaleidoscope of different value systems and beliefs. It is also delivered through a variety of mechanisms which often differ greatly among cultures. If the goal of international medical collaboration is to provide access to medical care and to establish an effective medical practice across borders, then those practices must be understood and owned by the local partners. Medical professionals must be able to connect with the values of their partners and convey medical knowledge in order to make sense in their partners' world and vice versa. Gaining *cultural self-awareness* by positioning oneself to create the mental and attitudinal foundation necessary to practice behavioral and cultural adaptability across borders is essential to this process. Medical teams with this level of cross-cultural competence will be ideally positioned to skillfully navigate the requirements of successful international medical collaboration. The stepwise process for creating a new working culture which promotes understanding and compromise between partners may seem difficult, but it only requires one party to have the willingness to change. This process may take time and effort, but this is the very nature of international medical projects. However, with the recent trend toward cultural self-awareness and globalization and with many dedicated teams of medical professionals embarking on international medical efforts, healthcare professionals from differing cultures will become more efficient in educating each other on how to practice high-quality medical care in the low-resource environments where it is so desperately needed.

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6 Radiology Readiness™, Research, and Relationship Development

Ezana M. Azene and Michael P. Reiter

> Before anything else, preparation is the key to success
>
> Alexander Graham Bell

Introduction

Competently delivered diagnostic and interventional radiology services have become essential components of modern medicine. Patients who entrust their care to hospitals and physicians in high-income countries have come to expect access to readily available radiology services. It seems radiology has become so ubiquitous that most living in high-income nations can scarcely imagine a healthcare system without it. Yet, the World Health Organization (WHO) estimates that somewhere between two-thirds and three-fourths of the global population lacks adequate access to safe, reliable, and competent radiology services [1]. The vast majority of people with limited access to radiology services live in the low- and middle-income nations of the world. This disparity in access to radiology services has been termed the "radiology divide" [2–4]. Governments, nongovernmental organizations (NGOs), and corporations have tried to address the radiology divide in many parts of the world at various times with varying degrees of success. The approach RAD-AID International has developed is termed Radiology Readiness™. This non-paternalistic, collaborative method is designed to address the radiology divide through a careful, stepwise, and evidence-based approach. The components and implementation of the Radiology Readiness™ approach are discussed in this chapter.

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The Radiology Divide

The reasons underlying the radiology divide are numerous and interrelated. However, they can be classified into two broad categories. The first is limited resources. Most LMICs, particularly low-income nations, lack the financial and capital resources to invest in what are often expensive radiology development projects. However, even when the financial and capital resources are available, human resources in the form of technical support, maintenance, and trained radiology professionals are often not locally available; this is often the case in middle-income countries.

The second broad category underlying the radiology divide is a lack of appropriate device procurement and planning. Unfortunately,

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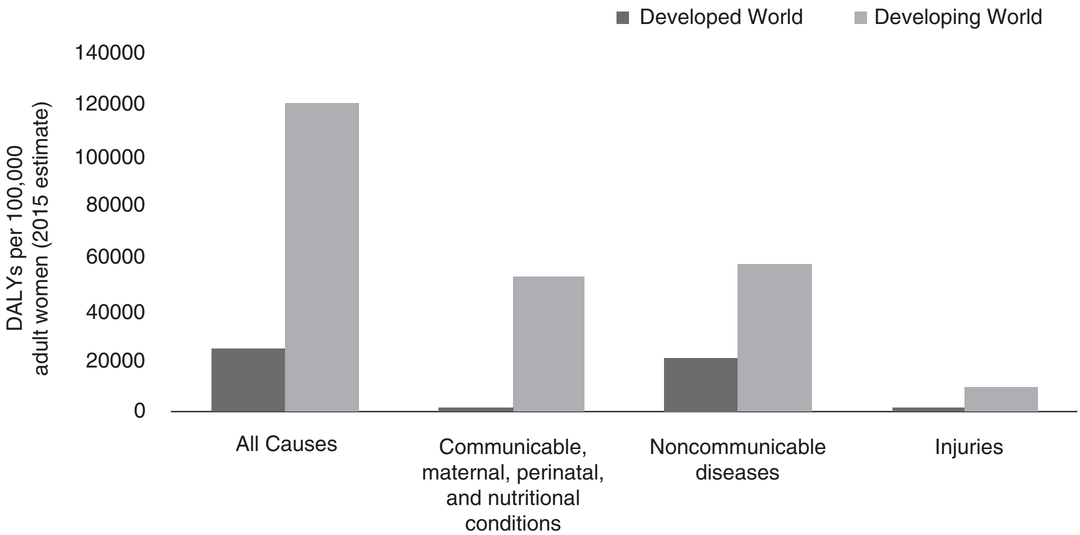

Fig. 6.1 Age-standardized disability-adjusted life years (DALYs) per 100,000 adult women stratified by development status. Data was obtained from the World Health Organization Global Burden of Disease summary for 2004 [6]. In the developing world, noncommunicable diseases like heart disease, cancer, and major depression result in twice as many years of healthy life lost as communicable, maternal, perinatal, and nutritional conditions. This is in stark contrast to decades past when noncommunicable diseases were common only in the developed world. The epidemiology of disease in the developing world is rapidly approaching that of the developed world

well-meaning groups and individuals often bypass the necessary steps required to ensure the sustainability of radiology improvement projects in LMICs. In part, this can be explained by the historically peripheral consideration granted to medical devices during healthcare development projects [1]. According to the WHO:

> At present, health care technologies are seen as peripheral to health care delivery and subsequently receive little attention from health care planners. Similarly, donor aid in the form of equipment is seen merely as an addition to the peripheral aspects of health care delivery and seldom as part of an integrated health care plan [1].

In past decades, the primary conditions impacting health in LMICs, including malnutrition, limited access to potable water, and acute infectious diseases, did not require much support from radiology services. However, as the quality of life and access to medical care has increased in these countries, the spectrum of disease has also changed. Today, in LMICs, noncommunicable diseases like heart disease and cancer result in twice as many years of healthy life lost as communicable, maternal, perinatal, and nutritional conditions [5] (Fig. 6.1). These noncommunicable diseases, and chronic infectious diseases like HIV-AIDS and tuberculosis, are best managed when radiology services are available as part of patient care.

Careful Assessment and Planning: Radiology Readiness™

Using the combined experience of its members and partners, RAD-AID has developed a streamlined, reproducible approach to helping develop radiology services in LMIC healthcare facilities. Termed "Radiology Readiness™," this approach assesses existing radiology infrastructure, medical imaging needs, other clinical and diagnostic services, human resources and workflow, and physical, technical, and financial infrastructure prior to designing a development project [2]. According to WHO, in project planning "The most important pre-requisite… is that the potential recipient truly needs the… equipment and has the expertise and the means to operate and maintain it [1]." This spirit of sustainability is at the heart of the Radiology Readiness™ approach, which has been adopted by the WHO's Pan-American Health Organization (PAHO) for radiology assessment in its member nations [7].

The evidence-based core of the Radiology Readiness™ approach is a customizable 16-part survey tool. The most recent version of the survey is available on the Internet [8]. The 16 survey sections are listed below:

1. General and Background Information
2. Community Involvement and Patient Satisfaction
3. Clinical Specialties and Disease Epidemiology
4. Patient Demographics, Capacity, and Referral Patterns
5. Clinical Tests
6. Pharmaceutical Agents and Other Clinical Consumables
7. Human Resources
8. Training and Continuing Medical Education
9. Structural, Electrical, Climate Control, and Transportation Infrastructure
10. Communications
11. Information Technology
12. Medical Imaging Capabilities and Limitations
13. Medical Imaging Device Maintenance
14. Patient Financial Issues
15. Financial Infrastructure
16. Funding of Medical Imaging Services

The individual survey sections can be included or not included in an assessment based on the particular circumstances and needs of the local healthcare facility. For example, the survey section "Medical Imaging Device Maintenance" does not need to be included when evaluating a facility with no existing radiology equipment. The survey should be deployed in a format that allows easy data collection and transfer to a database for later analysis. RAD-AID uses computer- or tablet-based PDF forms with editable data fields. After a survey is completed, data fields can be automatically exported into a spreadsheet or database program. Following the original publication of the Radiology Readiness™ assessment, it became apparent that certain situations required more detailed data acquisition and analysis, and supplemental readiness assessments have since been developed to address specific additional topics of interest. These include the dedicated PACS-Assessment and Interventional Radiology Assessment, with future plans to complete a Breast Health Assessment as well. These tools can be utilized to further analyze more detailed data on these specific topics at a given site as the need arises. Additionally, the document has also been translated into the Spanish and Russian languages, which are available for use on the RAD-AID website [8].

Evaluation and assessment using the Radiology Readiness™ survey is not an end in itself. The survey is a tool that should be used as part of a holistic, evidence-based, iterative approach to program development. A similar series of steps, customized to the specific needs of the local facility and project, should be used for every assessment. This allows the development of expertise and efficiency as the team works through each step during successive projects. RAD-AID has adopted such a series of steps (Fig. 6.2) into which the Radiology Readiness™ assessment tool has been incorporated.

The first step of the RAD-AID approach is identifying a local partner. Contacting all important stakeholders must be done from the beginning. Their cooperation through the process is critical to project success. Stakeholders may include NGOs on the ground, national and local government, transnational organizations, corporations involved in the country, and national medical/radiology societies. Local buy-in by the partnered facility and healthcare workers (ideally including a radiologist or other radiology expert) is most critical. One person in the local facility should serve as liaison and primary collaborator. The authors strongly recommend that this person have the legal and leadership ability to initiate change. It makes no sense to spend resources on collecting data and developing a program if that program cannot be implemented. This person must also have a strong vested interest in project success. Without such an interest, you may find your project abandoned as your partner grows disinterested or distracted by other priorities.

Fig. 6.2 Summary of the RAD-AID approach to assessment and program development. (Reprinted with permission from RAD-AID International)

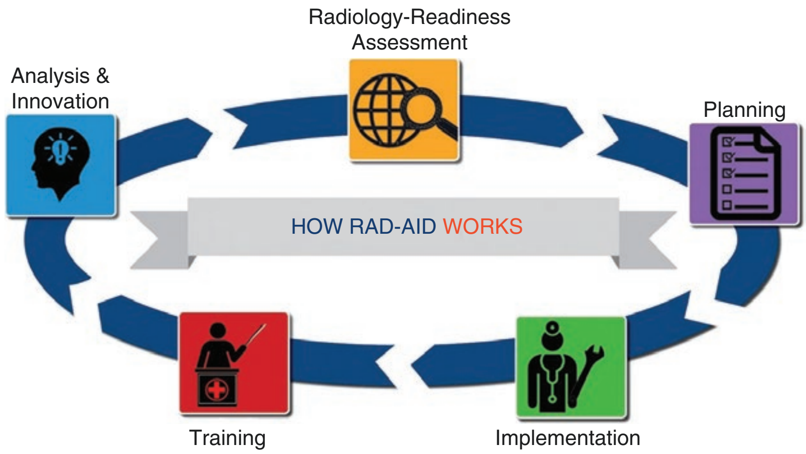

Table 6.1 Sources of data for background research

Category	Examples
Search engines	Google, Bing
Host country websites	Ministry of health, national medical societies, local and national news outlets
US government websites	State Department (http://www.state.gov/countries/) CIA (https://www.cia.gov/library/publications/the-world-factbook/) USAID (http://www.usaid.gov/) CDC projects (http://www.cdc.gov/globalhealth/countries/) CDC travelers' health (http://wwwnc.cdc.gov/travel/destinations/list.htm)
Transnational organization websites	World Bank Data Catalogue (http://data.worldbank.org/data-catalog) United Nations (http://data.un.org/) Human Development Report (http://hdr.undp.org/en) World Health Organization (http://www.who.int/research/en/) International Telecommunications Union (http://www.itu.int/ITU-D/ict/statistics/)

Prior to conducting an on-site evaluation, project members should learn as much as possible about the culture, economy, politics, and healthcare system of their host nation, region, and locality. More specific information on the facility and local partners should also be obtained. Much of this information can often be found on the Internet (Table 6.1). An Internet search engine such as Google (http://www.google.com) or Bing (http://www.bing.com) is a common and easy place to start a search for information. Specific online data that may also be useful for collecting background information can be found in government websites (e.g., ministry of health, embassies, US State Department) and the websites of transnational organizations (United Nations, World Bank, World Health Organization).

A search of academic, peer-reviewed literature for published manuscripts is useful also. RAD-AID and other organizations involved in radiology projects in LMICs often publish their methods, findings, and recommendations in peer-reviewed journals. Organizations that regularly participate in radiology development projects should consider keeping track of academic publications in the intersecting fields of global health and radiology development as they are published. RAD-AID uses the Medline (PubMed) platform of the National Library of Medicine to stay abreast of the academic literature. The My NCBI feature of PubMed (http://www.pubmed.com) allows the user to create personalized searches tailored to the specific needs of an organization. The query results can be screened and saved into user-defined collections for later retrieval. These collections can be kept private or made visible to anyone on the Internet.

Finally, sometimes there are no substitutes for primary sources. When information is not readily available on the Internet, project members may have to interview selected people in the ministry of health, embassy, or local partnered facility to collect needed background information prior to the on-site visit.

The on-site visit and Radiology Readiness™ assessment are performed after the preparatory work of identifying a partner and conducting background research have been completed. Conducting a Radiology Readiness™ assessment is more than simply collecting data. It is often the first in-person encounter with the host facility and local partner(s). As in the business world, all successful international radiology development projects succeed (or fail) in large part based on the strength (or weakness) of relationships among the involved parties. The time spent performing a Radiology Readiness™ assessment allows the project team to learn about the partnered facility. Equally important, it allows the host facility and partner(s) to learn about the project team members. As the process of assessment unfolds, the host partner(s) will consciously or unconsciously be assessing and evaluating the project team members. Are they honest? Are their intentions pure? Do they understand our culture and healthcare system? Will they include us as equal partners? Do they listen? Although clichéd, you only get one chance to make a first impression. The initial on-site visit and Radiology Readiness™ assessment can build the foundation for a long-term, successful, collaborative relationship.

After the on-site visit and Radiology Readiness™ assessment, the collected data must be carefully analyzed. The method of analysis will vary depending on the project team expertise and preferences. RAD-AID employs the widely used SWOT (strengths, weaknesses, opportunities, and threats) analysis method [9]. SWOT analysis forces the project team to identify the inherent strengths and weaknesses of the host facility and how these contribute to opportunities and threats facing the organization. In his paper entitled "The importance of strategy for the evolving field of radiology," Dr. Stephen Chan summarizes the value of SWOT analysis by identifying its "dual virtues of being simple and of providing an overall summary of the current strategic situation. It also offers the first glimpse about the range and types of strategic choices that may be available to the organization [9]." Implicit in the process of SWOT analysis is determining if enough data has been collected to adequately list and describe strengths, weaknesses, opportunities, and threats. If team members identify a gap in the data, additional information should be collected.

As a natural by-product of data analysis, team members will be faced with a number of potential projects. Each of these must be carefully evaluated based on likelihood of success, magnitude of risk, how well it fits into the organization's mission and vision, and overall cost [9]. The local partner(s) must be meaningfully involved in this process. Once the team has decided on a project, the project goals and objectives should be clearly defined. Goals and objectives should not be confused. Goals are the "what" of a project. In other words, goals define "what" the project will accomplish. Objectives are the "how" of a project. Objectives are specific statements that support the stated goals. Each objective should begin with an action verb. This helps ensure that the objectives have measurable outcomes. Each goal may have many objectives. The following is an example that illustrates the difference between a goal and an objective:

Goal: "Improve understanding and appreciation of women's health issues in rural India."

Objective 1: Assess the baseline understanding of women's health issues and percentage of people who identify women's health issues as important by administering a survey to a representative sample of the rural population.

Objective 2: Develop, produce, and perform at least five 30-min culturally appropriate skits to teach the rural population about women's health issues.

Objective 3: Ensure that at least 80% of adult men and 80% of adult women in the community view the live or recorded performances.

Objective 4: Host a town hall meeting after each live performance to discuss the performance and women's health topics in general.

Objective 5: Assess the post-intervention understanding of women's health issues and percentage of people who identify women's health issues as important by administering a survey to a representative sample of the rural population.

After developing a project plan, it must be executed. Every effort should be made to leverage the identified strengths of the facility to take advantage of opportunities, deal with threats, and mitigate weaknesses. Relationships with other organizations, especially (but not exclusively) other radiology development organizations, should also be leveraged. Whenever possible and cost-effective, involve people and organizations with unique and needed expertise. Seek out synergy wherever it may lie, and always avoid attempts to "reinvent the wheel." Most radiology NGOs have limited resources, so working with like-minded groups to achieve a common goal is often the most prudent path to follow. Finally, although not always possible, try to develop programs that can be replicated with minimal difficulty in other facilities and countries.

Regardless of how the project is managed, it must be continuously reassessed by measuring its specific outcome(s) at predefined intervals. If the measured outcome is not meeting the predetermined threshold, changes should be implemented to the project plan. Sometimes this involves collecting additional data relevant to the project objective. Alternatively, it may be the case that the predetermined outcome threshold is unrealistic and will need to be changed. The cycle of data analysis → plan development → plan execution repeats indefinitely. Ideally, the local partner will become facile with this iterative process, thus helping to ensure program sustainability into the future.

RAD-AID has successfully utilized the Radiology Readiness™ assessment tool numerous times since its inception in initiating and building sustainable global radiological projects throughout the world. One such example is the Laos Friends Hospital for Children (LFHC). The LFHC was founded by the Friends Without a Border Charitable Organization to become only the second free-standing children's hospital in Laos, an impoverished country with a shortage of resources. The LFHC reached out to RAD-AID to complete an on-site Radiology Readiness™ assessment in 2015, utilizing the abovementioned strategies in program building at that time, and to assist in development of radiological services within this new facility. Utilizing the Radiology Readiness™ assessment tool, an on-site RAD-AID team accumulated the data to complete the assessment and forged the initial relationship with the hospital administration and staff to determine a set of goals and objectives.

Based upon analysis of these data, a trip report was generated in conjunction with hospital administration and members of the RAD-AID management team to bring together previous shared experiences and to extract and subsequently better formulate a set of goals and objectives. One such example of this analysis was the clear need for radiology health professionals. The country of Laos has a lack of trained medical professionals, and the hospital experienced substantial difficulty in finding personnel with the needed skill set to work at the hospital. The administration addressed this need by working with RAD-AID to hire local nurses without previous radiological training and used RAD-AID's extensive volunteer pool to identify excellent candidates who could provide on-site long-term direct supervision and mentorship of these local personnel without any previous training or exposure to radiography and sonography. Since the time of its inception, the hospital has hired three staff members who have been working to gain proficiency as radiologic technologists for the hospital under the supervision of RAD-AID professionals. To date, this collaboration has included the contribution of 14 RAD-AID imaging health professional volunteers to work at the LFHC, many of whom were present on-site for 8-week rotations.

A second goal which was derived from the Readiness Assessment with the supplemental PACS assessment was the need for technological support. Evaluation of the data yielded the conclusion that the site could benefit from and also support the successful installation of a PACS system donated from Merge Healthcare through RAD-AID Informatics. This was installed in

2016, becoming one of the first sites in this joint collaboration, with the PACS system allowing the hospital to organize, manage, and view patient imaging data sets at multiple workstations throughout the hospital. Utilizing the Radiology Readiness™ assessment tool has allowed the LFHC and RAD-AID Laos program to jointly identify needs and set priorities for the overarching program and has propelled the development of the radiology department into a 24/7 operation offering radiographic and sonographic imaging with a fully functional PACS system, staffed by three local radiological technologist personnel. This program's stage of development over this brief time period would not have been possible without the data and analysis provided by the Radiology Readiness™ assessment.

Conclusion

In summary, careful planning and execution are required to create a successful radiology development project. The Radiology Readiness™ approach created by RAD-AID is an evidence-based method that can help project planners and managers achieve their development goals. Whatever method is used, relationship-building, background research, data collection, data analysis, development of goals and objectives, and continuous reassessment during project execution are critical steps that must be carefully executed. Taking these steps will increase the likelihood of a successful and sustainable radiology development project.

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7 Economics of Sustainable Radiology in Global Health

Frank J. Lexa and Sarah Iosifescu

Introduction

As we come to the end of the second decade of the twenty-first century, we continue to live in a world of profound disparities. Depending upon which country you are born in, there will likely be significant differences in your life circumstances. The differences begin at birth with the highest infant mortality in Angola at 96 deaths/1000 live births. The lowest infant mortality is in Japan at 2/1000, an approximately 50-fold difference [1]. When looking at one of the most important summary statistics for health and environment, life expectancy, the disparities are even more apparent. Based on 2011 estimates, the worst nation for lifespan is Swaziland at 49 years, while Hong Kong has a life expectancy almost twice this number (84 years) [2]. Among many contributing factors that are thought to underlie these disparities, one important cause is the country's investment in medical care; there are significant differences in healthcare spending as a percentage of a country's gross domestic product (GDP) among these countries. The World Health Organization (WHO) data showing the average 2008 percentages indicated the highest value (15%) in the United States, while the lowest figures were in Qatar (1.8%) and Myanmar (2%) [3] (Tables 7.1 and 7.2).

As one might expect, these disparities in healthcare expenditure extend to radiology services. Both as a specialty medical discipline and as a field that heavily relies on complicated, expensive technologies, radiology is often treated as a secondary consideration in health planning for deployment in low-resource settings. Since the costs of investing in medical imaging infrastructure and in specialty training are large, diagnostic imaging rates vary substantially around the globe. Some nations have little or no access to life-saving advanced imaging technologies, while others have so much that overutilization is a concern. Another concern regarding medical imaging infrastructure in developing countries is the dilemma that occurs when older imaging tools are donated, yet there is minimal follow-up regarding appropriate training, usage, or technical support of the said imaging tools.

In addition to recognizing population disparities *between* nations, it is also important to recognize that many nations have substantial *internal* disparities in income, education, and health. These are related to regional differences

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Table 7.1 2014 WHO rank of top 20 countries by ratio of healthcare expenditure to national GDP [3]

Country	GDP (%)
United States	17.1
Marshall Islands	17.1
Tuvalu	16.5
North America	16.5
Maldives	13.7
Micronesia, Fed. Sts.	13.7
Post-demographic dividend	12.7
OECD members	12.3
High income	12.3
Sweden	11.9
Switzerland	11.7
France	11.5
Malawi	11.4
Germany	11.3
Austria	11.2
Sierra Leone	11.1
Cuba	11.1
New Zealand	11.0
Netherlands	10.9

Reprinted from WHO Global Health Expenditure Atlas, 2014 WHO rank of top 20 countries by ratio of healthcare expenditure to national GDP, p. 211–7, September 2014. http://www.who.int/health-accounts/atlas2014.pdf

Table 7.2 2014 WHO rank of bottom 20 countries by ratio of healthcare expenditure to national GDP [3]

Country	GDP (%)
Timor-Leste	1.5
Lao PDR	1.9
Turkmenistan	2.1
Qatar	2.2
Myanmar	2.3
Pakistan	2.6
Brunei Darussalam	2.6
South Sudan	2.7
Bangladesh	2.8
Indonesia	2.8
Madagascar	3.0
Kuwait	3.0
Syrian Arab Republic	3.3
Angola	3.3
Nauru	3.3
Eritrea	3.3
Seychelles	3.4
Gabon	3.4
Sri Lanka	3.5

Reprinted from WHO Global Health Expenditure Atlas, 2014 WHO rank of bottom 20 countries by ratio of healthcare expenditure to national GDP, p. 211–7, September 2014. http://www.who.int/health-accounts/atlas2014.pdf

or urban/rural economic gradients which may be comparable in magnitude and impact to those in traditional cross-national comparisons. This highlights a persistent myth that poverty only impacts quality of life in homogeneously poor nations; in fact, economic inequality also exists among developed countries, including the United States according to a 2011 study by the Congressional Budget Office (CBO) [4]. While the data is often incomplete or contradictory, it is known that over half of the world's poor live in China and India, nations currently classified as middle-income rather than low-income nations that have enjoyed a great deal of prosperity and economic growth overall in recent decades [5]. From the standpoint of increasing access to life-saving medical imaging in the face of economic disparity, it logically follows that independent of overall national statistics regarding population wealth, health care, and other metrics, efforts to improve access to radiological services should focus on human need wherever it exists rather than strictly national boundaries, which may not appropriately reflect this need.

Sustainability

One of the key challenges for building radiology services in low and middle-income countries is finding "sustainable models," a term often associated with economic and environmental development [6]. Most successful project development models include considerations for financial and social sustainability when designing a wide variety of enterprises in public and private sectors. In the context of this chapter, we will define applications of radiology services that provide a good fit for the target nation along several important components of economic program development: planning, project execution, and project evaluation. These include (1) the role of imaging in the larger system of healthcare delivery; (2) financing that is realistic both in the short term and on a longer trajectory toward future self-sufficiency, rather than perpetuating dependence on outside donor agencies; (3) a high positive impact on health outcomes; and (4) improvement of local health delivery operations and infrastructure, including perhaps a long-term plan for expansion and development of medical services. We will use examples from analytic toolkits for evaluating opportunities, managing projects, and employing both innovative technologies and services that can help meet these goals.

Radiology services are currently paid for in a wide variety of ways around the globe, ranging from full coverage by the state, private pay-for-service, donated services by religious organizations or other NGOs, and mixed systems with elements of two or more of those mentioned. All nations must manage to pay for expensive technologies and to make them fit well within the present healthcare system. The relationship between source of payment and utilization of services by the general public is an important question for national health systems to consider.

In the United States, the historical use of payment on a fee-for-service basis is often blamed for a substantial portion of the high cost of health care and for driving unnecessary care. This has led to the promotion of alternative models for paying for and evaluating healthcare service delivery such as accountable care organizations (ACO) [1]. These forms of risk sharing may lead to more controlled delivery of care and perhaps lower costs in the future [7]. At the other extreme, in nations where the availability of imaging services is centrally planned and paid for with different incentives, there is often slow adoption of new technology and substantial waiting times for existing services. Whether deliberately planned or de facto in nature, this is a form of rationing.

A related issue for introducing radiology services is the fit with, or "radiology readiness" of, the local health system. For example, installing an MRI facility in a rural hospital for diagnosis of neurological disease must be preceded by consideration of its impact upon the local health system. How will the information be used, and are there resources to treat the illnesses once detected? While the knowledge that a patient has a high-grade brain tumor would always have some value to the patient and their caregiver in any situation, it would have the greatest impact in a setting with the infrastructure to provide appropriate treatment. In a site where the information will not lead to surgery, let alone the postsurgical care, establishing the diagnosis will have far less impact.

However, beyond the question of appropriateness looms the bigger issue of economic constraints. In all societies, the cost of buying and maintaining, as an example, an MRI, has to be compared with the cost and impact of alternative technologies and services. Under a condition of economic scarcity, it is much more likely that less expensive goods and services will be chosen over those that are more expensive. Priority is given to providing basic necessities: clean water, vaccinations, well baby visits, etc. before investing in more expensive, lower-impact technologies. As a result, a detailed cost-based analysis and consideration of the types of imaging technologies that would have the greatest benefits would be necessary to better inform choices for first steps in improving population access to radiological services.

There are wide variations in how projects are designed and implemented. On one hand, this is a good thing since diverse situations require individualized approaches. On the other hand, lack of a structured approach can lead to haphazard planning that can in turn lead to poor outcomes. This may have ramifications beyond local failure of a single project by damaging the reputation of the NGO leading donors to reassess their commitments. Therefore, the demand for heightened scrutiny and accountability has led to the development of structured approaches to the design, implementation, and post hoc evaluation of imaging projects. RAD-AID is among the first organizations to develop a robust document for analyzing project appropriateness [8]. More broadly, project planning, analysis, and management require a template or checklist-driven approach to guarantee that all important issues have been considered. Adopting a disciplined approach maximizes the chance of success.

Microfinance: Applications in Sustainable Healthcare Projects

Accounting and financial considerations are a requisite component of any analysis seeking to understand how to maximize the benefits of delivering healthcare services. Due to the enormous costs of implementing medical imaging, there have been efforts to develop alternatives to traditional financing mechanisms. One of the most interesting models is microfinance.

Microfinance institutions (MFIs) seek to provide access to financial services to groups and to individuals who are normally excluded from the traditional, formal financial service sector. In some nations with a low Human Development Index per the United Nations Development Programme, individuals who are not at a certain economic level are often excluded from access to financial services due to institutional constraints [9]. Historically, access to financial services (loans, bank accounts, credit) has been limited to those individuals with a credit history or who have assets to borrow against. People who did not own property to serve as collateral were marginalized and kept out of the established banking system, leaving them in the informal or black market systems where money lenders could charge exorbitant interest rates to compensate for the perceived risk associated with poorer and less-established clients. Formalized microfinance sprang from the idea that individuals with no collateral and with no credit history were not necessarily as risky as once perceived.

In 1976, future Nobel Laureate Professor Muhammad Yunus launched a project to provide access to financial services to the rural poor in Bangladesh. The project soon came to be known as Grameen Bank. The bank was highly successful; their borrowers boasted a 99% repayment rate [10]. Since the popularization of microfinance, this model has been propagated as a potential commercially sustainable model of aiding the poor. MFIs can charge interest allowing them to cover their operational costs, and therefore they can eventually become commercially sustainable. At this point in time, with limited formalized research and data aggregation, many MFIs on average still rely on donor funds. MFIs also face the dilemma balancing commercial sustainability while providing interest rates that may be feasible for the "very poor" clients they are designed to serve.

The MFI group-lending model involves assembling a group of borrowers together to borrow money as a unit in the following sequence of events. First, a group of varying size begins by completing a financial education course. Once completed, each member of a designated group is deemed eligible to take out an individual loan. Loans start at a small size and require a guarantee from another individual in the group such that if the borrower defaults, the individual guarantor or the group as a whole is then responsible for providing the loan repayment of the member that defaulted. The group cannot borrow again until each individual debt has been repaid.

There are many benefits in having groups of individuals borrow as a group rather than each borrowing alone. First, the group functions as a joint-liability unit, therefore providing a mechanism of social security equivalent to Western collateral measures. The group-lending model allows the lender to place a certain amount of screening and monitoring regulation on the borrowers within the group. Group members have the incentive to ensure that other group members repay their loans. In addition, groups often organize mechanisms to track the members to ensure repayment and approved use of loan funds for the stated purposes. Finally, from the perspective of the lender, group-lending arrangements lower the transaction costs of the institution, effectively allowing the MFI to reach more clients in more difficult-to-access areas [11]. As individual borrowers within a group establish their own credit history, they are often given the opportunity to borrow individually.

Although not universal, many MFIs target women. MFIs have been innovative in their methods of creating products and services that help to lower the barriers of entry for women trying to gain access to financial services. There are numerous studies that have demonstrated that "improved gender equality is a critical component of any development strategy" [12]. This same population of women would be a critical population to target to convey healthcare information and direct them to health services.

Recently, as microfinance lending grows more prominent in developing nations, MFI organizations have begun to expand on the traditional microfinance model in order to offer additional services that would be beneficial for poor communities. Designated "microfinance plus," these MFI arrangements include services related to education, health care, and environmental awareness. The appeal of using MFIs for additional services, specifically health care, stems from the networks that MFIs have established. MFIs have penetrated both the urban and rural settings, developing relationships with clients and often possessing in-depth understanding of the local politics, social structures, and customs in different geographic settings.

Illness (either personal or within the immediate family) is one of the most common reasons clients default or struggle to repay their loans. Areas in which there have been studies demonstrating positive results from tying together health services with MFIs include reproductive health, preventative and primary health care for children, nutrition, breastfeeding, diarrhea, HIV prevention and awareness, and malaria. While healthcare needs and difficulties vary from country to country, the overwhelming trend is that MFI clients have severely limited access to even basic healthcare services. In addition to the lack of services available, the indirect costs of seeking health care are often overwhelming for clients. Voyaging to a hospital or medical center in developing nations requires extensive travel as well as time spent waiting for services. Individuals lose valuable time ranging from days to weeks, which is time they could be working [13]. MFIs therefore have incentive to integrate health services into their institutions for two primary reasons: first, the mission of offering healthcare services is in line with the social mission of the institution, and second, offering health services to clients helps to prevent situations in which a client or family member fall sick and consequently cannot repay the loan.

BRAC, the Bangladesh Rural Advancement Committee, has been a pioneer in the microfinance plus model, providing services in education, community empowerment, social development, and community health. The community health model involves training members of microfinance groups to be community health promoters. As of 2010, there were over 88,000 individuals who received basic training and were providing health education, selling essential medicines, treating basic illnesses, referring individuals to relevant health centers, and providing pre- and postnatal care. Individuals are paid for their services and have opportunity for career growth within the BRAC organization [14].

In 2006, Freedom from Hunger conducted a study using five different MFIs to gain an understanding of how clients spent money on health services, and how microfinance could be used to expand on health services available. Most clients are spending personal funds on health services since they do not have insurance or government-subsidized options. In 2014, the private health expenditures, as a percentage of total national healthcare expenditure, were 78.7% (India), 61% (Philippines), 40.2% (Bolivia), 53.5% (Benin), and 54.1% (Burkina Faso). Also in 2014, the out-of-pocket expenditures, as a percentage of total private spending on health, were 98.5% (India), 45% (Philippines), 81.3% (Bolivia), 90.3% (Benin), and 98.9% (Burkina Faso) [15].

In India, the MFI Bandhan reported an average monthly income of respondents to be in the range of 60–100 USD, while these individuals spent 12–20 USD monthly on average for health services—20% of monthly income. In Benin, the MFI PADME reported an average monthly income to be less than 95 USD with individuals paying 24–31 USD monthly on average for health services—33% of monthly income. Other MFIs included in the study were CARD from the Philippines, CRECER from Bolivia, and RCPB from Burkina Faso. MFIs in these nations reported from focus groups and interviews that conditions with highest impact on women included gynecological problems, childbirth complications, female cancers, amebiasis, typhoid, fever, diarrhea, anemia, gallbladder, and vaginal infections. Diseases and conditions with the highest impact on children included appendicitis, jaundice, pneumonia, developmental problems, scabies, anemia, malaria, stomach illnesses, measles, coughs, and eye pain. The Freedom from Hunger study found that the primary demands for health services include health education, health financing, and health products and services [15].

While advanced medical technology can often be both expensive and challenging to install and monitor due to weak infrastructure and corporate governance in many developing countries, the rising popularity of mobile phones and mobile networks has transformed the ability to bring advanced medical knowledge and capacity to developing nations. The increasingly ubiquitous use of personal cellular phones, now predominantly equipped with largely high-quality cameras, opens possibilities for innovative methods of imaging in developing regions. For example, phone cameras and the associated data connection capabilities mean that phones can essentially function as mini-computers, using digital imaging in addition to keeping medical records, and have already been used in the field to send images for pathologic examinations, dermatology, and limited patient follow-up/tracking for diseases like TB. In the setting of medical imaging, similar development and implementation of low-cost mobile imaging services with easy access based on cellular phones could potentially realize similar beneficial outcomes. While using a mobile-based radiology services would require maintenance and training, the capital investment would be significantly reduced [16].

While research is limited, to this point MFIs offering healthcare products are generally offering health savings, health education, health loans, and health microinsurance. RAD-AID began an initial assessment in Kenya related to the possibility of using a microfinance organization to provide loans for structured healthcare education. Preliminary findings in Kenya showed that there are few loan products available for education and there may be potential for MFIs to provide loans to marginalized clients for pursuing technological level degrees. These loans would include a requirement to return to borrowers' home of origin after graduation to provide medical services to the local community. In rural communities where there are fewer physicians, the role of providing and analyzing imaging, often using donated equipment, falls to radiology technician level employees. Challenges in launching a formal program as described above included structuring a new loan product and guaranteeing individuals a job after graduation. There is significant room to explore the field of loans for certificate programs in radiology.

Conclusion

In conclusion, there are many challenges inherent in achieving sustainability in managing and operating a radiology service in the developing world, not the least of which is the acquisition and management of financial resources. We have outlined the economic components of different radiology services and discussed the impact of different national systems and practice management strategies inherent in promoting the growth of imaging services. Current and emerging strategies for economic sustainability can be applied to imaging in the developing world. Microfinance may be well positioned for the purpose of creating imaging service models that can work in emerging economies.

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Medical Imaging in Global Public Health: Donation, Procurement, Installation, and Maintenance

8

Robert Malkin and Billy Teninty

Introduction

There are compelling reasons to donate medical imaging equipment. The equipment can have tremendous clinical value and it is often lacking. For example, in a recent study of Zambia and Uganda, only 40% of hospitals that use X-ray for diagnosis had a working machine; no rural health center in Zambia had a functioning X-ray machine [1, 2].

Yet, important considerations are often overlooked when donating. For example, maintenance and repair are two areas not often provided with donation of medical equipment. Considering many developing world hospitals have no trained biomedical technicians, and there are even fewer technicians trained in the maintenance of X-ray equipment, the required maintenance and repair may be challenging. Indeed, nearly 40% of all medical equipment in the developing world is out of service, with a significantly higher rate (nearly 50%) for X-ray equipment [3]. In other words, donating X-ray equipment does not guarantee an improvement in patient care.

When considering a donation of imaging equipment to a resource-poor hospital, steps can be taken to improve the chances of an effective donation. And, there are many alternatives to donation that might better serve the recipient hospital or clinic [4]. This chapter reviews the major considerations for provision of medical imaging equipment to a resource-poor hospital.

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Donated Imaging Equipment Categories

Before discussing medical imaging equipment donations in detail, it is important to understand that there are some categories of imaging equipment that should never be donated (MRI), some that require additional, often challenging, infrastructure (digital X-ray and CT), and some that offer a high probability of success with fewer infrastructure considerations (ultrasound, mobile X-ray, and C-arm).

Magnetic resonance imaging (MRI) equipment requires infrastructure that makes it nearly impossible to successfully donate to a resource-poor setting. Most MRI systems will require a regular supply of a difficult-to-obtain (in the developing world) coolant, such as liquid nitrogen. Ready access to high-speed Internet will often be required to conduct maintenance and repair. Both the Internet and coolant are often in limited supply in the developing world. In many cases, maintenance schedules are programmed into the machine, meaning that a service contract

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is required to keep the machine running, even if there are no repair issues. The machine will simply shut down without a certified technician with the proprietary restart codes. In addition, electrical and physical infrastructure requirements will often exceed the capabilities of all hospitals outside the capital in many developing world nations. In short, donated MRI machines rarely, if ever, function long enough to substantially benefit the local community.

At the other end of the scale for imaging equipment are ultrasound machines. These machines have become inexpensive and highly reliable. They have been used in extremely resource-poor settings such as refugee camps and rural clinics with few problems [5]; however, this is not to say that donations of the ultrasound equipment are problem-free. The donation of an ultrasound machine involves approximately the same level of complexity, and the same barriers to success, as a bedside monitor or an electrosurgery unit [6].

Digital X-ray (including fixed fluoroscopy) and computed tomography (CT) are closer to MRI machines than to ultrasound machines. One of the most often overlooked considerations when donating a digital X-ray or CT machine is the required information technology (IT) infrastructure. In many cases, the device will require temporary or permanent access to high-speed Internet in order to be installed, repaired, and maintained. In most cases, the manufacturer's representative will be required to install the system. In some cases, the installation and routine maintenance may require a code or software that is only available to technicians who are authorized by the manufacturer. Such authorized technicians may only be available in neighboring or even distant countries, and thus have to be flown in to help the local facility.

For these reasons, the donation of a digital X-ray, fixed fluoroscope, or CT machine should only be considered when a service contract from a manufacturer's representative is purchased along with the donation. Since the cost of the service contract will be, by far, the largest cost involved in the donation—and may even exceed the purchase price of used equipment—it rarely makes economic sense to donate a used digital X-ray, fixed fluoroscope, or CT to a resource-poor setting. Donation of a new machine can only be expected to be successful as long as the service contract is maintained.

Stationary, film X-ray, like digital X-ray, will require a dedicated room in the recipient hospital, specialized cabling, and special power considerations. A technician must be flown in from outside the country for both types of installation because the local technician can rarely, if ever, handle the installation of fixed X-ray machines. Of course film and film development chemicals will be required if a digital system is not donated. A film processor may also be part of the donation, though obtaining chemicals for automated film processors can be difficult. However, because there is no IT infrastructure for most film X-ray machines, donations of these machines can be made with a service contract from local providers in most cases. It is sometimes stated that digital X-ray reduces the burden on the developing world because film is not required. However, there is little data to support this statement, and there is ample evidence that the maintenance requirements and adaptation requirements are considerable [7]. Service for a software bug in a digital X-ray machine may be thousands of miles away.

The most successful X-ray imaging system donations are mobile systems, including C-arms and mobile film-based machines. These machines can often be shipped, be plugged in, and be reasonably expected to work at the recipient hospital. From this perspective, they are like an ultrasound machine. These machines do not require a special room or power to operate. Many newer C-arms and some mobile X-ray machines will require some IT infrastructure and annual maintenance visits. A service contract is thus still required or advisable for these models. But, these machines are more common, and therefore manufacturers' representatives can often be found within the target country.

Medical Equipment Donation in General

It must be remembered that medical imaging equipment is first and foremost medical equipment. Therefore, all the considerations for donating medical equipment must also be made when donating medical imaging equipment.

Before considering any donation, the appropriate guidelines should be consulted. A starting spot is the WHO Medical Equipment Donation Guidelines [8, 9]. According to the WHO guidelines, the principles at the core of all medical equipment donations are: (1) healthcare equipment should benefit the recipient to the maximum extent possible; (2) donations should be given with due respect for the wishes and authority of the recipient and in conformity with government policies and administrative arrangements of the recipient country; (3) there should be no double standard in quality. If the quality of an item is unacceptable in the donor country, it is inappropriate as a donation; and (4) there should be effective communication between the donor and the recipient, with all donations made according to a plan formulated by both parties.

Satisfying all four of these principles is quite challenging, particularly when used medical equipment is being donated. The application of a double standard appears to be the most difficult principle to adhere to. For example, it would certainly be unacceptable to an American physician to be expected to practice with a broken X-ray machine; however, 60% of hospitals in one survey admitted to donating broken medical equipment [10]. No American physician would consider the quality of an expired drug acceptable, yet 90% of respondents in the same survey donated expired goods [10].

While the definition of effective communication could be considered vague, there are published checklists and flowcharts that can serve as a base for organizing the communication [11, 12].

Financial Considerations for Donations

As mentioned above, the cost of servicing the donated imaging equipment should be the primary driving factor in any donation plan. In the USA, equipment maintenance is the second largest budgetary expense (second only to personnel) in large radiology departments [13]. In the developing world, the personnel costs are typically lower, but the maintenance costs may be an equal or even higher portion of expense. This depends on how often experts must be imported for maintenance and repair, and whether the local staff has the technical expertise to substitute aftermarket parts [14].

The critical concept for donation planning is the total cost of ownership [15]. The total cost of ownership considers all associated costs for the recipient hospital over a given time period including installation, energy, repair, upgrade, maintenance, training, and disposal.

In the USA, a good first estimate of the total cost of ownership is about twice the original purchase price over 10 years [3]. For example, the total cost of ownership of a CT scanner over 10 years is estimated to be 3.4 million USD for a 1.5 million USD purchase price [3]. So, even if the purchase, renovation, and installation costs are removed, the total cost of ownership to a recipient hospital of a donated CT scanner over 10 years would still be 1.45 million USD (about 9.7% of purchase price per year). Similarly, a donated breast MRI machine would be expected to cost the recipient hospital 1.49 million USD over a 10-year period (about 10.1% of the purchase price per year).

While these estimates are useful, they are only guidelines. Getting more precise estimates of the total cost of ownership for donated equipment can be difficult. In the developing world, equipment may be expected to last much longer than 10 years, lowering annual costs. But, imported service may be much more expensive, raising costs. For film X-ray, processing chemicals for dip tank development are available everywhere. However, automatic film development chemicals are not typically easily available. If supplies, such as automated processing chemicals, are not locally available, they must be imported, again raising costs.

Another increase in the cost, and frustration, of donation is that about half of donated X-ray machines do not work [3]. Forgotten accessories (e.g., cables) and a hospital that cannot handle the installation/preparation of the equipment are cited as the most common reasons [3, 6]. However, some of the donations have no hope of working from the start due to errors in preparing the equipment before shipping it out. Hospitals replacing broken equipment will often hire the company providing the new equipment to decommission the old equipment, an expensive process that can require days of work in order to insure that it can be reinstalled successfully. Most US hospital technicians are not qualified or experienced at decommissioning for reinstallation. The end result is that hospitals donating decommissioned equipment may be dooming the recipient hospital to equipment that will never work.

Even a donated working unit may fail to reach the patient. Without radiographers trained in X-ray equipment, the receiving hospital cannot be expected to understand or operate what they are accepting. They probably do not have the knowledge to understand the infrastructure, power, accessory, temperature, and other considerations required for turning a donation into a working machine. This represents an additional cost, as the donor must engage an expert, often an NGO, to act as the installation manager.

The service contract purchase may be quite expensive, especially for sophisticated equipment such as CT and fluoroscopes. The Ministry of Health may have contacts with competent service contract providers, but, in a resource-poor setting, it can be common for a service contract provider to promise to service the equipment, and accept the payment, only to inform the donor 1 or 2 years later that they are not able to service that device or have not serviced the device for other reasons. At the time of this writing, it is unusual for a developing world hospital to have successful service contract monitoring capabilities, and in many cases, any service contract monitoring at all. Even for reliable equipment, such as mobile X-ray and ultrasound, a visit once per year by a qualified technician should be considered necessary but may not happen if there is no service contract oversight.

Another consideration is disposal costs. There is very little data on the cost of disposal of medical waste in the developing world, and even less on the disposal costs associated with medical equipment. Indeed, many hospitals simply store the old broken equipment on site: However, older imaging machines may release toxic substances from the transformers and displays. Furthermore, improper disposal of the equipment will take up space in a hospital that is already understaffed and overburdened.

In summary, the donation of a working piece of medical imaging equipment from one US hospital to another US hospital would—at most—only save the recipient 50% of the total cost of ownership. And, in the developing world, the cost savings is probably much less. In short, donating a piece of sophisticated imaging equipment may cost the recipient hospital more than if they purchased a less sophisticated but more adequate piece of equipment locally.

Shipping and Preparing to Receive

Every piece of equipment needs to be prepared for shipment. This can be a complex process. For example, GE's X-ray Quickstart Installation Guide outlines 12 major steps to a successful installation of an X-ray system. Nine of those steps are before shipment [16]. Even the import and export regulations around shipping medical equipment can be complex. The USA has increased its export regulations, and many recipient countries have begun to develop policies on equipment donations [17]. Partially due to the large number of failed donations, some countries have simply banned used equipment donations, and others have greatly restricted those donations.

Even when the equipment is small and hand delivered, like a portable ultrasound machine, preparing for shipment must include setting the machine to the frequency and power of the target country. Each country has its own frequency (usually 50 or 60 Hz) and voltage (any of 110, 117, 120, and 240 can be encountered). Some hospitals operate on multiple voltages and with multiple outlet configurations. It is rare that a donation can be plugged into the wall and be expected to work in a new country. Failure to properly adapt to the local power grid or failure of the machine to tolerate local power grid brownouts and surges is probably responsible for 14–19% of donated medical equipment being out of service [6, 18].

With the exception of the smallest pieces of medical imaging equipment, shipping complexities and adaptation preclude the direct donation of medical imaging technology from an individual, physician group, or hospital, to a recipient hospital. All donations are made through a shipping intermediary, and often through an NGO dedicated to donating used medical equipment. While these NGOs will charge a fee beyond the crating, shipping, and custom costs, they will be able to offer invaluable advice on the probability of success for any target equipment and hospital.

An NGO with experience at successful medical equipment donation will know that at the time of shipping, receiving the equipment must also be considered, for everything except mobile X-ray and ultrasound. Preparation for equipment arrival can take several months [4, 16, 19]. There are many questions like: Can the ceiling support the machine? Can the floor? Where does power enter the room and in what type of cables? What is the required size and shielding for the room?

Again, a reputable partner NGO will have a history of completing many successful imaging equipment donations and can offer guidance on hospital preparation. They will often insist on visiting the site with their engineering team, perhaps several times, and this cost must also be considered in the total cost of donation.

Maintenance After Delivery

For all but mobile X-ray and ultrasound, the cost of maintenance will exceed the cost of the equipment donation many-fold. If careful consideration is not given to maintenance, any donation can become a burden to the recipient hospital, a burden they did not anticipate and may not be able to absorb.

Medical imaging equipment should only be donated to hospitals with qualified technicians. But finding such a hospital can be difficult. A recent survey of Cambodia completed by our laboratory showed that of 31 interviewed technicians, only 21 had graduated high school (unpublished data) and none had received diploma-level training in medical equipment; in fact, there were no biomedical technician training programs in Cambodia at the time of that survey. A survey of Namibia found that only 24% of hospitals have anyone assigned to maintain the medical equipment, while 23% use an outside service. The rest (53%) simply do without medical equipment maintenance [20]. In the same report, only 57% of surveyed hospitals report having any preventative maintenance schedule [20].

The lack of biomedical technicians with specific medical equipment imaging training may not completely disqualify a hospital from receiving a donation. Without any additional training, a technician can check for loose connections, fuses, and other common problems. These may account for as much as 66% of all out-of-service equipment [18], but this only applies to the simplest equipment and the simplest problems.

Medical imaging equipment is often donated along with training for the users of the device. Unfortunately, training the biomedical technician on the maintenance of the equipment is much less common. Considering that about 25% of all out-of-service medical equipment can be traced to user-related issues [6, 18], training can be a simple way to boost the likelihood of a successful donation. The local technician should always be able to operate the machine correctly, at least to check if a service contract repair is successful and to check for user errors. This makes donating a user manual, and preferably also a service manual, an essential element in any successful donation. The manual should be in a language the technician speaks and reads.

All higher-end medical imaging equipment should be donated with a service contract, but very few technicians are involved in the management of the service contract. This can result in payments being made for services which are not performed, and ultimately machines that do not work. Ideally, the technician would be trained and empowered to manage the service contract. This can be a major shift in the administration of the hospital. At a minimum, the technician needs to be trained to know when to call for service and how to review the performance of the service contract.

Many donors expect that the donating partner NGO will field calls on machines that do not work, cannot be installed, or perform poorly. However, in most cases, the donating partner organization does not have the resources or knowledge to support their donations. Likewise, older equipment may no longer be supported by the manufacturer, leaving the recipient hospital with nowhere to turn.

When the Maintenance Ends

In a wealthy hospital, when a piece of medical equipment can no longer be maintained to manufacturer's specifications, due to lack of funds or parts, it is retired. However, in a resource-poor setting, this is rarely the case. In many cases, donated imaging equipment will be kept operational even after it can no longer be repaired. The equipment is effectively re-engineered with improvised procedures and parts. Simple modifications, such as changing a digital display to an analog gauge, or replacing the power supply probably do not affect safety or efficacy. Larger modifications, on the other hand, may have an unknown impact on efficacy and patient safety.

If a donated imaging system can no longer be repaired or re-engineered, it may be reduced to components. In some countries, a thriving barter system allows equipment technicians to obtain parts that they could otherwise never afford by trading for components from donated equipment.

In light of these post-maintenance realities, donations of equipment from common manufacturers and lower technology equipment should be favored.

Alternatives to Shipping a Donation

Given all the problems associated with a donation, the relatively low probability that a donated imaging machine will meet performance expectations, and the cost of a donation, it is reasonable to ask if there are alternatives. Fortunately, there are.

The first alternative is to find an imaging system in the target country. Every recipient country will have dozens of donated X-ray machines in-country that have never been installed because the recipient hospital does not have the power or room to install it. If you can verify that the original machine was properly decommissioned, it can be much cheaper to donate something that the current owner's hospital wants and needs in exchange for their machine.

A common practice in hospitals that regularly receive equipment is to request a new donation when a current piece breaks. Indeed, it is much easier to find donors of medical imaging equipment than it is to find donors of medical imaging equipment service. Nevertheless, it is almost always cheaper to repair an imaging system that was known to have worked at the recipient hospital than to look for a newly donated machine. Often, the cost of repair of a machine, even if repaired with outside experts, can be much less than the cost of installation of a new donation.

Along the same lines, it is often possible to upgrade the capabilities of the recipient hospital's imaging system. A tube stand and table do not need to be replaced. A new generator, better power, new cassettes, a stationary grid, or a new tube may produce superior results at a fraction of the cost of a new donation.

If a donation appears to be the only alternative, consider an ultrasound, C-arm, or mobile X-ray before donating a larger, fixed device. Although these donations are often considered to be of a lower clinical value, larger fixed installations rarely operate at peak efficiency once donated to the developing world—if they operate at all.

Conclusion

Obtaining a decommissioned imaging machine for donation to a poor hospital is only the first step in a long series of complicated and difficult considerations before that same machine will help patients in a resource-poor hospital. The donation of an imaging system is a long-term commitment to financial and structural operation of a distant hospital's infrastructure in collaboration with that hospital's technical staff.

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9 Medical Imaging Safety in Global Health Radiology

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Disclaimer and Warning

This chapter serves as an introduction to basic concepts regarding safety that may be useful to individuals setting up or running imaging facilities in low- and middle-income countries, but this information is not intended to be, and should not be, relied upon as a technical manual or instructional document on how to perform various safety measures or mitigations. While reasonable attempts have been made to provide useful information in this chapter, no warranty is made as to the accuracy or completeness of information presented. Especially in the context of imaging in regions with limited resources, it would not be possible to anticipate every potential scenario with relevance to safety that might be encountered.

Failure to address appropriate safety measures can result in injury to patients, staff, and the general public. The reader assumes all risks associated with setting up and running a safe imaging operation, and neither the authors nor publisher assume any liability for the accuracy, completeness, or applicability of any information covered in this chapter to a particular imaging setting. It is the responsibility of the reader to ensure that properly trained and qualified medical physicists, radiation safety officers, equipment installation and service personnel,

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clinical safety experts, and regulatory individuals be consulted to assess and address specific safety needs, issues, and requirements in a given imaging facility, that appropriately trained and qualified staff operate the equipment, and that appropriately trained and credentialed healthcare providers oversee the medical utilization of imaging devices.

Context for Considering Medical Imaging Safety in Low- and Middle-Income Countries

Advances in medical imaging have led to substantial improvements in medical diagnostics in the past several decades. From simple applications such as x-ray and ultrasound imaging to more complex procedures such as magnetic resonance (MR) imaging, positron-emission tomography (PET), computed tomography (CT) angiography, and the burgeoning field of molecular imaging, the ability to record anatomical and functional information in viewable form has greatly improved the ability of physicians to diagnose disease and monitor effectiveness of treatments. While medical imaging is generally quite safe, there are important safeguards that need to be put in place in order to minimize risk from these procedures to patients, staff, and the general public. This chapter will provide an introduction to the types of safety concerns that may be relevant to imaging in a resource-limited region. This chapter will not cover all possible hazards, nor will it provide a step-by-step approach to discovering and mitigating safety concerns; rather, it will provide the reader with an idea of the types of issues that may be of importance in a low-resource setting. The reader must engage the services of qualified safety experts to assess and address the specific safety issues in a given imaging installation.

As discussed elsewhere in this book, there is an unfortunate disparity in access to many types of medical imaging procedures in resource-limited regions of the world. As a result, many of the more advanced medical imaging techniques and devices may not be available in a given location. Recognizing that there may be a wide disparity in the types of devices available, a general description of both elementary and advanced imaging procedures will be given. The term *elementary procedures* refers to techniques that are generally available in most locations, including projection x-ray imaging and ultrasound. *Advanced procedures* will include everything else, such as CT, MR, and nuclear medicine. In many settings in the developing world, only *elementary procedures* are available, and thus they will receive the most attention in this chapter.

There are several features of operating a healthcare facility in low- and middle-income countries (LMICs) that present particular challenges regarding safety that might not be experienced in high-income nations. While this list is not exhaustive, such challenges include (1) lack of adequately trained personnel to install and service equipment, (2) lack of required test equipment to verify safe operation, (3) difficult access to parts for service or maintenance of equipment, (4) lack of adequately trained personnel to properly operate equipment, (5) lack of properly trained personnel to identify issues that need attention (e.g., image quality issues that are harbingers of equipment malfunction or need for service), (6) lack of equipment that is up to contemporary standards, (7) self-referral by patients without consulting a qualified healthcare provider, and (8) lack of adequate regulatory or governmental oversight bodies to monitor proper installation and use of equipment. As one can see, many of these issues relate to the need for adequate infrastructure of trained staff.

Another concern is the effect of limited resources on the ability of a healthcare facility to obtain equipment in good working order. The authors are aware of several anecdotal cases where imaging equipment was donated to a hospital or healthcare facility in a resource-limited region without adequate finances to install or maintain the equipment. In one case, in a hospital associated with a medical school, there were several pieces of x-ray equipment that had been donated but were not operable due to lack of parts. Some of these devices were not even unpacked from their shipping crates. In other cases, x-ray equipment had been installed but was not functional due to lack of parts to repair the equipment. In another setting, ultrasound equipment had been donated but stood unused due to lack of acoustic gel to use with the device. Thus, in certain settings in LMICs, a lack of financial resources makes it virtually impossible to install or use imaging equipment properly, which can have ramifications for safety as well as optimal clinical utilization. As an example, in one poorly resourced country as recently as 2016, cabinet ministers and later parliament had to meet over a span of 6 months to decide whether to allow repair of a radiotherapy machine. As a result, more than 50 cancer patients missed their treatment doses. Clearly, a lack of resources is a major issue confronting imaging in LMICs, and there are no easy answers to the problem of limited resources.

In many LMICs, medical services are provided by governments, which unfortunately, are often stretched thin by multiple demands for resources and are unable to meet the population's need for medical services. This situation has paved the way for competing private medical outlets to emerge. Private imaging centers compete with physicians in terms of who sees a patient first, resulting in unnecessary exposure of the patients and staff to risks from exams that are not appropriately authorized based on medical need. Recently, one prominent retired gynecologist in East Africa has lamented the overzealous use of ultrasound during pregnancy. She argued that technologists were not well trained, the quality of the scans was lacking, the cost to patients was exploitative, and there was inadequate attention to any inherent risk. Furthermore, the increasing reach of the Internet in resource-limited regions has resulted in the public accessing more information on medical issues, some of which has been used to demand particular services without referral by a physician or credentialed healthcare provider. Some independent private centers are under pressure by patients to provide imaging services without appropriate medical supervision, thus causing concerns for safety due to overutilization.

In the context of LMICs, there is more likely to be a wide disparity in the types of imaging utilization between large cities and rural environments than in higher resource areas. For example, in the United States, Europe, and in many parts of Asia, if a particular imaging device (such as CT or MR) is not available in a rural region, then patients are referred to imaging centers generally not far away where such devices are available. Transportation to such advanced imaging facilities is generally not prohibitive in cost to the patient. However, in some LMICs, there can be a substantial difference in the type and quality of equipment in more distant regions than in the larger cities. It is not uncommon in under-resourced regions for there to be no advanced imaging (CT, MR, nuclear medicine) in regional medical centers serving up to a million people. At such locations, the only imaging may be an x-ray or ultrasound machine, and some of these may be of substantially lower quality or more antiquated than is common in the larger cities. Also, it can be a real hardship on patients or families to travel to larger cities to have more extensive imaging performed. Thus, there tends to be a wider disparity between the imaging devices available in rural and urban settings in the developing world, making it more difficult to generalize about the types of imaging safety requirements needed in these countries.

In most high-income countries, there are usually well-defined standards by which devices are used and maintained that do not vary substantially from region to region. Thus, if one has an x-ray, CT, or MR scan done in one region, the risk is likely to be similar to that in other regions. In LMICs, one may find that regulations, training, and utilization may vary substantially from place to place, further making it difficult to establish appropriate safety standards and practices. All of these considerations make it difficult to implement a "one-size-fits-all" approach to imaging safety in LMICs.

One then faces the ethical dilemma of whether it is better to provide some medical imaging—and thus better medical care—in a place where all safety issues may not be addressable; or whether it is better to ensure that all imaging be done under the highest accepted standards of safety, realizing that such constraints may mean that some places will not have adequate imaging devices available. Resolving this ethical debate is important but beyond the scope of this chapter. The authors would simply point out that the reader may face a situation where limited resources will impact the ability to perform some recommended safety procedures. It will be up to the reader to consult qualified safety experts to determine what safety procedures are feasible and essential in a given location. The authors emphasize, however, the importance of addressing all safety issues adequately. While providing access to medical care is a matter of ethical concern, it is also a matter of ethics to ensure that one does not jeopardize the safety of patients, staff, or the general public in the process.

Importance of Minimizing Dose from Ionizing Radiation

While the use of ionizing radiation in medical imaging has led to vast improvements in diagnostic capabilities and is generally safe, there are two factors that have led to increasing concern over the level of radiation dose delivered to patients. These factors are (1) cases of radiation injury from improperly used equipment, and (2) an overall upward trend in the dose to the population from increased utilization of techniques such as CT imaging over the past three decades. These two factors highlight different ways in which ionizing radiation can pose a hazard. The first factor (tissue reactions, previously known as deterministic effects) causes a hazard to individual patients through damage to tissues. The second factor (stochastic effects) causes risk by increasing the statistical likelihood of inducing cancer in an individual patient or producing genetic mutations in the population at large from imaging studies. Risks from both of these must be minimized.

In the United States, several high-profile cases of radiation injury have demonstrated the importance of using proper imaging protocols and having adequately trained staff. In one such case, erythema and hair loss were caused by an improper protocol for using CT in brain perfusion studies. Over 200 patients were affected, and this case made news in the popular press [1]. It was discovered that the imaging center was delivering about eight times the correct radiation dose for this type of exam. As a result of this and other cases of overexposure, a law was passed in California that requires CT scanners to be accredited, radiation dose to be recorded for CT exams (if the scanner is capable of such recording), and that radiation doses exceeding 20% above what was intended be reported to the state Department of Public Health, among other provisions [2]. In other reported cases, there have been instances of skin injury (including necrosis) due to excessively long exposures to fluoroscopically-guided interventional procedures such as cardiac catheterization [3]. While these events are rare, they point out the possible hazard from using exams with the potential for high radiation doses.

In cases of radiation tissue reactions (injury), harm is caused to specific patients. More difficult to track are the potential effects from increased utilization that has led to an increase in the overall radiation dose to the population at large. In the 1980s, the per capita average radiation dose to a person living in the United States was 3.7 mSv per year, of which 14% was due to medical imaging. By 2006, the average annual radiation dose to a person in the United States was 6.2 mSv, with 48% due to medical imaging. The vast majority of this increase in population-wide radiation exposure was from increased utilization of CT imaging and nuclear cardiology procedures [4]. Devices such as dual-source, dual-energy CT machines with now sub-0.3-s rotation time have opened the possibility for uses of CT in new and expanded applications such as nearly “whole body” CT, CT angiography, and organ perfusion studies, including cardiac analysis. Such high-tech imaging is often not as readily available in the developing world, and as such, there will not likely be similar trends in CT utilization in under-resourced regions as was seen in the United States, although use has increased and techniques remain variable, resulting in a wide range of exposures. There is still a global concern for dose from increasing utilization of CT.

The concern for patient dose from medical imaging is particularly important in pediatric patients. While the past few years has seen a leveling off, and in some age groups indications of a decline in the use of CT, the trend over the past three decades in the use of imaging, especially in the emergency department, has increased in both adults and children [4–8]. Overall, about 4 billion examinations using ionizing radiation have been performed per year globally [9]. Approximately 5–10% of all imaging examinations in the United States are performed in the pediatric age group [10]. The use of CT has increased over the past two decades in the emergency setting, and in one large population, nearly 43% of children underwent evaluation using ionizing radiation in a three-year period, and nearly 8% of the study population had a CT exam over the same period [11]. Doses for some modalities, particularly CT, can be quite high when compared to exams such as chest radiography.

The pediatric population is a special group compared to the adult population due to more vulnerable tissues, higher organ doses for identical exposures in small children, and a longer lifetime in which to manifest radiation-induced cancer. Pediatric imaging evaluation may be more complicated than that for adults for several reasons. First, the clinician who does not regularly care for children may be unfamiliar with the spectrum of pediatric diseases, and inappropriate imaging evaluations may be requested. Second, there is often a great deal of anxiety in the setting of an acutely injured or ill child that may prompt more aggressive imaging evaluation. Third, the actual imaging evaluation of the child may be carried out by individuals who are relatively less experienced with technique and technical factors, which may result in an increased number of images being obtained, suboptimal projections or technical factors, or inappropriate CT parameter selection that may provide excessive radiation exposure. Recent data on global CT practices indicated a great deal of variability in justification and utilization [12, 13]. Finally, there is a recognized elevated responsibility for the protection of children. Of note, there has been a connection between CT examinations and increased risk for cancer in children, although these studies have been challenged [14–19]. These factors contribute to increased public scrutiny and regulatory surveillance of medical imaging in children and mandate a responsibility to manage radiation dose by all involved with imaging practice.

Safety for Patients

There are several key components to ensuring a safe imaging environment for patients. First, it is important to ensure that an examination is warranted and that the proper examination has been requested, so that patients do not undergo needless radiation or other exposures that do not contribute meaningfully to proper medical diagnostic evaluation. Ordering proper examinations depends heavily on having a well-trained staff of healthcare providers, both referring physicians and radiologists. In remote settings where there may not be a full complement of medical specialties, there should be some mechanism for physicians who recommend imaging examinations to consult with radiologists by phone, email, Skype, or other electronic means if there is uncertainty about the most appropriate diagnostic imaging procedure to order. Proprietors of imaging centers should advise their patients of the need to get a physician's referral prior to seeking imaging tests and should not offer procedures without such referrals. Second, there needs to be a thorough review of the imaging equipment by trained and qualified medical physicists, radiation safety personnel, and service engineers to ensure that equipment has been properly installed, maintained, and evaluated for safe operation. A medical physicist should carefully check to ensure that appropriate filtration, shielding, and imaging protocols are established. Third, it is important that the staff who acquire the images be adequately trained on how to use the equipment properly and safely, and that they understand the proper imaging protocol for a given exam. It is important for each institution to have properly vetted and posted imaging protocols for all exams that will be performed. Often, individuals taking diagnostic images will be trained in radiologic technology, but the specific requirements for a given jurisdiction should be followed. Fourth, it is important to ensure mechanical and electrical safety for all equipment that is used on patients. Some x-ray imaging equipment, for example, is quite heavy, and proper engineering must be done to ensure that overhead equipment is properly mounted. Electrical safety should be evaluated on all equipment as well. Properly trained installation or service staff should be consulted. Governments and professional bodies should ensure regular inspections of imaging facilities. Fifth, in the case of magnetic resonance imaging, it is important that patients be evaluated for metallic implants or objects that could give rise to local heating or other deleterious effects. Also, patients undergoing magnetic resonance imaging should be evaluated for the potential for claustrophobia and appropriate remediation measures taken.

Another important feature regarding imaging safety is ensuring good image quality. While image quality may not initially be considered a safety issue, it has a potential impact on safety because images of low quality may need to be repeated or may provide inadequate information or may lead to erroneous clinical decision making. Covering all of the issues related to image quality is beyond the scope of this chapter, but some issues in x-ray image quality include having proper beam filtration, choosing appropriate kVp, having adequate tube current (mA) in order to use short exposure times that do not result in motion blur, and using anti-scatter grids (when appropriate) to minimize scattered radiation. With digital imaging devices, it is also important to properly select image-processing parameters. It is important to have a qualified medical physicist evaluate a given imaging installation for proper image quality and to work with the radiologist on staff to select image processing parameters that suit the clinical need and the preferences of the radiologist.

The above list of safety factors for patients is not exhaustive, and there may be additional safety issues in a given healthcare setting that require attention. It is important to engage appropriately trained individuals to evaluate these issues related to patient safety before any imaging is performed at a new facility, and also periodically afterward to ensure continued safety. There may also be regulatory issues in a given location that must be understood and followed. It would be important to communicate with the minister of health or appropriate professional bodies in a given country to learn about requisite regulatory issues.

Safety for Staff

Many of the same safety concerns listed above for patients also apply to staff. For example, it is important to ensure the mechanical and electrical safety of all equipment. There are other safety issues related to staff, however, that go beyond those for patients. One of the primary concerns for safety of staff is understanding how to properly use the equipment. In addition to putting patients at risk, if the imaging staff is not properly trained in equipment operation then it is possible that staff may expose themselves to unnecessary risk. One key way in which staff are subject to risk is through repeated exposure to ionizing radiation. There are standards in the United States and other countries for the amount of radiation exposure an occupationally employed person is allowed to experience as part of their work duties. These levels of radiation are specific to work-related exposures and do not include any medically related exposures for the individual's own medical care. The limit for occupational exposure in the United States is 50 mSv per year. Staff should be continuously monitored for their occupational exposure to radiation, through the use of "radiation badges" or equivalent monitoring devices. It is especially important to set up proper safety equipment and training for staff that will be involved in high-exposure procedures such as fluoroscopy, nuclear medicine, and CT. In many of these cases, staff must wear approved radiation-blocking aprons. In the case of fluoroscopy, there should be adequate hanging leaded barriers to shield the operator from scattered radiation from the patient. It is important for the staff to understand the proper location for wearing radiation-monitoring badges when wearing leaded aprons.

Special attention must be paid to the protection of the developing embryo and fetus in pregnant staff members, based upon the principles that rapidly dividing, undifferentiated tissues are highly sensitive to the adverse effects of ionizing radiation. In the United States, pregnant women who have declared their pregnancy to their employer, and are exposed to ionizing radiation as a consequence of their employment, are subject to a dose limit of 5 mSv during the period of gestation. It is also recommended that dose be limited to 0.5 mSv during each month of gestation. Compliance with dose limits may be documented by having the woman wear a passive radiation dosimeter at waist level, on the front of the body, which is changed monthly. If the employee wears a shielding garment, the dosimeter is generally placed underneath the garment in order to get the best estimate of fetal dose. In addition to appropriate shielding, other methods of limiting fetal dose should be undertaken. These include minimizing the amount of time spent in radiation fields and maintaining the maximum practicable distance from radiation sources.

Safety for the General Public

In addition to considerations of safety for patients and staff, steps must also be taken to minimize risk to the general public when setting up an imaging facility. Certain principles apply to providing proper shielding for ionizing radiation in x-ray facilities and protection from harm due to the magnetic field in MR installations. In certain jurisdictions, there are regulatory considerations for public safety that must be met.

One of the main types of protection for the public is providing shielding from high-energy photon radiation in x-ray, CT, or nuclear medicine. In some health facilities in the developing world, old rooms have been repurposed to house x-ray machines but without regard for appropriate shielding based on activities in surrounding parts of the building. In one facility familiar to one of the authors, an x-ray room was placed adjacent to a post-natal room and another high-traffic clinical area. The room originally served as a storeroom for the facility, but after acquiring an x-ray machine by donation, the room's role was changed to that of an x-ray facility without adequate attention to shielding, indicating how easily the public could be exposed to the risk of ionizing radiation from imaging equipment.

The number of considerations in shielding design is too extensive to be covered in detail in this chapter, but a qualified medical health physicist can work with a given imaging installation to provide a suitable shielding design. The basic principles of shielding include providing a barrier in walls, ceilings, and floors where the public (or employees) may be present; shielding of scattered radiation (such as from the patient and imaging hardware); and shielding of leakage radiation from the x-ray tube housing [20]. Structural shielding is typically in the form of lead that is constructed into the wall. In buildings constructed of concrete, the concrete barrier in the floor and ceiling may be able to serve as part of the barrier, if thick enough. Doors can be purchased that have lead lining. For places with windows that separate workers or the public from a radiation area, leaded glass is available.

The general considerations for shielding calculations include the type of ionizing radiation, the distance from the point of emanation to the location of a person who could be exposed, the "workload factor" (the approximate amount of time per week that the radiation is present), the anticipated average intensity of radiation emitted, the fraction of time that a radiation beam will be directed at the intended barrier, and the anticipated occupancy of the area beyond the barrier. If a barrier separates an x-ray room from a closet that is rarely occupied, for example, less shielding may be needed than for a barrier facing a waiting room. Thus, it is not enough to merely consider that an x-ray machine may be present; it must also be taken into consideration what types of x-ray exams may be performed and what the environment is like surrounding the x-ray room. Safety for nuclear medicine facilities also includes proper shielding for holding the sources and adequate safeguards for securing the radionuclides (e.g., locked cabinets with access to the key limited to authorized personnel).

In magnetic resonance facilities, it is important to keep the general public outside the strong magnetic field of the magnet. Barriers should be provided that limit access to regions with strong magnetic field; these precautions should be taken with regard to the general public and all staff members, including cleaning staff, who may not be adequately informed of safety hazards.

In all of the considerations for protections for patients, staff, and the general public, trained and authorized safety personnel should provide recommendations, design, and evaluation of safety features for any proposed facilities.

Specific Issues of Importance in Various Imaging Modalities

X-Ray and CT

The most important safety consideration in x-ray and CT imaging is protection from excessive radiation exposure. An excess of radiation exposure can come from a number of different sources, including inadequate equipment, improper imaging protocols, staff inexperience, clinical overutilization, and perhaps surprisingly, from inadequate attention to image quality. Each of these will be discussed briefly.

There are several components to ensuring proper equipment to reduce radiation exposure in radiography. First, there should be adequate beam filtration. Regulations concerning filtration requirements may vary by jurisdiction, but in typical use in the United States, recommended beam filtration amounts are 0.5 mm Al (or equivalent) for <50 kVp, 1.5 mm Al equivalent for 50–70 kVp, and 2.5 mm Al equivalent for >70 kVp. This filtration removes the lowest energy photons from the beam that are almost all absorbed in the patient, thereby contributing to patient dose but not to the usable image. Filtration is said to “harden” the beam, meaning that it makes the mean beam energy higher. Special filtration considerations may exist for particular types of imaging such as mammography or dental radiography.

A second equipment-related exposure consideration is the use of beam collimators. It is important that the beam be collimated down to the smallest overall field size that can appropriately image the desired anatomy. A trained technologist will know the proper amount of collimation for a given exam but an inexperienced user may expose too large of an area. Inadequate collimation can lead to unnecessary exposure to regions of anatomy that do not contribute to answering the clinical question at hand. It is also important to ensure that the positioning light field be adequately aligned with the actual exposed image area. A medical physicist can do an alignment test to determine the fidelity of the light field to the x-ray field. Using appropriate collimators also ensures that the beam is restricted in size so that imaging staff are not unintentionally exposed. Following the same principle, adequate shielding of x-ray tube units must be confirmed to ensure that leakage radiation is not exposing patients or staff.

A third factor to consider is the use of anti-scatter grids. X-ray photons interact with tissue in two predominant ways at the energies used in diagnostic radiography: photoelectric effect and Compton scattering. Compton scattering (along with the less prevalent coherent scattering) contributes partially to image contrast, but also leads to photons that spread across the detector adding to image fog but not to usable image content. The scattered photons have the net effect of adding to image noise (mottle) and reducing the net contrast of an image. This added image noise may be compensated for by increasing the overall beam flux, thereby increasing patient dose. The loss of contrast can lead to inadequate visualization and consequently may lead to inadequate clinical usefulness of the image. The main mechanism by which scattered radiation is addressed in radiography is through the use of anti-scatter grids. Grids significantly improve image contrast (and thereby, visibility of anatomy) but can require an increase in tube output. It is important to select grids with appropriate parameters for a particular application. For example, with fixed geometry upright chest radiography, it is common to use grids of 12:1 or 14:1 grid ratio (the grid ratio is one measure of a grid’s effectiveness). However, for angiographic use a lower grid ratio may be used. For bedside imaging, it is customary to use no grid at all due to the difficulty of positioning the grid in the variable geometry of bedside application. Reduction in scattered radiation can also be achieved by air gaps (a large distance between the patient and the image receptor), and in some rare cases by scanning slit devices.

A fourth equipment factor of importance is the type of x-ray generator used. The generator constitutes the circuitry that supplies the high-voltage and regulates the current to the x-ray tube. Most x-ray generators in the developed world are of the three-phase/12-pulse, constant-potential, or high-frequency types. However, it is quite possible that in some installations in the developing world, older single-phase x-ray units will be in operation. These older single-phase units have the disadvantage of having very large swings in the rectified x-ray tube voltage; in fact, these units have 100% ripple, meaning that they have voltage waveforms that are half-sinusoids. By comparison, three-phase/12-pulse units have voltage waveform ripple of only a few percent, providing a much more constant tube voltage. There are several negative aspects to the wide swings in the single-phase waveform, including inability to make short exposure time pulses, and more importantly, a very wide range of effective kilovoltage output from the tube. For a reasonable fraction of each alternating current cycle, the tube kilovoltage drops to zero or is at a very low value. These low tube kilovoltages produce no usable image information but contribute to patient dose. Special considerations, such as tube-rating charts that specify the maximum allowable output of a tube, will vary with single-phase units relative to more contemporary type units. A qualified medical physicist should evaluate the particular installation and utilization of any single-phase unit to determine appropriate operating conditions.

It is important to have proper clinical utilization protocols, both for the acquisition parameters and also for the indications for which a particular x-ray exam will be used. Acquisition parameters include factors such as tube kilovoltage (kV), beam current (mA), and exposure time (ms). A medical physicist, in consultation with a radiologist and x-ray technologist, should derive a set of standard best-practice acquisition parameters for each type of radiographic exam, and these parameters should be conspicuously posted by each x-ray machine. Using the wrong protocol can lead to exposure that is beyond that required to produce a proper image. This over-exposure ironically becomes more of an issue with digital detectors (which generally have better image quality efficiency than film) because they produce a usable image over a wide range of exposures; by comparison, film will produce a properly exposed image only in a narrow range of exposures. Thus, with digital detectors, it is important that users of the radiographic equipment not allow “dose creep” to occur, whereby one notices that the images get better as the dose increases, with the unintended consequence of slowly over time increasing the actual exposure factors beyond that required for the imaging task at hand. Imaging staff must be adequately trained in the proper use of x-ray exposure factors with digital radiographic equipment.

It is especially important to consider proper clinical utilization when using fluoroscopy. Exposure rates can be exceptionally high in fluoroscopy, up to 5 or 10 Roentgen (R) per minute, which can lead to some of the highest radiation doses of any x-ray imaging procedure. It is very important in fluoroscopy that the purpose for the examination be carefully considered from the perspective of information gained and its medical usefulness. It is important that the x-ray beam be on for as short a time as possible, consistent with clinical need. Equipment with the most current safety features should be used, if at all possible. Adequate shielding (from lead drapes, movable barriers, or shielding garments) should be used to protect staff. The most important safety feature for use of fluoroscopy, particularly in high-dose procedures such as angiography or other catheterization protocols, is for the medical staff performing the procedure to be highly trained and credentialed for such procedures.

A final consideration for controlling patient dose in radiography is appropriate attention to image quality. Proper image quality uses the minimum amount of radiation required to produce an image adequate to the imaging task, and includes factors of spatial resolution, image noise, and potential imaging artifacts. A thorough discussion of image quality is far beyond the scope of this chapter, but useful resources for medical physicists on issues of image quality are listed in the references below [21–24]. In general, if image quality is inadequate, then radiation dose may increase by raising exposure factors to compensate for poor contrast-to-noise or by requiring retake images. A thorough evaluation by a qualified medical physicist or image quality expert should be undertaken when an imaging facility is first taken on line, in order to ensure that radiation dose is being put to best advantage. Subsequent follow-up evaluation should also be done periodically to make sure that image quality does not degrade over time.

Patient dose considerations in CT imaging follow many of the same principles as with radiography, but there are also several additional factors that are specific to CT. First, a CT scanner should have appropriate collimation of the fan beam and also a suitable "bow-tie" filter. The bow-tie filter selectively reduces the beam flux in the regions near the edge of the patient so as to minimize the very high dose possible in those areas. It should also be confirmed that there is an appropriate beam slice profile, so that there is not excessive overlap of one slice relative to the next, which can lead to excessively high dose for closely spaced narrow beams. There are a number of configurations and generations of CT devices that may be encountered, particularly in lower-resource regions where older or refurbished units may be found. The types of CT devices encountered may be older single-slice fan-beam units, newer generation models with multi-detector arrays and helical acquisition geometry, and very contemporary units with dual x-ray sources. It is not possible to address in this chapter all possible dose considerations with all of these possible units, so it is important to have a qualified medical physicist evaluate a given unit for proper operation based on its particular geometry and configuration.

CT has significant benefits in imaging the ill or injured patient, and it is widely recognized as one the most valuable tools in medicine [25, 26]. Radiation safety in CT should follow the principles of justification and optimization. The topic of justification is beyond the scope of this section, but a comprehensive discussion of the issues, potential solutions, and remaining challenges is available [27]. The imaging team, including the radiologist, medical physicist, and technologist, has a primary role in optimizing CT performance to manage radiation dose and balance dose with image quality. CT provides a relatively high dose compared with other imaging modalities that use ionizing radiation, and radiation management takes on increased significance.

There have been substantial technical advancements in CT equipment in the past decade designed primarily to lower radiation dose. The more recognized advancements include wider detector arrays (including volumetric CT), adaptive collimation to minimize wasted radiation at the beginning and end of scan acquisition, improved detector performance, automatic tube current modulation, improved dose display (CT dose index and dose length product) on the console, iterative reconstruction, size-adjusted protocols, and alerts and notifications for radiation doses beyond set values. In addition, there are improved educational materials to optimize clinical utilization. Equally important, there are a variety of strategies that can be successfully utilized in clinical operations to control radiation dose [28–32]. Safety in CT also requires adherence to appropriate infection control, patient monitoring, and minimization of contrast related events such as contrast reactions and extravasation [33, 34]. Protocols and policies should be in place to address these safety issues in both adults and children.

There are a number of factors to consider in safe use of CT imaging in addition to considerations of radiation dose. An important consideration is appropriate scan preparation. Scan coverage that is inappropriately restricted or too extensive to answer the clinical question constitutes ineffective use of medical radiation. It is especially important with severely ill or injured patients to have an understanding of what information is needed by the healthcare provider that requested the CT scan, in order to minimize the time the patient is away from the critical care setting. Next, while not every patient study will require adjustments in existing protocols, there should be mechanisms in place to consider optimizing the individual examination based on clinical needs. An example of such considerations is the appropriate use of contrast media, either by enteral or parenteral administration. Screening for renal insufficiency, prior IV contrast media reactions, and other medical conditions that warrant consideration of modified contrast administration must be included in patient preparation [33]. The appropriate vascular access in ill or injured patients should be identified, requiring communication with the clinical care team. The sedated child will also require additional teamwork and considerations in the CT suite, and a program to provide this service should be in place. Movement in a child who needs sedation may result in a non-diagnostic examination and wasted radiation. For any patient requiring monitoring, the appropriate equipment, visual contact, care personnel, and programs for emergency response (such as code activation or some other rapid response) must be in existence and up to date. Those at risk for falls should be identified and managed with additional care. For CT examination review, imaging experts, including radiologists, should be available to review the study for both diagnostic quality as well as identification of potentially urgent or emergent findings to facilitate timely and quality care of patients.

Dose reduction strategies for clinical CT use have been recently reviewed in both pediatric and adult patients and include the following: (1) Adjust acquisition settings based on the size of the patient. Smaller cross sectional areas (such as in young children, or thin adults) may not need higher tube currents (mA) or kilovoltage (kVp). (2) Adjust the techniques based on the indication. Large or high-contrast abnormalities may benefit from reductions in mA, kVp, or scan coverage [35]. (3) Adjust parameters based on the region scanned. Chest (lung), angiography, and skeletal CT may be performed with lower kVp and mA compared with abdomen, pelvis, and brain CT. (4) Avoid overlapping scans when covering adjacent regions, such as during large coverage trauma CT examinations. (5) Minimize the use of multiphase examinations, such as pre- and post-contrast examinations, and delayed sequences. These techniques should be determined in protocol development and review to have a justifiable benefit. (6) Consider the use of shields, such as bismuth breast shields. Adjustments in mAs have been promoted as a preferred method but shields can be of benefit [36, 37]. (7) Finally, and as important as any dose management strategy, consider alternative modalities such as MR and ultrasound that do not use ionizing radiation.

Equally important in dose management is a clear understanding of the equipment by technologists and radiologists. For example, inappropriate use of dose reduction technologies such as tube current modulation can actually result in unanticipated excessive radiation doses rather than reductions in dose. Protocol development, implementation (especially on new CT equipment), and review should be a regular part of radiation protection in CT with joint ownership by radiologists, medical physicists, and technologists. Such practices may include cumulative dose archiving and review, especially for quality assurance purposes. Finally, programs should be in place to review patient safety in CT for issues such as inappropriate techniques (contrast media use, wrong region examined), contrast reaction rates, extravasations, codes or medical emergencies. The responsibility for the safety and welfare of patients undergoing CT examinations is multifactorial and requires commitment by all stakeholders in the imaging practice. An existing program for patient safety will minimize the occurrence of incidents and errors, and it will optimize the response when these do (and will) occur.

MR Imaging

The equipment-related hazards of magnetic resonance (MR) are from the strong main (static) magnetic field (typically 60,000 times the earth's field and always "on"), induced electric currents from switched gradient magnetic fields ("the gradients"), heating of the patient from radiofrequency fields ("RF"), and loud acoustic noise from the gradients. The main field can attract ferromagnetic materials that, if large enough, could strike a patient with lethal force ("missile effect"). The gradient-induced currents can cause muscle twitching, which is uncomfortable for the patient, and in rare cases can cause painful nerve stimulation. The RF heating can also cause some discomfort from a sense of pulsed warmth in the skin and can possibly raise the core temperature, which could be serious in febrile or uncommunicative patients. Finally, the acoustic noise in an MR scanner can reach over 120 dB, which exceeds "rock concert" levels and can possibly damage hearing over the course of a 1 h exam. Fortunately, the gradient, RF and acoustic hazards have been addressed by manufacturers of such systems based on United States and European guidelines developed in concert with the scientific community. The gradient switching speed is not allowed to exceed the stimulation threshold, RF power levels are limited based on patient weight, height, age, and gender and noise has been minimized with pulse shaping methods. However, it is still important that patients and anyone else accompanying them into the magnet room wear hearing protection such as earplugs that can attenuate sound by at least 20 dB. For MRI systems in other jurisdictions it would be best to check with the manufacturer to see if the delivered equipment follows such safety guidelines. A good general reference for MR safety is a paper sponsored by the American College of Radiology [38].

The magnetic field of an MR system has a very strong attraction for ferromagnetic (iron, steel) objects. Such metal objects must thus be excluded from the vicinity of the magnet because the forces exerted by the magnet increase very rapidly as the metal comes near the magnet. This can lead to the metal being suddenly pulled from someone's control, becoming a dangerous projectile. The larger the metal object, the greater the force and destructive power of the object. Examples of things that have been attracted into an MR magnet are: oxygen bottles, floor polishers, pump motors, desk chairs, and gurneys. Modern shielded magnets, while they are good at restricting the magnetic field within the walls of the magnet room, have the added difficulty of an even more rapid increase in forces near the magnet, causing a very sudden pull on a metal object.

Smaller ferromagnetic objects such as surgical clips, body piercing jewelry, shrapnel, bullets, or metal in the eye (from, perhaps, an industrial accident) can also pose a hazard. The magnetic field can cause a twisting action on metal in the body that can cut surrounding tissue. Body jewelry can usually be removed and surgical staples, clips, or other metal in the body are usually immobilized by scar tissue (after about 6 months post-surgery), but metal in the eye or brain, unless it is known to be nonferrous, is nearly always a contraindication for MRI. Even some tattoos or cosmetics contain particles that conduct electrical current. In the MR system, the radiofrequency fields can induce currents in these materials that can cause local burns.

Patients with pacemakers and/or tissue stimulators (neuro, muscle, etc.) are also usually excluded from MR systems. The main magnetic field, the gradient magnetic field, or the radiofrequency fields can interfere with these devices and possibly cause life-threatening conditions. However, MRI-compatible pacemakers have been developed and at least one has been approved by the United States Food and Drug Administration [39]. Without certain knowledge of a patient's pacemaker make and model it is best to assume that MRI is contraindicated.

Many risks are controlled by the design of the MR clinical suite, clinical and support personnel training, and careful screening of the patients. The American College of Radiology recommends designation of four zones in the MR clinical suite: Zone 1, outside the clinic where the general public cannot encounter any effects of the MR system; Zone 2, which comprises the reception and waiting/gowning rooms; Zone 3, which is the MR system control room and which contains the entrance to Zone 4; and Zone 4, which is the room containing the MR magnet. Patients are screened by trained personnel in Zone 2 using a questionnaire that asks about jewelry, tattoos, cosmetics, pacemakers, electrical stimulators, prior surgery, etc.

The questionnaire answers are then evaluated for possible exclusion of the patient. A very valuable reference to the magnetic properties and safety of many medical implanted devices is found in reference [40] and is also maintained on-line (http://www.mrisafety.com/). Having the patient remove all clothing in a dressing room and put on a hospital gown without metal fasteners is another part of the safety effort. The clinic must be designed to have cupboards to secure a patient's clothes and possessions. The gowned patient is then verbally asked in Zone 3 again about surgery, pacemakers, or metal in the body before going into Zone 4. Anyone who accompanies the patient such as a family member must also be screened and have metal objects removed.

Zone 4 is carefully controlled to exclude all potential ferromagnetic objects. A very useful technique is for the clinic to have a system of special markings for any equipment that has been fully tested to be allowed in Zone 4. While all MR clinic personnel are responsible for safety and should be trained, the MR technologist, is charged with ensuring that only approved equipment is allowed in Zone 4. The technologist must also be trained to prevent other medical personnel from entering Zone 4 until they have removed all loose metal (stethoscopes, clipboards, pens, loose jewelry, etc.). Especially during emergency situations, personnel must be trained that ferromagnetic material cannot be brought into Zone 4. The usual emergency plan is to have a non-ferromagnetic gurney close at hand so that the patient can be rapidly removed from the bore and onto the gurney for removal from Zone 4 so that emergency procedures can be safely performed.

Prisoners may pose a special problem. They must be accompanied by law enforcement officers who are trained in MR safety. The prisoner/patient must have metal restraints replaced with plastic restraints and if an officer is to be in the magnet room he/she must have a backup officer in Zone 3 to keep active control of weapons, etc. In other words, the officer in the scan room must not carry any ferromagnetic items (guns, knives, handcuffs, etc.).

MR imaging is frequently performed using a comparison of images obtained before and after a contrast agent (CA) has been injected into a vein in the patient. The most common form of contrast agent contains gadolinium (a heavy metal) contained within a buffering molecule that prevents the known toxic effects of gadolinium in tissue. Such CAs have been used in millions of patients with only occasional minimal effects such as dizziness or a metallic taste for a brief period. The CA in the blood serum is rapidly eliminated from the patient through the kidneys. However, there is a class of patients with severely compromised kidney function who have had a rare but severe reaction known as nephrogenic systemic fibrosis (NSF). Some formulations of these agents appear to be safer in terms of association with NSF than others. Any patient with suspected kidney insufficiency should be evaluated for estimated glomerular filtration rate (eGFR) with a creatinine level test. At some institutions patients with eGFR >60 ml/min/(1.73 m^2) are considered acceptable for gadolinium CA injection; those in the range of 30–60 ml/min/(1.73 m^2) should be carefully evaluated for CA use, and those with eGFR <30 ml/min/(1.73 m^2) should avoid gadolinium CA unless vital for their condition. Recently, studies have shown [41] that subjects with normal kidney function who have undergone multiple MRI exams that use gadolinium based contrast agents can be shown to have a noticeable, cumulative deposition of gadolinium metal in the body/brain tissues. It has not been determined yet if such persistent buildup of gadolinium in tissues is harmful, but since gadolinium has a known toxicity, the best practice is to try to minimize exposure to gadolinium contrast agents as far as possible consistent with needed patient management.

MR has been used very effectively and safely with both pregnant patients and children. Contrast agents should be considered very carefully for use during pregnancy or for breastfeeding women since CAs cross the placental barrier and appear in breast milk. Breastfeeding women who are scheduled for CA use should express and store enough milk to avoid breastfeeding for 24–48 h (expressing and discarding milk during that time).

Nuclear Medicine

Nuclear medicine employs radiopharmaceuticals for the diagnosis and treatment of disease. Nuclear medicine has an outstanding safety record; however, this has only been achieved through diligent attention to basic radiation safety practices and compliance with regulatory standards. Of utmost importance is ensuring that a "radiation safety culture" exists in any institution that performs nuclear medicine procedures. An effective nuclear medicine radiation safety culture incorporates the patients, the staff, and the public, and applies standard radiation safety practices on a daily basis.

An effective patient safety culture ensures that every patient undergoes the medically appropriate examination or treatment course, and that the examination or treatment be conducted so as to ensure that the risk of adverse health effects of ionizing radiation is minimized. Of prime importance is that the medical and technical staff of a nuclear medicine facility be appropriately trained and credentialed. In addition, careful attention must be paid to compliance with local governmental regulations regarding the transport, handling and medical use of radioactive material. Finally, quality control procedures that ensure the correct measurement of administered activity and the quality of the final images must be in place and the results of quality control procedures diligently documented and available for audit by regulatory authorities. Quality control procedures include ensuring the accuracy, constancy and linearity of dose calibrators, and the uniformity and linearity of gamma imaging equipment.

It is important to correctly identify each patient prior to the administration of a radiopharmaceutical. Identification may be aided by the use of a paper or plastic wristband containing the patient's name and birthdate, and by asking the patient for his/her name and other identifying information in a way in which the patient must actively respond. For example, asking the patient "Are you Mr. Mhunzi?" may elicit only a nod, which may be incorrectly interpreted as a positive response. This is especially true when a language barrier exists. Instead, directly asking the patients their names or other identifying information and verifying it with other documents, helps ensure that the correct patient receives the radioactive drug. Similarly, it is imperative that every patient receive the correct radiopharmaceutical in the prescribed dosage. A dosage that is too low may lead to inadequate image quality and the necessity to repeat the examination. A dosage that is too high also results in unnecessary radiation exposure. Similarly, administering the wrong radiopharmaceutical will lead to a repeat examination and unnecessary radiation exposure. To avoid these problems, all vials and syringes should be properly labeled with the radiopharmaceutical and amount. For "unit dose" preparations, the vial or syringe should also be labeled with the patient's identifying information, which must correlate with the information found on the wristband.

The risk of adverse radiation-related health effects may be minimized by using the lowest dosage of radiopharmaceutical that is consistent with adequate diagnostic image quality. To consistently achieve this, each institution should prepare and follow standard procedures for each diagnostic examination. Procedures should include the indications for the radiopharmaceutical and a weight-based scheme for determining the administered radioactivity. To avoid radiation exposure to a pregnant patient, an appropriate social and menstrual history should be obtained to exclude pregnancy. In situations where the examination of a pregnant woman cannot be delayed, further reduction in the administered radioactivity should be considered. Mothers who need an examination while nursing an infant should be advised to interrupt nursing for a specified period, the length of which depends upon the metabolism and dosage of the radiopharmaceutical. As with all drugs, radiopharmaceuticals can have adverse pharmacologic effects, the most serious being an allergic or anaphylactic reaction. For therapeutic procedures using iodine-131, dose-related adverse radiation effects can occur, including myelosuppression or sialoadenitis. Patients must be carefully monitored for these adverse treatment effects.

Measures that reduce radiation exposure to patients, such as administering the minimum radioactivity and avoiding the necessity to repeat examinations, also act to reduce exposure to the technical staff. Technologists may also reduce their exposure by keeping the time spent performing an examination, including the time spent preparing the dosage, to a minimum. Safety should not be compromised by speed; practicing procedures with non-radioactive material will improve both technique and confidence. Rotation of staff between nuclear medicine and regular diagnostic radiology work will reduce staff exposure. Maintaining the maximum distance from a patient, consistent with good patient care, is very effective in reducing exposure. Preparation of the dosage while shielded by a simple lead "L-block" reduces body exposure dramatically; similarly, syringe shields can minimize hand exposure. It should be noted that shielding aprons of the type used in diagnostic radiology do not provide sufficient protection against most radiopharmaceuticals, especially iodine-131.

Just as it is appropriate to minimize the radiation exposure of patients and staff, it is also important to minimize the "collective dose" to persons not directly involved in the local practice of nuclear medicine. Dose to the public may be minimized by posting the appropriate warning signs, as specified by international and local standards, to limit access of the public to areas where radioactivity is being used. In addition, radiopharmaceuticals must be secured when not in use, and any waste must be properly disposed. Safe disposal of waste may be achieved by allowing it to "decay in storage" for a specified time, usually ten times the half-life of the longest-lived radionuclide in the waste stream. For most radiopharmaceuticals, this period would range from several days to several months.

Patients who have undergone diagnostic radiopharmaceutical examinations do not pose a health risk to family members or the public. However, care must be taken in the case of the treatment of thyroid disease with iodine-131, where the photon energies, half-life, and physiological properties of the radionuclide increase the potential hazard significantly. Patients receiving iodine-131 for therapeutic purposes should be instructed on how to interact with family members, including children and pregnant and nursing women, in order to minimize radiation exposure to others. Simple time and distance measures, such as avoiding sleeping with spouse for several days may be employed, as well as simple measures to reduce the possibility of ingestion of radioactive contamination that may be present in the patient's urine, saliva, and perspiration and transferred to surfaces or persons. Such measures include attention to personal hygiene, avoiding sexual relations, and washing individual clothing separately from that of others.

Ultrasound

Diagnostic ultrasonic imaging systems are generally quite safe when used as recommended, although there are potential reasons for conservative use and concern. Potential bioeffects from acoustic exposure arise from two sources: tissue heating and mechanical effects. The expected tissue heating under normal scanning conditions is quite small (under 1 °C) and is not associated with safety concerns. However, long scan times of the same location, the use of Doppler methods over extended periods, or scanning of bone-tissue or air-tissue interfaces will induce larger temperature increases. Mechanical effects are anticipated when gas or air bubbles are present in tissue, such as near the lungs or bowels, or after contrast agent injection. Ultrasound can interact with these bubbles to mechanically disrupt adjacent tissues. Most ultrasonic scanners have operator-selected levels of acoustic exposure which are displayed on the monitor as MI (Mechanical Index) and TI (Thermal Index), reflecting the potential mechanical bioeffects and tissue heating, respectively. Scanner operators are strongly encouraged to use lower exposure levels and to increase them only when required to achieve diagnostic image quality. A resource listed in the references describes methods for measuring acoustic output [42].

Fetal imaging raises additional safety concerns. A large number of animal and human studies have examined ultrasonic safety, and most experts agree that there is little cause for concern when diagnostic scanners are used with appropriate attention to minimizing scan times and intensity levels. It is also recommended that Doppler flow imaging methods be used conservatively in fetal scans given the greater tissue heating associated with Doppler methods, especially in the first trimester. Ultrasonic fetal monitors use very low ultrasonic levels and, like diagnostic imaging scanners, are generally considered to be quite safe. It is not considered appropriate to use ultrasonic scanners to acquire "keepsake" images of fetuses. Resources listed in the references provide guidelines for obstetric use [43, 44].

It is difficult for clinical users and clinical engineering staff to measure ultrasonic exposure levels or system performance. Studies have shown that as transducers age or are subjected to harsh treatment, they will degrade in their imaging sensitivity and resolution. These gradual degradations can be difficult to detect but may become severe over time. These losses in performance are not, however, expected to be associated with increases in acoustic intensity levels. If the transducers' lenses or housing peels or cracks, however, the transducer may represent an electrical safety hazard and should be discarded.

It should be noted that the discussion above does not apply to ultrasonic physical therapy devices, which are designed to heat internal tissues. These devices can easily overheat tissues and should only be used by skilled operators on skeletal muscles.

Infectious Disease Safety and Imaging

The radiology department is an area where hygiene, and the control of infectious disease, is a fundamental and significant responsibility for the welfare of the patients, their caregivers and personnel. Infectious disease precautions can be overlooked for many reasons, including the fact that most imaging procedures are perceived as devoid of contact by radiologists, such is in radiography or CT, unlike most medical visits in other settings that include some sort of examination necessitating physical contact. Moreover, the radiologist is often physically removed from any patient interaction, and thus awareness of and accountability for infection control programs may be lower than with other physician groups. Arguably, however, the radiology environment has even greater potential for the spread of infectious diseases than other medical settings for several reasons. First, there is high traffic from both inpatients and outpatients with potentially communicable diseases. Many practices may do several hundred thousand examinations (patient encounters) per year, and essentially all require some sort of physical contact by technologists for exam preparation, including positioning. Second, imaging is used as a problem-solving tool, so that individuals with nonspecific symptoms, which might be a result of as yet undiagnosed infectious conditions, may require imaging evaluation. Third, transmission of medical information to the radiology department is often recognized as deficient, limited to a few words or lines on a requisition for a particular study, thus minimizing the opportunity to be aware of the need for infectious disease precautions. Fourth, engagement with patients may require some assistance by radiology personnel, increasing the possibility of transmitting certain infectious diseases. Interaction with radiology personnel may involve preparing for diagnostic imaging examinations, such as moving from bed to imaging table, from stretcher or wheelchair to imaging table, and general assistance for the relatively young, elderly, injured, or ill patient. Fifth, numerous patients per day can come into contact with surfaces touched by previous patients. There may be a lack of recognition of some "surfaces" that transmit disease, such as shielding garments, patient transfer devices, and even door handles and surfaces in restrooms. Moreover, many imaging procedures may be emergent in patients with known or unrecognized infectious diseases, such as blood borne pathogens or tuberculosis. Often times, inpatients as well as patients from the emergency setting may have open wounds or surgical sites as well as support apparatus such as urinary catheters, central venous catheters, thoracostomy tubes, enteric tubes, and endotracheal tubes which obviously would be at higher risk for harboring and transmitting infections. In addition, imaging procedures such as MR and CT require an intravenous catheter placement or access of existing catheters. The opportunities for blood-borne pathogens to be transmitted with frequent access for delivery of contrast media are increased.

Radiology is also an environment of interventional procedures that require by their very nature some access to the body, including blood vessels, organs, or body cavities. A significant portion of these procedures involves management of infectious processes such as abscess drainage, fluid aspiration, or biopsy of potential focal lesions in organs that may be due to infection. This intervention includes performance of common fluoroscopy studies, such as luminal exams and tube placements. These procedures, while generally low risk, do carry a finite risk of transmitting infections. Frequently, imaging equipment such as ultrasound transducers or cassettes for portable radiographic examinations will be used on a number of patients sequentially.

Together, these conditions conspire to provide a significant opportunity for the spread of communicable diseases between patients and among personnel, as well. The imaging department needs to subscribe to, as much as any area in the hospital, optimal hygiene, including the use of gloves for all patient interactions, and mandatory hand washing as outlined in mandates such as the National Patient Safety Goals in the United States. In regions where tuberculosis is common, the use of portable HEPA filtration units and appropriate personal protective equipment should be employed when imaging patients for whom tuberculosis is known or suspected. Where feasible, intravenous catheters and other devices specifically designed to prevent needlestick injuries should be employed. Individuals such as physicians, nurses, technologists, administrators, compliance experts, medical physicists, engineers, and risk management staff must be identified to develop, manage, and monitor the radiology safety program, including external review to assure sufficient adherence to institutional infectious control policies and reporting of metrics as part of departmental performance. Various articles listed below [45–48] contain useful information on infection control in the imaging department.

Safety Related to Trauma

Trauma assessment, which often includes imaging evaluation, is a source of great anxiety for those involved due to the urgency of traumatic conditions, uncertainty of potentially significant complications requiring critical decision pathways, and often times the medical instability of the patients. It is in these situations that safety issues, including medical errors, are often encountered. Adherence to appropriate principles of patient safety during imaging evaluation of trauma is a shared responsibility for all individuals in the imaging department, including technologists, transporters, nurses, and radiologists. Of utmost importance is communication of information regarding the medical status of the patient between healthcare providers in the emergency setting, such as an emergency room physician or trauma surgeon, and the appropriate imaging personnel.

Of particular importance is proper recognition and immobilization of potential injuries involving the skeleton, particularly the vertebral column and extremities. For these injuries, unnecessary manipulation may result in vascular or neurologic complications as well as more difficulty in treatment (i.e., reduction/stabilization) of such injuries. Often times, portable examinations such as radiography are required and these provide additional challenges in terms of study quality. For example, a repeat examination at the patient's bedside may be required, with relatively greater time to obtain adequate images and diagnostic information compared with a patient who travels to the imaging department for evaluation, where repeat examinations may be more expeditious. Portable (i.e., bedside) examination may include an ultrasound survey (FAST survey), which may be used to direct further care by imaging professionals, and potential need for urgent interventional such as thoracostomy tubes, pericardial drainage, or emergency surgical intervention for significant intraperitoneal hemorrhage. However, adequate expertise must be assured to make the use of such procedures and any resulting interventions safe and effective. Some issues that may increase the likelihood of difficulties in managing trauma patients include the distance from the stabilization setting to equipment such as the interventional suite, MR scanner, or CT suite. References on imaging safety in trauma are given below [49, 50].

Importance of Safety Planning, Inspection, and Training by Qualified Personnel

This chapter has highlighted many, but not all, of the issues that may be relevant to imaging in an LMIC. Often, the devices encountered may be significantly less advanced than the more modern counterparts in high-income nations. Therefore, it is important to engage the services of qualified safety experts to help address the particular issues with a given device or installation. There are several principles that may apply to many such installations. First, it is important to address structural safety considerations of a given facility. These structural issues may include radiation shielding for x-ray, CT, or nuclear medicine applications, and electromagnetic shielding for MR installations. These shielding considerations are generally not issues that can be addressed by novices, and so qualified medical physicists, health physicists, radiation safety officers, and device service engineers will need to be consulted. Second, a facility needs to be inspected after installation to ensure mechanical and electrical safety as well as proper radiation limits. The installation should also be inspected for appropriate use of safety protocols specific to the clinical use. In many cases, these inspections may be subject to regulatory control, and so the particular requirements of a given jurisdiction should be followed. In cases where specific regulations may not exist, using best practices from regions with established safety regulations would be a good starting point. However, it would be important to consult the ministry of health (or comparable body) in a given region to make sure that legal and regulatory standards are satisfactorily met.

Following planning, installation, and inspection, it is important to ensure that the staff that will use a given device be adequately trained in proper clinical utilization and in relevant safety standards. Such staff may include imaging technologists who will acquire the images and radiologists who will interpret the images. In cases where there are no trained technologists or radiologists, it would be advisable to enlist the services of trained individuals who can consult on specific clinical cases. Again, the ministry of health should be consulted to find out any requirements on who may be considered authorized to acquire or interpret images in a given situation. It should always be considered standard practice to have the relevant staff undergo appropriate formal training in the utilization of any imaging equipment, even in remote areas where trained staff may be rare.

There are a number of stakeholders in ensuring adequate safety of imaging centers, and it is not always possible for someone wanting to start a new imaging center in a resource-limited region to have complete control of the efforts of all of these individuals. While every effort should be made to ensure that each of these individuals performs their respective duties, there are sometimes resource limitations that cause complications. Although not an exhaustive list, the general responsibilities listed here are good starting points for assigning duties to different agencies or individuals. First, at the national or regional level, ministries of health (or comparable bodies) should enact specific guidelines governing acceptable safety standards for equipment operation and for what constitutes adequate staff training and credentialing. These standards should be evidence based, and when possible, should make use of existing international standards. Second, imaging center operators should verify that the installation, design, and shielding have been properly done by qualified individuals, and that staff are properly trained and credentialed to operate the equipment and to make clinical decisions based on the images. Imaging center operators should ensure that patients do not self-refer without appropriate medical supervision, even though self-referrals might mean additional revenue to the center. Proprietors of imaging services should not abdicate their responsibilities of ensuring safety by providing services not prescribed by credentialed healthcare providers. Physicians should be properly trained and credentialed in the various imaging procedures to ensure safe and appropriate utilization. Imaging technologists and other staff who operate the equipment should be properly trained and credentialed in the respective modalities. Installation and service staff must be adequately trained, and must not "cut corners" when installing or servicing equipment. And finally, medical physicists, health physicists, radiation safety officers, and others with responsibility for the technical design and use of equipment should be adequately trained, and where required, credentialed to do their assigned tasks. Such individuals should assume general responsibility to guide the imaging center operator on proper safety and utilization standards from the technical perspective, even if they are hired specifically for other tasks. In other words, in resource-limited regions where a full complement of skills and expertise may be lacking, each individual should assume responsibility to see that the operation of the center is safe and should raise concerns any time something is seen that does not seem right. It is everyone's responsibility to work cooperatively to ensure safety.

While this chapter has not given an exhaustive list of all possible safety considerations, it is hoped that the reader has gained a general understanding of some of the basic issues involved in safe imaging practices. It is important to engage the services of appropriately trained individuals to evaluate, design, utilize, and maintain a safe imaging facility [51, 52]. If appropriate safety standards are met, then the use of imaging technology can bring a very valuable addition to the clinical services that are available to serve the population in resource-limited regions.

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10 Information Technology in Global Health Radiology

Andrew Kesselman, Dale Gerus, and Alan Schweitzer

Introduction

According to the World Health Organization (WHO), nearly half the world has little or no radiology services. Even less have access to picture archiving and communication systems (PACS), electronic health records (EHR), radiology information systems (RIS), or hospital information systems (HIS) [1, 2]. New technologies can offer promising opportunities for overcoming healthcare access barriers in low- and middle-income countries (LMICs) [3]. The establishment of diagnostic radiology services at international sites requires a comprehensive understanding of the public health needs, disease patterns, and the public healthcare system.

Equipment and software selection are critical in low-resource settings; however, many options are available with continued exponential growth within the marketplace. Radiology imaging platforms primarily utilize the DICOM format. This DICOM standard as a part of PACS is the means by which medical imaging devices transfer images electronically. It consists of both communication protocols that allow machines to communicate with one another and a file format that allows information about the patient, medical problem, and how the image was created, to be transmitted along with the images.

The goal of this chapter is to explore strategies for accomplishing sustainable informatics programs in LMICs. The current applications of the information technology (IT) particularly PACS will be explored. Strategies for future improvements to the imaging infrastructure will conclude the chapter.

Benefits for Radiology Informatics/PACS in LMICs

Expansion of informatics platforms to LMICs has the potential to bridge the gap in accessible imaging solutions between low- and high-resource countries. EHR and PACS are just a few examples of technology that can help streamline care with improved diagnosis and relay of important medical information. Teleradiology services and teleconferencing provide additional avenues for teaching and instruction to remote locations.

PACS has been utilized in the USA since the 1980s for electronic storage and access to diagnostic images from various modalities. This eliminated the need to manually file, retrieve, and transport film. A range of new possibilities was available with PACS including improvements to

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workflow and increased accessibility of radiological images [4]. Proper use of PACS has led to improved patient care, the primary goal of any informatics system [5].

Some key benefits of PACS use in LMICs are as follows:

1. Just as in high-income countries, making images available to both clinicians and radiologists in a timely manner can be a significant challenge. PACS can eliminate the logistics associated with distributing film to the practitioners involved in diagnosing and treating the patient by making images available simultaneously to all clinicians participating in patient care.
2. Access to prior imaging studies is most frequently a significant perceived benefit. In many areas of LMICs, hospitals do not store images in analog (i.e., film) or electronic format, and prior studies are only available if the patient brings them with him/her.
3. Cost and availability of film and film processing chemicals and, in addition, the difficulty in maintaining film chemistry in the absence of climate control, and/or hazards associated with disposal of used chemistry, can present significant challenges in LMICs. PACS can eliminate or reduce this challenge by reducing the reliance on film.
4. The acquisition of new digital equipment such as a multi-slice CT or MRI scanner, with its attendant increase in the number of images per study, can frequently precipitate the need for PACS. Image data sets can be manipulated on PACS to create different reformations or 3D volumes, and DICOM tools allow for image adjustments that aid in diagnosis.
5. Enabling remote interpretation for either primary interpretation or consultation is often a key benefit. Shortage of radiologists and up-to-date training is often a challenge in LMICs. In many of these settings clinicians often have to interpret their own patients' radiography and ultrasound exams. PACS and image sharing systems can enable clinicians to consult with radiologists and specialists around the world to review treatment options.

As web-based technology expands, PACS has the ability to deliver immediate and unhindered access to images, interpretations, and related information even in the most remote of locations. An example of these benefits in LMICs can be seen after successful PACS installation in Laos as demonstrated in Fig. 10.1.

Fig. 10.1 PACS transition in Laos. (Reprinted with permission from RAD-AID International). (**a**) Prior to implementation, printed film or modality screens were used for viewing diagnostics images. (**b**) After implementation of PACS, workstations were used for viewing diagnostic images throughout the hospital

Challenges for Radiology Informatics/PACS in LMICs

It is critical for all stakeholders at the local level to be completely involved in the implementation process. They must have a thorough understanding of their departmental responsibilities and changes to workflow that will be required. There should also be a process to establish an effective medical record number (MRN) system, including an identification of returning patients with previously assigned MRN, prior to PACS implementation.

In LMICs, the reliability and quality of electrical power, trained personnel, climate control, and Internet access will often be inconsistent. In addition, many sites lack both a robust local area network (LAN) within the facility (wired or Wi-Fi) and deployment of computers in treatment areas [4].

Another concern with implementation of IT platforms and in particular EHR and PACS in LMICs is data security. These systems create the potential for both remote and local theft or loss of digital medical data. Consideration of basic data safety policies and procedures, along with backup of existing and collected data, should be part of any initial deployment. Network design in LMICs should be predicated on the assumption that any computer connected to the network is vulnerable and requires safety precautions that limit risk but allow for proper clinical usage including firewalls and open ports [4].

Software and hardware costs can raise issues when deploying IT in LMICs. Although hardware costs are declining rapidly, including monitors, workstations, and network switches/routers, software costs including licensing remain a barrier to adoption. Many of the comprehensive informatics platforms require licensing fees for their storage. Imaging hardware components often come without the requisite DICOM licenses in order to adequately transmit imaging files. Vendors often times charge separately for these DICOM licenses, and they can be difficult to attain for donated equipment.

Commonly, imaging facilities in low-resource countries use free open source DICOM viewers to download images to a computer from a CD or DVD or view images directly on workstations tied to the modalities. In terms of storage, these DICOM files are then either saved to small local hard drives or flash drives and/or printed to film for physical filing. Therefore, even if there is digital imaging available at a low-resource health facility with computers for image viewing, the entire structure for radiology informatics is still lacking [2].

Radiology Informatics/PACS Applications in LMICs

RAD-AID is one organization that approached the radiology informatics deficit aggressively in 2015, launching the International Imaging Informatics Initiative, in partnership with Merge Healthcare (now an IBM company). Donations of merge software licenses enabled RAD-AID teams (with Merge support) to install PACS at health institutions in Nicaragua, Laos, Ghana, Nepal, and Haiti. The essential data collection preparation for these installations is the RAD-AID PACS-Readiness Assessment tool, adapted from RAD-AID's more comprehensive Radiology-Readiness Assessment tool, to engage in preinstallation data analysis on the availability of necessary health IT resources [6–10]. Table 10.1 demonstrates the components of this PACS readiness assessment which is completed prior to any implementation stage.

Advanced knowledge of this information before installation allowed for planning the most appropriate site-specific architecture and maximize the success of installation. The basic steps for implementation are demonstrated in Table 10.2. Various platforms are available for implementation including both open-source and proprietary software. For example, some institutions are better suited for a "mini-PACS"

Table 10.1 PACS readiness assessment

Main components
Power integrity
Internet integrity
Imaging logistics
Image viewing
PACS implementation

Table 10.2 Implementation model

Steps	Details
1. PACS readiness assessment	Completion by staff on-site; tailored evaluation
2. Project charter	Define the goals for the site, highlight the solution design and facilitate the approval process for software licenses
3. Installation/ education	On-site technical support; training materials and didactics on PACS use and maintenance; local IT support
4. Follow-up and remote support	On-site and remote services; remote desktop tools

platform such as eFilm given limited resources and experience with radiology informatics. However, at sites with more experience with radiology informatics, such as Ghana, where ClearCanvas PACS was installed at Korle Bu Teaching Hospital in 2013, implementing a comprehensive enterprise PACS solution was more appropriate. Assessing the learning curve and readily available informatics resources maximizes the institutional adoption of PACS platforms [2].

Another vital element for archiving information in resource-limited countries is the incorporation of cloud architectures rather than solely on-site storage. In Nepal, RAD-AID partnered with Ambra to offer additional cloud storage for images at the National Academy of Medical Sciences Bir Hospital, in contrast to using primarily local on-site storage as with PACS in Ghana. Therefore, having a spectrum of deployable architectures in the LMICs is vital for flexible design of a viable solution. Combining storage solutions between local- and cloud-based systems allows for redundancy in data and accessibility both within and outside the medical institution [2]. This architecture has also been utilized effectively at INCAN Hospital in Guatemala and will likely continue to expand.

Endeavors in PACS implementation in Tanzania were recently described by Song et al. [11]. The focus of their project was on Muhimbili Orthopaedic Institute (MOI), a public academic tertiary care referral center in Dar es Salaam, Tanzania, East Africa. The PACS implementation experience was described in four phases: planning, installation, expansion, and maintenance phases. They concluded that the benefits of PACS far exceed the disadvantages and cost of hard-copy film with the ability to pan, zoom, save, retrieve, and compare images on PACS workstations. This experience markedly improved the radiology resident learning experience at MOI, and they found that the growing PACS image archive is becoming an important research asset for MOI.

The Future

The future of imaging in low-resource environments is very promising. Infrastructure for data transmission is improving in quality and declining in cost. Electronic hardware needed for image transmission and display is dramatically declining in cost and increasing in performance. Storage costs can be low, and more cloud services are becoming readily available.

Rapid expansion of Internet access across the globe is currently being pursued by both the private and public sector. Use mobile devices for workflow will likely continue to expand and play a larger role in rural settings. Finally, artificial intelligence (AI) and deep learning systems are currently being applied to aspects of imaging and may solve a lot of the on-site issues with current systems. For example, (IBM) Watson Health can help learn from prior studies to flag pertinent findings and create useful dashboards for in country users.

Conclusion

In conclusion, these and other improvements in information technology infrastructure will make it easier for sustainable radiology informatics projects to be successfully implemented in rural and under-resourced regions. Further research and objective evaluations of new endeavors will be needed to better understand the potential advantages of these and other technologies in supporting medical imaging delivery to low-resource settings.

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11 Interprofessional Collaboration in Global Health Radiology

Jay Shah, Joshua S. Harford, Patricia A. DuCharme, Bartram Pierce, Thomas Alberico, and Christopher B. Steelman

Introduction

In the context of healthcare, interprofessional collaboration is the process by which professionals from two or more professions work together to provide patient-centered care [1]. In 2007, the World Health Organization (WHO) created a WHO Study Group on Interprofessional Education and Collaborative Practice to address gaps shown in the *World Health Report 2006: Working Together for Health*, which "revealed an estimated worldwide shortage of almost 4.3 million doctors, midwives, nurses and support workers" [2]. WHO calls for "innovative approaches to teaching" to cover these shortages long term [2]. The Study Group created a framework, which acknowledges that many health systems around the world face the challenge of limited resources in attempting to address care needs for populations and which seeks to integrate interprofessional education to support collaboration.

Interprofessional education (IPE) of health workers is a step toward fostering interprofessional collaboration within the workforce team. When professionals are aware of and comprehend the roles of colleagues, then they "understand how to optimize the skills of their [team] members, share care management, and provide better health services to patients and the community" [3]. The Study Group suggests that health and education systems must work together to coordinate human capacity development strategies. Since the initial Study Group, health literature has documented efforts of interprofessional education and collaboration in various systems [4–17].

By its structure, the field of radiology works closely with other medical specialties—via an *interdisciplinary* approach—so that imaging findings and procedures can benefit patients. A radiology study and its report affect the care plan for a patient. The pediatrician calls the radiologist to discuss findings or to inquire about appropriate

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imaging or differential diagnoses. This interdisciplinary characteristic transfers into global health and enables radiology to become part of reducing global disease burdens and addressing World Health Organization targets [18].

For radiology to become integrated fully and sustainably in global health, WHO guidelines of *interprofessional* education and collaboration can be applied to the radiology team and global partnerships. This chapter discusses the need for interprofessional education and collaboration of the radiology team itself. Departments of radiology are composed of many professionals, including but not limited to radiologists, advanced practice providers, radiologic technologists, trainees, medical physicists, nurses, biomedical engineers, biomedical technicians, administrative leadership, administrative staff, informatics personnel, researchers, patient transport, and environmental services. This text is not meant to be exhaustive but intends to demonstrate that interprofessional collaboration within radiology is essential for global health integration.

Radiologists, Trainees, and Advanced Practice Provider

In the early days of "medical volunteerism" abroad, many frontier global health physicians practiced in remote missionary hospitals. This was typically arranged as a single physician and his assistant(s), with a demanding way of life that often led to burnout; however, as the twentieth century progressed, global health efforts increased—both in number of volunteering practitioners and in the scope of problems being tackled [19]. Trans-governmental entities, such as WHO, and nongovernmental agencies, such as Médecins Sans Frontières, emphasize organization, assessment, and awareness. These groups began championing public health initiatives for specific diseases that were previously the responsibility of individual regions or governments, for example, the coordinated global elimination of smallpox [19]. This transition in approach has led to the current framework of interprofessional collaboration.

For the practicing radiologist and advanced practice provider in radiology, the changing landscape of available infrastructure and technology in low- and middle-income countries (LMICs) is opening doors thought previously unavailable given their career choice. Despite interest in global health volunteer work prevalent across the spectrum of medical practitioners, radiology has historically ranked among the least represented specialties in these efforts [20, 21]. At the same time, radiology is well-positioned to provide value to reduce global health disease burden. In LMICs, obstacles for radiology may include lack of funding for capital-intensive imaging equipment, poor infrastructure, low access to care, and not enough human resources for radiology integration. These present unique challenges and often require long-term human capacity development solutions. New processes and models for sustainable partnerships with emphasis on education lend themselves to radiology's entrance into global health. Oncology Commissions on global surgery and radiotherapy emphasize the need of radiology to address global health targets [22, 23].

In many places, limited resources dictate that radiologists practice with fewer tools, depending much more heavily on ultrasound and plain-film radiography. In addition, or perhaps because of this, many radiologists interact closely as consultants for their physicians colleagues, performing teaching rounds or face-to-face discussions daily, adding to the clinical decision-making of the team [21]. In other places, where trained specialists are scarce, primary care organizations are introducing basic imaging modalities such as ultrasound and radiography into their clinical practice, regardless of radiology support [24]. Furthermore, the clinical models developed to solve the difficulties associated with remote and low-income populations can rarely accommodate adequate radiologist coverage in every community, particularly in rural areas, suggesting the need for increased interdisciplinary involvement [25, 26].

For most of its history, global health work has primarily been a hands-on clinical endeavor. Indeed, the obstacles of infrastructure and access discussed above have long limited the role of radiology in global health, even in relatively populated areas. Not only does much of the technology required for the practice of radiology require stable power grids, roads, and personnel, but the sheer cost associated with acquiring and operating the equipment is often a barrier. However, the incorporation of basic diagnostic imaging, especially plain-film radiography and ultrasound, is becoming more recognized as essential elements of modern healthcare [27]. As many nations and NGOs invest in improving the healthcare landscape of their people, opportunities arise for increased involvement from the radiology community. In addition, the continued advancement in imaging technology, making many devices more portable and affordable, has sparked interest among the radiology community to become more involved in international outreach [28].

Another significant motivation for the recent increase in the scope of the global health radiology landscape is owed to significant interest on the part of radiology trainees—residents, fellows, and medical students. These training years are a highly formative time for most physicians, full of career exploration and new experiences. To highlight this point, trainee interest in international outreach has grown significantly and steadily over the last 30 years [29]. According to the 2016 Association of American Medical Colleges (AAMC) Medical School Graduation Questionnaire, 28% of graduating medical students participated in a global health experience abroad [30]. Nearly a quarter of students learned or refined skills in a second language to work with underserved groups in the US and abroad [30]. Many students who go on to pursue global health work in their careers begin with experiences during medical school. Indeed, radiology residents are interested in global health experience, but opportunities have traditionally been scarce [25]. In a recent survey of radiology residents across the United States by Lungren et al., 85% perceived an unmet need for international medical imaging, and nearly all respondents believed that these needs would only increase going into the future [20]. Over 60% of these respondents planned on pursuing international medical aid work in the future [20].

As the idea of "global radiology" continues to gain traction, many academic medical centers have become focal centers of such work. Whereas 15 years ago, the idea of radiology trips abroad seemed counterproductive, many faculty radiology professors have become ambassadors for their programs, contributing to the development of two-way partnerships, specific volunteer pathways, and even in-country radiology residency programs. This new focus on creating sustainable global health programs is important given the ever-increasing connectedness of today's world and the projected increasing volume of medical imaging to be performed in LMICs [21].

Radiologic Technologists

As radiology enters the field of global health, addressing gaps via interprofessional collaboration is the best means of improving overall radiology for patient care [2–4]. To that end, the role of the radiologic technologist is critical, along with the radiologist, in increasing accessibility to imaging services in LMICs. The production of consistent, high-quality images is a cornerstone of radiology and requires the participation of imaging technologists. Many terms are used throughout the world to define this profession, including *radiologic technologist*, *medical radiation technologist*, and *radiographer*. In order to prevent confusion, the term "technologist" will be used in this text to denote these individuals regardless of their geographical location or modality specialty (radiography, sonography, etc.). The role of the technologist in a global health partnership is dependent upon the related objectives in an initial assessment, such as a Radiology Readiness Assessment, which is discussed in another chapter in detail. Regardless, there are three main roles that encompass the vast majority of what a technologist will be asked to complete. These roles include (1) department workflow assessment; (2) education of on-site technologist, radiologists, and other imaging personnel; and (3) protocol assessment and development (Fig. 11.1).

Fig. 11.1 An exchange between a radiologist and technologist in a fluoroscopy suite in Liberia. (Reprinted with permission from RAD-AID International)

Department Assessment

During an initial assessment, the workflow of the imaging process and its translation into efficient patient care depends upon the technologist as a critical component. Although the scope of practice for a technologist may vary depending on national and local laws, training, education, and experience, the primary responsibility is related to the acquisition of medical images to be used in patient care. In a global health partnership, an experienced technologist volunteer can go beyond simply counting the number of ultrasound or radiography units, determining whether there are adequate units to perform the necessary exams or determining if there are adequate personnel available for the current and future workload. The availability of medical supplies is an item frequently included in an imaging department assessment. Given the remote localities of many imaging departments requesting outreach support, as well as limited funding available for routine stocking of examination-related items (contrast media, IV starter kits, etc.), it is not uncommon for imaging departments within LMICs to require patients to pre-purchase exam-related items. In settings where supplies may be entirely unavailable, knowledge gained from a detailed departmental assessment can provide future outreach teams an opportunity to solicit needed supplies in advance to their site visit [31].

Finally, departmental infrastructure can be assessed and documented in order to better prepare future radiology outreach teams that will be visiting the clinical partnership site. Overall condition of facilities should be reported, specifically when they impact department workflow and quality of imaging services. For example, in a setting known for frequent power outages, how is equipment downtime managed when patients are still in need of imaging services? In makeshift imaging departments where radiation safety is inadequate, how are departmental staff and patients protected from unintentional radiation exposure? Again, having a technologist volunteer with strong work experience and the ability to recognize and report departmental infrastructure limitations is essential. Through a comprehensive imaging department assessment, a report can be generated that will play a key role in the planning of meaningful project objectives, customized specifically to the needs of the host-imaging department, as well as the needs of the technologist personnel and patients for whom they care [31] (Fig. 11.2).

Education of On-Site Technologists, Radiologists, and Other Imaging Personnel

One of the most significant challenges faced by the technologists as they travel to areas of the world that have limited resources is the potential discrepancy in the educational standards between the teacher and the student. The education of the technologist wishing to join an outreach team and teach and the education of those individuals that will be taught can have a significant effect on the overall success of the objective. In the United States, although the educational avenues vary significantly from hospital-based certificate programs to associate degree programs to baccalaureate programs, the curriculums are standardized and well-structured. In addition to their technical or clinical education, technologists receive education in terminology, anatomy, physiology, pathol-

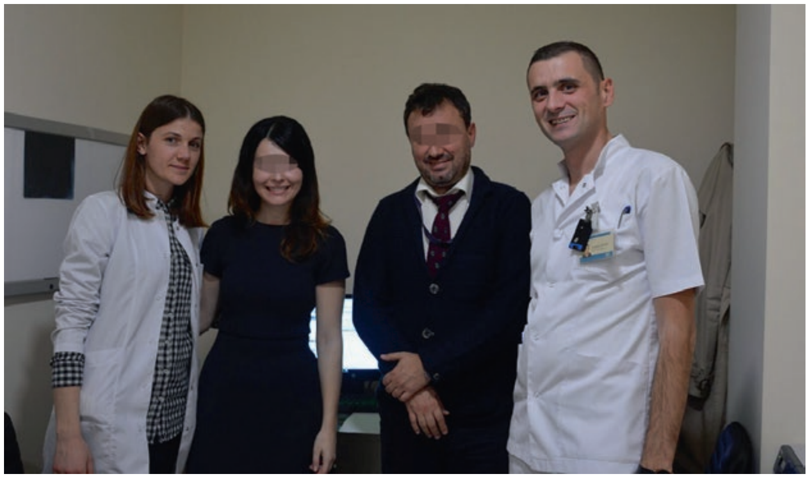

Fig. 11.2 Interprofessional discussions within the department in an Albanian hospital. (Reprinted with permission from RAD-AID International)

ogy, pharmaceuticals, infection control, and professional ethics. In the 2016 Wage and Salary Survey by the American Society of Radiologic Technologists (ASRT), over 50% of respondents have a 2-year college degree with an additional 30.5% holding an advanced educational degree (bachelors, masters, or doctorate) [32].

Unfortunately, according to the International Society of Radiographers and Radiological Technologists (ISRRT), there are no international standards for the training of technologists. According to a paper published by the ISRRT in 2008, countries including Jamaica, Barbados, Trinidad and Tobago, Uruguay, Brazil, Kenya, Uganda, Malaysia, and Hong Kong have successfully gained national recognition for their respective radiologic technologist professions and are currently moving toward a degree, or some equivalent, as an entry to professional practice. In contrast, countries such as Nepal, India, Bangladesh, some Central American countries, and some African nations still do not have formal recognition of their radiologic technologist profession and do not have an established national standard for radiography education [31, 33].

A thorough partnership assessment and established objectives are essential for the success of a technologist on a global health team. To teach patient positioning, radiation biology, and radiation physics, for example, to individuals who already have this basic educational background, can be a challenging task; teaching these concepts to individuals without the foundational sciences is even more difficult. The arriving technologist may have to be prepared to not only teach the technical aspects of the modality but backfill with what would be considered "basic" medical knowledge. Perhaps the greatest determinant of whether a radiology outreach initiative focused on didactic education of local technologists will be successful is the level of preparation that goes into the selection, development, and implementation of the educational content to be delivered. Regardless of how impressive an individual technologist's clinical skill set may be, volunteers who can exhibit prior experience serving in roles as radiologic science educators may be better suited to this type of assignment [31].

Attempts should be made to communicate and ascertain or assess the educational background and clinical training of the in-country needs prior to departure to be prepared and understand what is expected as well as to prepare appropriate educational content. The visiting technologist should be capable of addressing the necessary didactic information through the use of lectures, group discussions, and support materials. Cultural considerations including language and teaching styles may present a barrier to learning. Ensuring clear and concise translations for foundational concepts and anchoring lessons to universal themes are key to effective communication. In addition, volunteer technologist educators should be prepared to try a range of educational strategies, such as visual, written, and audio materials. It is critical that the technologist understand the tech-

Fig. 11.3 The demonstration of a CT-guided interventional radiology procedure in Nigeria draws excitement during teaching session. (Reprinted with permission from RAD-AID International)

nical limitations of the area they will be visiting such as the availability of computers, printers, and internet access. Arriving with a computer only to find that there are no printing resources could easily sabotage the entire trip. The visiting technologist should plan to arrive with hard copies of all pertinent material. Educational resources that will be left behind should be assessed as to their ease of use [31] (Fig. 11.3).

Protocol Assessment and Development

Focused education and training efforts can result in substantial department improvements. However, these initiatives alone most likely will not address all the possible issues affecting the ability to produce consistent high-quality images. Besides preparation of local technologist personnel, a comprehensive radiology outreach initiative will also work to prepare the host-imaging department through addressing department protocols and procedures.

> Departmental protocols and procedures are terms often used interchangeably, with the primary difference being that protocols are generally followed under all circumstances, while procedures are more systematic in nature, and although followed closely, they can still be altered or modified to suit specific situations. It is the protocols and procedures that dictate the daily activities and flow of services provided within an imaging department, and the necessary steps taken to reach desired outcomes [31].

When compared to the tasks of department assessment and education of personnel, protocol development is arguably one of the more challenging tasks assigned to technologist volunteers.

Unlike the tasks of assessment and education, the task of protocol development often requires participation of staff from outside the host-imaging department including, but not limited to, radiologists, referring physicians, department heads, and nursing staff. The visiting technologist must be aware of institutional and cultural issues and, for this reason, should be careful and strive to serve in an advisory capacity only making suggestions as issues are identified. One of the main advantages an experienced technologist with a robust clinical background can bring to bear in a department is the standardization of exam protocols. This standardization serves many purposes, but increasing the confidence level of both the technologist and radiologist has a tremendous impact on patient care. A technologist that can consistently produce protocol-driven high-quality radiographic images begins to understand what each view should look like, the contrast latitude and the pertinent anatomy. They then gain the ability to recognize “right” so when “wrong” occurs it is obvious. In the same manner, a radiologist reading MRI scans becomes confident in their ability to identify normal pulse sequence variations and recognize artifacts or peculiar pathology.

> Another area in which implementation of departmental protocols and procedures can prove valuable pertains to overall departmental sustainability. For example, in resource-limited settings in which access to service engineers and spare parts could mean weeks or even months of downtime, it is crucial that the local technologist personnel participate in departmental quality control measures aimed at ensuring early detection of equipment malfunctions. Furthermore, addressing methods for reducing wear and tear on imaging equipment to include an understanding of proper environmental conditions for equipment (temperature, humidity), physical limitations of equipment (patient weight limits, maximum technique settings), as well as routine steps for equipment warm-up can all lend to the longevity of the equipment being used. For this reason, technologist volunteers should take an active role of introducing protocols and procedures related to preventative maintenance and monitoring of equipment and supplies into routine departmental workflow. By doing so, the host imaging department will become less dependent on outside assistance and subsequently more reliable for servicing the community’s medical practitioners and the patients under their care [31].

One additional task that should be evident to all who participate in international radiology outreach initiatives is the technologist volunteer’s role of serving as an ambassador for the radiology outreach organization who coordinated the outreach. It should be the goal of every technologist volunteer to create a learning environment based on mutual respect and collaboration, approaching all assigned tasks with the mind-set that the local technologist personnel are equal partners in the outreach efforts. An interprofessional collaborative approach, including the role of the technologist, in global health allows for the delivery of high-quality sustainable healthcare. By allowing each professional to take charge of and excel at his or her expertise, the overall impact is synergistic. Working with common purpose and toward common goals benefits the well-being of the team and improves quality and safety of patient care [31, 34, 35].

Medical Physicists

Medical physicists are a critical part of the radiology team. According to the American Association of Physicists in Medicine (AAPM), medical physicists are involved with three areas of activity, which include (1) clinical service and consultation, (2) research and development, and (3) teaching. Physicists are consultants for physicians and other stakeholders in diagnostic imaging, nuclear medicine, and radiation oncology. In diagnostic radiology, physicists assess equipment performance and accurate radiation output; they consult on dose optimization for patients and occupational radiation protection. Additionally, physicists guide the creation of quality control plans for imaging systems, design installation plans, conduct acceptance testing on equipment, and control radiation hazards within departments. In the area of nuclear medicine, physicists work with physicians to use radioactive isotopes for functional imaging and ensure safe handling of those materials. In radiation oncology, the medical physicist consults with the radiation oncologist and team to create treatment plans for cancer therapy based on location, needed dose, and type of source [36]. The impact of the physicist on patient care spans from initial imaging, to staging, and into treatment.

Radiation safety culture in the medical field is a worldwide goal. As countries and technologies continue to advance, access increases to ionizing radiation for diagnostics, staging, and treatment. International entities, such as the World Health Organization, International Radiation Protection Association, International Atomic Energy Agency, and International Organization for Medical Physics (IOMP), among others, provide guidelines and directives regarding radiation safety. By developing a framework for stakeholders in different regions of the world, these organizations work toward making a culture of radiation safety accessible, and they offer healthcare institutions insight into planning and best practices [37]. According to the IOMP, "As medical technology evolves and patient needs increase, the need for well-trained and highly professional medical physicists (MPs) becomes even more urgent…It is obvious that training, continuing education and professional development of MPs have become essential" [38]. Training and education for this professional scope should be integrated into global health partnerships.

Because medical physicists are experts on ionizing radiation and its related physics principles, they are essential members of the global health radiology team. The teaching component of a physicist's role is critical for sustainable global health partnerships. Within an academic medical center, physicists teach radiology residents, medical physics students, and medical students. They consult with attending radiologists, provide guidance to staff technologists, and give information that is critical for administrative decisions. This flexibility in communicating with different audiences and the ability to collaborate with different stakeholders can translate well to education and training within LMICs.

Medical physicists are actively involved in global health and addressing disparities to radiology around the world. The AAPM has a program that provides resources to medical physicists in LMICs as "Developing Country Educational Associates" [39]. Also, they provide opportunities for International Scientific Exchange so that physicists in LMICs may obtain continuing education courses [40]. Additionally, the AAPM provides opportunities for its members to travel to LMICs to provide "educational and training programs in cooperation with medical physics organizations throughout the world." This attention by the physics community to global health includes international organizations, such as the IOMP, and has resulted in a substantial effort to include the role of the medical physicist in global health [41].

Physicists are critical parts of the effort by non-state actors in official relations with the World Health Organization to address global health targets. One example is the organization of RAD-AID International. Medical physicist involvement in RAD-AID global health initiatives includes 1) consulting on room design and radiation safety practices in Lao Friends Hospital for Children, 2) training and continuing education for radiation oncology medical physics colleagues in Kenya and Tanzania, and 3) guidance on the implementation of functional imaging in areas with nuclear medicine technology emerging—such as Tanzania. Within the CT educational programs in Guyana and Haiti, medical physicists provide education to local radiology colleagues about dose optimization, physics, and best practices, guide the creation of quality management programs, and consult on protocol development. All types of medical physicists are critical in global health interprofessional education and practice collaboration because diagnostic, staging, and treatment technologies are a growing part of the worldwide demand to address noncommunicable diseases and other global health targets [42].

Nurses

Global health focuses on improving health and achieving equity in healthcare access for all people worldwide and involves numerous disciplines, including nursing and those beyond the health sciences [43]. With nursing comprising over 80% of the healthcare workforce globally, it is at the forefront in advancing global health efforts and is increasingly being called upon to deliver complex care in multicultural environments [44]. Moreover, in low-income countries (as defined by the World Bank) where availability and access to healthcare is scarce, nursing's role takes on even greater dimensions, oftentimes with the nurse being the only trained healthcare worker to provide care to poor and rural populations. "Of the estimated 32.3 million nurses and midwives in 2030, 20% will be in the Americas, and 25% will be in Europe. Less than 5% of the world's nurses will be in Africa" [45]. One major factor contributing to this regional workforce disparity is the financial constraints in many countries that significantly impact nursing employment and pay levels and tend to deter nurses from staying in nursing altogether or encourage them to seek employment opportunities in other countries [46].

WHO Sustainable Development Goals

Globalization has transformed the ever-changing horizon of emerging diseases, the rising mortality from noncommunicable diseases, and advances in technology and science. With the world becoming more interconnected, and people becoming more interdependent on each other, the United Nations offers a global perspective and stated objectives to encourage collaboration among key players that contribute to global goals. "The United Nations (2015) ambitious agenda, *Transforming our World: The 2030 Agenda for Sustainable Development,* contains 17 sustainable development goals and 169 global targets to help shift the world onto a more sustainable and resilient path" [45]. Nursing's impact on achieving this global vision of universal access to healthcare is directly evident in several of the stated goals, including advancing the health and well-being of the world's communities (goal #3), through direct clinical care; supporting quality education (goal #4), through health promotion and disease prevention programs; and advancing gender equality (goal #5), through the support of women's health programs, such breast and cervical screenings [47]. These measures highlight some of the important roles that nursing plays in addressing the United Nation's global vision. Moreover, with interdisciplinary support, nursing's efforts to contribute to improving the health of the world's communities can positively influence progress to maintain health in the home and in the workplace, thus leading to reductions in poverty and hunger (goals #1 and #2).

Nursing Subspecialty Roles in Radiology

Nurses who work in global health and radiology oftentimes have challenging and complicated roles [48]. As global citizens, radiology nurses work with patients undergoing a wide range of diagnostic, interventional, and therapeutic procedures and yet must look beyond these imaging procedures and adopt a holistic framework of care, taking into account an individual's personal and family history, financial constraints, educational levels, and cultural influences. Additionally, they function in a variety of roles and settings ranging from maternal-fetal to geriatrics, from inpatient to outpatient, and from acute care to chronic care and oversee the management of patients during and after diagnostic and therapeutic imaging procedures [48].

Nurses involved in primary care play a crucial role in addressing the world's growing healthcare concerns, including noncommunicable diseases, such as cancer, heart disease, and diabetes. "GLOBOCAN, a comprehensive cancer surveillance database managed by the International Association of Cancer Registries (IARC), estimates about 14.1 million new cancer cases and 8.2 million deaths occurred in 2012 worldwide. Over the years, the burden has shifted to less developed countries, which currently account for about 57% of cases and 65% of cancer deaths worldwide" [49]. Factors affecting this increase in cancer mortality are multifactorial and due to aging populations and increased prevalence of risk factors such as smoking, obesity, and lack of physical activity, along with delays in childbearing [49]. In tackling these problems head on, primary care nursing utilizes radiology in everyday practices as seen with nurse midwives' use of ultrasound in prenatal care and delivery, nurse clinicians facilitating breast and cervical cancer screenings, the use of x-ray and ultrasound in emergency management and triage settings, and the management of infection control practices in radiology clinics.

Nurses who work with patients undergoing inpatient radiological procedures in hospitals manage patients undergoing diagnostic, interventional, and therapeutic procedures while accounting for the patient's comfort and well-being [50]. Patient care in radiology differs from other subspecialties, especially with managing patients undergoing procedures requiring contrast. These nurses need to have the technical expertise and knowledge of radiologic science while they work under time constraints to prepare patients for procedures, obtain informed consent, review medical histories and medication lists, monitor and record procedures, and provide post-procedure education and care [48].

In regard to promoting radiology in the public health sector, nursing plays a crucial role in tackling health crises in communities where there is little access and availability of healthcare. Due to the diversity in cultures and political and economic situations, there are also differences in challenges faced among specific populations [46]. With issues ranging from maternal-fetal health to chronic health conditions, the nurse acts as gatekeeper for the community and identifies key problems, promotes health and wellness, and provides referrals to the next level of care when indicated [46]. For example, nurses involved in breast cancer screening outreach programs are core members of multidisciplinary teams, working in concert with technologists, radiologists, administrators, and social workers to support improving organizational workflows, developing a defined screening structure and evaluation process [50]. Within this framework, nurses work to ensure coordination and continuity of patient care through pre- and post-screening education in order to manage patient anxiety, and increase knowledge of choices for follow-up and treatment, with the aim to ultimately increase overall patient compliance and health outcomes. Nursing's collaborative efforts in patient care management "involves assessment, planning, facilitation, and advocacy for options and services to meet an individual's health needs through communication and available resources to promote high-quality, cost-effective outcomes" [50].

Radiology Nursing and Global Health Outreach

Nurses interested in radiology and global health play a key role in RAD-AID International, a nonprofit organization whose mission is to increase and improve radiology services and the health and well-being for low-income countries (as defined by the World Bank) around the world [51]. RAD-AID's nursing program provides leadership in the advancement of nursing practice through the development of sustainable evidence-based educational nursing programs that advocate for health and wellness of populations in low-resource communities, through the support of multidisciplinary relationships with international healthcare partners, academic institutions, and local communities [52]. Education encompasses not only the physical needs of the patient but the psychological and cultural needs as well.

The five strategic pillars of RAD-AID's educational nursing program are centered on (Fig. 11.4):

1. Public health: to increase community awareness on the importance of radiology's role in early detection and screening for noncommunicable diseases such as breast cancer
2. Innovative technology: to support in-country and long-distance learning
3. Research: to explore questions that address improving healthcare outcomes
4. Healthcare policy: to develop and improve organizational workflows
5. Clinical models: to provide mentorship and education through the application of evidenced-based clinical training and improve the quality of patient care

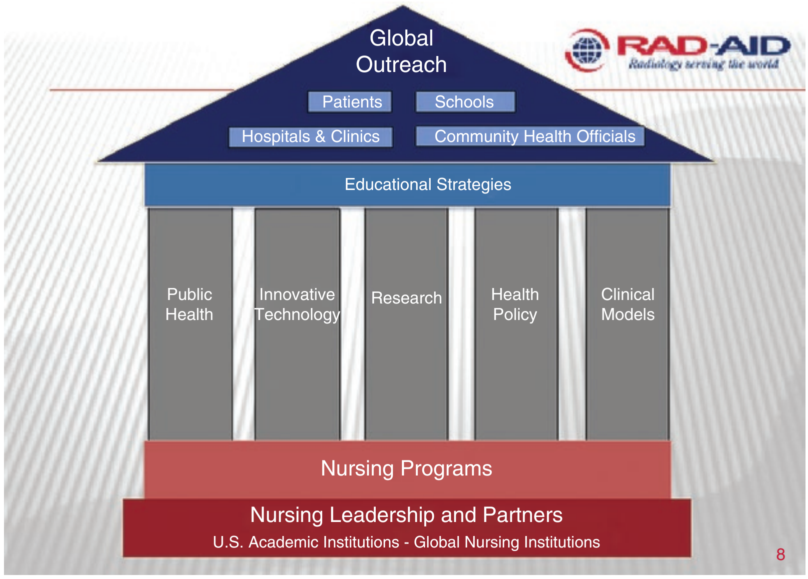

Fig. 11.4 RAD-AID global outreach organizational model. RAD-AID. (Reprinted with permission from RAD-AID International)

Overview and Target Goals for RAD-AID Nursing Programs

Innovative and sustainable grassroots nursing programs are being developed in Africa, South America, and Asia. In Tanzania, a nursing needs assessment was initiated with an in-country partnering medical center, which provides primary care, dialysis, and outpatient radiology services to the surrounding underserved community. Priorities addressed in the survey centered on the nurses' learning needs, developing a strategic plan for continuing education and training to empower the nursing staff and advance the quality of patient care. Identified areas of education included triage and assessment skills for patients undergoing radiologic procedures, workflow organization to reduce patient waiting time and increase efficiency, and advancement of clinical skills including sterile technique, infection control, and BCLS/ACLS certification. Future goals include further collaboration with the Kilimanjaro Christian Medical Center Nursing School to develop strategies for students in the wider nursing academic community to extend their learning of radiology through the management of patients undergoing advanced imaging techniques including x-ray, ultrasound, mammography, CT, and MRI.

In Guyana, RAD-AID's nursing program is focused on the education and training of emergency department nurses in support patient care management for those undergoing advanced radiology procedures including ultrasound, fluoroscopy, and CT scanning capability. Current initiatives include the development of a radiology nursing training module to be included as an educational adjunct for nurses and nursing students pursuing advanced education in emergency and radiology nursing. Goals for this program include extending this training for nursing students involved in the public health sector in order to support increasing community awareness on the role of advanced radiology technology and the importance of early detection and screening for health promotion and disease prevention.

In South Asia, RAD-AID's India program, *Asha Jyoti*, is comprised of a mobile imaging van that provides women's health outreach, including cervical, breast, and osteoporosis screening, to women with little or no access to radiology ([51]; see http://www.rad-aid.org). RAD-AID nursing has partnered with a premiere nursing school, the National Institute of Nursing Education (NINE), in Chandigarh, India, to develop a community health nursing education program. Student nurses interested in women's health, oncology, and radiology participate in clinical rotations on the imaging van and learn best practice methods for conducting patient triage and assessment, educating women on the importance of early detection and screening for breast and cervical cancer, following up on abnormal test results and channeling appropriate referrals [52]. RAD-AID volunteers mentor and provide education and training to the nurses, student nurses, and technologists, in order to enhance their clinical knowledge of patients undergoing radiologic procedures and provide support to improve general workflow organization. Future goals for this program include incorporating distance-learning opportunities for the nursing students, reassessing the challenges in workflow efficiency while maintaining quality patient care, and exploring research questions on the benefits of nursing's role in the primary and secondary prevention of breast and cervical cancer and the relationship to early detection and improved health outcomes.

In today's world, globalization, migration, terrorism, poverty, natural disasters, and infectious disease are all shaping the nursing profession's role in global health. Addressing these critical factors demands the strengthening of the global nursing workforce and supporting nursing's overall professional status worldwide through the advancement of education and training [53]. The WHO Global Strategy on Human Resources for Health: Workforce 2030 supports this goal and calls for all countries to strive for universal access to healthcare services and work toward sustaining development goals to address the shortage of healthcare workers globally [45]. These twenty-first-century goals require a global mind-set from our nursing leaders involved in critical decision-making at both the clinical and management levels and a commitment to expand nursing skill sets in order to manage and provide quality services in challenging multicultural environments [46]. Central to the success in the development of radiology-focused nursing education programs within global organizations such as RAD-AID is the support of all members of the interprofessional team, both within partnering US academic institutions and with international alliances. Moreover, communication and collaboration among global health teams consisting of radiologists, technologists, nurses, administrators, and other members of the healthcare team are critical to enacting effective health policy development and population-based disease prevention measures, as well as promoting healthy lifestyles and improving the overall quality of healthcare delivered to individuals and communities worldwide.

Radiology as an Interprofessional Collaboration in Global Health

To meet the needs addressed by the World Health Organization for interprofessional education and collaborative practice and to ensure optimal integration of radiology into global health, a team approach can be used within educational partnerships. Departments of radiology are composed of many professionals, including but not limited to radiologists, advanced practice providers, radiologic technologists, trainees, medical physicists, nurses, biomedical engineers, biomedical technicians, administrative leadership, administrative staff, informatics personnel, researchers, patient transport, and environmental services. Starting with an initial assessment, stakeholders can establish goals to address gaps in radiology access. Then, a mutually agreed-upon plan can be implemented in a stepwise framework with measureable deliverables. To establish a comprehensive plan, the professional roles within the radiology team should be represented. By understanding the professional scope and role of all members, the stakeholders can more effectively proceed with working toward improving human capacity, infrastructure, supply chain, and other needs.

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12 Ultrasound in Global Health Radiology

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Introduction

In many remote areas of the world, access to radiologic services is limited and often nonexistent. Ultrasound has emerged as an extremely valuable clinical diagnostic tool and a powerful component of global health. It is a unique modality that uses high-frequency sound waves to provide real-time grayscale images without the use of ionizing radiation. The earliest applications of diagnostic ultrasound came in the 1940s through Dr. Karl Dussik, an Austrian psychiatrist and neurologist. Seven years later, he and his brother Friedrich worked to create the first diagnostic ultrasound equipment capable of producing intracranial images. This same technique was expanded in the late 1960s paving the road for echocardiography, breast and abdominal ultrasound [1]. Today, the use of ultrasound has spread across multiple specialties and has become an integral part of clinical decision making and patient care, regardless of location in the world. In addition, ultrasound machines have become smaller, increasingly portable, and more affordable, which improves access for patients globally.

Global health seeks to address healthcare disparities, and sonography has a key role to play in achieving global health targets. Individuals in low-resource areas and/or without insurance are often subject to a lower quality of care or complete lack of access. The World Health Organization (WHO) reports that the lower an individual's socioeconomic position, the higher their risk for poor health. Healthcare inequities in low- and middle- income countries (LMICs) lead to increased mortality among pediatric populations from diseases easily treated or prevented in high-income nations. Maternal mortality is a significant indicator showing wide gaps in numbers with 99% of annual maternal death occurring in resource-poor countries [2]. Lastly, noncommunicable diseases including cardiovascular disease, cancers, and respiratory disease are responsible for 80% of deaths in LMICs and 63% of all deaths worldwide [3]. Ultrasound is widely used in women's health, and in pediatrics, to manage comorbidities associated with noncommunicable disease. These patient populations benefit greatly from the use of ultrasound and can have a significant impact in patient care decisions further supporting the need for ultrasound education in the global health arena.

The growing impact of ultrasound in low-resource settings has prompted a need for access to qualified personnel who can perform ultrasound, ultrasound education for those individuals as well as functional and reliable ultra-

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sound equipment [4]. Examples include the use of ultrasound in two rural district hospitals in Rwanda where ultrasound exams had major impact on patient management; in 43% of the 345 patients included in the study, surgical outcomes and plans were the most significantly altered by ultrasound examinations. In another study, 62% of patients in a Liberian hospital who received ultrasound examinations had changes in patient management with highest impact being seen in first trimester ultrasound patient outcomes and emergencies/traumas [5, 6].

Ultrasound education is in demand across all specialties from emergency medicine to primary care. A diverse group of providers, including physicians, nurses, and advanced practice providers, increasingly use ultrasound clinically, and in some cases practitioners have little or no access to formal ultrasound training. Dr. Joia S Mukherjee, associate professor at Harvard Medical School stated, "Few tools have proven more valuable in the hands of well-trained health care workers than ultrasound.... It is our firm belief that providing the tool of ultrasound and adequate training and support is a critical component in global health delivery and should be part of the evolving pedagogy of global health" [5] Improving access to diagnostic ultrasound and ultrasound education are key components of a successful radiology outreach program.

Medical Landscape, Access to Care, and Ultrasound Providers

The medical landscape today is strongly influenced by imaging services and the information they provide. As previously mentioned, the WHO reports that half the world has little to no access to radiology equaling three to four billion people with scarcity in radiologists, formally trained sonographers and technologists, and radiology equipment. In stark contrast, a recent publication from the Mayo Clinic reported a number of exams conducted on a typical day across its hospital organizations; among those, 790 ultrasound exams were performed across 12 specialties with over 2000 staff including 284 radiologists and 2120 health staff. This all being accomplished with hundreds of pieces of equipment including 187 ultrasound units [7].

Furthermore, the types of providers using ultrasound in their daily practice is very diverse. Ultrasound is heavily used in emergency room settings, primarily in a point-of-care manner. Midwives and nurse practitioners are using ultrasound to monitor pregnancies. Ultrasound is being placed into the hands of medical students, advanced practice providers, and even nurses. It is important to understand the type and extent of training of each provider to better identify what sort of clinical information could be gleaned from that intervention as well as clinical information that could be missed due to lack of formalized ultrasound training. As ultrasound machines become easier to acquire and types of providers become more diverse, there is some concern about lack of diagnostic quality and possible negative outcomes associated with false-positive or false-negative findings.

In some high-income nations, such as the United Kingdom and United States, there are many checks and balances in place surrounding quality control in ultrasound. Ultrasound exams are ordered in clinical settings by individual providers who feel it will be a helpful diagnostic tool. The request will be routed to an ultrasound department where formally trained sonographers or physicians will perform that exam in a standardized fashion with a protocol of images necessary for interpretation by the radiologist or equivalent. In some nations, ultrasound exams are conducted by radiologists themselves. The ultrasound equipment is maintained, under warranty, and tested periodically to ensure optimal working conditions. The ultrasound exam is uploaded to an electronic picture archiving system (PACS), and images are reviewed with a radiologist to determine if the study has been done completely. Those images are reviewed and interpreted often by residents or one or more radiologists through overread and review. This information is formally documented in the patient's medical record, and images are associated with this interpretation. The report and images are made available to the ordering provider to use for management and decision making. At each step in the process, there are quality control measures in place to ensure that the exam ordered is relevant, that the ultrasound performed is done in a standardized fashion by a qualified provider, and that the ultrasound exam is interpreted by a radiologist or the equivalent. The clinical setting provides a platform for effective patient care.

In areas of low resource and in some LMICS, the settings where ultrasound is performed can vary widely. Sometimes, equipment being used is donated and functions sub-optimally. Situations may exist where there is no means to store images and much interpretation is done by the person performing the ultrasound. This information may be shared with the patient; sometimes images are printed and an informal report can be written and sent with the patient to take back to the ordering provider. The information shared is used to make medical decisions regardless of the accuracy of the information or the images to support it. Information given may travel through different channels and must be monitored to ensure patient safety and appropriate diagnosis and management. Workflow must be relevant to the needs of the institution and local radiology stakeholders.

Ultrasound Volunteers

Ultrasound providers, including radiologists and sonographers, are a key part of global radiology ultrasound outreach. Their skill and experience can bring an immeasurable amount of education to even the most remote patient care site. Volunteers will be providing care for a wide range of patients, many suffering from disease or illness rarely seen in the United States. It requires that those ultrasound volunteers be very qualified to participate in sustainable projects. Not only must they have a strong command of ultrasound and its uses, but they must be comfortable functioning in low-resource and high-stress situations. They must be quickly adaptable and able to provide the highest quality ultrasound with what is provided. For example, ultrasound transducer selection is crucial for diagnostic ultrasound images, and some scenarios require creative use of what is available; carotid ultrasound with endovaginal ultrasound probe can provide adequate diagnostic information.

Ultrasound-specific considerations for volunteers can include but are not limited to separation between educator and provider, equipment challenges, intended use of diagnostic ultrasound information, adapting education to learner audience, medical ethics challenges and infection control strategies.

Ultrasound volunteers are a critical part of any team working to provide ultrasound education in LMICs. Their goals should be to provide high-quality relevant ultrasound education. It is not uncommon for patients to make special efforts to receive an ultrasound when it is available to them, especially if word of a volunteer team of specialists will be on site. Patients with a variety of complaints may arrive hoping for access. The number of patients can increase significantly leading to increased burden on the staff providing care for those patients. It can be challenging to find protected time away from patients to provide hands-on education, and it is likely that the volunteer will be asked to provide ultrasound exams for the patients. There is a delicate balance here. Ultrasound is best learned by doing. It will be critical that those being taught have as much "hands-on time" as possible. When the volunteer is gone, what they taught them will sustain the learners; if learners scan little, they will learn little. One will have to use their best judgment but always think toward empowering the learner first and foremost. There should be a clear distinction made between learner, educator and provider.

Ultrasound units found in LMICS are often outdated and may function sub-optimally. Power to run the ultrasound machine can often be interrupted, and the transducers needed may not be available. It is important to make the most of the time on the ground for the volunteer. If the machine breaks down, then consider using that time to provide diagrams or demonstrate hand position of the transducers on the patient to obtain certain views, and use nontraditional probes like an EV for carotid or pediatric ultrasound. If an ultrasound unit is unsafe, has frayed cords, or if the unit is not connected to the appropriate protective power supply, explore options to correct the problem. Lastly, inquire about machine repair resources and try to help establish a process for managing equipment problems, perhaps a phone number for a vendor to provide support via phone or contacting an organization with replacement parts or even individuals who may be able to provide support. A malfunctioning ultrasound machine can have an extremely negative impact on a site's ability to provide quality care for their patients.

Volunteers who provide ultrasound education should be aware of the local resources in place to provide care and follow-up for the patients scanned. For example, if a learner requests demonstration and teaching of high-level obstetric ultrasound exams, are there resources in place to address obstetrical emergencies should they arise? If not, perhaps the focus in education should be more fundamental to include, fluid, placental location and fetal lie. These considerations are crucial for maternal safety during delivery allowing caregivers to be proactive when dealing with any special needs of the mother. Work to understand what happens with the information gleaned from the ultrasound. What sort of patient care decisions can be made with what information is given, and is the site appropriately equipped to manage it? In global health partnerships, ultrasound volunteers may be given unquestioned trust that what they report is accurate. It will be up to the volunteer to handle these scenarios in a professional manner. If the ultrasound volunteer is not equipped to make final diagnoses in the United States, like a sonographer or trainee, then those same rules apply in LMICs. Findings should be shared with the most qualified medical provider on site to ensure the safety and well-being of the patient.

Ultrasound volunteers must be sensitive to the societal and cultural norms of the specific patient community. For example, touching a learner to provide hands-on ultrasound teaching might be considered inappropriate. Female patients may not allow male sonographers to perform their ultrasound exams. Volunteers will often have to dress modestly, especially female volunteers. Family planning may be a taboo topic for conversation. Ultrasound volunteers will be asked to teach a variety of learners. They can range from physician, medical student, and nurse and include a variety of nontraditional learners. Physicians will have a good foundation in anatomy and clinical education and will likely learn ultrasound quickly. Other types of learners may have to start at the beginning—lack of formalized training in ultrasound could lead to extensive time spent providing information about basics. It is crucial to be aware that any ultrasound education provided could lead to a false sense of competency and proficiency. It is crucial to caution the learner about their scanning level and create appropriate expectations for their use of ultrasound.

What Is Ultrasound?

Ultrasound generates real-time images through high-frequency sound waves primarily providing two-dimensional cross-sectional images of the body. The lack of ionizing radiation makes it an ideal modality for pediatric and obstetrics, and its real-time image capture abilities allow evaluation of structures in motion such as the heart or a fetus. Ultrasound acquisition through use of a transducer allows for multi-planar imaging with flexibility to move rapidly between planes, further allowing for determination of the origin of structures and providing a better understanding of the spatial relationships between pathology and normal tissue. Furthermore, it provides excellent resolution for superficial structures, and its Doppler capabilities allow evaluation of the quality and quantity of blood flow [8]. Clinical applications for ultrasound are growing daily. Abdominal ultrasound is well-suited for imaging the liver, gallbladder, spleen, kidneys, abdominal vascular structures, and lymph nodes. Pelvic ultrasound allows for evaluation of the prostate, bladder, reproductive organs, and adnexal masses, while obstetric ultrasound provides assessment of the fetus. Cardiovascular ultrasound allows evaluation of the heart and peripheral vascular structures. Small parts ultrasound provides high-resolution imaging of superficial structures like the thyroid, scrotum, and breast. Lastly, transfontanelle ultrasound can be used to image the neonatal brain prior to fontanelle closure [9]. See Fig. 12.1.

While an ultrasound unit consists of multiple components including transducers, monitor, keyboard/touch panel, computer processor, and some form of data storage and transfer, for the purposes of this discussion, key components will be emphasized. The transducer or probe is a central part of the ultrasound unit. It contains ceramic crystals that deform and vibrate when they are

Fig. 12.1 Hands-on training is essential to ultrasound education. (Reprinted with permission from RAD-AID International)

electronically stimulated generating and receiving the sound pulses used for diagnostic ultrasound. The size and configuration of the generated sound pulse determine the image resolution. The type of image and the associated resolution is determined by the type of transducer. There are three basic types: phased array, linear/sequenced array, and curved array. In phased array probes, every crystal element is used in the formation of each pulse resulting in a sector or pie-shaped image. These probes are known for their ease of use in tight spaces, such as in between the ribs, their large deep field of view good for deep Doppler imaging. Unfortunately, they have poor near-field views and poor superficial focus. Linear array or sequenced array probes do not use all elements for a single pulse; instead different elements are fired in a specific sequence generating a rectangular-/trapezoidal-shaped image. These are known for their excellent resolution and large superficial field of view but suffer from a limited depth of field view and a larger footprint. Curved array probes are similar to linear arrays; however, the crystal elements are placed in a curved formation allowing for a wider far-field view but somewhat reduced resolution. These probes are known for their overall good resolution and have a large deep and superficial field of view. Lastly, intraluminal probes can be placed close to the organ of interest, yielding higher resolution and higher frequency with less image degradation through the abdominal wall. One downside would be limited imaging depth, and examples include endovaginal, endo-rectal, and esophageal (Fig. 12.2).

Each transducer will often be marked with numbers referring to the range of frequencies it generates, for example, a C1–C5 will be a multihertz probe that may send echoes between 1 and 5 MhZ. Lower numbers suggest imaging of structures deeper into the body due to ability to penetrate more deeply. The higher frequency probes can image structures at more shallow depths. This is directly related to the wavelength of the sound. Higher-frequency sound waves are shorter, while lower-frequency sound waves are longer and travel farther. To summarize, when selecting a transducer for an ultrasound exam, try to select the highest-frequency transducer possible that can provide the best resolution while minimizing scan time.

The ultrasound image will be displayed on a monitor. The size and type of monitor will vary based on vendor. This image can be optimized through the keyboard and general knobs and buttons available. The configuration and function of each knob or button will be specific to the ultrasound machine being used. It will be important to have an appropriate understanding of knobology and image optimization in order to provide diagnostic ultrasound information.

Image optimization is key for diagnostic quality ultrasound images. While there are many factors to consider, this discussion will briefly touch on a few key concepts including power, gain,

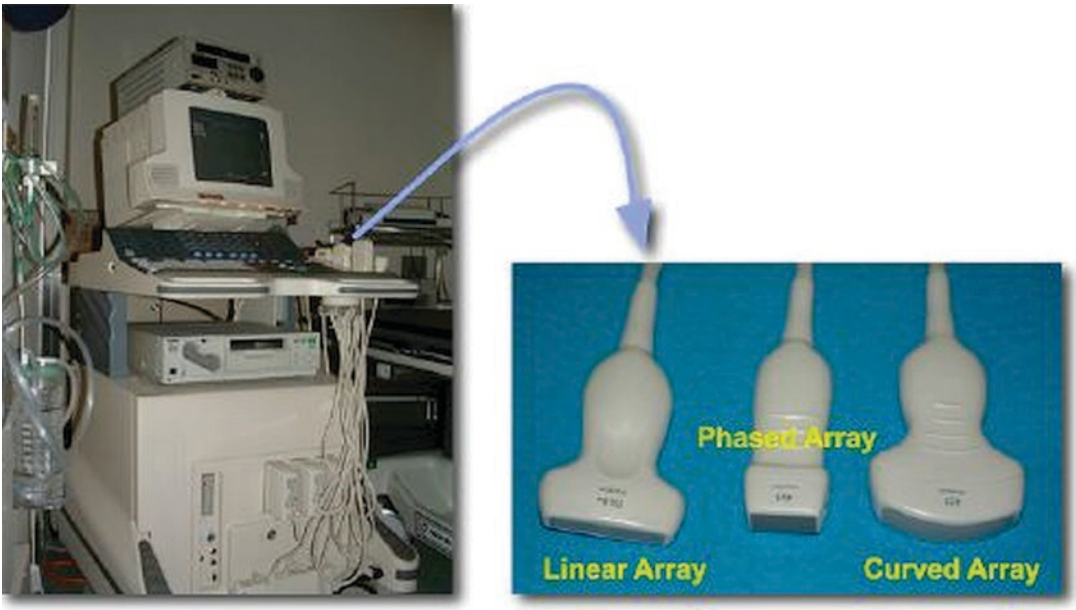

Fig. 12.2 Ultrasound transducers (Image Licensing Wikimedia Commons; Public Domain) [10] (Reprinted from USMachTxPhoto, Wikimedia Commons. KieranMaher. https://commons.wikimedia.org/wiki/File:UsMachTxPhoto.jpg)

field of view, line density, and dynamic range. Power refers to the strength of a generated ultrasound pulse. The stronger the pulse, the returning echoes will have increased strength and the image will be brighter. This is normally preset in the ultrasound machine and should be minimized. Gain provides the operator with a method to manage the effects of sound attenuation. This is highest at deepest depths so it is necessary to amplify the deeper signals. The depth of the dot placed on the screen is determined by time. There are two ways to adjust gain, overall gain and time gain compensation or TGC. As tissues attenuate differently, it will be necessary to optimize the image often. The time gain compensation allows for specific adjustment and multiple levels in the screen sometimes referred to near field being more superficial and far field being deeper. In addition to TGC, there is also opportunity to adjust the overall brightness of the entire image. It is best to optimize through the use of the TGC first because overall gain does not affect the pulse; it only amplifies it. The focal zone provides a means to focus transmitted sounds at different depths. It is often placed at the level of interest to improve resolution. It is possible to have multiple focal zones at multiple different depths, but care must be given if many are used. This can greatly decrease frame rate and have significant impact on image quality when evaluating moving objects such as the heart or during interventional procedures. Field of view allows you to make adjustments in regard to depth and width. As the field of view increases, the frame rate decreases. Line density can be adjusted. As you increase line density, the pixel size decreases and improves resolution, but a decrease in frame rate will be noticed. Dynamic range varies with the range of displayed grayscale. It represents how many shades of gray can be used to make the image; the better the dynamic range, the image resolution should improve [8].

Lastly, data storage/transfer capabilities will vary based on equipment being used. Most units will have the ability to store a pre-specified amount of ultrasound studies, and some will have a way to send images to a PACS and download them to a USB or a CD. Some units will actually be connected to a printer so images can be provided at the time of exam. It is important to know that a DICOM license will be required for an ultrasound unit to send images to a centralized image storage system. In some LMICs and areas of low resource, it can be uncommon to find ultrasound machines with appropriate DICOM licensing for image transfer. It is also common to see studies printed onto paper with no archiving of images. Data storage is an important consideration when providing patient follow-up or comparison imaging for repeat studies [9].

Artifacts found during the use of ultrasound can be a key diagnostic tool, some providing diagnostic information, while others can hide or provide false information. One example is a shadowing artifact. It is probably one of the most commonly seen and occurs when the sound beam strikes something that prevents sound from continuing forward and either absorbs, scatters, or reflects the sound striking it. This prevents visualization of structures posterior to this hard interface. While important structures beneath the area of artifact may be obscured, it does suggest this structure is calcific and has very different properties than those of soft tissues or fluid. Another example is edge shadowing. This occurs when sound strikes a smooth rounded structure at an angle. The sound will refract, or bend, and cause shadowing from the side edges. This can inhibit the view of tissues in that path, but it is also quite helpful because this artifact will only occur when the aforementioned scenario is presented. This will help the performing provider to know that the structure has a smooth border and a rounded or oval margin. Examples include cysts and some benign breast masses and blood vessels. Lastly, enhancement is another artifact, opposite of shadowing. It occurs when a structure attenuates little to no sound so echoes posterior to the structure will appear brighter. This is a valuable information supporting the fact that simple cysts are fluid filled and this fluid will not attenuate sound.

Having a robust understanding of the ultrasound unit, transducer selection, image optimization, resolution, attenuation, and ultrasound physics along with artifacts are critical when performing ultrasound and providing ultrasound education. See Fig. 12.3.

Diagnostic Versus Point-of-Care Ultrasound

The type of ultrasound being performed goes beyond the organ or structure being imaged; it is important to consider the expectations of the ultrasound exam as well as the quality of the

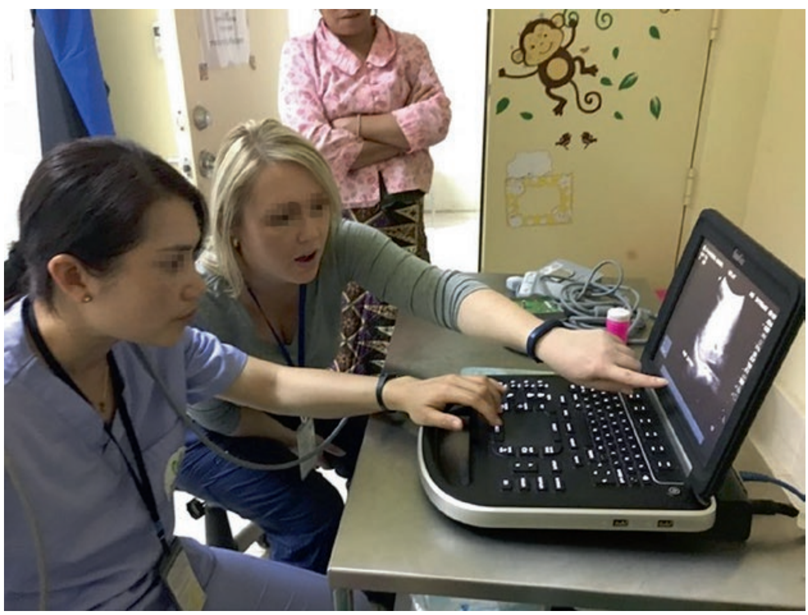

Fig. 12.3 Ultrasound is a low-cost and high-impact imaging modality for global health. (Reprinted with permission from RAD-AID International)

images acquired during the exam. Sonographers are formally trained to perform diagnostic ultrasound exams. The technique for acquiring ultrasound images is taught in a formal setting and evaluated through competency testing and rigorous standardized examinations. The sonographer performs the exam independently based on a formal protocol established by the radiology department. A series of images will be required including grayscale, color, and Doppler for a specific indication and body system. This complete series of images will be presented to a radiologist for interpretation. Certain images will be required for formal dictation and reimbursement for the department and providers for the selected ultrasound exam. The selection of images is recommended through various governing bodies including the American Institute of Ultrasound in Medicine and American College of Radiology [11]. Images will be assigned to a dedicated accession number, placed in the medical record for review and used by the ordering provider to guide medical decisions.

For example, a provider may order a renal ultrasound in the setting of flank pain or elevated creatinine due to concern for hydronephrosis. The sonographer will be asked to provide representative images of each kidney at the superior, mid, and inferior pole in the transverse plane as well as medial, mid, and lateral images in the sagittal plane. Measurements will be taken to evaluate the length and symmetry of the kidneys to each other. Color Doppler will be used to rule in or out any obstruction of the kidney by showing that there is dilation of the calyx. In some cases, such as concern for renal artery stenosis, pulsed wave Doppler is used to measure velocities in renal artery and veins as well as within the kidneys. It is customary to provide images comparing the kidneys to surrounding structures such as the liver and spleen as well as imaging the bladder in both planes. Color Doppler can be used to look for ureteral jets and post-void residuals can be obtained. Renal ultrasound studies can be accomplished with 30–40 images and cover all relevant topics. Keeping in mind, these are only representative images, but scanning throughout the entirety of both kidneys and bladder is performed. These images are uploaded to a PACS system for interpretation by a radiologist, and a formal dictation is placed in the medical record. Images are required for formal dictation and billing purposes [11].

In contrast, point-of-care ultrasound, or POCUS, is used to answer a specific clinical question. This type of ultrasound is often found in emergency room settings, images may or may not be stored, and formal dictation is not provided by a radiologist. Medical decisions can be made quickly, and patient care is often driven by these findings. For example, a patient presents with RUQ pain. The physician has concern for gallstones. A POCUS ultrasound would likely involve a brief scan solely in the region of the gallbladder for a quick "yes" or "no" to the clinical question. There may be a comment placed that an informal bedside ultrasound was performed and revealed a normal gallbladder.

The type of ultrasound is further driven by the patient population, the expertise of the provider, and the equipment capabilities. In LMICs, a spectrum of ultrasound exams is being seen. Diagnostic ultrasound may be performed rarely due to lack of formalized training and human capacity resources. Departments may lack formal scanning protocols or guidelines. Patient volumes can be in the hundreds providing little to no time for formal diagnostic ultrasound. It is less common to find radiologists to interpret images or sonographers with formal education to perform them. This leads to a more POCUS style of ultrasound. It is important to understand the limitations of this type of ultrasound exam. It may not rule in or out the disease process in question, and there are many factors that contribute to that limitation. Lack of functional PACS, film, or film printer or inadequate storage space on the ultrasound unit leaves no way to store, save, or archive images. Sometimes, diagnoses are made on the fly by the provider performing the ultrasound with no real way to prove or support findings should a negative outcome occur.

Ultrasound education should be driven as much toward diagnostic ultrasound as possible within the constraints of that ultrasound department and those performing ultrasound. With little means to order additional imaging or perform corresponding lab evaluation, diagnosis made through ultrasound can have profound impact on patient clinical decision making. This puts a great deal of responsibility in the hands of the person performing the ultrasound and the person interpreting those images. POCUS ultrasound can provide very useful clinical information in settings where other imaging or evaluation will take place; however, it is a worthy goal to provide as much formal and hands-on ultrasound education as possible. This will need to be done in a thoughtful and sustainable manner. Frequent educational trips and numerous hours standing next to the learner will be required to ensure that ultrasound is being performed appropriately, interpreted correctly and patient outcomes are protected.

Operator Dependence

Ultrasound is a unique modality. It relies heavily on the performing provider to create diagnostic images leaving it easily susceptible to errors. A recent article addressing errors in ultrasonography in emergency room settings highlighted that misinterpretations of sonographic images should be considered a serious risk in ultrasound-based diagnosis. Causes are many but include lack of clinical information, lack of ability to properly optimize and use equipment, overestimation of individual skill, and resistance to continue diagnostic work-up [12].

Diagnostic ultrasound is the most clinically useful when performed by a highly trained provider. It is important to understand the value of the information provided in regard to patient medical decision making. When a concerning finding is found, it is necessary to consider the image quality and the skill of the creator. For example, if the clinical question being posed such as appendicitis will be surgical in nature, the ability of the ultrasound provider to rule in or rule out this as a cause of the clinical history is crucial. A false-negative or false-positive finding could have a huge impact on patient outcome and lead to unnecessary use of resources in already low-resource settings.

It is important during volunteer opportunities to be cautious about information shared with the patient or on-site medical team. Much like in the US, it will be necessary to confirm findings with radiologist or other specialized personnel trained in the interpretation of images. In the United States, sonographers are formally trained to perform diagnostic ultrasound, and radiologists are formally trained to interpret those exams and make recommendations for diagnosis. In the United Kingdom, consulting radiographers are advanced practitioners with education to complete some diagnostic reporting. It is important to note that while ultrasound is very operator dependent, the interpretation of these images is also very subjective and will heavily rely on the expertise of the radiologist or professional interpreting them. Ultrasound volunteers in global health must respect the laws regarding professional scope of the nations in which they are working and from which they originate.

Challenges for Education Globally

The lack of formal ultrasound training programs in most of the world adds a significant layer of complexity for volunteers who travel abroad to provide ultrasound education. Even volunteers with educational experience can find it challenging to adjust to teaching a variety of individuals with a diverse subset of educational and cultural differences. Thus, it is critical to develop a curriculum and training program based on high-impact areas (such as maternal fetal health) using sustainable methods and models that have been successful in the past in partnership with the host country/medical providers. See Fig. 12.4.

First, it becomes vital to research the area to which this education is to be provided. This is done best through an assessment tool with quantifiable results that drive sustainable projects. The Radiology Readiness Assessment tool, trademarked in 2010, is a thorough assessment tool that analyzes the target community infrastructure, telecommunications, equipment, power, staffing availability, access to medications, laboratory testing, pathology, and resources for

Fig. 12.4 Education is critical for successful global health implementation of radiology services. (Reprinted with permission from RAD-AID International)

biopsy/surgery along with ability for referral into our out of the target system for treatment. Ultrasound-specific information might include what equipment is available, who will be learning, what sort of exams are needed, how are images stored, patient follow-up and availably for training [13, 14] (Table 12.1).

Table 12.1 mentions many things to consider when developing a sustainable education program; however, these just scratch the surface of complexity involved. It is important to understand that it takes great perseverance, patience, and flexibility to see visible results. It requires working with a strong team of ultrasound professionals and educators with experience in global health. Any curriculum developed will undergo many modifications and changes as progress is made to fine-tune a program best for the target site. In many cases, it will be important to meet the learners where they are and build; in some settings, it may be necessary to completely start over or create a program from scratch. Take the time to observe each learner, identify the strongest candidates, and express an interest in them as educators to begin training others. It is important to create a sustainable education program that can go on when the educator leaves.

Patient Care and Safety

The patient is at the center of the healthcare team. Above all else, patient safety is paramount. This received global attention by the World Health Organization during the World Health Assembly in 2002. While the member states were urged to pay close attention to patient safety, little improvement has taken place resulting in poor quality of health services and increased risk for negative patient outcomes. In 2004, the WHO launched the World Alliance for Patient Care Safety, which facilitates the creation, coordination, dissemination, and acceleration of improvements in patient safety and managing risks in healthcare to prevent patient harm worldwide [15].

Much as the WHO has invested significant time and effort to increase awareness about the importance of patient safety, it is critical to keep these same initiatives in mind when providing ultrasound education in LMICs. There are many relevant concerns when discussing patient safety as it applies to the use of ultrasound. Some consistent themes emerge including infection control, equipment safety, informed consent, patient privacy, patient access to care, protection of patient information, patient advocacy, and health literacy.

Table 12.1 Important considerations for sustainable ultrasound education programs

Ultrasound equipment	How old are the units? What type of ultrasound units? Where were they acquired? Any service available? DICOM capability?
Patient population/access to care	What are common etiologies for mortality and morbidity: maternal, communicable disease, stroke, malnutrition, poor antenatal care, cardiovascular disease? Referral or walk-in, how far an average patient travels for exam How patients afford exams, out of pocket, assistance programs through governmental organizations
Who performs the ultrasound?	Physicians Sonographers Nurses Medical students Nonmedical providers
Ultrasound exam performed	Abdomen (liver, gall bladder, kidney, spleen, bladder) Obstetrics/gynecology (1st–3rd trimester, pelvic) Pelvic (male: prostate) (female: uterus, ovaries, adnexa) Cardiac (adult, fetal, pediatric) Vascular (venous, arterial, abdominal, extremity) Small parts (thyroid, breast, scrotum, superficial mass) Musculoskeletal (joints, tendons, muscles, ligaments, nerves, soft tissue tumors, hernias, foreign bodies) Endocavitary ultrasound (vaginal, esophageal, rectal)
Who dictates/interprets exams?	Performing technologist Nurse Physician Medical student Radiologist On site or remotely
How is exam stored/archived?	Film at time of ultrasound Saved to hard drive of ultrasound unit Transferred to disc or USB Sent to archiving system either wirelessly or through wire connections Archiving or saving images not possible Is the machine DICOM capable?
What is done with information?	Transcribed notes in patient chart Preliminary exam sent with images Verbal handoff to ordering provider Is there a way to save or document information?
How will patients follow-up?	Will patient be given return date? Can patient afford return visits? Will trained staff be available when patient returns? Will prior information be available for review?
Can patients be referred?	If significant finding, life-threatening, or otherwise, who manages? Can patients be referred out for more complex care? How will referring provider communicate with specialist? What exams performed yield results or information with no infrastructure to treat it?
Infection control	What supplies are in place – gloves, disinfectants, hand washing stations? Ability to clean exam space in between patients For endocavitary exams, how are the transducers being cleaned? Is there a policy in place for infection control? Is there a means to record a negative event to trace infection source?
Quality control	Who will be reviewing images for accuracy? How will education be reinforced?

(continued)

Table 12.1 (continued)

Service	Existing contract System for repair Ordering replacement parts Performing calibration of unit Over the phone troubleshooting
Education	Ultrasound training programs Through volunteer teaching, how often? Ability to handle remote learning Handoff process between volunteers Access to education for prerequisite training (anatomy, physiology, medical terminology) Who will be able to provide ultrasound training (train the trainer), physics, etc.?

It is important to understand how patient information is used and to be an advocate for their healthcare literacy and autonomy. It is not uncommon that a patient will be a willing participant for whatever is deemed necessary by the medical team. They may rarely ask questions or participate in their plan of care. In some cases, patients do not know what to ask; in other situations, they have complete trust in the medical team and assume they are making the best decisions for them. Patients should be allowed to participate in their care, ask questions, or even refuse if they do not feel comfortable. Appropriate screening should be done when possible including detailed history, allergies and necessary lab evaluation relevant to clinical question, such as pregnancy tests. Patients should receive a detailed explanation about the type of ultrasound exam and what is required of them, especially in the setting of endocavitary ultrasound. Considerations should be given to patient comfort and privacy. Providing a private space to disrobe and the use of sheets/towels are recommended to preserve patient dignity. Ensure that the area to be scanned is as private as possible to minimize distraction during exam and protect patient privacy. Make sure that the table used for exam is safe and provides appropriate safe access to the patient.

Patient populations in remote care settings have little access for preventative care and often seek medical attention in late stages of chronic disease or emergent settings where they are incapacitated in some way. This leads to "one-off" or problem visits leaving many patients lost to follow-up. There are scarce resources available to follow patients leaving them ultimately responsible for their outcomes. In the patient care setting, testing can be sub-optimal. Some tests needed may not be available, and some may be chosen specifically because there are no other options, skull x-ray for headache when there is no access to MRI or CT, as an example. This can lead to unnecessary testing and exposures not without risk.

Infection Control

The need for infection control is a worldwide concern. Healthcare-associated infections (HAI) are among the most common adverse events in healthcare delivery causing a significant impact on morbidity, mortality, and quality of life. In 2011, WHO reported that at any given time 7% of patients in high-income countries and 10% in LMICs will acquire at least one HAI. Death occurs in about 10% of affected patients, and in the United States, it was estimated that around 1.7 million patients are affected by HAI each year accounting for 99,000 deaths. A large portion of these are preventable, and increasing awareness globally about the need for appropriate disinfection is critical [16]. In both LMICs and many low-resource settings, this has become a bigger challenge because infection prevention and control policies are nonexistent, poorly adapted or lack government funding leading to a 2–6 × higher risk of infection [17]. While the need for infection control is clear, it is important to highlight the need for appropriate disinfection in the setting of ultrasound exams including ultrasound machines and transducers used in semi-critical and non-critical settings.

There can be significant risk of transmission of organisms when endocavitary ultrasound is performed during transesophageal, transrectal, and transvaginal exams. Some studies have revealed that despite low-level disinfection, ultrasound transducers have remained substantially contaminated by organisms including mycoplasma, coagulase-negative staphylococci, *Staphylococcus aureus*, streptococcus, corynebacterium, pseudomonas, protozoa, intestinal parasites, and fungal pathogens [18].

Further concern exists that some pathogenic bacteria can be transmitted by ultrasound procedures and lead to spread of the organism. Some of the most commonly known pathogens include methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci, multiresistant gram-negative organisms, mycobacterium tuberculosis complex, atypical mycobacteria, *Clostridium difficile*, and sexually transmitted diseases including gonorrhea, chlamydia, and syphilis. Consideration must be made for transmission of blood-borne viruses such as HHV 1 and 2, HIV, HBV, and HCV. Many high- and low-level chemical disinfectants can inactivate blood-borne viruses; however, improper cleaning prior to disinfection limits the effectiveness of the chemical disinfection process and results in persistent active virus. Studies have shown that these agents can be introduced even with the use of transducer covers. Transducers may not appear visibly soiled but could still be contaminated with a variety of pathogens, making proper disinfection critical in avoiding healthcare-associated infections. Prevention is key [19].

Different Types of Disinfection Requirements

Disinfection is the selective removal of microbial life and is divided into three major categories: high-level, which causes destruction or removal of all microorganisms except bacterial spores; mid-level, which causes inactivation of mycobacterium tuberculosis, bacteria, most viruses, and some bacterial spores; and lastly, low-level, which causes destruction of most bacteria, some viruses, and some fungi [11]. When deciding what ultrasound disinfection protocols are relevant, it is important to understand how ultrasound will be used and in what clinical setting. The Spaulding classification system classifies medical instruments into different categories based on their potential for transmission of infection: critical, semi-critical, and non-critical [20]. This is determined by how invasive the medical instrument will be in regard to penetration of skin or mucous membranes. Ultrasound machines and transducers typically require high- or low-level disinfection based on use; mid-level disinfection is rarely indicated.

In the majority of clinical settings, ultrasound is performed with a transducer placed on intact skin over a variety of anatomic locations. This use would be considered non-critical, and low-level disinfection is recommended for appropriate disinfection. Low-level disinfection is no longer sufficient if the transducer is passed over non-intact skin, such as in a wound or areas of skin breakdown. If a transducer is used to provide ultrasound guidance for an invasive procedure, a protective barrier should be used, such as a transducer cover, and high-level disinfection will be required because intact skin was breached.

In some settings, semi-invasive techniques, such as transvaginal, transesophageal, and transrectal ultrasound, require the use of endocavitary transducers. This includes any associated procedures performed where the endocavitary transducer is used for imaging guidance. While a transducer cover should be used whenever possible, the CDC recommends that all endocavitary ultrasound transducers without a transducer cover be treated as semi-critical because they have direct contact with mucous membranes. When a transducer cover can be used, it may give the impression that the classification should change because there was no direct contact with mucous membranes; however, there is reliable evidence that probe covers fail due to high rate of perforations [20]. Some recent studies have reported leakage rates for single-use disposable transducer covers to include 0.9–2% for condoms and 8–81% for commercial transducer covers. For maximum safety, one should therefore perform high-level disinfection of the transducer between each use and use a transducer cover or condom as an aid to keeping the transducer clean [19].

Conclusion

In conclusion, ultrasound is a beneficial and critical imaging modality for global health radiology because of its affordability and effectiveness in the imaging of noncommunicable and infectious diseases. Ultrasound can be successfully integrated into global health partnerships but must be thoughtfully supported by assessment, training, and human capacity development.

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13 Education in Global Health Radiology

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Introduction

Radiologists and radiology professionals have noted the gaps in diagnostic and interventional imaging access worldwide as documented by the World Health Organization (WHO) [1–3]. With the introduction of the United Nations' Sustainable Development Goals, the push for access to radiology in global health can be further justified by promoting good health (#3); quality education (#4); good jobs and economic growth (#8); industry, innovation, and infrastructure (#9); and reduced inequalities (#10)—all through partnerships for the goals (#17) [4]. Diagnostic and interventional imaging, as radiology is described by WHO, promotes global targets of reducing noncommunicable diseases (NCDs), increasing cancer imaging and treatment, and continued support for the goal of reducing and managing infectious disease [5, 6]. If "global health" focuses on issues that transcend national boundaries, emphasizes solutions that often require global cooperation, and is multidisciplinary, then the concept of radiology in global health, or global radiology, should consider this broader context of international partnership and collaboration [7].

In the context of global health, education is the effective transfer of knowledge so that it can be applied and translated to a healthcare professional's clinical practice [8–12]. The educational efforts of radiology professionals in high-, middle-, and low-income nations, as defined by the World Bank, combine to promote the advancement of radiology in global health. The integration of education in global health allows for human capacity building and strengthening partners bilaterally so that the field of radiology can more effectively address WHO target goals, like the reduction of NCDs, and United Nations'

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Sustainable Development Goals. Education can be used as a mode for sustainability and is critical for the advancement of radiology in global health.

There are several models in place for education in the global health setting with emphasis on radiology. This chapter discusses faculty exchanges, scholarly collaboration, partnership, formal education, online education as a tool, integration of global health concepts into radiology curricula, and socially responsible collaboration. This chapter is not an exhaustive collection of educational models, but it serves to demonstrate samples of potential pathways for educational exchange and advancement.

Faculty Exchanges and Scholarly Collaboration

Faculty exchanges are a well-established model for collaboration and international learning. Professional societies have opportunities for radiologists, physicists, technologists, and other health professionals to give presentations at national meetings or attend conferences internationally. These exchanges are part of the continuing medical education process. The Radiological Society of North America has an international visiting professor program. The American Roentgen Ray Society (ARRS), Radiological Society of North America (RSNA), and other international associations have opportunities for radiologist faculty exchange [13, 14]. Many radiology subspecialty societies have faculty exchanges also, and the concept can be applied to all parts of the radiology team. A similar program exists between the American Society of Radiologic Technologists (ASRT), Canadian Association of Medical Radiation Technologists (CAMRT), and College of Radiographers (CoR) [15]. The benefits of these faculty presentations at professional society meetings are the ability to reach a large audience and to impact practice based on new knowledge and up-to-date research [13–15].

With the advancement of technology and connectivity, the platforms for exchanging knowledge and information among colleagues have increased among high-, middle-, and low-income nations—for the entire global health community. There are examples of this in the medical imaging literature where there are regular contributions and even entire scholarly journals devoted to the topic of global radiology [12, 16, 17]. Access to up-to-date refereed content on radiology topics is necessary for the continued learning of health professionals regardless of their practice location. With that in mind, the World Health Organization launched Hinari in 2002. The program "provides free or very low cost online access to the major journals in biomedical and related social sciences to local, not-for-profit institutions in developing countries" [18].

In addition, radiologists and radiology professionals have integrated social media as a frontier of engagement with Twitter journal clubs, Tweet chats, and Twitter accounts for journals [19–21]. Kelly et al. note a positive association between impact factor and journal presence on Twitter [21]. Discussing journals and social media as modes of exchange is noted to demonstrate that the "locations" for collaboration and for the advancement of radiology in global health are becoming more robust. The field of radiology can leverage this increasing connectivity to discuss evidence-based medicine, healthcare policy, and global health with a broad reach. Faculty presentations at conferences, discussions of radiology in the context of global health, and access to peer-reviewed research on advancements in the field are all modes of educational exchange that support the goal of radiology's advancement in global health.

On-Site Partnership Models

On-site partnerships are becoming increasingly common via university collaborations, professional societies, and nonprofit focus in global health. In any educational program, the initial step should be an objective assessment of needs with discussion between the stakeholders to establish roles, goals for learning, an assessment plan for that learning, and clear communication regarding expectations and next steps. Forming relationships with partner colleagues is critical and takes time. As discussed at length elsewhere in this textbook, a useful initial assessment tool is the RAD-AID Radiology Readiness Assessment™ [22, 23]. Initial data collection should take into account the equipment available, current educational pathways of all stakeholders, staffing, related clinical services, supply chain, energy for powering imaging equipment, infrastructure, and available resources. The educational intervention should consider long-term sustainability, human capacity development, and a multidisciplinary approach to comprehensively address identified target goals.

Partners should review the needs assessment data together and approach the relationship as colleagues and peers. Each stakeholder brings valuable insight and experience into the program, and the partners should agree mutually on goals that are appropriate based on available partnership resources and initial assessment. Communication and cultural intelligence are critical as a foundation for moving forward. Caution is urged to avoid the framework that one stakeholder knows better than another; paternalism does not support the mission of equal partners [24]. According to Tedros Adhanom, the director general of the World Health Organization, “For any change to succeed, staff ownership of the change agenda at all levels is a must. External support can only complement” [25]. With the rationale that educational goals promote local human capacity, reduce the risk of dependency, and support collegial exchange of information, on-site partnerships with an educational emphasis can promote long-term sustainability. The on-site educational partnership is a long-term commitment between stakeholders. After the partnership is established, then objectives can be set to support the goals of the program. The following sections discuss examples of a bilateral partnership model and a multi-institutional partnership model.

Bilateral Partnership Model

The University of California Davis (UCD) radiology residency partners with the radiology residency at the Hôpital de l’Université d’Etat d’Haiti (University Hospital of the State of Haiti, HUEH). This relationship started when the UCD radiology residency director accompanied the American College of Radiology on an education outreach trip in early 2013. Based on initial assessment data, faculty at UCD and HUEH agreed to form a bilateral educational partnership centered on radiology residency education at both institutions.

Since 2013, UCD has conducted numerous weeklong radiology education trips, bringing UCD residents, faculty, and alumni to HUEH to teach radiology and pediatric residents. UCD’s radiology residency program director, who is also the director of UCD radiology department’s Global Education and Outreach, organized and led most of these trips. UCD faculty have also participated in two of RAD-AID’s trips to HUEH. UCD residents apply to travel to Haiti as seniors. In preparation for the trip, they are expected to read portions *Radiology in Global Health: Strategies, Implementation, and Applications*, as well as a book about recent Haitian history. They prepare two interactive lectures and usually deliver them on 2 days, for a total of 5 or more hours, and they provide hands-on teaching. In addition to enhancing the Haitian residents’ education, these trips provide a valuable opportunity to UCD residents as well as faculty, and these lectures complement those provided by visiting UCD faculty. UCD residents gain tremendous insight into how radiology is practiced in resource-limited environments and how healthcare systems function with different resources and diseases that are uncommon in the United States. They have the opportunity to recognize that despite the increasing reliance on CT and MRI in the United States, practitioners elsewhere make difficult diagnoses using radiography and ultrasound alone.

As an exchange, Haitian radiology residents travel to UCD for month-long observerships. This program was started in order to enhance their education with in-depth exposure to the expertise and the learning environment encountered at a partnership academic medical center. The Haitian observers are selected with the assistance of the residency director at HUEH. Efficacy of visits to HUEH and observerships at UCD is assessed with pre- and posttests. Haitian observer visits to UCD have been limited to 1 month because longer visits to UCD Medical Center require detailed and expensive background and security checks. Successes of the partnership include increased educational opportunity for UCD and HUEH residents, targeted subspecialty education for HUEH residents with emphasis on modalities found in Haiti, and rewarding collegial relationships within the partnership.

Benefits of a partnership model include the opportunity for well-established relationships that can strengthen and grow over time. This model allows for some degree of simplicity, in that two partners can align and have clear communication regarding goals and objectives. The partners become invested in one another at the institutional and collegial level to ensure success and forward movement in the educational endeavor.

Multi-institutional Partnership Model

Partnership educational models can also be multi-institutional. Kline et al. discuss an educational partnership with focus in Malawi as a "long-term collaboration between volunteers from five ACGME institutions, two European institutions, and a Malawian hospital—in affiliation with RAD-AID International." Based on initial assessment data, the partners agreed that "Human capacity development is a major focus with emphasis 1) on professional development opportunities for the Malawian medical officers, consultant radiologist, and radiographers in the form of targeted education on requested topics by [RAD-AID] faculty, staff, and trainees; 2) on providing funding for attendance by Malawian colleagues at regional radiology conferences within Africa; & 3) on a long-term goal of training additional radiologists for Malawi" [26].

Team members include radiologists, radiology residents, technologists, nurses, and medical physicists. Members that have participated provide reports and feedback on their objectives so that the next team has continuity and can continue to build the program. As noted by Kline:

> ...the radiology resident traveling to the site during 2014 collected part of the Radiology Readiness Assessment data on which the full program was established. She noted that because of workflow and resource limitations, radiographs typically leave the department without radiologist review and are interpreted by clinicians; therefore, it was decided—with the guidance of the Malawian consultant radiologist—1) to strengthen radiology services within the Malawian hospital's department of radiology and 2) to educationally support Malawian clinicians on radiology best-practices and appropriateness criteria. This initial trip report led to subsequent radiology faculty and trainees working with the Malawian radiologist and directly with Malawian internal medicine and pediatric clinicians. Additionally, an objective was incorporated to provide the Malawian consultant radiologist with opportunity for conference attendance on subspecialty areas [26].
>
> In this way, each team passes information on objectives met and suggestions for process improvement so that the partnership continues in a sustainable manner. Based on the input and work of radiology residents and fellows within the context of the program, 1) sonography curricula have been developed for Malawian radiology professionals and clinicians from multiple departments, 2) CT protocols have been adjusted for dose optimization, 3) targeted education is provided on pediatric and trauma imaging, 4) feedback has resulted in process improvement among stakeholders, and 5) informatics & interventional radiology assessments have been completed. Team leaders return annually to conduct formal program assessment with in-country stakeholders. In this programmatic fashion, several institutions collaboration to achieve global health goals, and the involved radiology trainees make a lasting impact by their involvement to overall progress... [26].

The stakeholders of educational partnerships may include community health workers, radiology professionals, and clinicians from other services [27–30]. A benefit of a multi-institutional model in global health radiology is a shared distribution of resources required; success is not dependent on one sole partner. Additionally, communication among the involved stakeholders can avoid duplication and ensure the most effective use of partnership resources. Implementation of these programs should consider that the "promotion, development, and expansion of high-quality, culturally sensitive global health education" are used to address "the health needs and human rights of populations around the world" [31]. With this target in mind, it is necessary to consider formal training as a result of on-site educational partnerships—as the next section discusses.

Establishing or Supporting Formal Education

The creation of residency programs for specialized care has been successful in other branches of medicine. In 2012, Anthony Charles, MD, MPH, and his colleagues from the University of North Carolina at Chapel Hill, Haukeland University Hospital in Norway, and the Department of Surgery at Kamuzu Central Hospital (KCH) created a surgery residency in Lilongwe, Malawi. When Charles began working at the site in 2007, there were only two Malawian consultant surgeons; the trauma registry and needs assessment demonstrated objectively that more surgeons were needed in the nation of 16 million [32]. A key point of this educational partnership is that the surgery residency at KCH is accredited by the College of Surgeons for East, Central, and Southern Africa so that physicians completing training are recognized as being educated formally. Surgery residents and faculty from the partners in Norway and the United States spend time in Malawi with their peers and learn about surgery methods; therefore, surgeons on both sides of the partnership experience education through the collaboration. An evaluation of the residency stated, "At the outset, a needs assessment revealed a substantial requirement to augment surgical capacity not through intermittent visits by overseas surgeons, but by the creation of a new surgery residency-training program...The creation of this program was based on several important principles: strong partnerships, locally relevant curriculum development, early program assessment, and substantial involvement of local partners for program leadership and accountability" [32].

If appropriate based on partnership assessment and if resources can support, then this type of initiative is possible for consideration in global health radiology. For example, if an assessment shows that an area has ample radiologic technologists, but no radiologist, then the long-term sustainable solution is the formal education of radiologists for this area and development of local human capacity. Several examples of on-site partnership with emphasis on formal training exist in radiology. During 2015, Dr. Teodora Bochnakova completed a Radiology Readiness Assessment™ at Georgetown Public Hospital in Georgetown, Guyana. A partnership was formed between in-country clinicians, the director of Latin America at RAD-AID International, and faculty from Northwell Hofstra. Partnership discussions found a major goal of the collaboration to be the creation of radiology residency training opportunities for physicians in Guyana [33].

Georgetown Public Hospital Corporation (GPHC) already had several residency programs which were built in collaboration with institutions based in the United States. The administrators and clinicians at GPHC felt that the radiology department had fallen behind in provision of service for the hospital. The Radiology Readiness Assessment™ revealed an overall lack of coordination for imaging services with workflow challenges that limited capacity and poor communication of imaging interpretation and limited human resources, specifically radiologists. The central solution to address these problems was identified by the hospital staff as development of a radiologist training program to eventually foster quality, capacity, and service development. Collaboration between Guyana Ministry of Health, Georgetown Public Hospital Corporation, University of Guyana, Northwell Hofstra radiology residency program, and RAD-AID International has resulted in an approved residency curriculum. The curriculum is planned over 3 years and focuses on imaging modalities available at GPHC. Currently, nuclear medicine and MRI are not available but may be offered as fellowships after the initial training. Advanced IR is not currently part of the curriculum although the partners hope to incorporate basic image-guided procedures as warranted. Residents will spend a part of their training at Northwell Hofstra to build competence in physics, quality assurance, safety, and basic ultrasound performance. The remaining time will be spent at GPHC with on-site RAD-AID volunteer teaching radiologists and remote teaching conferences from Northwell Hofstra.

Curriculum design for this unique program began by collecting goals for each of the rotations at Northwell Hofstra. These were subsequently reviewed and modified to address the specific needs of the environment at GPHC based on initial assessment data. In addition, both formative and summative assessment models were incorporated to allow for continuing evaluation and improvement of the program and its residents. The Ministry of Health of Guyana and the University of Guyana were instrumental in guiding the process so that the program graduates will be recognized as specialists in the field of imaging by Guyanese standards. The residency directors and their administrative staff at Northwell Hofstra have examined the logistics to address issues from visas to housing and transportation to mentorship to provide a successful learning environment for the time at Northwell intended for the first year. The first class of residents started in 2018. Rwanda is another location in which a radiology residency has been established in this manner [34].

Another example of the integration of formal education in the context of global health is the training program of Engineering World Health (EWH). According to EWH, approximately 40% of critical medical equipment in low- and middle-income countries is in need of repair or replacement [35]. Donated and purchased equipment sits idle due to the lack of skilled biomedical engineering technicians (BMETs) who can install, maintain, or repair it. As a result, physicians and healthcare professionals are hampered in their ability to deliver care. EWH developed a training program for biomedical technicians in response to this dire need. The mission of the formal education is to build a local, sustainable, and trained workforce of BMETs in low- and middle-income countries to repair and maintain medical equipment [35]. Other examples of formal education implementation include creation of subspecialty fellowships, such as the pediatric radiology fellowship at the Addis Ababa University Department of Radiology in collaboration with the Department of Radiology at the Children's Hospital of Philadelphia, or the implementation of formal education for radiologic technologists, medical physicists, and other radiology professionals [34, 36]. The creation of these relationships should take into account the health systems and education systems of both parties involved. Appendices 1 and 2 provide additional examples.

Online Educational Tools

In conjunction with on-site visits based on initial assessment data, education can be supported by content via distance education. Many professional organizations and consortiums, such as Image Gently, Image Wisely, World Federation of Pediatric Imaging, and the RAD-AID Learning Center, have existing models for this type of delivery [37–44]. Global disparities in healthcare delivery are a complex problem of scarcity and unequal distribution of resources. The workforces in LMICs often have limited access to educational content or, in some locations, a lack of structured curricula to ensure competency. To achieve the goal of promoting radiology in global health, two initiatives have to work in parallel: (1) investing in infrastructure and technical resources for imaging acquisition and (2) investing in the education of the local healthcare providers.

The United Nations highlights the role of promoting education. This was reflected in the Millennium Development Goals and is now in the Sustainable Development Goals. Emphasis was placed on healthcare education during the WHO 2013 Global Health Professional's Forum [45, 46]. In this forum, healthcare educators worldwide were called into action to utilize innovative teaching methodologies and communications advancements to increase human capacity development. Online learning management systems (LMS) have significantly facilitated distance-virtual learning, which is an appealing attribute for global education initiatives. These systems possess the versatility of course assignments, case presentations, quizzes with ease for grading, and discussion forums for in-depth analysis of topics while allowing learners to move at their own pace with monitored progress and the added benefit of cost savings [47, 48].

In order to succeed, online learning resources should:

- Follow sound educational framework and objectives.
- Integrate the entire healthcare team.
- Adapt to and supplement the existing educational program needs.
- Be relevant to the available healthcare resources.
- Be easily accessible.

Blended Educational Models

Recently there has been a call for a transformation in teaching methodologies to "change the way we teach" [49]. This change in education, including radiology education, employs the blended learning models. This instructional strategy entails several models of combined online courses and varying degrees of instructor oversight or face-to-face interactions [50]. These methodologies have been shown to engage "millennial learners" who are technology savvy and prefer a more learner-centered approach [51, 52]. The assigned online courses and activities promote active learning by providing control over the pace and order for some of the content while at the same time are very accessible for distance learning [50, 53].

In global health educational partnerships, the varying degrees of instructor oversight and face-to-face components can be timed with on-site teaching through coordination with local training programs. Delivery of safe, effective, and efficient radiologic services requires an integrated radiology healthcare team; therefore, to upscale these services, educational initiatives should target the entire team including radiologic technologists, radiology nurses, practicing physicians, trainees (medical students and residents), and IT personnel [54].

There are three common blended learning models which include:

- Supplemental Model: this model supplements in-person teaching. For example, prior to clinical trips, specific online lectures are assigned to learners, and then applied knowledge is tested with in-person case conferences or scheduled web conferences.
- Replacement Model: this model partially replaces in-person teaching. For example, certain topics are assigned as online lectures while restricting in-person teaching to hands-on training.
- Emporium Model: this model replaces in-person teaching. For example, in-country learners are given full access to educational content and allowing students the freedom to choose. This last model is especially relevant if direct learner supervision is conducted by in-country educators [55].

Applications in Global Health Education

Before integration of online learning tools, bandwidth and access availability should be evaluated as well as acceptance of online learning tools into the educational framework of a culture and system. To assess the feasibility of online delivery of radiology educational material, qualitative surveys to evaluate the experience, benefits, and limitations of this method can be delivered. Information technology indicators, such as web traffic, user log-in data, and individual progression through the content, can be monitored also. The integration of online educational programs is dependent on Internet accessibility, which may be unreliable in resource-limited areas; however, ease of accessibility through mobile devices can often guarantee access to educational material [56]. Mobile-friendly development can be targeted for regions in which cellular phone access is reliable even if Internet LAN connections are not.

Online content should address fundamental topics in diagnostic and interventional services in a radiology department. The curriculum should be based upon existing published national and international societal practice parameters, accreditation guidelines, certification study guides, and published literature in radiology. Examples include the American Board of Radiology (ABR) Core study guide, the WHO World Alliance for Patient Safety Reports and Guidelines, the ACR Practice Parameters, and the ACR accreditation programs' requirements and guidelines. The online delivery allows for using multiple media, including presentations, selected peer review articles, online videos, or recorded lectures that are pertinent to each topic. Formative and summative assessments should be incorporated to examine variable levels of knowledge for the learners, including factual, conceptual, procedural, and metacognitive knowledge [57]. Clinical vignettes with relevant scenarios can be used for assessing higher-order learning and problem-solving skills. The development of interactive and tailored online learning resources is a useful educational tool for promoting global radiology education.

Socially Responsible Global Collaboration

Voluntourism

Educational initiatives should be approached as long-term partnerships and collegial collaborations. The act of voluntourism, or a short-term volunteer trip, can be dangerous and potentially harmful to local economies [58–60]. In a discussion of voluntourism for orphan care, Maya Wesby of *The Wilson Quarterly* speculates, "A more suitable long-term solution would be to provide parents with the resources and knowledge to care for their children, or investing in a more permanent educational infrastructure, rather than focusing solely on short-term necessities...These examples reveal the core danger of voluntourism: It creates a dependency between host communities and Western societies rather than the infrastructure needed for sustainable self-reliance" [61]. The goal of educational partnerships should be bilateral agreement among stakeholders based on initial joint assessment and feasible objectives that promote human capacity development locally. *The New York Times* author, Jacob Kushner, claims, "Unless you're willing to devote your career to studying international affairs and public policy, researching the mistakes that foreign charities have made while acting upon good intentions, and identifying approaches to development that have data and hard evidence behind them — perhaps volunteering abroad is not for you" [62]. These deep systemic challenges should be considered during partnership establishment.

In the context of bilateral and multi-institutional partnership models, shorter time commitments under the leadership of consistent key stakeholders can be implemented to complete objectives and can create an effective educational model. Sending teams to transcribe images, obtain images, or do procedures in an LMIC is not a sustainable solution to the gaps in radiology in those locations. The critical factors for sustainability are focusing on education as a model (rather than completing clinical services for a site), having measurable objectives to evaluate transfer of knowledge and competence, and having agreement among the key stakeholders about what educational topics are relevant in the context of the partnership based on initial assessment data.

Bioethics and Cultural Competency

The discussion of voluntourism, education, and sustainability emphasizes the importance of bioethics in global health radiology education. When establishing a partnership, the integration of ethics is essential and ranges broadly from ensuring that involved radiology residents are following the guidelines of their accrediting organization (ACGME or other national equivalent) to ensuring team safety to following IRB procedures for educational assessment. The bioethical tenets of nonmaleficence, beneficence, autonomy, and justice apply in global health radiology, and a partnership culture should be fostered in which stakeholders feel comfortable discussing dilemmas and issues [63]. *The Journal of Business Ethics* suggests two potential frameworks for creating a culture of ethics: (1) one led by the leadership to create an established organizational ethics or (2) another through which leadership promotes individual self-assessment in a broadly managed framework [63]. The integration of a process to support the open discussion of ethics should be based on the stakeholders in the educational partnership and their agreement.

Also, stakeholders should learn about the cultures and customs of their partners. One bilateral benefit of educational and collaborative international exchange is finding that there is more than one correct process. The process for dictating images and radiologist/clinician workflow that is appropriate for one partner, based on resources, may not be appropriate for the other partner. Communication styles vary among cultures, and understanding these differences and being able to shift to be respectful of your partners are critical—as communication is the foundation of partnership [24].

Learning from Failure

As in the fields of business and organizational science, educational partnerships should look at failures as opportunity for learning and reassessing to decrease the probability that mistakes will be repeated. Arino and de la Torre document "a longitudinal case study of the interaction between two partners to a failed international joint venture" and conclude "that positive feedback loops are critical in the evolutionary process, that relationship quality is both an outcome and a mediating variable, and that procedural issues are critical from the start in fostering a climate for positive reinforcement and the building of mutual trust and confidence in the relationship" [64]. An agreed-upon means for feedback, mutually established processes, and time spent building relationships were primary findings in their discussion. As an example, some partnerships may require formal feedback meetings based on cultural styles, and other partnerships may depend on informal discussions for stakeholder assessment. It is better to ask upfront which feedback style is most appropriate so that these conversations are productive [24]. In 2011, David Damberger reflected on the open culture created at Engineers Without Borders for discussion of failure and error. Cross-organizationally, the engineers are encouraged to "publically admit, scrutinize and learn from their missteps" [65]. The take-away being that these concepts should be applied to global health educational initiatives; organizations and partnerships must continually self-assess, seek systematic improvement, and document progress.

Curricula for Global Health in Radiology

As more radiologists, technologists, physicists, nurses, and radiology professionals recognize the importance of radiology in global health, there is opportunity for joint education and collaboration. If pursuing an on-site partnership model or a partnership that establishes or supports formal education, then stakeholders in those organizations or collaborations, regardless of professional scope, benefit from a structured framework within which to operate for their long-term initiatives [66, 67]. General public health and global health educational opportunities are available, such as the MD/MPH degree combination or graduate degrees in public health or global health.

Because of the special considerations in radiology for technology and equipment, curricula are being created with emphasis specifically on radiology in the context of global health. Recommendations for global health electives and project experiences for radiology residents include global and public health education, targeted travel medicine education, basic imaging proficiency, and consideration for practice attitudes and accountability. Additional global health curricula place emphasis on ultrasound education of radiology residents because of its prevalence as a modality in LMICs [68–70]. This structure and need can be applied to other professional scopes, as is evidenced by the ASRT's Medical Relief Readiness educational product which is targeted for technologists traveling abroad in educational or disaster relief capacity [71].

Other organizations, like RAD-AID International, offer learning opportunities, like the Certificate of Proficiency in Global Health Radiology, which is a facilitated online learning experience for a multidisciplinary cohort with mentorship for project planning and implementation. This cohort echoes the Koplan definition of global health [7]. From 2015 to 2018, cohorts have included healthcare professionals from Australia, Cameroon, Canada, Egypt, Germany, Guyana, Ireland, Kenya, Malawi, the United Kingdom, the United States, and Seychelles. The certificate of proficiency is open to an international cohort with two annual scholarships for participants in LMICs. Also, cohorts have included consultant/attending radiologists, health informatics specialists, primary care physicians with interest in future radiology training, radiologic technologists, radiology registrars/residents, and sonographers. The multidisciplinary interaction and exchange provide a unique learning environment.

A sample of competencies covered by the cohort include (1) *radiology's context in global health* including broader implications of interactions, concepts of resource accessibility versus availability, and implications of economy and infrastructure; (2) *socially responsible global collaboration* including cross-cultural intelligence, communication, responses to failure, and legal and ethical considerations; (3) *partnership and educational* structures including the importance of initial assessment and continuous assessment to measure impact; and (4) *radiology-specific issues* including sustainable approach to equipment and technology issues (such as addressing supply chain, warranty and maintenance for equipment, stakeholder agreement), the role of education in human capacity development, and the usefulness of multidisciplinary approach for holistic success [72, 73]. These competencies are applied in the context of professional scope: How would these topics apply to a breast imaging radiologist, an interventional radiologist, a medical physicist, a radiologic technologist, a sonographer, a nurse, and other professional specialities? How would they apply to the team and partnership as a whole?

Training and student variants of this curriculum have been used via a combined RAD-AID and Columbia College of Physicians and Surgeons Global Health Radiology Clerkship for medical students, a combined RAD-AID and UCLA Global Health Radiology Clerkship for medical students, and a self-directed tutorial for radiology residents [73]. Regardless of the source of global health curriculum or framework, it is helpful for stakeholders to have education and knowledge about the context of global health and radiology's role internationally when moving forward to establish educational partnerships.

Conclusion

In summary, radiology is a critical field in the advancement of global health, and education is a method of achieving sustainable progress. Faculty exchanges, scholarly collaborations, partnership models, formal education, online educational platforms, and global health curricula are some educational tools that are used in global health. Regardless of the type of model used, educational goals and objectives should be based on initial assessment data and address the appropriate needs. Curricula should be established in partnership with all stakeholders and with consideration for ethical best practices, continuous evaluation and improvement of the program, and open communication among stakeholders.

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Part II

Global Health Radiology Clinical Applications

14 The Role of Radiology in Global Health

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Global Health

The term "global health" has various interpretations. It is often used to refer to a discipline that engages in collaborative international research and action to promote health and achieve health equity for all [1, 2]. The discipline is founded on the belief that the world's health is determined by issues that transcend national boundaries, having social, economic, environmental, and political dimensions [3]. The discipline of global health is thus not limited to the health sector; it is concerned with all strategies for health improvement across all sectors, whether on population or individual level [4]. At the heart of the discipline is the quest for health for all, which resonates with the Alma Ata Declaration. This places global health at the forefront of a multi-sectoral approach to health improvement, which advocates the strengthening of primary healthcare as the foundation of all health systems [1, 5].

The term "global health" may also refer to the global burden of disease (GBD), as reflected in the World Health Organization (WHO) Global Health Estimates (GHEs). These collate and audit mortality figures and disability-adjusted life years (DALYs) at global, regional, and country level. The DALY is a metric that combines years of life lost due to premature death with years lived in less than full health. The GHEs thus serve to highlight key health trends, disease profiles, and potential interventions [6].

Diagnostic imaging has a key role to play in the discipline of "global health" and in confronting the global burden of disease.

The Global Burden of Disease (GBD)

The GHEs for 2015 provide an overview of worldwide mortality trends since 2000 [6]. Ischemic heart disease and stroke have been the leading causes of death across the globe throughout the new millennium. Furthermore, deaths due to these conditions are increasing in number; in 2015 they accounted for approximately 8.8 million (16%) and 6.2 million (11%) of the 56.4 million global deaths, respectively. Deaths from hypertensive heart disease, chronic obstructive airway disease, diabetes, road accidents, dementia, and cancers of the lung, liver, colon, and stomach have also shown steady increases in the new millennium. By contrast, there have been slight decreases in mortality from lower respiratory tract infections, diarrhea,

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tuberculosis (TB), human immunodeficiency virus (HIV) infection, prematurity, birth asphyxia, malaria, measles, and congenital abnormalities. Thus, since 2000, deaths due to communicable diseases have been decreasing globally, while those attributable to noncommunicable diseases (NCDs) have been increasing. These trends are deemed to reflect an overall decrease in global health inequality. This interpretation is underscored by a decrease in the DALY rate in the WHO African region from 1071 to 637 per 1000 people between 2000 and 2015 [7].

Notwithstanding these encouraging trends, striking regional differences in the global disease burden remain a stark reality [6]. Among the estimated 900 million people living in the 47 countries comprising the WHO African region in 2015, maternal/perinatal conditions (11%), lower respiratory tract infections (11%), HIV infection (8%), diarrhea (7%), tuberculosis (TB) (5%), malaria (4%), meningitis (2%), protein energy malnutrition (2%), and congenital anomalies (2%) accounted for more than half (53%) the 9.2 million regional deaths. These same conditions accounted for less than a quarter of the deaths in the WHO Southeast Asian (24%) and Eastern Mediterranean (23%) regions and for less than one-tenth of all deaths in the Western Pacific (7%), European (5%), and American (4%) regions. An analysis of country-level mortality by World Bank classification reveals that the overwhelming majority of maternal/perinatal (99%), infectious/parasitic (97%), and nutritional (94%) deaths globally occur in low- and middle-income countries (LMICs). These deaths are potentially preventable and are strongly related to poverty and poor healthcare infrastructure [6].

Sustainable Development Goals

Global inequalities, including those in healthcare, provided the context for the September 2015 adoption of the United Nations (UN) 2030 Agenda for Sustainable Development [8]. The 17 sustainable development goals (SDGs) integrate the economic, social, and environmental dimensions of sustainable development, acknowledging that eradicating poverty, creating inclusive economic growth, and protecting our planet are inextricably linked (Table 14.1). Health is centrally positioned within the 2030 Agenda, with one comprehensive goal (SDG 3) comprising 13 targets which cover all major health priorities (Table 14.2). The SDGs are ambitious and far-reaching, and entrench the

Table 14.1 Sustainable development goals (SDGs)

Sustainable development goals (SDGs)	
1	End poverty in all its forms everywhere
2	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
3	Ensure healthy lives and promote well-being for all at all ages
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5	Achieve gender equality and empower all women and girls
6	Ensure availability and sustainable management of water and sanitation for all
7	Ensure access to affordable, reliable, sustainable, and modern energy for all
8	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all
9	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
10	Reduce inequality within and among countries
11	Make cities and human settlements inclusive, safe, resilient, and sustainable
12	Ensure sustainable consumption and production patterns
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
15	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Table 14.2 SDG health targets (SDG 3)

SDG health targets (SDG 3)	
3.1	By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births
3.2	By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least 12 per 1000 live births and under-5 mortality to at least 25 per 1000 live births
3.3	By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases, and other communicable diseases
3.4	By 2030, reduce by one-third premature mortality from noncommunicable diseases through prevention and treatment and promote mental health and well-being
3.5	Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol
3.6	By 2020, halve the number of global deaths and injuries from road traffic accidents
3.7	By 2030, ensure universal access to sexual and reproductive healthcare services, including family planning, information and education, and the integration of reproductive health into national strategies and programs
3.8	Achieve universal health coverage, including financial risk protection, access to quality essential healthcare services, and access to safe, effective, quality, and affordable essential medicines and vaccines for all
3.9	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination
3.a	Strengthen the implementation of the WHO Framework Convention on Tobacco Control in all countries, as appropriate
3.b	Support the research and development of vaccines and medicines for the communicable and noncommunicable diseases that primarily affect developing countries; provide access to affordable essential medicines and vaccines, in accordance with the Doha Declaration on the Trade-Related Aspects of Intellectual Property Rights (TRIPS) Agreement and Public Health, which affirms the right of developing countries to fully utilise the TRIPS provisions regarding flexibilities to protect public health; and, in particular, provide access to medicines for all
3.c	Substantially increase health financing and the recruitment, development, training, and retention of the health workforce in developing countries, especially in least developed countries and small-island developing states
3.d	Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction, and management of national and global health risks

achievements and commitments of the millennium development goals (MDGs) drafted in 2000 [9]. The MDGs provided a framework and stimulus for progress in a number of key healthcare areas. However, MDG progress proved uneven, with some targets not realized, particularly those relating to maternal and child health [10]. The SDGs are more comprehensive and seek to prioritize the needs of the poorest and most vulnerable in society, and to combat inequalities by championing equitable and universal access to quality healthcare, education, and social protection.

The SDGs are underpinned by the conviction that the eradication of poverty (SDG 1), particularly extreme poverty, remains the greatest global challenge. Poverty eradication is also key to improving global health, since poverty is strongly associated with ill-health. The poorest of the poor experience the worst health, and there is a social gradient in health that runs from top to bottom on the socioeconomic spectrum. This is seen in low-, middle-, and high-income countries [11].

From a radiological perspective, the key SDG health targets are those relating to maternal health (SDG 3.1), child health (SDG 3.2), tuberculosis and human immunodeficiency virus (HIV) (SDG 3.3), noncommunicable diseases (NCDs) (SDG 3.4), road traffic accidents (RTAs) (SDG 3.6), reproductive health (SDG 3.7), universal health coverage (SDG 3.8), and healthcare personnel (SDG 3.c).

Diagnostic imaging has the potential to contribute to achieving six of these targets, while global radiological services would be substantially enhanced by the realization of a further two targets. Thus, there exists considerable interdependency between the realization of health-related SDG targets and the extension of global imaging services. To better understand this co-dependency, global radiological services are briefly reviewed.

Global Radiological Services

The primary global challenges confronting diagnostic imaging are inequality in access to services, the injudicious use of existing resources, and the paucity of appropriate data to inform future strategic planning, policy, standards, and guidelines.

Over the past 60 years, there have been major technological advances in diagnostic imaging. Ultrasound, computed tomography (CT), magnetic resonance (MR), digital radiography, and minimally invasive interventional techniques have all been incorporated into routine clinical practice in well-resourced environments [12]. Over the same period, exponential progress in information technology in well-resourced environments has seen the emergence of picture archiving and communication systems (PACS), radiology information systems (RIS), filmless and paperless digital radiology departments, and tele-radiological services. These advances have revolutionized the practice of clinical medicine. Progress continues, with on-going expansion of the clinical indications for diagnostic imaging, as well as improvements in image acquisition time, resolution, and tissue contrast. As a simple illustration, a high-resolution CT scan of the entire body can now be acquired in a single breath-hold. These technical advances have resulted in a substantial increase in the demand for radiological services worldwide.

The WHO recognizes health technology, including diagnostic imaging, as one of the six essential building blocks of any healthcare system and considers basic radiological services essential for effective primary care [12–16].

The increasing use of radiological services in well-resourced environments can best be appreciated if one considers that from 1988 to 2008, the number of imaging studies performed worldwide increased from 1.38 to 3.14 billion, annually [17]. Furthermore, in the periods of 1991–1996 and 1997–2007, the global annual per capita effective medical radiation dose increased from 0.4 to 0.62 milliSieverts [17–19].

The increasing demand for diagnostic imaging remains a considerable challenge in modern healthcare, since high-end radiological services are expensive and labor-intensive, require substantial technical expertise, and may involve hazardous ionizing radiation. There are concerns that current patterns of utilization in well-resourced settings are not sustainable. The increasing use of radiological services and the resulting rise in healthcare expenditure and exposure to ionizing radiation have not always shown incremental patient benefit [20–23]. Consequently, some modern radiological practices may be deemed ineffective, wasteful, and hazardous [24]. There are thus mounting pressures to ensure responsible and effective use of global radiological resources [25, 26].

Although much work has been done drafting best practice guidelines to govern the use of sophisticated radiological equipment in well-resourced healthcare systems, not all published protocols are substantiated by a rigorous evidence base. There also exists considerable discrepancy in international imaging practice. There is now a groundswell of opinion that imaging protocols should be limited to evidence-based applications. Reconciling the costs with benefits of new technology is one of the major challenges of modern healthcare systems [27].

Paradoxically, technological advances in radiology have compounded inequalities in global access to imaging. At one end of the continuum are well-resourced countries with an aging population, a high burden of NCDs, and an expectation of the best medical care. These countries generally have a ready supply of well-trained radiology staff and state-of-the-art equipment but are confronted by potential over-servicing, unsustainable imaging practices, and increasing population exposure to ionizing radiation. At the other end of the spectrum is more than half the world's population, living in LMICs, with diseases largely related to poverty and poor medical infrastructure, and no access to the most basic medical imaging [16, 28, 29].

Plain X-rays and ultrasound are considered the minimum essential imaging modalities in any healthcare system [30]. Both modalities are relatively affordable when compared to more sophisticated imaging equipment. It is believed that approximately 90% of all imaging needs in LMICs could be addressed by the provision of one plain X-ray unit and a basic ultrasound machine for every 50,000–100,000 people [14, 30]. However, this figure is untested since there have been no formal analyses of the minimum imaging needs of populations, based on demographics, burden of disease, and economic capacity.

To date, the drivers and determinants of a country's radiology equipment resources remain poorly understood and inadequately researched. Marked resource disparities have been documented among countries in the same World Bank economic grouping. Furthermore, stark inequalities exist between geographical regions, as well as between private and public healthcare sectors within the same country [27, 31, 32].

Inequalities in the distribution of global radiological equipment resources are reflected in the worldwide availability of trained medical personnel. Currently, there is a critical shortage of healthcare workers globally, and the demand is increasing, driven by population growth, longer life expectancy, the rise in NCDs, the HIV pandemic, and technological advances in healthcare [33]. In 2013, the estimated global health workforce was approximately 42 million, including 9.7 million physicians, 19.7 million nurses/midwives, and approximately 12.6 million other health workers. The global deficit of healthcare workers in 2013 was estimated to be approximately 17.6 million, of which approximately 2.5 million were doctors, 9 million nurses and midwives, and the remainder other healthcare cadres. The greatest healthcare worker deficits are in low- and lower middle-income countries.

The imaging enterprise, which includes the acquisition, storage, and interpretation of images, as well as the maintenance of imaging equipment, requires relatively highly skilled medical personnel. Given that healthcare personnel are another essential building block of the healthcare system, increasing access to diagnostic imaging in underserved areas will require careful workforce planning [34].

There is a growing awareness of the need for careful strategic planning at a national and international level, to meet worldwide imaging demands within budget constraints [35]. However, meaningful planning requires robust data. Surprisingly, there is limited published country-level data on the installed base of diagnostic imaging equipment. Furthermore, there have been few population-based analyses of the utilization of radiological services [31, 36]. Although the World Health Organization (WHO) has published national estimates of high-end medical imaging resources based on questionnaire surveys of member countries, these data do not include basic equipment such as X-ray units and ultrasound [37]. A better understanding of radiological services and usage rates in different healthcare settings would help define population-based equipment norms and standards, inform healthcare planning and policy, and provide guidelines for sustainable imaging practices. Such planning requires accurate data and should incorporate all equipment and personnel needs of the imaging enterprise, including physicians, radiographic technicians, medical physicists, and clinical engineers [38, 39]. Innovative approaches will be required to meet personnel needs, with task-shifting likely assuming prominence in this regard. Task-shifting involves the delegation of tasks from more- to less-specialized healthcare workers who can competently and safely perform the assigned tasks. As such, it is a method of strengthening and expanding the healthcare workforce. The WHO recommends that task-shifting be pursued wherever there is evidence that it is safe and cost-effective, with quality of care and patient safety being the guiding principles [40].

Radiology and the SDGs

Universal Health Coverage

Health technology, including diagnostic imaging, is seen as an essential building block in any healthcare system. However, more than half the world's population currently has no access to radiological services. Universal access to basic imaging, such as ultrasound and X-rays, should thus be seen as integral to achieving universal health coverage (UHC) (SDG 3.8). Furthermore, since healthcare represents a complex adaptive system, there is increasing recognition of the inter-connectedness of each component and the need to enhance sustainability through collaborative initiatives across components. The extension of global radiological services should thus not be seen as an end in itself, but should proceed in step with all other components of a comprehensive and integrated healthcare system, with the emphasis on prevention of disease. Similarly, the impact of increased access to radiological services should not be assessed in isolation. The truisms "the whole is greater than the sum of the parts" and "a chain is no stronger than its weakest link" are particularly apt in healthcare systems.

From a radiological perspective, the SDG health targets relating to maternal, perinatal, and pediatric health, together with those pertaining to TB, NCDs, and RTAs, are particularly pertinent. The potential role of the basic imaging modalities, plain X-rays and ultrasound, in addressing these targets will now be considered.

Basic Imaging Modalities

In order to better appreciate the role of basic imaging in the healthcare system, some strengths and limitations of plain X-ray and ultrasound imaging will be highlighted.

Plain X-Rays

Plain X-ray units are relatively affordable. However, they utilize ionizing radiation and thus typically require customized installation, including standard radiation protection. They usually require high-power and stable electricity supply, although mobile and battery-operated units exist. Analogue, hard-copy X-ray facilities require a darkroom and a film processor. Such installations have relatively high X-ray consumable costs. Digital imaging facilities are film-free and display images on diagnostic monitors. Such units have substantially lower running costs but higher capital outlay. Digital images can also be transmitted for remote interpretation. Plain X-ray units should only be operated by registered radiation workers. Maintenance costs of both analogue and digital systems are considerable, since highly trained technicians are required, and the X-ray tube is a costly component that will need replacement from time to time. Plain X-ray units provide excellent imaging of the lungs and bones. Abdominal X-rays demonstrate bowel obstruction and perforation with very high sensitivity, but soft-tissue masses are not optimally detected. The penetration of the X-ray beam is limited in patients with a high body mass index.

Ultrasound

Ultrasound has a number of characteristics which make it uniquely suited to the provision of healthcare in low-resource environments; it is relatively affordable and it generates no ionizing radiation, making it completely safe and devoid of specific installation or radiation protection requirements. Similarly, it can be used repeatedly on the same patient and poses no threat to the unborn child. With appropriate training, ultrasound imaging can be utilized by a broad spectrum of medical personnel. It operates on a standard electrical supply but may also be battery-operated. Machines are robust, mobile, and potentially portable and require relatively little maintenance. The smallest available units can now fit into the palm of a hand. Ultrasound generates real-time, high-resolution digital images which can be interpreted during the examination. Captured images and video clips may also be stored in a digital archive and transmitted via the internet for expert remote reporting. Ultrasound provides excellent imaging of the soft tissues, which, together with the absence of ionizing radiation, makes it an ideal modality for antenatal imaging. Ultrasound also provides very satisfactory first-line imaging of the abdominal and pelvic organs, the heart, the soft tissues of the neck, muscles, and tendons. Doppler ultrasound affords exceptional vascular imaging. Some drawbacks include the following: ultrasound is not suitable for patients with a high body mass index, it is operator dependent, and the ultrasound beam is not transmitted through bone or air. The main use of ultrasound in the chest is the detection and characterization of pleural effusions. It has also been shown that ultrasound guidance is of substantial benefit when inserting chest drains. Unnecessary drain placement can be prevented with ultrasound as it can show when there is only limited fluid present. Its use in guiding procedures can help to avoid complications such as inadvertent organ puncture. Ultrasound is also useful in guiding tissue biopsy and minor interventional procedures such as abscess drainage. Furthermore, competence in ultrasound can be on a sliding scale from the very basic to the highly sophisticated, with incremental competence evolving over time.

From the above, it can be appreciated that the clinical roles of plain X-ray and ultrasound imaging are broadly complementary.

The Role of Basic Imaging in Decreasing Maternal Mortality

In 2015, there were approximately 303,000 maternal deaths globally, with maternal conditions accounting for approximately 19 million DALYs worldwide. The overwhelming majority of deaths and DALYs were in LMICs [6]. Most maternal deaths are preventable; the healthcare solutions for preventing or managing the complications of pregnancy and childbirth are well-known [41]. The primary causes of maternal death are hemorrhage, sepsis, hypertension in pregnancy, and the interaction of pregnancy with preexisting medical conditions. Access to antenatal ultrasound allows for confirmation of intrauterine pregnancy, accurate estimation of gestational age, and knowledge of the expected delivery date, with planned, term delivery at an appropriate facility. Antenatal ultrasound also allows for identification of "at-risk" pregnancies, most notably ectopic pregnancy, multiple pregnancy, fetal anomaly, and abnormal placental position; this knowledge facilitates appropriate referral and intervention. During labor, ultrasound can demonstrate abnormal fetal presentation and obstructed labor, prompting earlier intervention. After delivery, ultrasound can accurately identify retained products of conception within the uterine cavity. By identifying conditions predisposing to hemorrhage, such as ectopic pregnancy, abnormal placental position, obstructed labor, and retained intrauterine products, ultrasound can address one of the main causes of maternal mortality. Similarly, early identification of retained products facilitates early evacuation of the uterus and limits the risk of puerperal sepsis. Furthermore, there is evidence that provision of a low-cost antenatal ultrasound service in a poorly resourced rural setting is associated with an increase in overall utilization of antenatal services and thus may provide a broader benefit to the maternal and neonatal health of the community [42].

The Role of Basic Imaging in Decreasing Perinatal Mortality

Of the 2.7 million deaths in the neonatal period (first 28 days of life) in 2015, approximately 691,000 (39%) were due to birth asphyxia or birth trauma, which together accounted for an estimated 67 million DALYs. Ninety-nine percent of all such deaths and DALYs were in LMICs, with the highest levels in the WHO African region [6].

Antenatal ultrasound can play an important role in addressing birth asphyxia. Through accurate estimation of gestational age and the expected date of delivery, ultrasound facilitates planned delivery, at term, and at an appropriate healthcare facility. Knowledge of the expected delivery date is of particular importance in rural communities of low-resource nations, where mothers have to travel considerable distances on public transport, sometimes over days, to the nearest healthcare facility. If the expected delivery date is known, mother and family can undertake a planned trip to the healthcare facility, well in advance of the delivery date. Expectant mothers may be accommodated near the facility in the days preceding delivery, thereby ensuring easy access to care at the time of delivery. Furthermore, through the monitoring of fetal growth and amniotic fluid volume, ultrasound accurately assesses fetal well-being. Thus, patients may be referred to an appropriate facility at the earliest sign of growth retardation or placental insufficiency. During delivery, ultrasound can more accurately demonstrate complications of labor, facilitating early intervention.

Prematurity accounted for more than a million deaths and approximately 102 million DALYs in 2015. Management and outcome in the premature infant are enhanced by the availability of plain X-rays and ultrasonography.

The chest X-ray (CXR) facilitates identification of surfactant deficiency disorder and its complications, most notably pneumothorax. The incidence of surfactant deficiency disease is inversely related to gestational age. Abdominal X-rays can demonstrate features of necrotizing enterocolitis (NEC), the most common gastrointestinal emergency in premature infants, allowing for early diagnosis and intervention [43]. Of note, ultrasound is also emerging as a useful modality for the identification of NEC, through its ability to demonstrate small locules of gas in the bowel wall, as well as gas in the portal vein [44, 45].

Neonatal cranial ultrasound plays a pivotal role in the identification of intraventricular hemorrhage (IVH), which occurs in approximately 20% of very low-birth-weight infants (less than 1500 g) and in 45% of extremely low-birth-weight infants, weighing 500–750 g [46]. IVH is a major problem in premature infants, as approximately 50–75% of preterm survivors with IVH develop cerebral palsy, mental retardation, and/or hydrocephalus. Neonatal ultrasonography is used to identify the presence of IVH and monitor the evolution of complications such as hydrocephalus and extension of hemorrhage into the brain parenchyma.

Cardiac ultrasound (echocardiography) is also useful for the demonstration of a persistent patent ductus arteriosus (PDA). The overall incidence of symptomatic PDA in premature neonates is approximately 12% but varies according to the gestational age and respiratory status. Failure of PDA closure in preterm infants with respiratory distress syndrome results in a left-to-right shunt across the duct which may lead to pulmonary congestion and deterioration in respiratory status [47]. However, such usage is generally limited to facilities with neonatal intensive care facilities.

The Role of Basic Imaging in Decreasing Mortality in Children Less Than 5 Years of Age

Mortality due to pneumonia in children younger than 5 years has decreased from 1.7 million in the year 2000 to 916,000 in 2015 [6]. This significant decrease can be attributed to improvements in socioeconomic status, immunization programs, and HIV interventions. Despite this, pneumonia remains the leading infectious cause of morbidity and mortality in children less than 5 years, globally. Most of these deaths occur in LMICs, especially in Africa and Southeast Asia, where there is a very high prevalence of risk factors for severe disease including poverty, poor living conditions, malnutrition, and HIV infection or exposure [48, 49]. *Streptococcus pneumoniae* (pneumococcus) and *Haemophilus influenzae* type b (Hib) are the most important causes of vaccine-preventable deaths in children in this age group [50, 51]. HIV-infected children have an increased risk of developing invasive pneumococcal disease [52]. HIV has also affected the epidemiology of childhood pneumonia, changing the profile of causative organisms to include *Pneumocystis jirovecii*. It also increases the incidence of multi-organism infections and decreases organismal susceptibility to antibiotic therapy and overall clinical outcomes [52, 53]. Basic imaging plays an important role in the diagnosis and management of pediatric pneumonia, since diagnosis on clinical criteria alone remains challenging, since clinical findings are relatively nonspecific [54–58]. It has been shown that only 34% of children hospitalized with suspected pneumonia based on WHO clinical criteria actually have radiologically confirmed pneumonia [59]. A recent meta-analysis recommended that the diagnosis be based on a combination of clinical findings and the WHO-defined CXR features [60]. The CXR remains the most readily available imaging modality worldwide [16, 61] and is the most common investigation for assessing pediatric respiratory disease [16, 61–63]. CXRs are recommended to confirm the diagnosis, document the nature and extent of lung pathology, and determine complications such as empyema [64]. The CXR also provides some insight into the causative organism, broadly differentiating bacterial from viral disease, [65–68] although this is not conclusive [69–71]. The CXR also allows identification of features suggestive of underlying pulmonary TB [72–74]. It can also alert to the characteristic granular pattern of pulmonary opacification seen in *Pneumocystis* pneumonia, suggesting underlying HIV infection or other immunodeficiency [75]. The CXR affords some indication of disease severity. More extensive air-space opacification and large pleural effusions are associated with greater clinical severity and the need for mechanical ventilation and higher supplemental oxygen concentrations [76]. The CXR also monitors the evolution of chronic lung disease. The clinical utility of the CXR has been limited by wide interobserver variation in CXR interpretation [77, 78]. However, interobserver agreement can be enhanced by utilizing a systematic and standardized reporting approach [79].

Recent reports have documented the use of ultrasound in the diagnosis of community-acquired pneumonia in children admitted to the emergency department, although its usefulness in identifying the type of lung involvement requires further evaluation [80]. Ultrasound is also useful for confirming the presence of pleural fluid, the nature of the fluid, and in guiding its aspiration.

The Role of Basic Imaging in Decreasing the Prevalence of Tuberculosis

In 2015, there were an estimated 10.4 million new TB cases worldwide, of which 5.9 million (56%) were among men, 3.5 million (34%) among women, and 1.0 million (10%) among children. People living with HIV accounted for 1.2 million (11%) of all new cases. Six countries (India, Indonesia, China, Nigeria, Pakistan, and South Africa) accounted for 60% of these cases. Global progress depends on major advances in TB prevention and care in these countries [81]. There were an estimated 1.4 million TB deaths in 2015 and an additional 0.4 million TB deaths among people living with HIV. Although the number of TB deaths fell by 22% between 2000 and 2015, TB remains amongst the top 10 causes of death worldwide [6].

Pulmonary tuberculosis (PTB) is caused by mycobacterial species in the *Mycobacterium tuberculosis* complex and is transmitted by droplet spray. Droplets containing mycobacteria are generated when a person with active pulmonary tuberculosis coughs, sneezes, or speaks. Droplets can remain suspended in the air for several hours. They are inhaled and reach the terminal airspaces of the lung [82]. Not all individuals exposed to tuberculosis get active disease. In approximately 5% of infected individuals, the immune system is inadequate, and active tuberculosis develops within the first 1–2 years [83]. This category is referred to as *primary PTB*. In another 5% of infected individuals, the immune system is effective at controlling the initial infection, but viable mycobacteria remain dormant for many years, reactivating at a later time, more so in the presence of conditions that affect immunity (HIV infection, undernutrition, old age) [83]. This category is referred to as post-primary or *reactivation PTB*. The remaining 90% of individuals will never develop symptomatic disease and will harbor the infection at a subclinical level. This category is referred to as *latent PTB* infection. These individuals are asymptomatic and noncontagious.

Extra-pulmonary tuberculosis results from blood-borne spread, or direct extension from adjacent organs, and may involve the larynx, solid abdominal organs, bowel, genitourinary tract, central nervous system, or bones. With the exception of laryngeal tuberculosis, extrapulmonary disease is not contagious. *Miliary tuberculosis* is a blood-borne spread of disease characterized by numerous tiny lesions, measuring 1–2 mm, which can simultaneously involve multiple organs, such as the lungs, liver, spleen, and central nervous system. Miliary tuberculosis is also not contagious.

The onset of active disease is insidious, manifesting initially with minimal symptoms that worsen over the course of several months. Typical symptoms of disease activity include a productive cough, hemoptysis, weight loss, fatigue, malaise, fever, and night sweats [84]. The clinical diagnosis of PTB is thus challenging, since early symptoms can be nonspecific. Clinical suspicion of PTB may be heightened in patients with various risk factors. HIV infection is the strongest known risk factor [82].

SDG health target 3.3 includes eradicating tuberculosis by 2030. Since TB is spread by individuals with active PTB, strategies for disease eradication must include prevention of disease through extension of immunization programs in endemic areas, and limitation of spread through early identification, and effective treatment of individuals with active disease. Since HIV infection is associated with an increased risk of active TB, the eradication of HIV is also key to effective TB control.

The bacille Calmette-Guérin (BCG) vaccine is the only available TB vaccine. It was first administered in 1921, as an infant oral vaccine, and it is still the only vaccine licensed to prevent TB [85]. The BCG vaccine is widely used in TB-endemic countries, where newborns are immunized as soon as possible after birth, with a single intradermal dose [86]. To date, it is estimated that the BCG vaccine has been administered over 4 billion times and that 120 million children globally receive the vaccine every year [87].

The CXR reflects the pathophysiology of PTB and thus plays an important role in stratifying the risk of active infection. Infection through droplet deposition of organisms in the distal airways initiates an inflammatory response in the periphery of the lung. This may manifest as a small, poorly defined focal opacification on CXR. In the immune-competent patient, symptoms of TB infection are subclinical and the resulting small opacified focus is transient; thus, TB usually remains undetected both clinically and radiologically. Coincident with the focus of lung infection, there is drainage of infected material to the regional hilar and mediastinal lymph nodes, which may enlarge. Again, in the immune-competent patient who contains the infection, mediastinal abnormalities are transient and subclinical and usually remain undetected radiologically. This represents the classic *latent PTB*. The patient who has been exposed to TB and contained the infection remains unaware of the infection and shows no residual CXR abnormality [88].

However, in the cases where patients fail to successfully contain the initial infection, more extensive pulmonary opacification and clinically severe symptoms develop, in conjunction with more pronounced hilar and mediastinal adenopathy. At this stage the CXR will show the hallmark features of primary pulmonary tuberculosis, being a focus of poorly defined opacification in the lung, together with prominent mediastinal lymphadenopathy. Of note, lymphadenopathy can be the only CXR finding. This is the classic presentation of *primary PTB*, typically seen in immune-competent children [88].

After successful treatment of primary PTB, the CXR may revert back to normal. However, the sites of lung and mediastinal involvement may calcify. Such calcification may be visible on the CXR and would be interpreted as signifying *previous infection but no active PTB* [88].

Years after latent infection, dormant mycobacterial deposits in the lung may reactivate, resulting in *reactivation PTB*. This typically manifests on CXR as a focus of pulmonary opacification which may show central cavitation, most often in the lung apices. This radiographic appearance is the hallmark of *active PTB*. Cavitation is understood to develop as a result of the host's immune response to the reactivated bacilli. Patients with cavitary disease have a high mycobacterial load in their respiratory secretions, are highly contagious, and as a result are responsible for disease propagation [88].

After successful treatment of post-primary PTB, the CXR typically shows residual pulmonary scarring, nodules, and possibly cavities. This residual, so-called fibro-cavitary, disease can be monitored radiographically, to ensure no interval change. Radiographic stability is the diagnostic criterion which signifies *previous infection but no active PTB* [88].

The above broadly details the pathophysiology of PTB and its clinico-radiological correlation. The classic CXR appearances as outlined above only apply to immune-competent individuals. In HIV-infected individuals, reactivation PTB manifests as mediastinal lymphadenopathy with or without associated lung opacification. Thus, radiographic evidence of reactivation PTB in immunocompromised individuals is similar to those of primary PTB and typically does not show pulmonary cavitation.

Patients with CXR features suggestive of active PTB should undergo definitive workup for PTB. Laboratory evaluation begins with obtaining sputum for smear and culture. The results of a sputum smear are generally available within 1 day. The number of bacilli identified on the smear correlates with the patient's degree of infectiousness [82]. In instances in which the patient cannot produce sputum, expectoration of sputum may be induced with administration of nebulized hypertonic saline. In children, who commonly swallow sputum, gastric washings obtained in the early morning with nasogastric aspiration have a diagnostic yield of approximately 40% in those with radiographic signs of pulmonary disease [89]. Once a sputum sample is obtained, it is processed by using an acid-fast staining method. The sensitivity of the smear for acid-fast bacilli (AFB) with three successive expectorated sputum specimens is 68–72% in patients with culture-positive tuberculosis and 62% in HIV-positive patients [90]. Thus, the clinical context and imaging findings are important to determine the need for empirical antituberculous therapy. Culture can detect as few as 10 mycobacteria per milliliter of sample, whereas greater than 5000 mycobacteria per milliliter are required for a positive smear [91]. Traditionally, it can take up to 6 weeks for the growth of mycobacteria to be detected on solid culture media, whereas the use of liquid culture media can shorten this time to 2 weeks [82]. Once growth is detected, mycobacterial species can be identified, allowing for the distinction of *M. tuberculosis* from non-tuberculous mycobacteria. Mycobacterial culture remains the reference standard for diagnosing active tuberculosis, with a sensitivity of 80–85% and a specificity of 98%. The newly developed nucleic acid amplification test can detect genetic material of tuberculous mycobacteria from sputum samples within 48 h [92–94].

In summary, the CXR is regarded as an essential tool to help in the eradication of PTB. CXR has higher sensitivity for diagnosing pulmonary TB than symptoms. CXR is an essential tool in early TB detection and therefore fundamental to achieving the targets set by the WHO's End TB Strategy. CXR has high sensitivity (98%), but less specificity (75%) for detecting bacteriologically confirmed pulmonary TB. It is therefore suitable for TB screening and triaging.

Role of Basic Imaging in the Diagnosis and Management of NCDs

Between 2000 and 2015, global deaths due to NCDs increased by 26%, from 31.3 to 39.5 million. More than two-thirds of NCD deaths in 2015 were attributable to cardiovascular disease (17.6 million, 45%) and malignancy (8.7 million, 22%) [6]. The potential role of imaging in the diagnosis and management of each of these groups will be discussed.

The Role of Basic Imaging in the Diagnosis and Management of Cardiovascular Disease

The risk factors for cardiovascular disease are well recognized and include genetic predisposition, co-morbidities such as diabetes mellitus, and lifestyle factors such as smoking. Although prevention is the most effective intervention for limiting premature death from cardiovascular disease, basic imaging provides an important adjunct to patient care. CXR and echocardiography can monitor the natural history of both hypertensive and ischemic heart disease, identify early-onset congestive heart failure, and monitor response to treatment.

Cardiovascular disease is an important consideration in any patient presenting with chest pain or dyspnea. CXR is a useful first-line study in this setting as it allows for the exclusion of non-cardiac causes such as pneumothorax, pneumonia, pleural effusion, and pulmonary or mediastinal masses. The CXR also provides insight into the possible cardiac nature of symptoms, by allowing assessment of heart size and features of cardiac failure.

Echocardiography is the most frequently utilized cardiovascular imaging investigation after CXR and provides extensive detail on cardiac chamber size, function, valvular dynamics, pericardial disease, and aortic root pathology. For example, echocardiography allows definitive evaluation of left ventricular hypertrophy in early hypertensive disease, abnormal ventricular wall motion in acute myocardial infarction, as well as the sequelae of ischemic heart disease such as left ventricular dysmotility, ventricular thrombi, and mitral regurgitation. A limitation to the widespread use of echocardiography in resource-limited settings is the need for highly trained ultrasonographers.

The Role of Basic Imaging in the Diagnosis and Management of Malignancy

Lung carcinoma is by far the most common cause of cancer death worldwide and is also the leading cause of cancer mortality in males, while breast cancer is the most common cause of cancer death in females. The role of basic imaging in the diagnosis and management of lung and breast cancer will be discussed. The two conditions will be used to illustrate juxtaposed approaches to early disease detection in addressing the global burden of malignant disease [6].

Lung Cancer

Lung carcinoma is the leading contributor to the global cancer mortality rate, accounting for approximately 1.2 million deaths and 41 million DALYs in 2015. Smoking, chronic obstructive airways disease, occupational dust exposure, and a family history of lung cancer are among the strongest predisposing risk factors. The primary intervention required to decrease lung cancer worldwide is to decrease tobacco usage. Tobacco is the world's leading cause of preventable death. There are an estimated 1.25 billion smokers worldwide. Tobacco-related illness is estimated to have killed 100 million people in the twentieth century. If current trends continue, a billion people will die of smoking-related illness in the twenty-first century. As a result of new marketing strategies, the burden of tobacco use is increasing in LMICs [7].

Patients presenting with first-time hemoptysis, finger clubbing, dysphagia, or shoulder pain should have a CXR within days. Additionally, patients with known risk factors for lung cancer, who have new-onset cough or respiratory signs persisting for 3 weeks, or who develop loss of appetite, weight loss, or hoarseness should have an urgent CXR [95].

In practice, the CXR is pivotal to the diagnosis of lung cancer, since an abnormality on CXR usually provides the first evidence of disease. Patients with lung cancer frequently present with nonspecific respiratory symptoms for which a CXR is an appropriate initial investigation to narrow the differential diagnosis which includes respiratory tract infections, interstitial lung disease, exacerbation of chronic obstructive pulmonary disease (COPD), bronchiectasis, and heart failure. The CXR is also the first investigation recommended by the National Institute for Clinical Excellence (NICE) for the investigation of lung cancer symptomatology in patients [96]. The lack of specificity of CXR findings reported as suspicious of lung cancer means that it is usually necessary to perform more sophisticated diagnostic procedures before a definitive diagnosis can be made. The CXR acts as a preliminary screening test to identify a population requiring further investigation. Several large randomized controlled trials (RCTs) have demonstrated that screening for lung cancer using CXR does not reduce the number of deaths from lung cancer [97].

Breast Cancer

Globally, there were an estimated 570,000 deaths and 19.6 million DALYs attributed to breast cancer in 2015 [6]. However, in the past there have been promising developments in breast imaging, which have resulted in earlier detection of cancers and substantial improvements in its cure rate. Mammography, which utilizes plain X-rays for image production, is the only routinely used modality for breast cancer screening, although breast ultrasonography is now used as an adjunct in mammography screening programs. Numerous studies have shown the effectiveness of screening mammography in reducing breast cancer mortality in those well-resourced environments where breast screening programs have been implemented.

Screening mammography in women aged 40–69 years is associated with a reduction in breast cancer deaths across a range of study designs, and inferential evidence supports breast cancer screening for women 70 years and older who are in good health. Current recommendations are that women with an average risk of breast cancer should undergo annual screening mammography from 45 years to 54 years of age, followed by biennial examinations [98].

Over the past few decades there have been significant improvements in the technical quality and reporting of mammograms. Film-screen mammography (FSM) has long been considered the "gold standard" for screening [99]. Its particular strength is the ability to depict subtle microcalcifications that are typical for breast cancer. While FSM is a powerful tool for initial detection and subsequent follow-up of suspicious breast lesions, it has certain inherent limitations in detecting very subtle lesions, particularly in the presence of dense glandular tissue. Standard film-screen mammography (FSM) has advantages in terms of cost and availability over the newer full-field digital mammography [100]. Special computer algorithms have been developed to assist in the detection of suspicious findings such as spiculations and calcifications [101].

Ultrasonography is playing an increasingly important role in the clinical diagnosis of breast cancer. In recent years, there have been important technical advances in this modality. These include panoramic high-resolution extended-field images of the entire breast, tissue harmonic imaging with improvement in lesion to background contrast, as well as enhanced color Doppler and power Doppler technology, allowing more sensitive evaluation of blood flow within lesions. Tissue elasticity ultrasonography is another new development, which is based on the stiffness of tissue used to characterize disease. The quantitative assessment of tissue elasticity, known as sonoelastography (SE), allows for the comparison of the relative stiffness of lesions to surrounding tissue. Additional advances have been the increased use of ultrasound-guided interventional procedures such as needle aspirations, core-needle biopsies, and pre-excisional biopsy needle localizations of breast masses or calcifications [102, 103].

The Role of Basic Imaging in RTAs

Globally, road injuries accounted for 1.34 million deaths and 76 million DALYs in 2015, compared with 1.1 million deaths and 67 million DALYs in the year 2000. However, the increase in road injury mortality is substantially less than the increase in the number of registered vehicles, suggesting that interventions to improve global road safety have had some impact. While prevention is clearly the preferred intervention, basic radiological services play a pivotal role in the diagnosis and management of injuries, decreasing both mortality and long-term disability.

Plain X-rays allow for the identification and management of life-threatening conditions such as tension pneumothorax, unstable cervical spine fracture, and bowel perforation, while also alerting to the possibility of aortic rupture, bladder perforation, and intracranial hemorrhage. Plain X-rays also provide excellent baseline evaluation of a broad spectrum of non-life-threatening fractures, as well as with facilitating optimal management and follow-up of such fractures. Furthermore, plain X-rays allow for the accurate assessment of non-emergency thoracic injuries such as flail chest, hemothorax, and pulmonary contusion. Recent advances in plain-film polytrauma imaging include the low-dose whole-body digital X-ray unit which can complete an anteroposterior projection of the entire body in 13 s [104–106].

Point-of-care (POC) ultrasound, performed by a broad range of healthcare workers, is playing an increasingly important role in the assessment and triage of trauma victims. It can be used to assess for emergent pathologies such as pericardial effusion, free intraperitoneal air and/or fluid, hemothorax, and pneumothorax.

Global Radiology

In line with the precepts of the discipline of "global health," which engages in collaborative international research and action to promote and achieve good health and health equity for all, the fledgling subspecialty of "global radiology" has evolved in the radiological domain. "Global health" and "global radiology" have common core values and guiding principles, both sharing the visions of health for all and universal health coverage. While there has been extensive debate and a unifying discourse that has defined the collaborative role of "global health" as a disciple [1, 2], the "global radiology" fraternity is currently in the early stages of such dialogue [107]. As of today, global radiology is represented by an international community of separate individuals, groups, and organizations embracing outreach and advocacy programs to promote equity in access to radiological services globally. In the relatively short history of "global radiology," there have been extraordinarily inspiring outreach endeavors by a large number of institutions and organizations. These have facilitated services, training, and research collaboration in under-resourced environments and in many instances have demonstrated singular success. Notably, however, there has been no overarching coordination of such endeavors.

There would be great utility in broad collaboration and cohesion between the various role players in the domain of global radiology. An example of a potential collaborative project is data acquisition on global radiological practice. There is a striking paucity of published data on the already established basic radiological equipment resources worldwide. This applies to all countries, irrespective of World Bank income group, and is particularly true for ultrasound equipment. Accurate data on existing LMIC equipment resources are fundamental to defining deficits and planning redress. Similarly, we do not know the optimal quantity of basic radiological equipment needed in resource-limited settings. The figure of one plain X-ray machine and one ultrasound machine for every 50,000 people has been postulated, but it remains untested. The determinants of imaging utilization in such settings have not been studied and remain poorly understood.

Conclusion

Diagnostic imaging is seen as an essential building block in any healthcare system, and basic radiological services are considered essential for effective primary care. The main challenge confronting diagnostic imaging globally is inequality in access to services. Global access to basic imaging such as X-rays and ultrasound is thus integral to achieving universal health coverage and would make a substantial contribution to achieving the SDG health targets.

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Public Health and International Epidemiology for Radiology

15

Krit Pongpirul and Matthew P. Lungren

Introduction

The definition of public health as "the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities, and individuals" [1] has evolved since the discipline's formal debut in 1920 (Table 15.1). Many aspects of public health can be used for a better understanding of the relationship between radiology and public health (Fig. 15.1). While radiology as a part of clinical care focuses on individual patients, public health radiologists are concerned more about a group of patients or whole population. Moreover, they would pay more attention to applying diagnostic and therapeutic radiology technology in disease prevention rather than diagnosis and treatment of individual patients. Involvement of clinicians, specialists, and the rapid advance of technology have all played a significant role in how public health is practiced. As digital medical records and other electronic health information become increasingly prevalent in the twenty-first century, public health practitioners are continually seeking strategies to analyze these data in order to understand the characteristics of endemic disease and, disease outbreaks, and ultimately define new tools and strategies to intervene.

Truly at the forefront of digital health information, the specialty of radiology has been identified as a key player in the development of new public health strategies (Table 15.1). For example, in terms of informatics, the "backbone" of medical imaging and digital health information, Mollura and colleagues described a link between radiology and public health, ultimately concluding that in this context radiology can be considered an "information supplier" [10]. This notion was further expanded by Hillman, who advocated a paradigm shift in terms of the concept of radiology as an independent entity to one that builds a formal information network interconnected with a broad range of public health entities [11]. This capability would allow imaging studies and reports stored digitally to serve as readily accessible resources of population health data that can play "a critical role in surveillance, prevention, and diagnosis of disease" [12]. Effective networks and sophisti-

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Table 15.1 Public health definitions, mission and scope, functions, and relationship with radiology [1–9]

Aspects	Detail	References
Definition	The science and art of preventing disease, prolonging life, and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities, and individuals	[1]
	Organized community efforts aimed at the prevention of disease and promotion of health	[2]
	What we, as a society, do collectively to assure the conditions in which people can be healthy	
	Public health involves the application of many different disciplines including epidemiology, biostatistics, anthropology, medicine, sociology, and public policy, to name a few	[3]
	Public health is defined as health promotion by population-related measures. This is in contrast to the aims of medicine with its diagnostics and therapy which focus on the individual patient's health	[4]
	The approach to medicine that is concerned with the health of the community as a whole	[5]
	Science and art of preventing disease, prolonging life, and promoting health through organized community efforts	[6]
	An effort organized by society to protect, promote, and restore the people's health. It is the combination of sciences, skills, and beliefs that is directed to the maintenance and improvement of health through collective or social actions. The programs, services, and institutions of public health emphasize the prevention of disease and the health needs of the population as a whole. Additional goals include the reduction of the amount of disease, premature death, disability, and discomfort in the population	[7]
Mission and scope	Fulfilling society's interest in assuring conditions in which people can be healthy	[2]
	Public health is one of the essential institutions of society. It exists to promote, protect, preserve, and restore the good health of all the people, and it achieves these ends largely through collective action	[8]
	Public health emphasizes health promotion, the prevention, and early detection of disease, disability, and premature death. Many scientific disciplines, technologies, and practical skills are involved in public health, which can be viewed as a social institution, a collective discipline (one that focuses a large group of discrete disciplines on public health), and a practice	
	The programs, services, organizations, and institutions devoted to public health are concerned with the health needs of the entire populations. Professionals engaged in the field regard it as an organized effort directed at improving the health of populations by assuring the conditions in which people can be healthy. It thus differs from the healing arts such as medicine, dentistry, nursing, and pharmacy that aim their services at the health of individuals	
	It is concerned with threats to the overall health of a community based on population health analysis. The population in question can be as small as a handful of people or as large as all the inhabitants of several continents	[9]
	While public health is comprised of many professional disciplines such as medicine, dentistry, nursing, optometry, nutrition, social work, environmental sciences, health education, health services administration, and the behavioral sciences, its activities focus on entire populations rather than on individual patients. Doctors usually treat individual patients one-on-one for a specific disease or injury. Public health professionals monitor and diagnose the health concerns of the entire communities and promote healthy practices and behaviors to assure our populations stay healthy	[5]
Core functions	The assessment and monitoring of the health of communities and populations at risk to identify health problems and priorities	[5]
	The formulation of public policies designed to solve identified local and national health problems and priorities	
	To assure that all populations have access to appropriate and cost-effective care, including health promotion and disease prevention services, and evaluation of the effectiveness of that care	

Table 15.1 (continued)

Aspects	Detail	References
Common relationship with radiology	The component parts of public health include a wide array of intellectual disciplines, professions, trades, and practical skills: vital statistics, demography, epidemiology, and biostatistics; basic medical sciences such as microbiology, physiology, pharmacology, and toxicology; physical sciences such as physics and chemistry; engineering; social and behavioral sciences; and clinical sciences such as those that deal with communicable diseases, cancer, and heart disease. Mature professions such as medicine, nursing, dentistry, and law, as well as newly emerged professions such as psychology, nutrition, and dietetics are all engaged in public health	[8]
	Public health involves the application of many different disciplines including epidemiology, biostatistics, anthropology, medicine, sociology, and public policy, to name a few	[3]

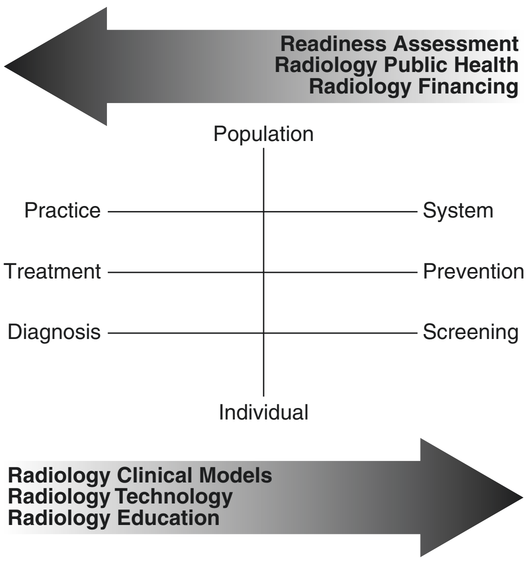

Fig. 15.1 A simplified schema of the relationship between radiology and public health

cated population-based surveillance can be based on this information, and will ultimately play an integral role in how public health is practiced.

Public Health Radiology: Role of Radiology in Public Health Programs

Public health programs already in place use medical imaging as an integral component; the Stop TB Partnership [13] and the surveillance of H1N1 influenza pandemic [14] are two such examples. In these and other programs, public health radiology is concerned with applying diagnostic and therapeutic radiology technology as a driver of disease surveillance and prevention at the population level rather than diagnosis and treatment of individual patients. While clinical radiologists' interests are the diagnosis and treatment of disease, public health radiology imaging efforts focus on population-level diseases that are largely related to screening.

The recent decade noted the emerging trend of machine learning (ML) or artificial intelligence (AI), that have incrementally been useful for analyzing complex data sets to find patterns and relationships without being explicitly programmed [15]. Three primary factors—availability of Big Data, high computer processing power, and advanced algorithms and optimization techniques [16]—contribute to the recent success of ML in other fields; public health and radiology are no exceptions. As machines could supplement and automate several functions radiologists currently perform [17], the changing roles of radiology in public health is inevitable.

Radiology images in digital imaging and communications in medicine (DICOM) format are rich in metadata and therefore become a great opportunity to uncover complex associations for public health applications [18]. These data, along with the electronic medical records and administrative claims database, are useful for constructing a predictive and/or prognostic model that uses thousands of variables [19]. While evolution in the radiologists' role might be anticipated because of automation [19], the field should be optimistic about emerging opportunities the machines will bring to the field of radiology [20]. ML can also help reduce radiation dose in computed tomography (CT) and scan time in magnetic resonance imaging (MRI) with relatively less compromised image quality than ever before [21].

Mammography for Breast Cancer Screening

Breast cancer was diagnosed in almost 1.4 million women in 2008, and approximately 460,000 deaths were recorded [22, 23]. Although high-income countries found higher incidence than low- and middle-income countries, 5-year relative survival estimates were much more (12% in Africa to 90% in the United States, Australia, and Canada) [23]. One potential explanation of this inequity is the different performances of health-care systems in terms of preventive measures.

Early detection by mammography screening was shown to reduce risk of breast cancer death [24]; mortality in the screened group was 35% lower than in the unscreened group [25]. Improvements in survival in parts of the world with higher resources have been attributed to the introduction of population-based screening using mammography [23], the systematic use of adjuvant therapies [23], and multidisciplinary medical care [26]. Based on the data from population-based mammography screening in Australia, Protani et al. were able to identify modifiable lifestyle factors associated with breast cancer, which is very useful for further development of public health interventions [27].

Nonetheless, like other tests, mammography screening does have some negative side effects such as false-positive results, which can lead to anxiety and discomfort [28]. Zahl and Maehien analyzed 14-year Norwegian data and reported that mammography screening resulted in “overdiagnosis” and “overtreatment” [29]. Patients, empowered by the ease of access to health information through health society websites, journal articles, and social media, have raised concerns about screening mammography guidelines and mammographic efficacy [30].

Information technology has helped reduce the time required for accessing prior mammographic images and therefore the report turnaround times in mammography, for instance [31].

Chest X-Ray for Tuberculosis Screening

Tuberculosis (TB) is the leading cause of death worldwide, only second to HIV/acquired immune-deficiency syndrome (AIDS) [32]. This disease is prevalent in the developing world; approximately 9.27 million people developed TB (139/100,000 population) and 1.77 million died in 2007 [33]. Among the incident cases, 14.8% were HIV positive. Approximately 10% of all new TB cases in adults were estimated to be attributable to HIV infection, and TB was the cause of about 10% of all adult AIDS deaths [34]. Not only does HIV increase the risk of rapid TB progression, but it can also reactivate latent *Mycobacterium tuberculosis* infection [35, 36].

Targets for reductions in global TB burden have been set within the context of the Millennium Development Goals (MDGs) and by the Stop TB Partnership that the incidence should be falling by 2015, that prevalence and mortality should be halved by 2015 relative to 1990 levels, and that TB should be eliminated (less than 1 case per million population per year) by 2050. Unfortunately, as surveillance systems in most countries are not comprehensive enough, infected patients either go undiagnosed (i.e., lack of healthcare access) or get treated but not notified (i.e., care by private practitioner).

Chest X-ray (CXR) has been an important tool for the diagnosis, prediction, and management of tuberculosis (TB) [13]. For instance, the presence of a cavity on a CXR taken during the first 2 months of treatment is associated with threefold higher risk of TB relapse [37], and the patients with cavity and positive sputum therefore require longer therapy [38]. However, limitations on the wider use of CXR, such as non-availability at health facilities in the prevalent areas and the difficulty of interpreting results, have been of great concern [39]. While better diagnostics for TB is not available as of yet [40], traditional tools like CXR are still essential.

Active case finding by using mass miniature radiography (MMR) has been anticipated to detect approximately 90% of prevalent tuberculosis cases [41, 42] and was suggested as a cost-effective strategy in low- and middle-income countries with high prevalence [32]. With this approach, the entire population would be screened every 7 years by using MMR, followed by sputum examination for those with suspicious lesions. Murray and Salomon suggested that active case finding, along with the WHO DOTS strategy, could reduce TB mortality by as much as one-quarter to one-third over several decades [43].

Nonetheless, specificity of the CXR has been questioned, especially among patients with AIDS, who may present with various respiratory illnesses. In the past, experts missed approximately one-quarter of tuberculosis cases in a series of films [44]. However, the reliability of radiographic interpretation has greatly improved [37], especially with digital advancement. While analogue CXR uses high X-ray dose, tends to produce poor-quality images, requires experienced staff to interpret, needs labor-intensive image archival, and causes environmental damage from chemical waste, digital technology has the potential to solve most of these problems at lower costs, higher speed, and better positive predictive value [45].

The Computer-Aided Detection of Tuberculosis (CAD4TB) project is one of the most promising developments of feasible digital technology to improve CXR interpretation in resource-limited settings [46, 47]. However, its diagnostic accuracy is supported by only a small number of studies that still have methodological limitations. A more recent development is the Deep Convolutional Neural Network for Automated Classification of Pulmonary Tuberculosis-Associated Radiograph (DAC4TB). In addition to the radiologist interpretation of CXR; clinical signs and symptoms, sputum AFB, sputum culture, and GeneXpert data are also integrated. Also, DAC4TB follows the WHO's recommendations on the systematic screening for active tuberculosis. This is a very good example of how concerns about varying reliability of interpretation of TB CXRs can result in the development of radiological technology that is not only innovative but also very useful for mass population screening for TB [46].

CT Colonography for Colorectal Cancer Screening

With more than 1.2 million new cases and 600,000 deaths, colorectal cancer is the second and third most commonly diagnosed cancer in females and males, respectively [22]. The significant higher incidence and mortality in developed countries than in the developing ones have suggested the importance of dietary and environmental exposures [48, 49].

Endoscopic screening with flexible sigmoidoscopy or colonoscopy has been widely regarded as the standard for detection of colorectal tumors [50]. Although it offers some advantages including instant removal of adenomatous polyps—the precursor lesions of colorectal cancer—it does not comply with many of the criteria for a screening test as it is not simple, it is expensive, and it requires highly trained clinicians for its application [51]. In addition, a number of disadvantages such as the need for full bowel cleansing, aggressive nature of the procedure, and possible complications such as bleeding and perforation do exist.

Computed tomography (CT) colonography was introduced partly to overcome some of those limitations [52]. With insufficient evidence to assess the benefits and harms, CT colonography has not been recommended in the United States [50]. However, more supporting evidence has been released, and its use for mass population screening is promising. For instance, Johnson et al. acquired CT colonographic images of 2600 asymptomatic adults and reported 90% sensitivity for detecting a 10-mm lesion [53]. A population-based screening study in the Netherlands reported that both CT colonography and colonoscopy can be used, but participation in CT colonography is better [54]. CT colonography can also be used for evaluation of the colon after an incomplete conventional colonography [55]. This is a very good example of how a feasibility concern from the public health perspective plays relatively more of a role than the technical aspect of a medical intervention.

Chest X-Ray for Lung Cancer Screening

Lung cancer is one of the most commonly diagnosed cancers as well as the leading cause of cancer death in 2008 globally—13% of the total cases and 18% of the deaths [22]. Case fatality rate is as high as 90% [56].

In 1987, the Japanese government introduced lung cancer screening using CXR and sputum cytology [57]. The matched case-control studies suggested that mass CXR screening for lung cancers contributed to a significant mortality reduction of about 40% [58]; however, potential bias from self-selection of the studies limited the generalizability of the findings. In 1997, a population-based cohort of almost 6000 heavy- or long-term smokers was invited to an annual CXR screening program and was followed for 13.5 years. The study found that screening participants who were diagnosed with lung cancer had more early-stage resectable disease and longer survival [59]. Recently, the effect of screening for lung cancer with CXR has been evaluated in the Prostate, Lung, Colorectal, and Ovarian (PLCO) Cancer Screening Trial, and the investigators found that annual screening with CXR does not reduce lung cancer mortality compared to usual care without screening [60]. Unfortunately, evidence on the risk and benefit of using low-dose CT, CXR, sputum cytology, or a combination of these tests for mass lung cancer screening has still been considered insufficient [61].

Recent data suggest that screening for lung cancer using low-dose computed tomography (CT) scans rather than CXRs may be a more effective way of detecting the disease. While still under investigation, researchers hope that these results, collected as part of the National Lung Screening Trial, will provide more detailed information about the benefits of various types of lung cancer screening available to patients and physicians. In the early results reported in 2012 and 2013, 26,309 participants received low-dose CT scans, and 26,035 participants underwent chest radiography to detect for signs of lung cancer. Among those who received CT scans, a total of 7191 participants (27.3%) had a positive screening result, compared to 2387 (9.2%) in the CXR group. Overall, lung cancer was diagnosed in 292 participants (1.1%) in the CT group compared with 190 (0.7%) in the radiography group. The prospect of screening CT remains controversial, mainly due to concerns regarding the high level of false-positive screenings that occur during CT scans, which would lead to undue stress, unnecessary additional testing, and high medical costs.

Radiation Safety

Radiation safety seems to be the best example to show how radiology can affect the health of the public. Despite its importance, data on radiation safety has been relatively limited and usually focuses on healthcare workers [62–68] and patients [69–71] who have been at greater risk of radiation exposure.

The concerns about radiation exposure from consumer electronics have been replaced by concerns about ionizing radiation from medical imaging procedures. There has been a significant increase in exposure to ionizing radiation from 15% in the early 1980s to 48% in 2006 according to the US National Council on Radiation Protection and Measurements [72]. Marwick et al. comparatively explored the life cycle of echocardiography, magnetic resonance imaging (MRI), and SPECT and revealed that echocardiography causes the least environmental impact [73]. They also estimated that the energy of a 3-T MRI scanner in 1 day equates to that of an average US household over the course of a month. The American College of Radiology (ACR) asserted that additional exposure of radiation from medical sources actually reflects improved health care; that the risks are often outweighed by diagnostic and therapeutic benefits, and that concerns about overutilization should be considered.

Education and training in radiation safety may not be keeping pace with the growth and availability of medical imaging technology globally, creating the potential for a "radiation safety gap" [74]. Evidence on radiation safety from medical imaging procedures is essential for the development of balanced solutions that benefit population health. While the lack of evidence is even worse in low- and middle-income countries, the World Health Organization (WHO) has proposed a basic operational framework and some useful guidelines on radiology policy, quality, and safety [12]. Fortunately, technological advances and changes in practice have helped to reduce the risk of radiation exposure [75, 76].

Conclusion

Radiology technology is an important component of public health programs, especially in disease surveillance and screening, whereas potential risk should also be considered.

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16 Infectious Disease Imaging

Ishita Desai and Kara-Lee Pool

Introduction

The topic of infectious disease imaging in low- and middle-income countries (LMICs) is vast, and this chapter is not intended to serve as a comprehensive reference. For that, we kindly direct the reader to the remarkable text on the topic entitled *The Imaging of Tropical Diseases*, authored by the distinguished Drs. Palmer and Reeder; their comprehensive work is truly a masterpiece on the subject of infectious disease imaging in LMIC settings and includes clinical cases in multiple modalities and exhaustive reviews on pathophysiology and medical management, all of which are based on meticulous epidemiology and pathophysiology discussions [1]. In contrast, what follows in this chapter is an introductory review of the available imaging modalities followed by the imaging presentations of common endemic infectious disease processes organized by disease processes in order to highlight the continued importance imaging plays in the diagnosis and treatment of infectious diseases in an ever-evolving world.

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Background

Infectious diseases continue to remain a major cause of morbidity and mortality in the world [2]. The use of diagnostic imaging has increased dramatically over the past several decades, with a particularly sharp rise in advanced cross-sectional imaging systems such as computed tomography (CT), magnetic resonance imaging (MRI), and molecular imaging such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) which are expected to continue to grow [3]. However, there are significant disparities in the availability of imaging services across the globe, as discussed elsewhere in this text, and most advanced imaging is generally available only to the higher economic strata in LMICs [4]. For example, as a result of strengthening emerging economies, imaging services are growing rapidly in Brazil, Russia, India, and China (also known as BRIC countries) [5–8]. The availability and relative cost of the various imaging modalities are shown in Fig. 16.1.

Imaging Modalities

There are a great number of options available to the modern, fully equipped hospital for the diagnosis and elucidation of a large number of diseases. These options range from those that are

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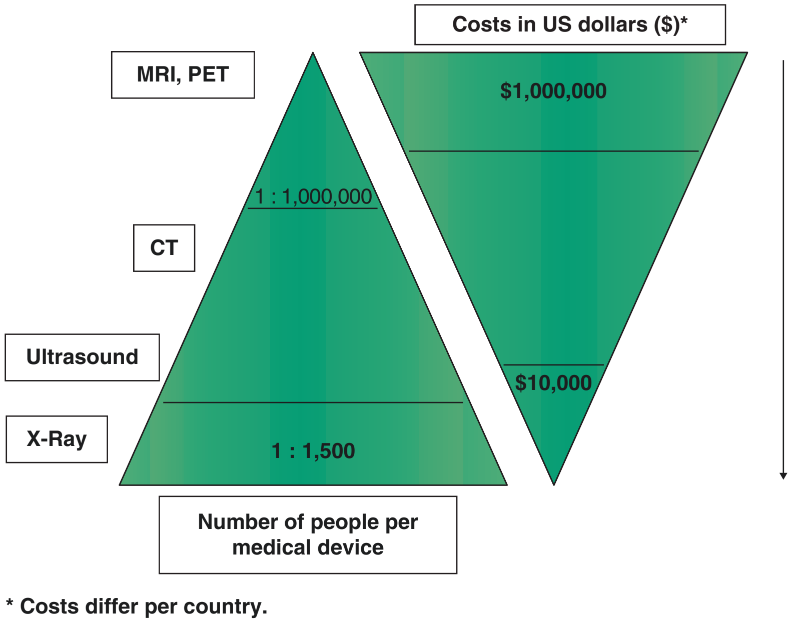

Fig. 16.1 Graphical representation illustrating the availability of the imaging modality (number of people per device) versus the cost of purchasing the imaging scanner (in US dollars) [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

highly complicated and time-intensive, such as MRI, to those that are simple but effective, such as ultrasound or radiography. Though this chapter is by no means an exhaustive atlas of the various uses and misuses of these imaging modalities, a small description of them is provided in order to better understand their role in global health.

MRI, the newest and perhaps least readily accessible of these modalities, was utilized in vivo in the first human in 1977 [10]. Since then, it has rapidly developed into one of the most widespread medical imaging techniques [11]. Because MRI uses a controlled magnetic field, some of the primary advantages are the lack of ionizing radiation, high spatial resolution, and excellent soft-tissue contrast. One of the main downsides to the use of MRI is the cost. Capital equipment, maintenance, and infrastructure costs alone exceed millions of dollars (US), while the technical skillset and high level of training needed to successfully acquire and interpret the images remain exceedingly difficult to obtain in low-resource countries. Though not as widely available in LMICs as other imaging technologies, emerging markets such as China are rapidly increasing the number of MRI scanners available to the local population (300–400 units per year) [12]. This is because of the increasing importance of MRI in many prior elusive diagnoses. MRI has become an exceedingly important diagnostic modality for the evaluation of the central nervous and musculoskeletal systems due to its great sensitivity [13].

CT imaging, on the other hand, has been around for decades and is more widely available. It is extensively utilized for evaluating disease processes in nearly every part of the body. Compared to standard radiography techniques, CT imaging provides three-dimensional images with excellent spatial resolution. It is relatively rapid, making it invaluable, especially in emergent or life-threatening situations [14]. However, as discussed elsewhere in this text, CT scanning, though relatively inexpensive when compared to other major advanced imaging modalities such as MRI, remains an infrastructure-intensive modality that continues to be out of reach for a majority of the world's population.

Despite the advent of advanced imaging modalities, it should be noted that plain film radiography and ultrasound continue to be mainstays in the field of imaging in low-resource areas. Radiography especially remains an important diagnostic tool for assessing pulmonary infections, but it should be noted that radiography has a limited scope in the evaluation of intraabdominal infections. Although radiographs are quite adept at picking up many of the secondary signs of infection, including bowel obstruction, ileus, pneumatosis (air in the bowel wall), or free intraperitoneal air, they have difficulty in assessing for actual signs of inflammation [15]. Many of these secondary signs would indicate that the disease has already progressed. The usefulness of radiography is increased somewhat by the ability to administer oral contrast agents (such as barium sulfate) for improved evaluation of the gastrointestinal tract. There are, of course, cost- and availability-related drawbacks to this type of examination. For this reason, ultrasound remains an incredibly powerful diagnostic modality in and out of low-resource areas, most notably in the diagnosis and management of abdominal and pelvic infections [15], in addition to soft-tissue and thoracic infections [16, 17].

Outside low-resource areas, point-of-care ultrasound has helped expedite diagnosis and treatment. In low-resource areas, however, it is often the only available diagnostic modality [18, 19]. Several studies have demonstrated the use of ultrasound as an irreplaceable tool, affecting diagnosis and altering clinical management [20–22] in not only infectious disease but also obstetrics and cardiology.

Incredibly, there are well-defined ultrasound presentations of a multitude of tropical infections, which can help narrow down differential considerations and lead to quicker treatment. These include but are not limited to paragonimiasis, clonorchiasis, and schistosomiasis [23]. The list is growing and presents an excellent argument for the increased use and study of ultrasound in global health.

On another end, we will not extensively discuss molecular imaging, PET, and SPECT, in this chapter due primarily to its limited availability in low-resource areas and relatively limited use because of the cost, need for trained personnel, and lack of networks for synthesizing, handling, and delivering the radioactive radiotracers. These imaging modalities are currently better developed for cancer and neurology [24, 25]. There are uses for SPECT imaging to identify the site of infection, diagnose types of infection, or locate a source of infection [26, 27]. In addition, there is active research on the utility of PET/CT in the evaluation of subclinical, active pulmonary tuberculosis in HIV-1-infected adults [28]. Though these current techniques are useful in anatomically localizing the infectious lesions, they are limited by being nonspecific; these techniques cannot fully differentiate true infections from sterile inflammation or cancer.

Pneumonia

Worldwide, pneumonia is a leading cause of death and hospitalization, particularly among children and the elderly [29]. The diagnosis of pneumonia remains one of the most common applications of radiographic imaging. A simple chest radiograph can aid in the identification of the involved pathogen, guiding treatment and identifying complications and/or treatment response. Further evaluation with CT is useful, but not necessary for the diagnosis of pneumonia, particularly if resources are limited.

For example, lobar consolidation, cavitation, and effusions suggest bacterial etiology (Fig. 16.2). Of note, however, in the proper clinical setting, these findings may also indicate polymicrobial (i.e., multiple pathogens at once), fungal, or mycobacterial etiologies [30]. Diffuse bilateral involvement can be an indication of an atypical infection, such as *Mycoplasma*, *Pneumocystis jirovecii*, *Legionella*, or a primary viral illness [30]. A chest radiographic appearance more severe than suggested by the clinical examination has been described in both viral and mycoplasma pneumonias [30]. As evident, specific pathogenic diagnosis is often not possible with radiography alone, but the role of imaging in pneumonia is not to provide a specific diagnosis but rather help: (1) localize the site of infection at diagnosis, (2) monitor progression versus regression, (3) estimate severity, and (4) diagnose complications such as pneumothorax, pleural effusions, empyemas, abscesses, and atelectasis. For this reason, radiography is a vital tool for managing lung infections even when the specific pathogen is not identified, particularly since

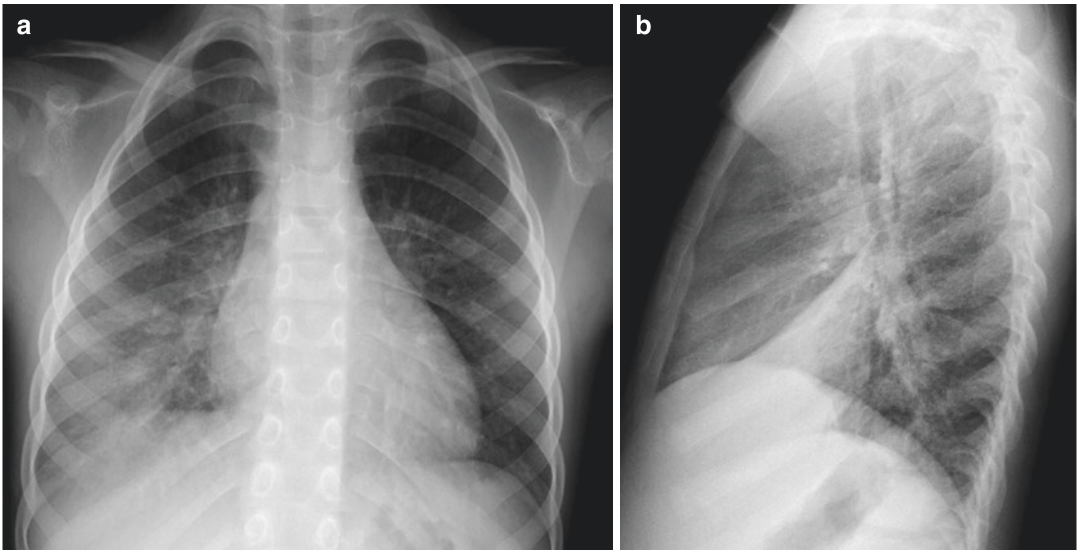

Fig. 16.2 Frontal (**a**) and lateral (**b**) chest radiograph demonstrating right lower lobe pneumonia in a 6-year-old male presenting with cough and fever

many antibiotic therapies can cover a wide range of the possible pathogens.

Empyema is the term used to describe an infected fluid collection in the pleural space. This can occur primarily but most commonly is attributable to a complication of pneumonia, previous surgery, or trauma [31]. The chest radiograph will classically demonstrate a large, lentiform (lens-shaped) pleural opacification [32] (Fig. 16.3). Pulmonary abscess, in contrast to an empyema, is an infected collection in the lung parenchyma and is often a complication of suppurative pneumonia that destroys lung parenchyma. The result is a pus-filled cavity, often demonstrating an air-fluid level on chest radiographs (Fig. 16.4) [33]. In contrast to empyemas and abscesses, necrotizing pneumonia describes the necrosis of infected pulmonary parenchyma with or without cavitation [34].

Symmetric perihilar ground-glass opacities, often termed "bat wing opacities," are frequently seen in the early stages of *Pneumocystis jirovecii* pneumonia (PCP), most often seen in HIV-infected patients [35]. In more advanced stages, PCP presents with diffuse ground-glass opacities and alveolar consolidation [35, 36]. Other less common patterns have been reported, including lobar infiltrates, pulmonary nodules, pneumatoceles, and other cystic changes [36]. These diverse features of PCP are important to recognize in imaging because this is a common opportunistic infection in HIV-infected patients and the treatment is different and longer term than the therapies for other lung infections.

Tuberculosis

Of all the infectious diseases, *Mycobacterium tuberculosis* deserves special mention due to the widespread nature of the infection, communicability, increasing resistance to treatment, and its long-term morbidity/mortality. According to the World Health Organization, new tuberculosis infections occur in about 1% of the population each year [37]. According to the 2016 WHO report on tuberculosis (TB), there were an estimated 10.4 million new cases (incident) of active TB and 1.4 million deaths, mostly occurring in LMICs [37]. There has been an effort to decelerate this incidence rate, but success in TB control also depends on the number of these cases that result in death. In Africa, for example, the case fatality ratio continues to range from 5% to 20%. In this case, imaging is invaluable to prevent progression and reduce the number of TB-related deaths [37].

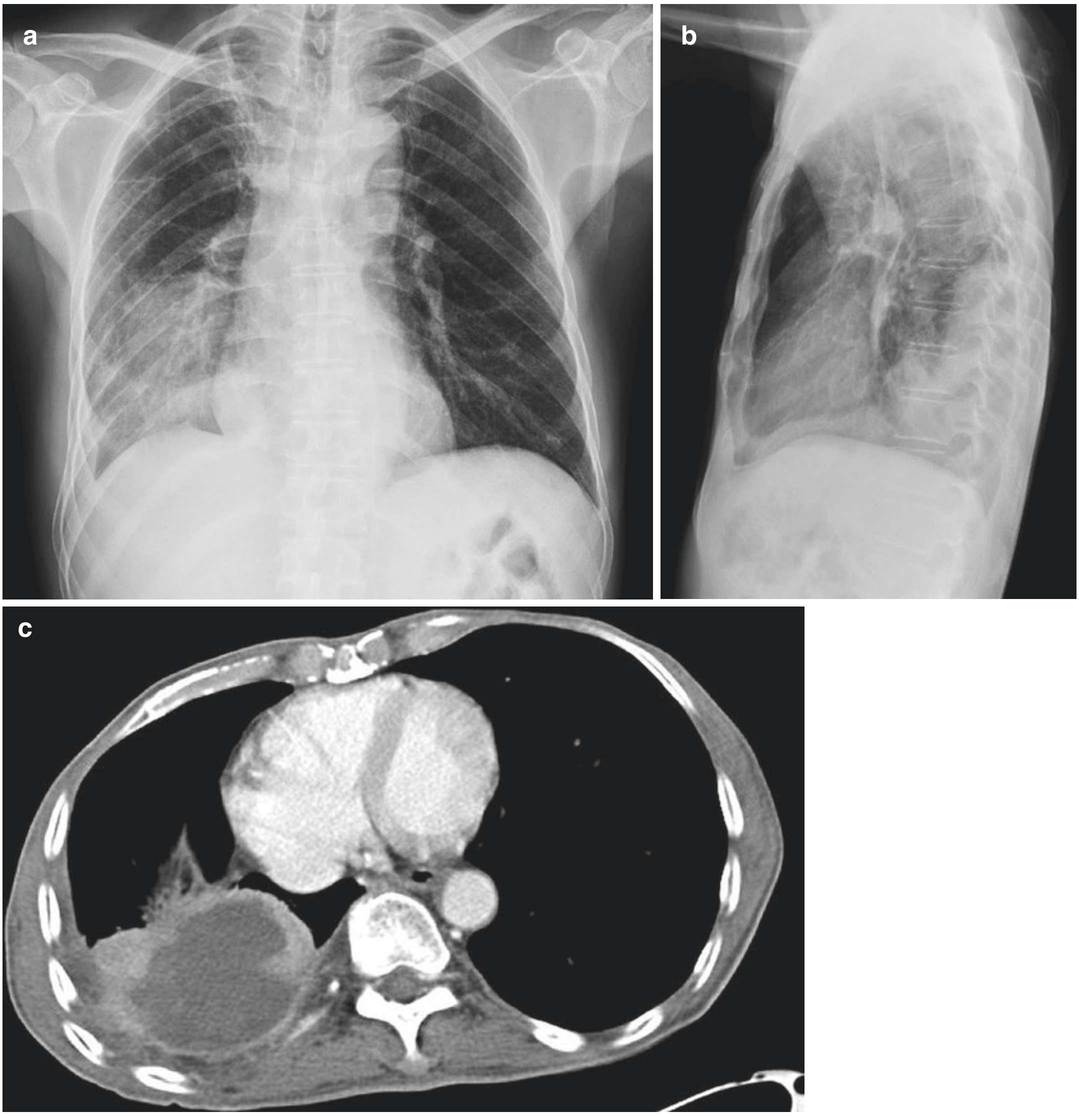

Fig. 16.3 Frontal (**a**) and lateral (**b**) chest radiographs and axial chest CT (**c**) of a 57-year-old male with a history of disseminated TB found to have an empyema, demonstrated by the lens-shaped opacity at the right lung base on the frontal radiograph, confirmed by CT

An important consideration in addressing TB prevalence and incidence is disease communicability. TB is transmitted through air by breathing in airborne particles that are generated when an infected individual coughs, sneezes, shouts, or even sings. The probability of transmission is dependent on several factors, including the concentration of infectious particles, air circulation, frequency of exposure, and physical proximity among a number of other considerations [38].

Diagnosis of active TB relies on imaging, as well as microbiological culture of body fluids, susceptibility testing, and/or nucleic acid amplification tests like GeneXpert MTB/RIF, while the diagnosis of *latent* TB relies on the tuberculin skin test (TST) and/or blood tests. Unfortunately, the acid-fast bacilli are found in the sputum in a limited number of patients with active pulmonary TB. Newer tests like GeneXpert are more rapid than mycobacterial culture and identify both the

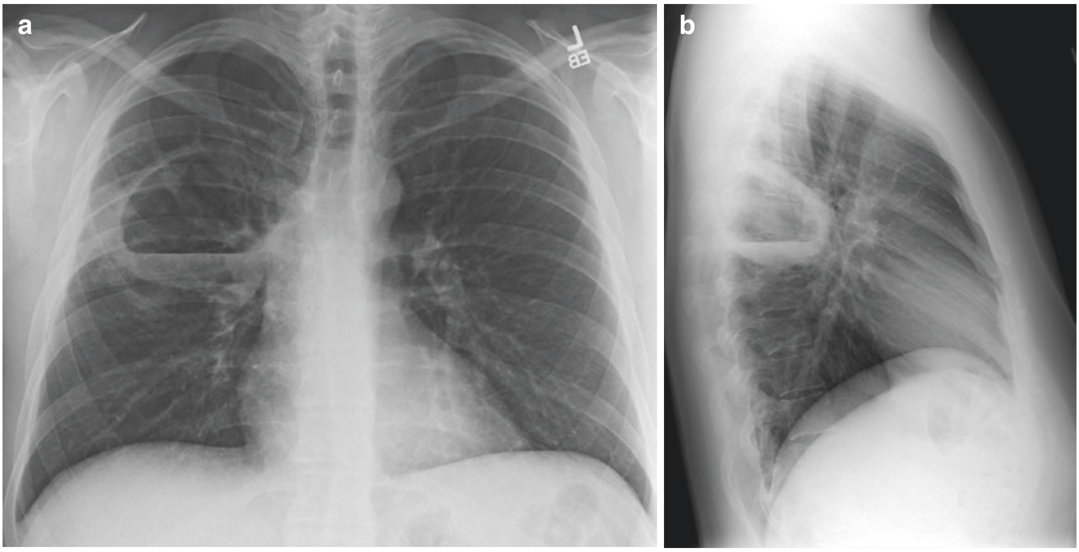

Fig. 16.4 Frontal (**a**) and lateral (**b**) chest radiographs of a 28-year-old male with a 1-month history of cough found to have a pulmonary abscess, demonstrated by a localized, walled cavity, with an air-fluid level in the right lower lobe

presence of *M. tuberculosis* and resistance to rifampin in a single test [39]. Imaging, however, still plays an important role in triaging patients, in aiding diagnosis when bacteriology cannot be confirmed, and in determining the extent of disease or complications of pulmonary TB [40].

There is also a growing role for ultrasound in the diagnosis of extrapulmonary TB. There are numerous studies that examine and enumerate the ultrasound presentation of extrapulmonary TB in the setting of HIV. The protocol for this rapid diagnosis is better known as FASH, or the focused assessment with sonography for HIV-associated TB, and has been used and tested repeatedly in resource-poor settings where CT and the described diagnostic lab tests are not easily available [20, 21, 41]. Oftentimes, the imaging provides rapid diagnosis for appropriate therapy before the definitive diagnosis by bacteriology. It is thought that more than 50% of infected patients remain undiagnosed, and lack of access to medical care, particularly medical imaging such as chest radiography, presents a significant barrier to diagnosis and disease monitoring [42]. Treatment is difficult and requires administration of multiple antibiotics, many of which are expensive, over a long period of time (i.e., greater than 6 months). Unsurprisingly, antibiotic resistance is a growing problem in multi-drug resistant TB (MDR-TB) infections.

TB can have a wide variety of radiographic appearances and thus has been termed “the great imitator.” There are three classic appearances of pulmonary TB on chest radiographs: primary, reactivation (also called secondary or post-primary infection), and miliary.

A first exposure to *M. tuberculosis* leads to primary TB, which has a nonspecific imaging appearance. It can be manifested by a homogenous consolidation, lymphadenopathy, or even a pleural effusion. Often, these findings will resolve, but in some cases a residual Ghon focus, or a calcified caseating granuloma, can be noted on radiography [43, 44]. Primary TB in children, for example, most often presents with lymph node enlargement, often unilateral hilar nodes, seen in 90–95% of cases [45, 46]. In contrast, the most common radiographic manifestation of reactivation pulmonary TB is focal or patchy heterogeneous consolidation involving the apical and posterior segments of the upper lobes and the superior segments of the lower lobes. Another common finding is the presence of poorly defined nodules and linear opacities, which are seen in approximately 25% of patients [45]. Cavities, the radiologic hallmark of reactivation TB, are

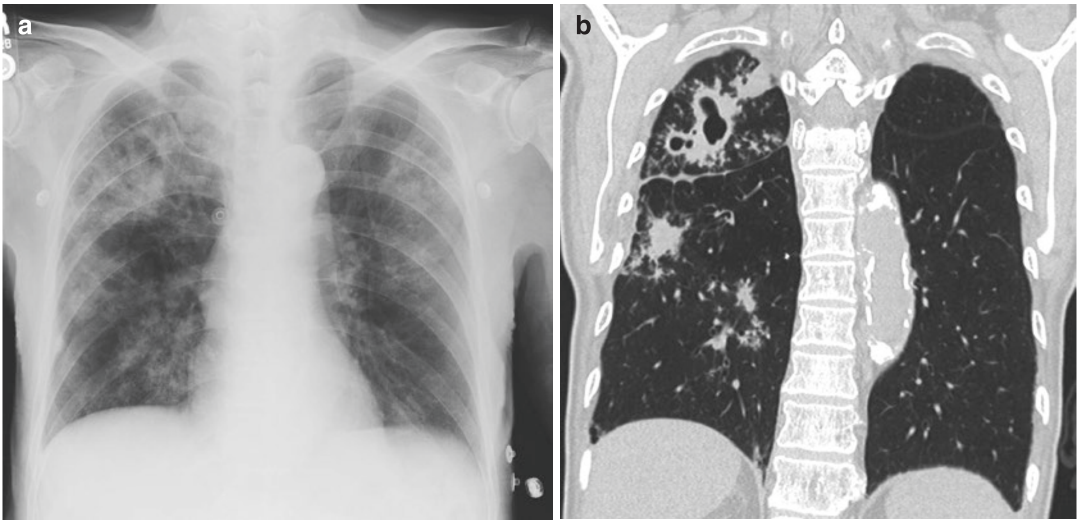

Fig. 16.5 Frontal radiograph (**a**) and coronal CT chest (**b**) in a 79-year-old male with right upper lobe thick-walled cavitary structures found to have reactivation TB

evident radiographically in 20–45% of patients (Fig. 16.5) [42]. Finally, in cases of miliary TB, the chest radiograph may demonstrate characteristic innumerable 1–3 mm diameter nodules randomly distributed throughout both lungs; thickening of interlobular septa is also frequently present [1, 45] (Fig. 16.6).

As TB can notably present with a normal chest radiograph, CT is an important modality for early diagnosis and in guiding management. Both in later stages of TB or during treatment, CT imaging can reveal early cavitation, pleural and pericardial effusions, lymphadenopathy, and other findings, which may not be suspected on chest radiographs [47].

TB is an infection that is not only confined to the lungs but has a tendency to proliferate throughout the body. In the heart, TB is known to cause pericardial effusions (Fig. 16.7) and pericarditis. Pericardial effusions can be diagnosed by echocardiography or by point-of-care ultrasound [48].

TB can also affect any organ or tissue in the abdomen and can be mistaken for other inflammatory or neoplastic conditions [49]. The most common sites of abdominal TB are lymph nodes; typical findings include lymphadenopathy with central low attenuation due to the presence of perinodal granulation tissue and central caseous necrosis [49]. Peri-portal and para-aortic lymphadenopathy are easily identified on ultrasound using the previously described FASH technique for the diagnosis of extrapulmonary TB in the setting of HIV (Fig. 16.8). Other sites that are affected include the genitourinary tract, peritoneal cavity, and gastrointestinal tract. In an HIV patient, the liver, spleen, biliary tract, pancreas, and adrenals are also commonly involved [49].

Central nervous system (CNS) TB is thought to occur in 2–5% of those infected with TB [43, 50] and can occur due to local or hematogenous spread. Infection can lead to varying manifestations, of which tuberculous meningitis and an intracranial tuberculous granuloma are the most common. Tuberculous meningitis most often presents with thick leptomeningeal enhancement at the base of the brain, which can result in obstructive hydrocephalus [43]. Tuberculous granulomas present as ring-enhancing lesions with surrounding edema, again more likely at the base of the brain, with or without associated meningeal enhancement [51]. These findings can be noted on contrast-enhanced CT or MRI (Fig. 16.9).

Tuberculous spondylitis, or Pott disease, is a common manifestation of TB in the spine, infecting the vertebral body and intervertebral disc.

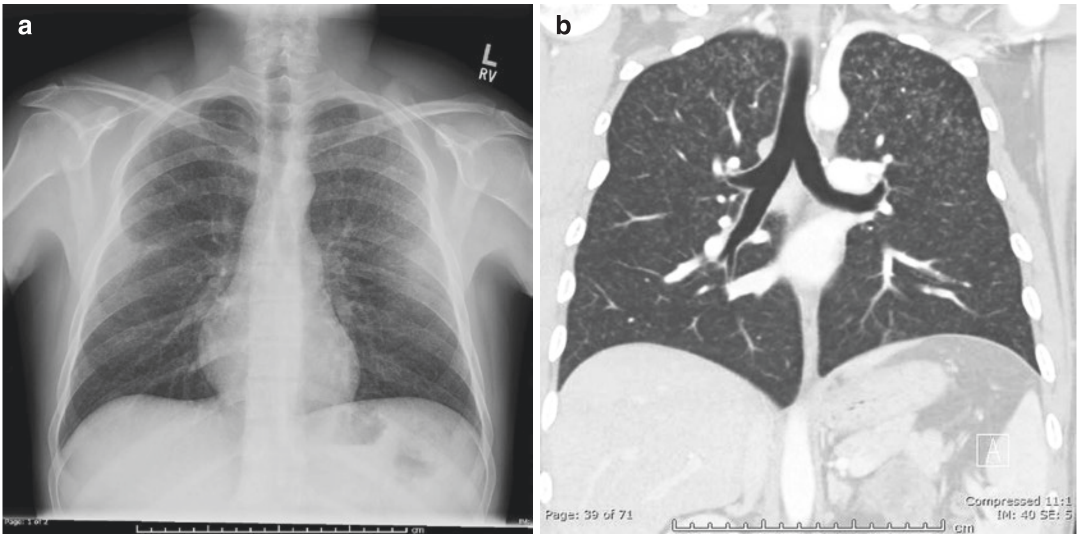

Fig. 16.6 Frontal radiograph (**a**) and coronal CT chest (**b**) demonstrating diffuse bilateral reticulonodular opacities in a 28-year-old male patient with miliary pattern of disseminated TB infection. (Images courtesy of Shaden Mohammad, MD)

Fig. 16.7 FASH protocol subxiphoid image of the heart demonstrates pericardial effusion in a 36-year-old male due to TB

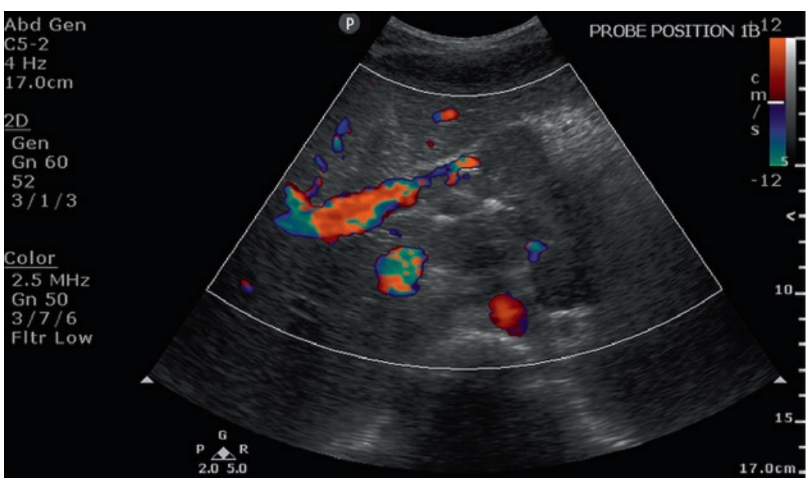

Fig. 16.8 FASH protocol transverse image of the upper mid-abdomen in a 28-year-old male demonstrates matted hypoechoic para-aortic and peri-portal lymphadenopathy due to extrapulmonary TB

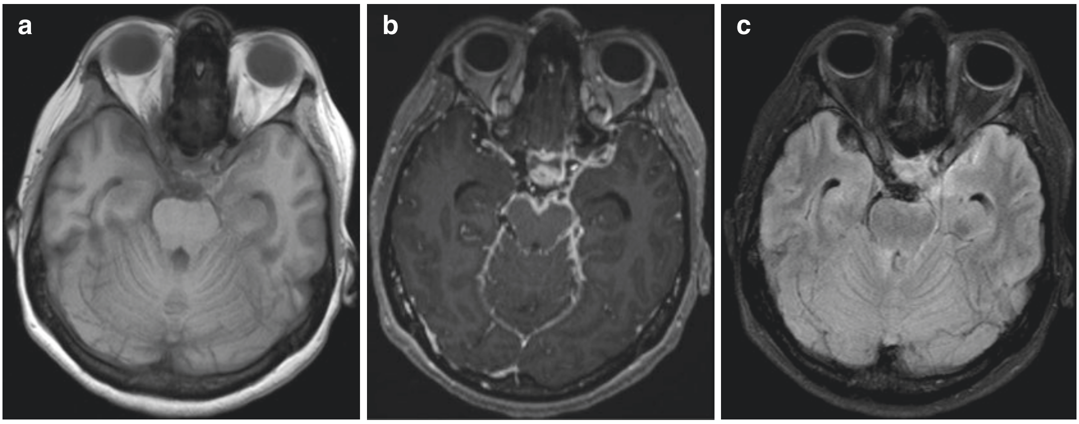

Fig. 16.9 Axial pre- (**a**) and post-contrast (**b**) T1-weighted and FLAIR (**c**) images through the base of the brain demonstrate thick, basilar meningeal enhancement in a 34-year-old female with AIDS, found to have TB meningitis

In the early stages and to assess the extent of involvement, MRI is the preferred modality. In later stages, reduction in vertebral body height, sclerotic vertebral bodies, or even compression deformities can be seen [43].

Tuberculosis: Differential Considerations

As in other endemic infections, the genitourinary (GU) tract is commonly involved in TB. Differentiation from other causes of calcification seen in the GU tract, such as in schistosomiasis, is often possible only in the later stages of the disease(s). For example, in schistosomiasis, calcification is first seen in the lower end of the ureters and the bladder and then extends *up* the ureters. In TB, the calcification extends *down* the ureters and the bladder, affecting the kidney much more often (Fig. 16.10) [52].

Another endemic parasitic infection commonly diagnosed on chest radiographs is paragonimiasis. The disease is most prevalent in populations of Asia (Korea, Japan, Taiwan, central and southern China, and the Philippines) as well as Mexico and South America (Brazil, Costa Rica, Honduras) [1]. Since 2001, the number of new cases of paragonimiasis has alarmingly increased in much of coastal Asia and Japan and has emerged as a significant public health issue [53]. Some of those with *Paragonimus* infections are symptom-free and unaware of their infection; others develop a chronic cough and chest pain, classically describing "chocolate-colored" sputum [1]. Hemoptysis can often occur irregularly and continue for years. The life cycle of this species of trematode predicates maturation to adulthood in snails and other shellfish and subsequently infects humans via ingestion due to poor water sanitation or undercooked seafood. The eggs hatch in the gastrointestinal tract and larvae migrate throughout the body, mainly to the lungs and pleural cavity to continue the life cycle.

Fig. 16.10 Coronal CT through the abdomen and pelvis of an 83-year-old male demonstrating multiple dense calcifications replacing much of the left kidney. This appearance is also referred to colloquially as "putty kidney"

On CT, pulmonary paragonimiasis presents as a subpleural or subfissural nodule with a necrotic low-attenuation area. Additional findings include subpleural linear opacities, presumably worm migration tracks, leading to necrotic and peripheral pulmonary nodules, adjacent bronchiectasis, areas of ground-glass attenuation, pleural effusion, and pneumothorax [54]. Later findings are thought to be caused by worm cysts and include solitary or multiple nodules or gas-filled cysts [55].

The radiographic appearance can make differentiation of pleuropulmonary *Paragonimus* and TB difficult in areas of the world where both infections are endemic; differentiation may require sputum or lesion tissue pathologic examination [56] (Fig. 16.11).

Melioidosis, a deadly gram-negative bacterial infection found primarily in Southeast Asia, can also cause a TB-like pattern of disease [1]. Pulmonary involvement is reported to be the most common form of melioidosis, accounting for >50% of cases. Melioidosis is often first noted on chest radiographs [57, 58] and can be easily confused with TB. A high index of suspicion is therefore required to make this diagnosis. In acute, nonsepticemic, pneumonic melioidosis, the most common radiographic pattern is focal consolidation with or without cavitation. As might be seen in primary TB, melioidosis typically begins in the upper lobes, often quickly spreading to other lobes, and forms nodules or patchy densities. Compared to TB, rapid clinical and radiographic progression with early cavitation favors melioidosis; hilar adenopathy is rarely seen in melioidosis [1].

Schistosomiasis

One of the most common and insidious endemic infectious diseases throughout southeastern Asia, coast South America, and Africa is schistosomiasis. More than 90% of patients requiring treatment for schistosomiasis reside in Africa [59]. There are two major forms of infection with schistosomiasis, intestinal and genitourinary. As discussed previously, genitourinary schistosomiasis presents with bladder and distal ureteral calcifications that extend retrograde. In the intestine, schistosomiasis presents with intestinal wall calcifications, which can be seen on CT [60]. For the diagnosis of hepatosplenic schistosomiasis, however, ultrasound is the preferred modality. Findings include peri-portal fibrosis, reduced portal blood flow, varices, and splenomegaly [60, 61] (Fig. 16.12).

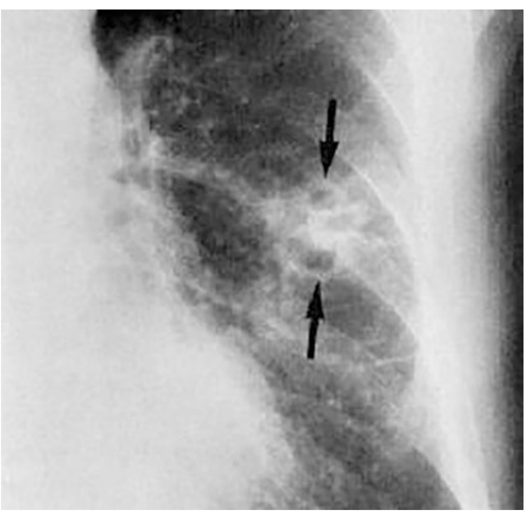

Fig. 16.11 Focal view of a left mid-lobe lesion demonstrating multiple small aggregated cysts in a patient with *Paragonimus* (arrows) [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

Fig. 16.12 Anteroposterior (AP) radiograph of the pelvis demonstrating thick circumferential calcification of the bladder and distal ureters, which are dilated in a patient with long-standing schistosomiasis infection. A large calcified bladder stone is also present [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

Echinococcus

Echinococcus granulosus is a cyst-forming tapeworm especially prevalent in parts of Asia, north and east Africa, Australia, and South America that is known to cause echinococcosis or hydatid disease, one of the most common hepatobiliary infections in the world. The tapeworm's life cycle involves dogs as definitive hosts and sheep, pigs, goats, horses as intermediate hosts; humans become inadvertent intermediate hosts after ingestion of the eggs excreted by infected dogs. The hatched larvae travel to the liver where they form fluid-filled hydatid cysts. Over time, daughter cysts may develop. In addition, an inflammatory granulomatous and/or fibrotic reaction may also occur [62]. The infection is endemic worldwide, with the highest prevalence in sheep-raising communities. Because of the wide prevalence, hydatid liver disease must be considered in the differential diagnosis of a cyst or mass in virtually any patient who is residing in, or has traveled through, an endemic area [1]. Ultrasound is highly helpful in the diagnosis/classification of hydatid liver disease, and a grading scale has been developed by the WHO [63] (Fig. 16.13). While MRI is increasingly being used in the advanced health systems, ultrasound of the liver remains the most cost-effective and available in the developing world. Unfortunately, ultrasonography is not always able to differentiate hydatid cysts from tumors or liver abscesses, and additional imaging, such as CT or MRI, may still be required (Fig. 16.14).

The tapeworm also affects the lungs and is, in fact, reported to be the most common parasitic lung infection worldwide [1]. It can present as a cavitary lung lesion, often containing smaller collections referred to as "daughter cysts" [32, 64]. They are often asymptomatic and recognized incidentally on CT [1, 65].

Chagas Disease (South America)

The parasite *Trypanosoma cruzi* causes Chagas disease (American trypanosomiasis) and is estimated to have infected 8 million people, predominantly in Latin America [66]. Chagas

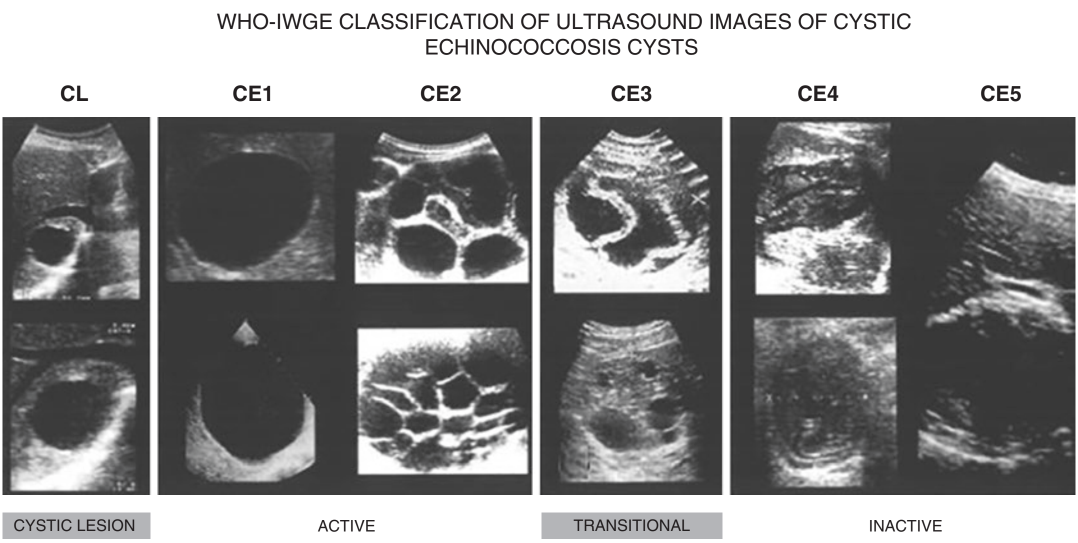

Fig. 16.13 WHO cystic echinococcosis (CE) grading scale by ultrasound. The classification is intended to follow the natural history of CE and starts with undifferentiated simple cysts, as presumably hydatid cysts evolve from these structures. The first clinical group starts with cyst types CE 1 and 2 and such cysts are active, usually fertile containing viable organisms. CE type 3 are cysts entering a transitional stage where the integrity of the cyst has been compromised either by the host or by chemotherapy and this transitional stage is assigned to the second clinical group. The third clinical group comprises CE types 4 and 5 which are inactive cysts which have lost their fertility and are degenerative [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

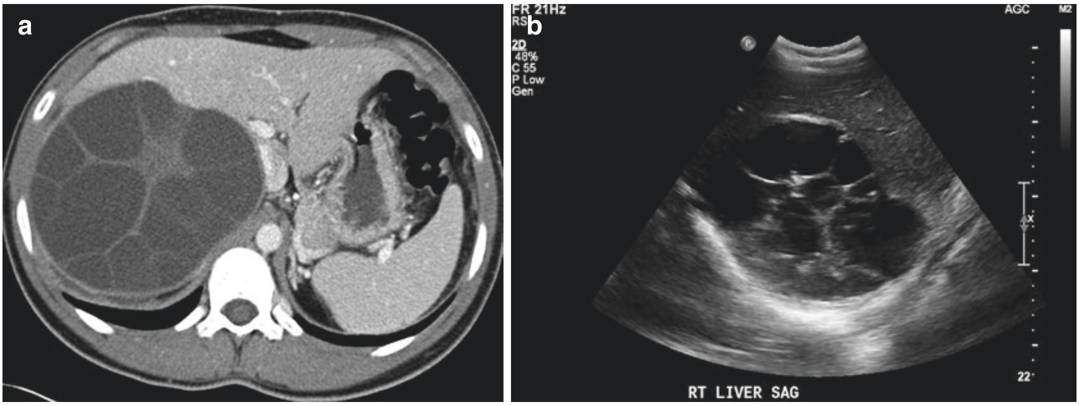

Fig. 16.14 Axial CT image (**a**) and sagittal ultrasound (**b**) of the liver of a 19-year-old male with hydatid liver disease. The CT demonstrates a large multiseptated, cystic lesion in the liver, and the ultrasound shows the same cyst's multiseptated, hypoechoic appearance

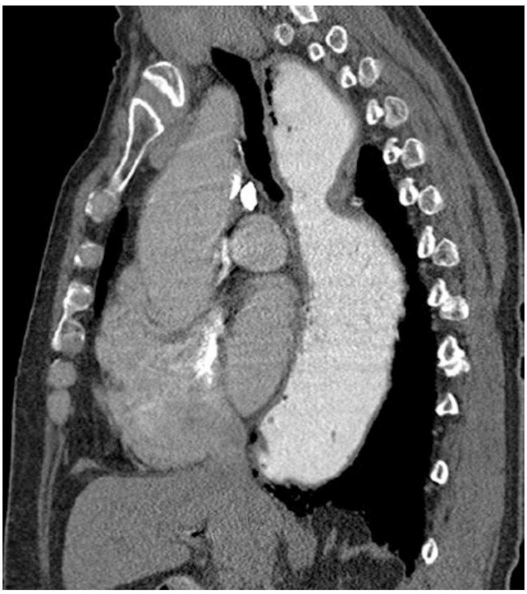

Fig. 16.15 Sagittal CT with oral contrast of a 78-year-old female patient with Chagas disease of the esophagus. The image demonstrates as significantly dilated, contrast-filled esophagus

disease can present with severe esophageal dysfunction; trypomastigotes, the differentiated offspring of the parasite, tend to invade the esophagus and give rise to a megaesophagus and/or achalasia (Fig. 16.15), which can be visualized with a lateral radiograph during a barium contrast esophagram. Chagas disease can also cause dilation of other segments of the gastrointestinal tract, particularly the proximal small bowel and the colon in severe cases, and can also be diagnosed with fluoroscopic and/or barium contrast studies [1].

Chagas disease may cause myocarditis in up to 5% of infected patients in the acute phase which can be cured with oral anti-trypanosomal medication [67, 68]. The acute-phase myocarditis can be diagnosed by echocardiography. Although unable to delineate the etiology, echocardiography is able to demonstrate cardiac function and can be used to track the progression of disease [67]. Many acute-phase Chagas infections are underdiagnosed or unrecognized. Approximately 30% of untreated patients progress to chronic-phase Chagas disease which can manifest as chronic Chagas cardiomyopathy (CCC). CCC can lead to progressive heart failure and sudden cardiac death. Cardiac MRI is not widely available in resource-poor regions but may detect myocardial involvement in untreated chronic Chagas disease [69–71].

Roundworms

Roundworms fall under a sub-group of soil-transmitted helminth infections and are exceedingly common in many parts of the world. More than 20% of the world's population is thought to have been infected with this type of parasite [72]. Infection due to *Ascaris lumbricoides* (termed ascariasis) is acquired by ingesting contaminated water or food that contains embryonated eggs. Numerous investigators have observed that the highest rate of infection with *Ascaris* is in children between 1 and 15 years of age. In hot and humid areas of rural Africa, Asia, and Latin America, up to 93% of all inhabitants in some villages may be infected [1, 37, 52]. While the diagnosis is mainly dependent on examination of stool samples, barium contrast agents are helpful in evaluating the presence of roundworm infection in the gastrointestinal tract (Fig. 16.16). In heavily infested patients, large collections of ascarids can frequently be identified on abdominal radiography without oral contrast [1, 73, 74]. In fact, large masses of worms in the bowel are best seen as a tangled group of thick cords and sometimes produce a "whirlpool" effect (Fig. 16.17). It is important to keep in mind the epidemiology of the region, as the differential diagnosis for an intraluminal worm identified by imaging is relatively nonspecific and can also represent a variety of other parasitic worm infections or noninfectious etiologies. Note that other worm infections, such as hookworms (*A. duodenale* and/or *N. americanus*), whipworms (*T. trichiura*), and capillariasis (*C. philippinensis*), are typically characterized on enterography by the inflammation or other changes in the bowel rather than direct visualization of the worms themselves due to their small size (10 mm on average in the case of *A. duodenale*). Stool examination and evaluation for worms and/or ova is diagnostic.

Leprosy

One of the most notorious and stigmatized infections in LMICs is leprosy, a chronic and debilitating infection caused by *Mycobacterium leprae*, which often in late stages dramatically manifests as skeletal changes. There are an estimated one million patients with leprosy in the world, and

Fig. 16.16 Barium examination of the stomach clearly demonstrates the outlines of individual ascarids (worms) as elongated radiolucent-filling defects within the barium column [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

Fig. 16.17 AP abdominal radiograph demonstrates a large bolus of worms in the cecum causing intestinal obstruction, manifest as thick tangles of cords within the air-filled large bowel [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

while radiology is not often necessary for an initial diagnosis, imaging does play a vital role in assessing the activity and extent of the disease and in helping to plan surgery and rehabilitation [1, 75]. The highest prevalence is in India and tropical Africa and South America; it also still occurs frequently in Southeast Asia, the Philippines, southern China and southern Malaysia, Indonesia, and some of the South Pacific islands [1, 75]. Leprosy presents in many different ways, both clinically and pathologically, but generally is divided into two different types: tuberculoid leprosy and lepromatous leprosy. The two differ primarily in the immune response generated by the infection. The differences in this characteristic result in lepromatous leprosy being the more severe form, with full body manifestations [76]. Primary skeletal changes are most frequent in lepromatous leprosy, and the bone findings are essentially destructive patterns with very little surrounding bone reaction or sclerosis until healing occurs [1, 75] (Fig. 16.18). The disease is usually diagnosed clinically (symptoms, physical exam, and history), and radiographs are most commonly utilized to monitor complications of the infection, including secondary pyogenic osteomyelitis due to the ulceration and neuromuscular changes of the infection in the extremities.

Fig. 16.18 Lateral radiograph of the foot demonstrates the final stages of leprosy characterized by the large areas of bone absorption. As the talus disintegrates, with weight-bearing, there is complete disruption of the foot, leaving the patient vulnerable to secondary infections which, in combination, leave little normal anatomy or function [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

Cysticercosis

Cysticercosis is prevalent in Africa, Asia, and Latin America. It is estimated to be the cause of 30% of epilepsy cases in regions where it is endemic [77]. Cysticercosis is acquired by ingesting food, water, or feces containing eggs of *T. solium*. The oncospheres (larvae) are released from their shells in the gut and invade throughout the body, developing into cysticerci, most commonly in the skeletal muscles and brain [1, 78].

Musculoskeletal involvement of *Taenia solium* (cysticercosis) infection can be readily diagnosed with radiography because the appearance is pathognomonic. They appear as oblong calcified foci parallel to the muscle fibers and have been described as rice grain calcifications. Calcified lesions have been demonstrated in up to 97% of patients examined 5 or more years after infection and can be easily demonstrated by radiographs of the extremities [1] (Fig. 16.19).

Patients with a central nervous system (CNS) infection with cysticercosis, or neurocysticercosis, present with seizures. Similar to the calcifications seen in skeletal muscle, head CT findings include multiple calcified lesions throughout the brain parenchyma measuring between 2 and 10 mm, with or without mass

Fig. 16.19 Frontal plain film radiograph of the bilateral knees of a 57-year-old female demonstrates calcifications in the soft tissues and muscles. The calcified cysticerci are aligned with their long axes in the plane of the muscle bundles of the legs

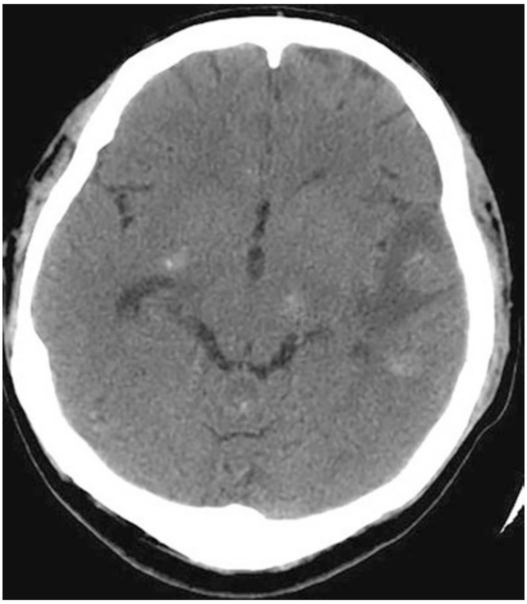

Fig. 16.20 Axial non-contrast head CT demonstrates multiple parenchymal calcified lesions, some with mild surrounding edema characteristic of the nodular calcified stage of cysticercosis [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

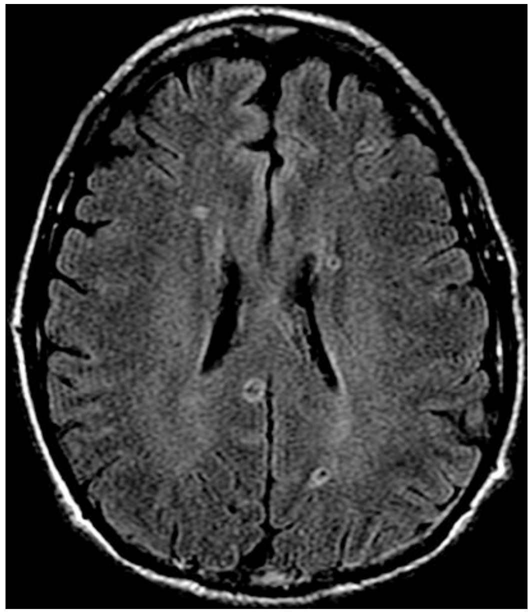

Fig. 16.21 Axial FLAIR brain MR of a 61-year-old Ecuadorian male demonstrates thin-walled cysts, one of which has a mural nodule. This is the vesicular stage of neurocysticercosis. (Image courtesy of Kevin Spitler, MD)

effect or contrast enhancement (Fig. 16.20). Treatment of cysticercosis depends on the form and the type of disease and the location and number of cysts [1, 79].

There are four main stages of neurocysticercosis. In the vesicular stage, the parasite is still viable and has an intact membrane, resulting in no reaction within the host. The cyst can be visualized on CT and MRI without significant associated enhancement on post-contrast images. The next stage is called the colloidal vesicular stage, in which the parasite dies with or without treatment. At this point, the cyst membrane is no longer intact, causing surrounding edema and cyst wall enhancement. In the granular nodular stage, this edema diminishes and the cyst retracts with persistent enhancement. In the nodular calcified stage, a calcified cyst can be seen on non-contrast CT without surrounding edema [80].

Although unlikely to be the most financially feasible or an available option in many regions, MRI is able to reveal even small cysts (Fig. 16.21). In addition, the accompanying edema is often well demonstrated on T2-weighted or fluid-attenuated inversion recovery (FLAIR) MRI sequences. MRI is also the study of choice for evaluation of ventricular neurocysticercosis, which is often impossible to diagnose by CT. The intraventricular cystic lesions are generally isointense to cerebrospinal fluid (CSF) and may demonstrate a thin hypointense rim particularly with T2-weighted sequences. Clinically, this form of neurocysticercosis is important to recognize as these lesions can grow to occlude the CSF, potentially leading to acute hydrocephalus and sudden death (Fig. 16.22).

Toxoplasmosis

One of the most widespread parasitic infections in the world is toxoplasmosis, caused by *Toxoplasma gondii*, a protozoan that infects humans and commonly involves the CNS. It is estimated that approximately 95% of the world has been infected with *Toxoplasma* [81]. It has a complex life cycle, but infection is most commonly via inadvertent ingestion of oocysts, often shed by domesticated cats, but also can be ingested via eating raw or undercooked meat, plants contaminated with oocysts, and unpasteurized dairy products and can be caused by organ transplantation and congenital transplacental infection. The oocysts hatch and the sporozoites quickly become widely distributed within the host blood stream and intestines. The preferred extra-intestinal sites for *T. gondii* include skeletal and heart muscle, brain, and other tissues of the CNS.

Fig. 16.22 Saggital T1-weighted MR image demonstrates a large cyst due to cysticercosis in the trigone of the right lateral ventricle [9]. (Reprinted from Lungren et al. [9], with permission from SpringerNature)

A CNS *Toxoplasma* infection is termed “neurotoxoplasmosis” and most often occurs in immunocompromised patients, including those with HIV/AIDS. On CT, this manifests as multiple, variable-sized, ring-enhancing hypodense regions, predominantly in the basal ganglia and at the corticomedullary junction (Fig. 16.23). These lesions will also demonstrate ring enhancement on post-contrast MRI [82].

Toxoplasmosis can undergo transplacental transmission from an infected mother to fetus. In most cases, this infection is asymptomatic. In those cases with symptomatic presentation, manifestations depend upon the timing of infection during pregnancy. On fetal ultrasound, the most common findings include fetal hydrocephalus and intracranial parenchymal calcifications.

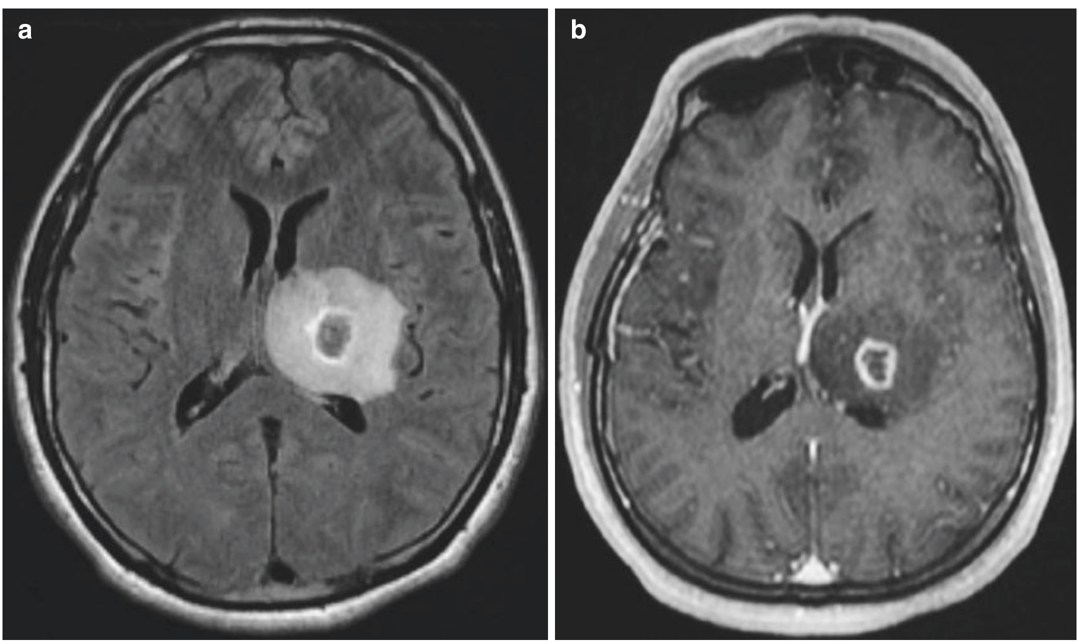

Fig. 16.23 Axial FLAIR brain MR (**a**) and axial post-contrast T1-weighted brain MR (**b**) in a 34-year-old male with AIDS demonstrates ring-enhancing lesions with surrounding edema consistent with toxoplasmosis brain abscess

Additional findings include intrahepatic calcifications, ascites, and hepatosplenomegaly [83].

Clonorchiasis

Clonorchiasis, also known as Chinese liver fluke disease, is caused by *Clonorchis sinensis* and is endemic to eastern China and southeastern Asia. Adult flukes infect dogs and other fish-eating carnivores, eventually infecting humans where they migrate into bile ducts and complete the life cycle [84]. Infection leads to recurrent pyogenic cholangitis, biliary strictures, and cholangiocarcinoma. Both ultrasound and CT demonstrate uniform intrahepatic dilatation of small bile ducts with relative sparing of large bile ducts. The flukes cannot be visualized on imaging. Chronic clonorchiasis results from protracted episodes of re-infection over time. Treatment of this chronic infection is important because of its strong association with cholangiocarcinoma [85, 86].

Entamoeba histolytica

Infection with *Entamoeba* is relatively widespread throughout much of the developing world. It is thought that approximately 8% of those in endemic regions are exposed and approximately 90% of those become symptomatic, resulting in an estimated 100,000 deaths annually [87]. *Entamoeba* is an amoebic parasite that is ingested orally and can invade the large bowel and progress from there to cause extra-intestinal infection. On ultrasound, extra-intestinal amebiasis most commonly presents as a single, hypoechoic liver lesion with a rim or capsule; this is known as an amebic liver abscess. This needs to be differentiated from a pyogenic liver abscess caused by biliary tree infections, diverticulitis, or abdominal interventions. These may mimic amebic liver abscesses on ultrasound, but pyogenic abscesses tend to be more variable in shape, are often multiple, and may have regions of markedly increased echogenicity representing gas bubbles (Fig. 16.24), all of which are not usually noted with amebiasis [23].

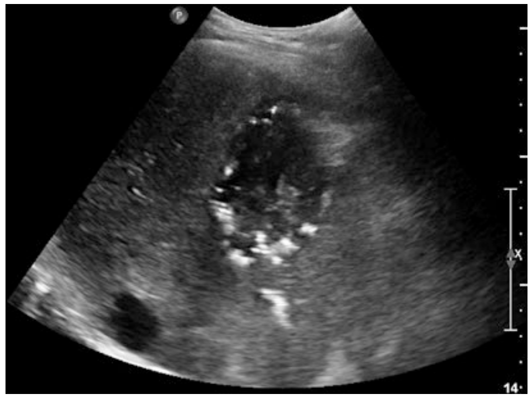

Fig. 16.24 Transverse view of the right upper quadrant in a 47-year-old male with colon cancer demonstrates a hypo- to anechoic lesion with irregular borders and echogenic foci representing gas bubbles consistent with a pyogenic abscess

Zika

Over recent years, Zika virus has come to the forefront of popular attention. Zika is a virus spread primarily by mosquitos of the *Aedes* species, generally causing only minor symptoms in those infected directly. Unfortunately, however, during pregnancy, the virus can be transmitted vertically to fetuses from infected mothers, causing primarily CNS abnormalities. Retrospective analyses of fetal ultrasound and MRI demonstrated normal fetal cerebral parenchymal development up to 24 weeks. Thereafter, decreased growth rate of fetal head circumference, asymmetry between abdominal and head circumference, increased nuchal skin fold thickness, neural cortical abnormalities, corpus collosum abnormalities, cerebral hemisphere hypoplasia, brainstem hypoplasia, calcifications in the gray-white matter junction, and posterior fossa abnormalities were observed on imaging [88–90]. Many of these findings can be seen on fetal ultrasound or MRI. At the time of birth, some of these findings can be seen on neonatal cranial ultrasound which can be obtained in resource-poor regions. Further evaluation of high-risk newborns, however, should include a head CT or brain MRI at a tertiary center with expertise in neuroradiology.

Other congenital infections include the TORCH infections. TORCH is an acronym standing for toxoplasmosis, other (syphilis, varicella-zoster, parvovirus B19), rubella, cytomegalovirus, and herpes infections. TORCH infections account for 2–3% of all congenital abnormalities [91]. Many of the neuro-imaging findings described above for Zika can also be seen in the TORCH infections. For this reason, it is important to obtain polymerase chain reaction (PCR) confirmation of Zika virus infection prenatally or in the neonate with presumed infection (Figs. 16.25, 16.26, and 16.27).

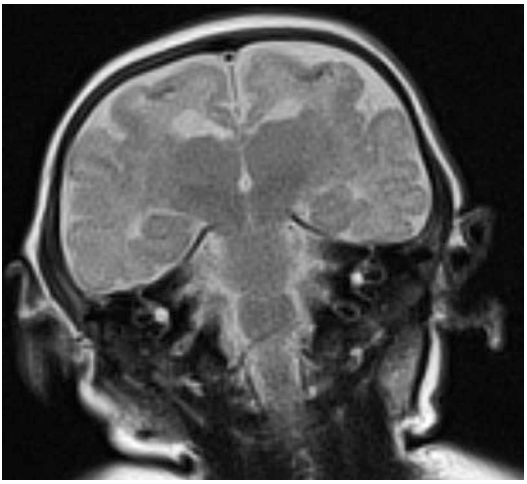

Fig. 16.25 Coronal T2-weighted images through the brain demonstrating T2 dark punctate calcifications at the gray-white junction and lissencephaly in a neonate with Zika virus infection. (Image courtesy of Karin Nielsen, MD, MPH)

Conclusion

Globally, infectious diseases make up a significant portion of treatable causes of morbidity and mortality. Imaging is essential in the diagnosis and management of many of these diseases. It also places a significant role in the monitoring and reporting of outbreaks and identifying public health threats.

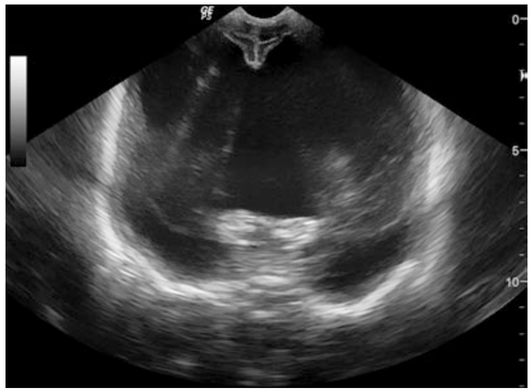

Fig. 16.27 Coronal head ultrasound demonstrating severe parenchymal volume loss and severe hydrocephalus in a neonate with Zika virus infection. (Image courtesy of Karin Nielsen, MD, MPH)

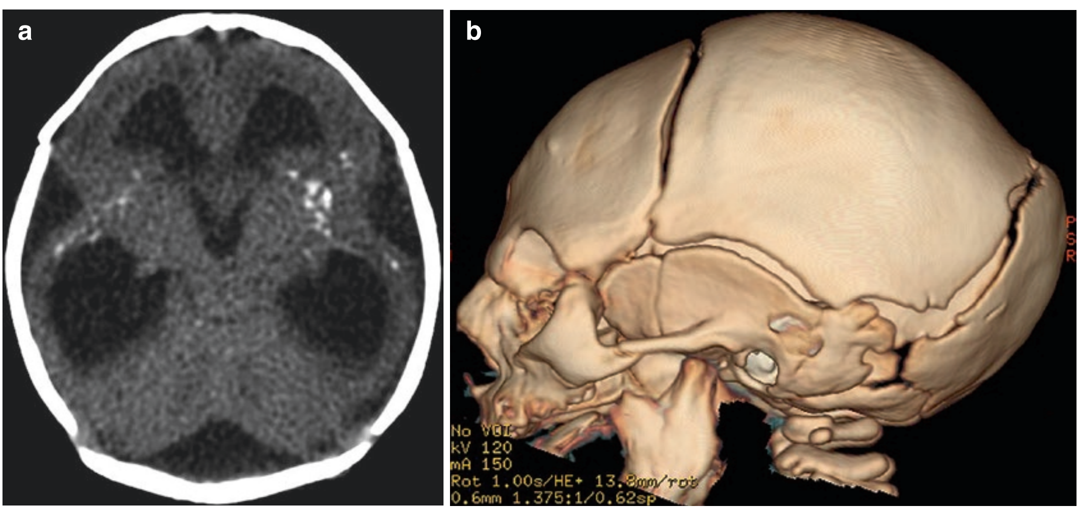

Fig. 16.26 Axial non-contrast CT (**a**) through the brain with 3D reconstruction (**b**) demonstrating microcephaly, hydrocephalus, lissencephaly, cerebellar abnormalities, basal ganglia calcifications, and calcifications at the gray-white junction in a neonate with Zika virus infection. (Images courtesy of Karin Nielsen, MD, MPH)

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17 Cardiovascular Imaging in Global Health Radiology

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
AIDS	Acquired immunodeficiency disease syndrome
CACS	Coronary artery calcium scores
CAD	Coronary artery disease
CCTA	Cardiac computed tomography angiography
CHD	Congenital heart disease
CMR	Cardiac magnetic resonance
CT	Computed tomography
CVD	Cardiovascular disease
EBCT	Electron-beam computed tomography
GDP	Gross domestic product
HCU	Hand-carried cardiac ultrasound
HF	Heart failure
HIV	Human immunodeficiency virus
IAEA	International Atomic and Energy Agency
IV	Intravenous
LMICs	Low- and middle-income countries
LV	Left ventricle
MDCT	Multi-detector computed tomography
MPI	Myocardial perfusion imaging
NCD	Noncommunicable disease
NGO	Nongovernmental organization
PCU	Pocket-sized ultrasound
RHD	Rheumatic heart disease
RP	Radiation protection
SPECT	Single-photon emission computed tomography
TEE	Transesophageal echo
TTE	Transthoracic echo
USA	United States
WHO	World Health Organization

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Introduction

Until recently, the global healthcare community has directed most of its efforts in low- and middle-income countries (LMICs) toward the prevention and treatment of infectious diseases. However, over three-quarters of deaths from noncommunicable diseases (NCDs) take place in LMICs, with cardiovascular disease (CVD) being the number one cause of death globally (Fig. 17.1) [1]. In 2013, approximately 12 million deaths from CVD occurred in LMICs, representing a growth of 66%, whereas the number of CVD deaths has trended to a decline in high-income regions [2]. Mortality from CVD is rising in these countries,

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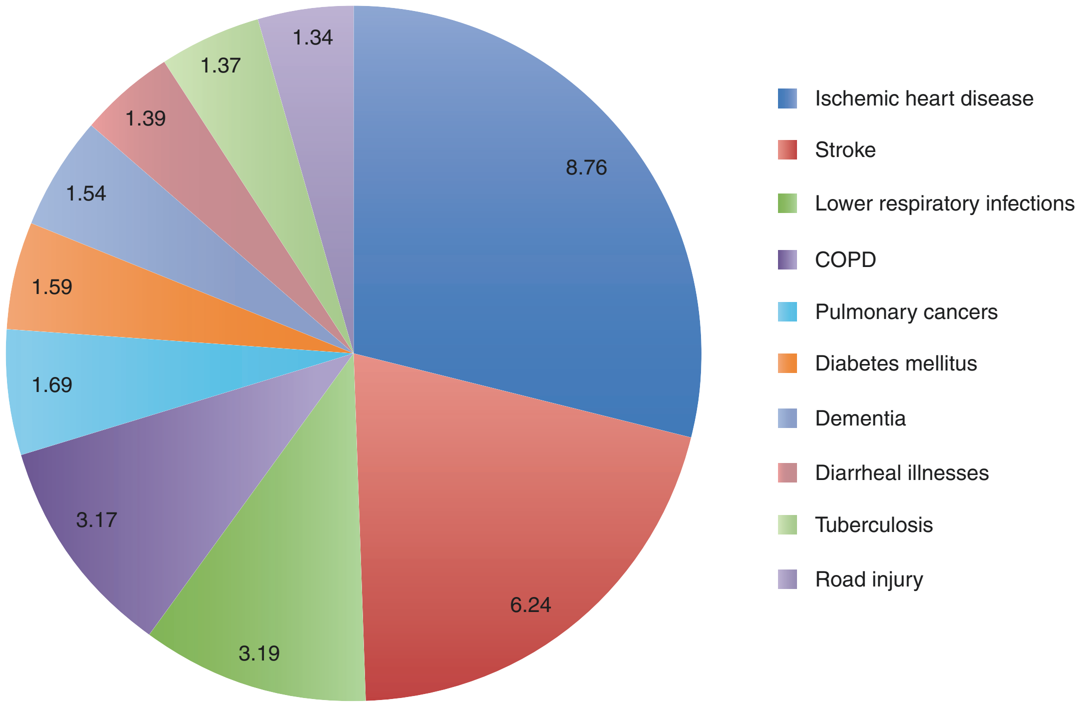

Fig. 17.1 Top ten causes of death (in millions) worldwide in 2015, according to the WHO. Cardiovascular disease (ischemic heart disease and stroke) is the number one cause, accounting for 15 million deaths [1]

and the World Health Organization (WHO) projects that deaths from NCDs will increase 15% beyond their 2010 predictions, especially in the African region [3]. Additionally, 87% of premature deaths from NCDs – deaths before the age of 70 – occur in LMICs [4].

Importantly, poverty is closely tied with this increase in NCD-related mortality, with fewer available medical resources in LMICs [4]. A survey revealed that four CVD medicines used for secondary prevention (aspirin, beta-blockers, angiotensin-converting enzyme inhibitors, and statins) were available in 95% of urban and 90% of rural communities in high-income countries compared to 25% of urban and 3% of rural communities in low-income countries (excluding India) [5]. It follows that patients with CVD in LMICs tend to have poorer outcomes and die younger than their counterparts in the United States (USA) and other high-income countries [1, 6]. The Prospective Urban and Rural Epidemiological (PURE) study showed that although cardiovascular risk is highest in high-income countries, major cardiovascular events (death from cardiovascular causes, myocardial infarction, stroke, or heart failure) occur at a substantially higher rate in LMICs (3.99 events per 1000 person-years versus 5.38–6.43 per 1000 person-years, respectively) [7].

Moreover, the economic burden on the individual, household, and societal level is considerable [8]. According to the WHO data, disability-adjusted life year (DALY) rates are highest in the African, Eastern Mediterranean, and Southeast Asian regions (Fig. 17.2) [9]. Deaths related to coronary artery disease (CAD) in Indian individuals aged 35–64 contributed to the loss of over 9.2 million productive years in 2000, which was 570% more than the corresponding figure for the USA and is expected to nearly double by 2030 [10, 11]. A 2007 estimate of median individual or household expenses for CVD treatment over a 15-month period after CVD hospitalization ranged from 354 international dollars (INT$) in Tanzania to INT$2917 in India [11]. According to the World Health Organization (WHO), the

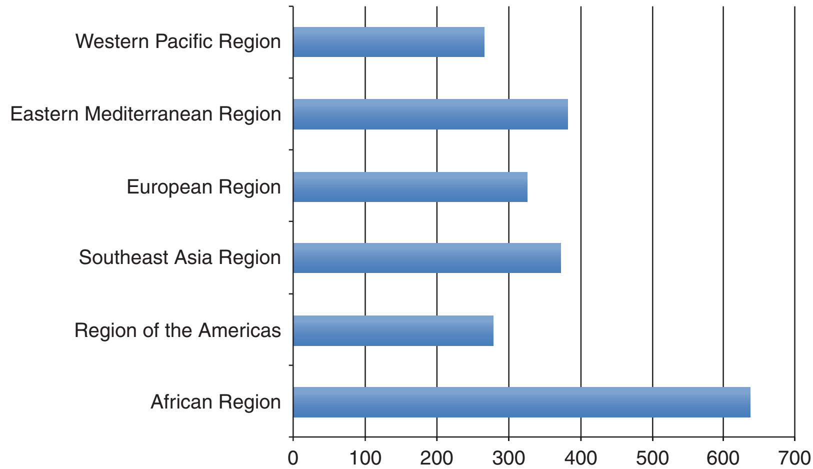

Fig. 17.2 2015 DALY rates (per 1000 population) across WHO regions [9]

combination of heart disease, stroke, and diabetes reduces gross domestic product (GDP) by an estimated 1–5% in rapidly growing LMICs [1].

Despite the disruptive effect of CVDs on health and economic development in LMICs, efforts to reduce their impact are grossly underfunded [6, 12]. Access to cardiac imaging services is particularly limited. Some equipment is prohibitively costly to install or maintain, and using it properly can be challenging. The WHO estimated that approximately 95% of imaging technology is imported into LMICs, even in countries such as India that produce and export imaging devices, and over 50% of this equipment is not utilized due to inadequate servicing or a shortage of trained personnel [13].

Comprehensive training programs in cardiac imaging for technicians and cardiologists do not exist in many LMICs, and consequently, images may be acquired incorrectly or patients may be exposed to unnecessary radiation. In addition, physicians may order tests inappropriately or incorrectly interpret the results, leading to erroneous diagnoses and poor patient outcomes. In advanced healthcare systems, most cardiac images are now transferred over wireless networks and stored digitally, but many LMICs do not have networks with the appropriate bandwidth in place. These realities are troubling because diagnostic imaging plays an important role in the detection and treatment of CVDs. Delay in intervention due to the absence of accessible and reliable cardiac imaging will only worsen the growing prevalence of CVDs [14].

In order to meaningfully expand the global availability of cardiac imaging, it is necessary to understand the etiologies of CVDs in low-income countries (Fig. 17.3) [15]. In contrast to the industrialized world, rheumatic heart disease (RHD) and infectious diseases with cardiac manifestations (e.g., Chagas disease, tuberculosis, or schistosomiasis) cause substantial morbidity and mortality. RHD was reported to affect 15.6–19.6 million people worldwide in 2005, with more recent estimates showing an increase to 34 million in 2010, causing up to half of a million deaths each year, 95% of which occur in LMICs [16–18]. Additionally, many children and young adults in these nations suffer from untreated or unrecognized congenital heart disease (CHD) [19]. In LMICs with a high burden of human immunodeficiency virus and acquired immunodeficiency disease syndrome (HIV/AIDS), the risk for CVD is increased due to chronic inflammation and infection or anti-retroviral treatment [20].

As in industrialized nations, ischemic heart disease is a growing problem, and cardiac risk factors are on the rise. In India and China, for example, the combined prevalence of diabetes is greater than 150 million, and the prevalence of hypertension in these countries together is predicted to be over 500 million by 2025 [21–23]. Effective control of this new epidemic of contributors to cardiovascular risk – physical

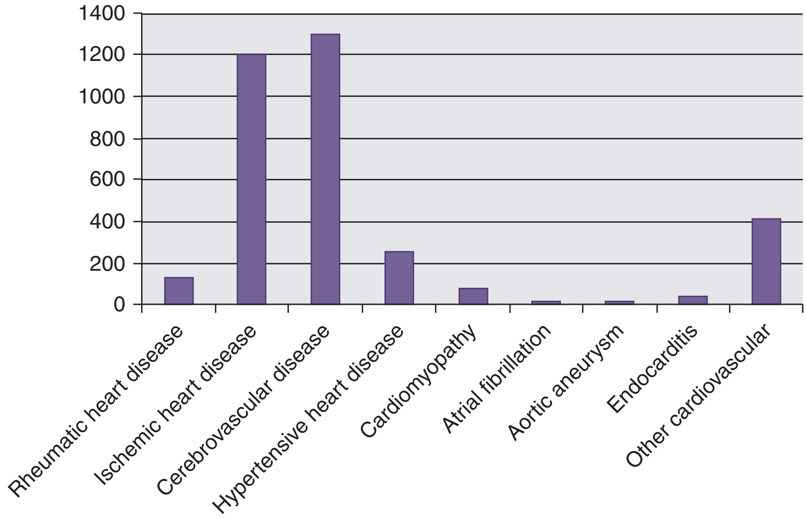

Fig. 17.3 Global Burden of Disease estimated DALY rates (per 100,000 population) by cardiovascular disease type in WHO low-income countries in 2015 [15]

inactivity, tobacco use, obesity, diabetes, hypertension, hypercholesterolemia – has been projected to potentially prevent 80% of premature heart disease, stroke, and diabetes, underscoring the need for earlier identification of patients whose cardiovascular fate is still modifiable [24].

This chapter will provide a review of techniques in cardiac imaging and then highlight approaches that have been successfully implemented in LMICs. Additionally, appropriate referral for cardiac imaging as well as follow-up after testing will be noted. Finally, future directions for the continued improvement of cardiac imaging globally will be discussed.

Current Cardiac Imaging

The field of cardiac imaging is rapidly evolving, with the frequent introduction of new or improved technologies into clinical practice. This section will survey the state-of-the-art technology.

Echocardiography remains the most common diagnostic imaging procedure performed in cardiac patients [25]. Echo can be used to obtain two-dimensional (2D) or three-dimensional (3D) images, which can be enhanced by color and spectral Doppler recordings or injection of intravenous (IV) contrast. 2D echo reliably measures cardiac chamber volumes and ejection fraction, but 3D echo may have an incremental advantage in the assessment of chamber volumes without necessitating geometric assumptions as well as for congenital heart disease (CHD) [26, 27]. Doppler provides hemodynamic information based on changes in frequency that result from the reflection of sound waves off of red blood cells. Color-flow Doppler is included in most echo exams in order to screen for disturbed or turbulent blood flow [28]. Doppler can also be used to evaluate myocardial contractile performance, either by quantifying regional strain (tissue Doppler imaging) or by speckle-tracking technique [29].

In most cases, transthoracic echo (TTE) sufficiently characterizes cardiac function and anatomy. However, because the esophagus is adjacent to the left atrium and thoracic aorta, transesophageal echo (TEE) is superior in visualizing these posterior cardiac structures, prosthetic cardiac valves, and small structures [30, 31]. Additionally, TEE is especially valuable in the diagnosis of infective endocarditis (Fig. 17.4) and aortic dissection, as well as in guiding interventional procedures [30–32].

Echo can also be used for stress testing. Images acquired before and after either exercise- or pharmacologic-based stress may indicate obstructive CAD by the presence of wall motion abnormalities indicating inadequate perfusion. Contrast echo is commonly employed in conjunction with stress echo. Intravenous (IV) microbubbles are injected to opacify the left ventricle (LV) so that

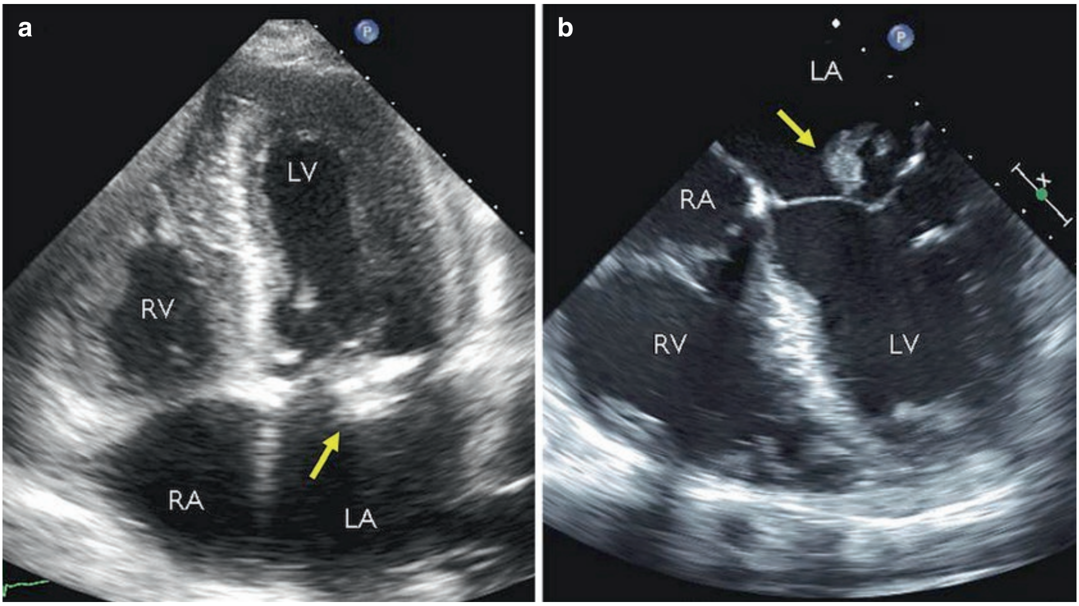

Fig. 17.4 Representative images acquired by transthoracic echocardiography (TTE; **a**) and transesophageal echocardiography (TEE; **b**) in the same patient with mitral valve endocarditis (arrowhead points to bacterial vegetation adherent to the anterior leaflet). The proximity of the mitral valve to the esophagus and superior acoustic window results in improved spatial resolution of TEE over TTE. RA right atrium, RV right ventricle, LA left atrium, LV left ventricle

areas of abnormal myocardial contraction can be more readily identified [28]. Angiography, however, is still the gold standard for directly visualizing the coronary anatomy.

Coronary angiography identifies atherosclerotic disease, stenotic lesions, coronary thromboses, areas of poor perfusion, and collateral vasculature [33]. Left ventriculography is included in most studies and employs contrast opacification of the LV to reveal wall motion abnormalities, which may be the result of myocardial infarction or other causes of cardiomyopathy. Angiography, though, is invasive and technically complex: it involves passage of a catheter through the femoral or radial artery, injection of IV contrast, and circling of an x-ray source and an image intensifier around the patient. Although complications are rare, the invasive nature of cardiac catheterization entails inherent risks, the most severe of which includes myocardial infarction, stroke, bleeding, and downstream effects such as cardiac tamponade from coronary dissection or creation of hematomas and arterio-venous fistulas at the access sites.

Nuclear imaging is useful for noninvasively assessing the likelihood of CAD in intermediate-risk patients (high-risk patients are better suited for cardiac catheterization) and revealing the coronary region or degree of ischemia in patients with known atherosclerotic disease. The vast majority of nuclear cardiology procedures are gated single-photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI) [34]. SPECT MPI can be performed at rest or with the patient under stress. Images are taken with a scintillation camera that detects IV-injected radiopharmaceuticals distributed within the heart in proportion to myocardial perfusion [34], and perfusion defects may signify obstructive CAD (Fig. 17.5). Commercial software packages can assist in image interpretation, but results should always checked by a trained individual [35]. Positron emission tomography (PET) has similar applications in the diagnosis and risk stratification of CAD but is less commonly employed. Positron-emitting isotopes of elements can be inserted into biomolecules, and the radioactivity concentrations of these tracers

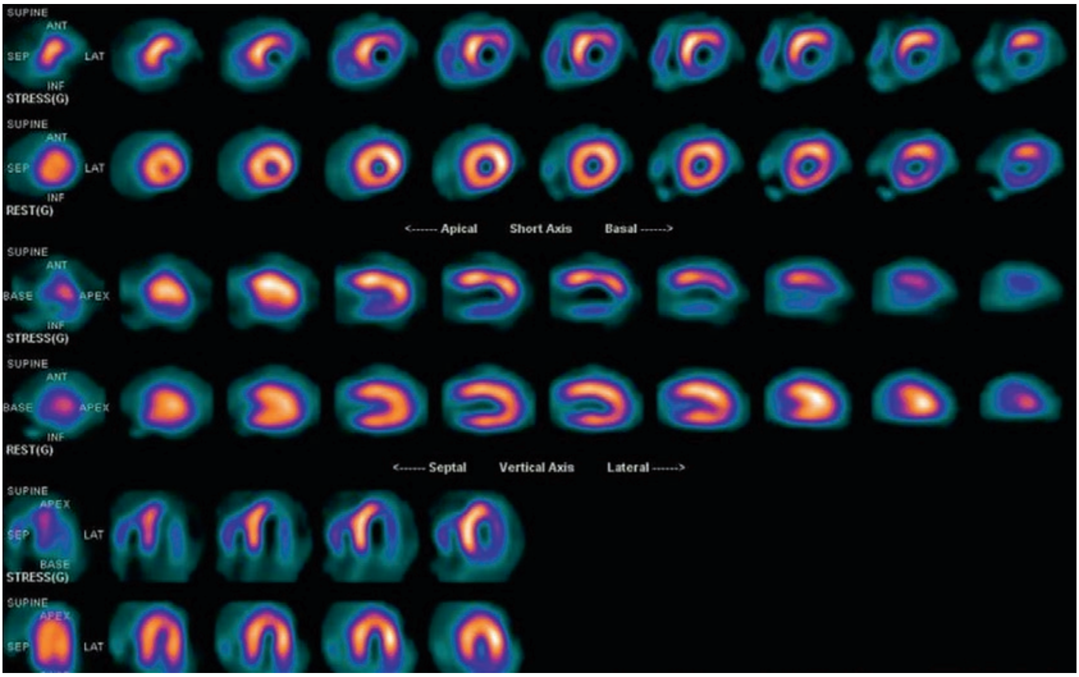

Fig. 17.5 Representative single-photon emission computed tomography myocardial perfusion imaging (SPECT MPI) demonstrating normal perfusion at rest (lower images in each series) and a perfusion defect after stress (upper images in each series). After exercise, a new perfusion defect was observed in the inferior and lateral walls, signifying severe ischemia. This post-bypass patient had a 99% stenosis of a saphenous vein graft supplying these territories

in blood or myocardium can be noninvasively determined over time. Both SPECT and PET have been used as well to distinguish viable myocardium from scarred, non-viable tissue.

Cardiac computed tomography (CT) has applications to many cardiac pathologies, including CAD, anomalous coronary arteries and other CHDs, valvular calcification or stenosis, pulmonary artery embolism, pericardial disease, and cardiac masses [36, 37]. Images can be obtained with multi-detector CT (MDCT) by advancing the patient through the circular trajectory of an x-ray tube or by generating x-ray images from an electron beam, as in electron-beam computed tomography (EBCT). EBCT is preferred for calculating coronary artery calcium scores (CACS), which is a useful method for cardiac risk stratification that relies on the assumption that increased calcium deposits indicate greater atherosclerotic burden, whereas cardiac CT angiography (CCTA) using MDCT is used for the determination of obstructive CAD (Fig. 17.6) [38]. CACS has been shown to correlate with conventional CAD risk factors and is an independent risk factor for future coronary events [39–41].

Cardiac magnetic resonance imaging (CMRI) utilizes sophisticated technology to generate a static magnetic field that is about 30,000 times that of the earth, transmit energy to the patient within the radiofrequency range, and interpret the resulting signal [42]. CMRI is the emerging modality of choice for determining ejection fraction; myocardial viability (Fig. 17.7) versus scar; and evaluating structural heart abnormalities due to CHD, infiltrative cardiomyopathies such as cardiac amyloidosis and sarcoidosis, or myopericarditis, among others [43]. CMRI also can be utilized in stress testing: vasodilator (e.g., adenosine) stress perfusion captures the transit of IV contrast, typically gadolinium-based, through the myocardium of the LV in order to evaluate ischemic heart disease, and CMRI with dobutamine stress perfusion assesses for wall motion abnormalities that may signify obstructive CAD [44–47].

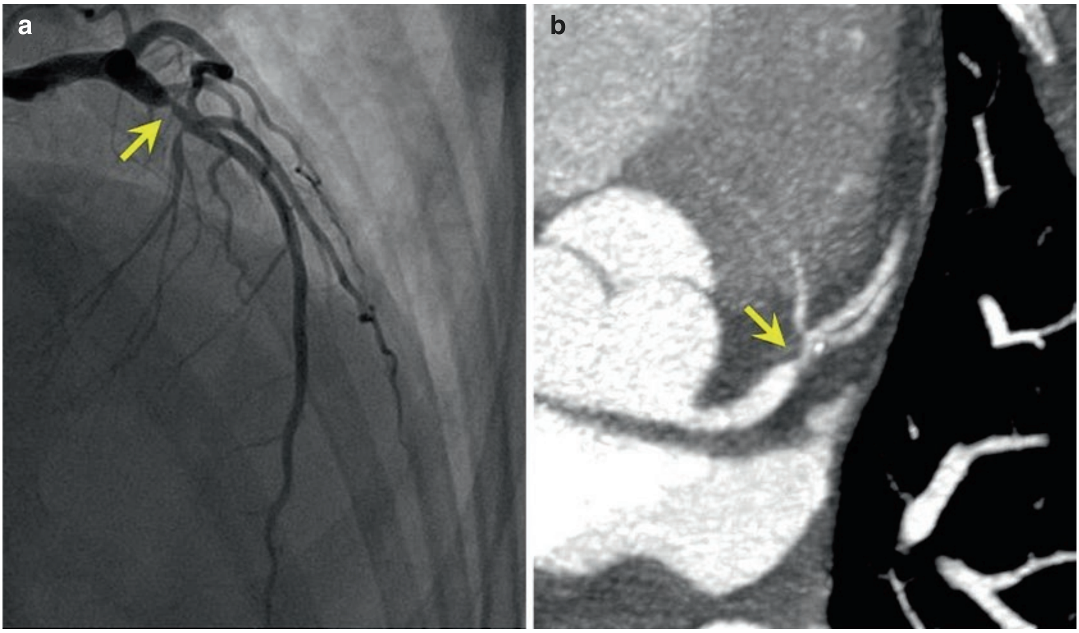

Fig. 17.6 Images of a proximal left anterior descending (LAD) coronary artery stenosis (arrowhead) obtained by cardiac catheterization (**a**) and coronary CT angiography (**b**). CT allows noninvasive imaging of the coronary arteries with some loss of resolution but without the complications associated with invasive procedures. (Images courtesy of Robert Zeman, MD, George Washington University)

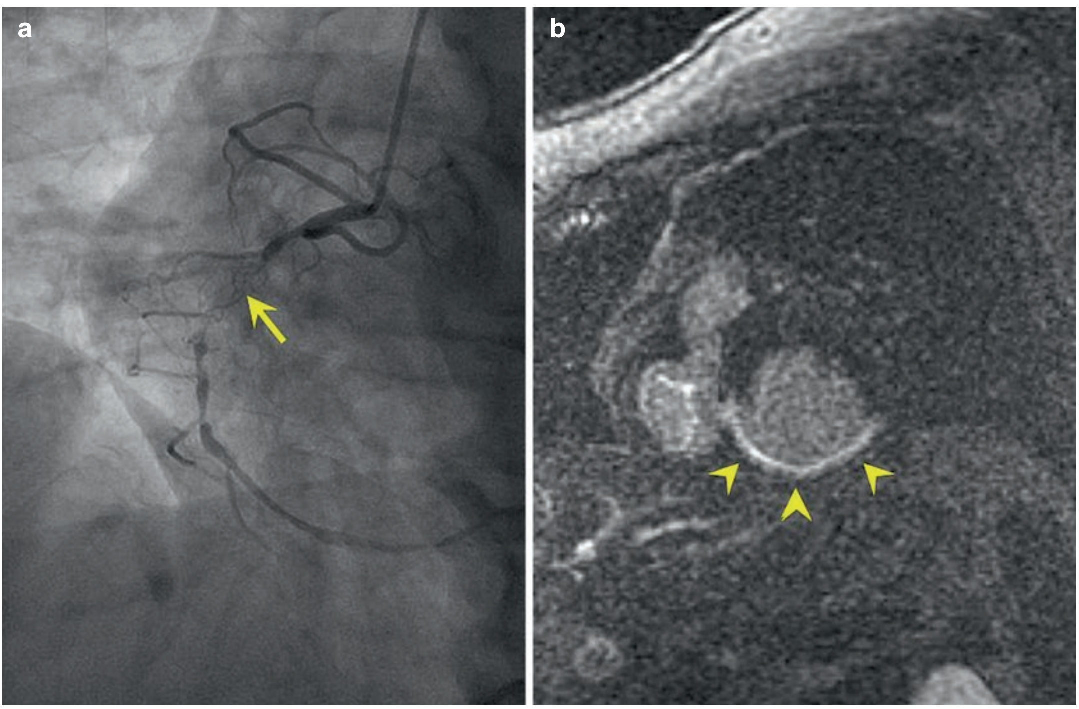

Fig. 17.7 Representative myocardial viability study by MRI. Cardiac catheterization (**a**) demonstrates a total occlusion (arrowhead) of the right coronary artery (RCA). Assessment of viability was done by MRI. In the short axis view of the left ventricle by MRI, late gadolinium enhancement is seen in areas of non-viable myocardium (arrowheads in **b**), suggesting that the myocardium supplied by the RCA would not benefit from revascularization. (Images courtesy of Robert Zeman, MD, George Washington University)

Approaches to Cardiac Imaging in LMICs

As previously discussed, there are various challenges to the implementation of cardiac imaging technology in LMICs. However, effective strategies to use cardiac imaging with patients in limited-resource settings will be reviewed in this section.

Echo is by far the most widely used cardiac imaging tool in LMICs. This modality is well suited for low-resource settings for the same reasons that physicians in high-income nations have so readily adopted it in the clinic or at the hospital bedside. It is small, portable, and relatively inexpensive and does not deliver radiation.

Moreover, although the incidence of CAD is growing in LMICs, hypertensive heart disease, cardiomyopathies, and valvular defects as sequelae of infectious etiologies contribute substantially to cardiac disease and are easily evaluated by echo.

Portable echo in particular has proven to be very useful. A group of German physicians were one of the first to describe their experience with echo in a remote tropical setting in 1990 [48]. They used a general-purpose ultrasound, as defined by the WHO, to evaluate 67 patients at a hospital in central Sudan. Cardiac abnormalities identified included valvular disease, pericardial effusion, dilated cardiomyopathy, congenital heart disease, mitral valve prolapse, and cardiac masses.

In particular, echo is very valuable in diagnosing RHD in LMICs. In the 1990s, a group of Kenyan physicians published their experience using echo to identify functional consequences of RHD and found that even in schools without electricity, it was feasible to carry out echo exams using a portable generator [49]. Marijon et al. took advantage of high-quality portable ultrasound equipment to screen for RHD in a large population of school-aged children in Cambodia and Mozambique [50]. They showed that systematic screening with echo, as compared with clinical screening, identified approximately ten times the number of cases of RHD, again highlighting the utility and practicality of echo in LMICs. Similar findings were reported for more than 10,000 children evaluated with echo versus clinical screening in the southern Pacific islands of Tonga and India [51, 52].

Because there is a shortage of dedicated echo technicians in RHD-endemic areas, training inexperienced practitioners to perform the exam is essential. Generally, echo screening for RHD is fast, inexpensive, and reasonably accurate even when performed by an individual with limited experience [53]. A trial of more than 362 children aged 5–14 years in Fiji showed that they could be evaluated by echo in less than 4 minutes on average by an individual with no prior echo experience and at an affordable cost. The World Heart Federation published standardized criteria for the echocardiographic diagnosis of RHD in 2012 [54]. However, these may be complicated to use in reality, especially by non-expert screeners. In a prospective study in Uganda, Lu et al. used simplified criteria (mitral regurgitation (MR) jet length ≥1.5 cm and any aortic regurgitation (AR)) to diagnose RHD with a sensitivity of 73.3% and specificity of 82.4% [55]. In Fiji, seven school-health nurses without imaging experience were trained to screen for RHD by focused cardiac ultrasound (FoCUS) to assess for MR or AR, with a diagnostic accuracy of 0.89 when compared to a standard exam performed by a skilled echocardiographer [56].

In addition to performing the study, interpreting the echocardiographic images to diagnose RHD can be a challenge in areas with limited professional resources. As part of a RHD screening program in a school in Brazil, six non-experts in the medical field who had varying experience with echo completed a 3-week self-directed, computer-based curriculum on interpretation [57]. Screening for MR and AR was performed in 1381 children aged 5–18 years, and the sensitivity and specificity of this simplified approach in detecting RHD were 83% and 85%, respectively.

In addition to screening for RHD, portable echo can also be used to identify congenital heart disease (CHD). Echocardiographic screening for RHD of 1023 schoolchildren in Peru resulted in discovery of 12 cases of previously undiagnosed congenital heart disease, which was comparable to the rate of RHD [58]. Four of the 12 children were subsequently referred for percutaneous or surgical repair. In a Kenyan hospital, portable echo was used to assess cardiac function and hemodynamic status in 30 children admitted with severe malaria [59].

Handheld or pocket-sized cardiac ultrasounds are particularly useful when travel between clinical sites is necessary or there is an unreliable power supply. Handheld cardiac ultrasounds (HCUs) reliably diagnosed a variety of cardiac conditions in a cardiology clinic in rural Mexico [60]. In this study, the HCUs were about the size of a laptop computer, were battery-operated, and weighed 2.9 kg. They generated 2D echo images as well as color-flow Doppler. In more than half of the patients (63 out of 126), a focused exam was performed to investigate signs and symptoms that included chest pain, dyspnea, fatigue, peripheral edema, palpitations, syncope, cardiac murmurs, or abnormal electrocardiograms. Images produced by the HCU clarified the clinical picture in 93% of cases and confirmed a cardiac diagnosis in 63% of cases.

The pocket-sized ultrasound (PCU) is approximately the size of a smartphone and has comparable accuracy to traditional echo modalities [61–63]. A collaborative group at George Washington University in Washington, D.C., used a PCU in a remote Honduran village where echo was previously unavailable to make point-of-care diagnoses; these were remotely verified by experts in the USA who reviewed the images on a smartphone-based application [64]. PCU assessments were performed by a cardiology fellow on 89 Honduran patients referred by local general providers for evaluation of arrhythmia, cardiomyopathy, or syncope. The PCU device measured just 1.4×7.3×2.8 cm and weighed 390 g, with an 8.9 cm diagonal display, and was equipped with color-flow Doppler. Acquired images were transmitted directly from the field via a dial-up modem or via a broadband connection in an urban center where connectivity was limited. Experts then viewed the images at a different location and modified diagnoses suggested by the fellow as needed (Fig. 17.8). This approach was validated against the standard workstation evaluation and enabled patients to receive sophisticated care in areas with minimal capabilities and expertise.

Using a similar approach, 1023 focused echocardiographic studies were performed on prescreened individuals in rural North India using pocket-sized or handheld ultrasounds [65]. The images were then uploaded via a Web-based viewing system and remotely interpreted by 75 physicians worldwide. Of the 1021 interpretable studies, over one-third diagnosed a major or minor cardiac abnormality. Of the 170 individuals with major abnormalities, 6-month telephone follow-up was possible in 41%, with reported improvement in symptoms.

In addition to immediate clinical applications, physicians in low-income countries are using echo as a research tool to advance clinical care. For example, in sub-Saharan Africa, decades of research have enhanced local and international understanding of the prevalence, natural history, and treatment of several CVDs, including CHD, left ventricular hypertrophy, systolic and diastolic dysfunction, dilated cardiomyopathy, and valvular heart disease [66–72].

Generally, the availability of all imaging modalities, including echo, is concentrated in capital cities [73, 74]. The cardiac imaging equipment in these facilities is comparable to what is available in the USA and other wealthy countries. For example, hospitals in urban areas of India have rapidly adopted advanced diagnostic techniques such as CMR, CT coronary angiography (CTCA), or coronary angiography [75]. However, they are often provided on a fee-for-service basis at a cost that is unaffordable for the majority of the population.

Availability of nuclear cardiology is heterogeneous, with rates of use reflecting a country's GDP and location bordering "high-user" nations, such as the USA or countries in the European Union [76]. Unfortunately, in areas where there is limited noninvasive testing, patients may be preferentially referred for cardiac catheterization, leading to higher rates of revascularization with a dubious effect on outcomes [77]. In some countries, creative methods are used to decrease the cost of a nuclear cardiology procedure to below what it would cost in a high-income country. These include greater

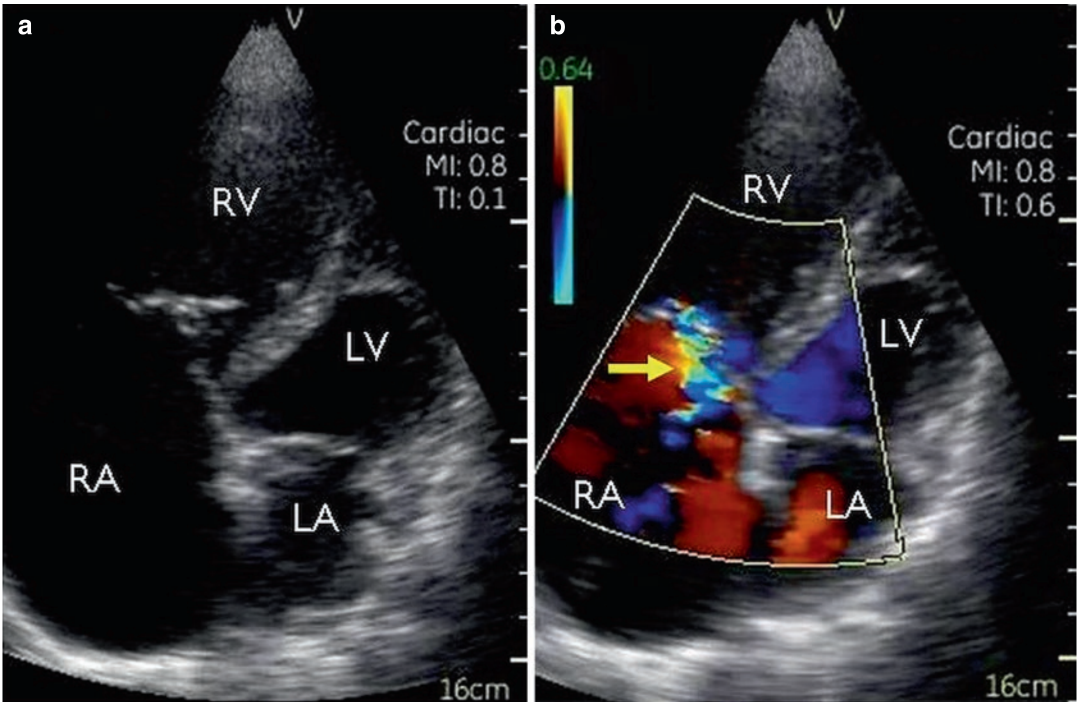

Fig. 17.8 A representative case in which expert remote interpretation corrected point-of-care diagnosis. During a medical mission in a developing country, a cardiology fellow sent for remote evaluation these echocardiographic images taken with a handheld ultrasound device from a 43-year-old man who presented for evaluation of dyspnea. The fellow correctly identified the markedly enlarged right atrium and ventricle (**a**), but the mosaic pattern seen with color Doppler (**b**) in the tricuspid regurgitant jet (arrowhead) led the fellow to believe that severe regurgitation was present; however, expert overread acknowledged that the small jet size was more consistent with high-velocity mild regurgitation [64]. RA right atrium, RV right ventricle, LA left atrium, LV left ventricle. (Reprinted from *Journal of the American Society of Echocardiography*, Choi et al. [64]. Copyright 2011, with permission from Elsevier)

use of generic drugs and radiopharmaceuticals as well as cheaper labor costs [76]. However, this may come at the cost of decreased quality control and inexperienced technicians.

LMICs frequently acquire costly equipment through international donation of used equipment. Additionally, many LMICs rely on training programs provided at minimal to no cost by high-income countries. The International Atomic and Energy Agency (IAEA) has created a module about radiation protection (RP) tailored to the needs of interventional cardiologists in LMICs [78]. However, RP is often inadequately implemented in many LMICs. For example, data collected from all nuclear cardiology procedures (SPECT and PET) performed during a single week in 36 laboratories across South America revealed higher radiation effective dose (ED) compared to the rest of the world [79]. In this study, areas for improvement included (1) use of stress-only imaging, (2) camera-based methods to reduce ED, and (3) weight-adjusted dosing of radioisotope. In some LMICs, cardiac imaging education is part of the curriculum for cardiology training, but there is often no formal accreditation process to mark expertise in a specific imaging modality as in the USA or Europe [73].

In addition to the IAEA, which focuses on the global expansion of nuclear techniques like SPECT MPI, there are several charitable organizations that work, at least in part, to advance cardiac imaging in LMICs. SonoWorld is dedicated to providing free or low-cost educational materials and information on ultrasound, which includes echo and vascular examinations. Its website features video lectures on echo and vascular ultrasound with Doppler, digital chapters on the vascular system, and case-based learning [80]. Imaging the World is a partner of RAD-AID and seeks to increase availability of echo and other types of ultrasound in sub-Saharan Africa. RAD-AID assists in areas of low resource to expand health imaging services, including echo and other types of cardiac imaging. The organization spreads awareness of cardiac imaging technology in low-resource settings through its annual conference and by online information, such as the bibliography of medical research available on its website. RAD-AID also facilitates volunteering opportunities and global distribution of cardiac imaging resources.

The Need for Optimized Referral and Treatment

Building cardiac imaging infrastructure in LMICs is only the first step. Patients must be appropriately referred for testing in a timely manner. Since many cardiac imaging tests are expensive and can have adverse effects such as radiation exposure, patients should be carefully selected. As suggested by Lele et al., appropriate patients should be identified by accessible, noninvasive testing, which can be followed by more expensive and invasive cardiac testing [75]. Performing a complicated study is sometimes not necessary if a simpler test can be ordered and achieve acceptable results. For example, the HCUs studied by Kobal et al. in a cardiology clinic in rural Mexico obviated the need for further comprehensive echo evaluation in 90% of patients [60].

Additionally, as pointed out by Vitola et al., thoughtful referral of patients for expensive and limited cardiac imaging studies, such as nuclear imaging, is essential because inappropriate use may restrict access of needy patients who would derive benefit from the test [81]. Analysis of the appropriateness of ordering myocardial perfusion scintigraphy at a public hospital in Brazil revealed a 12% prevalence of inappropriate requests [82]. The authors estimated that implementation of appropriate use criteria for this study in this hospital setting would generate savings in excess of $64,000 per year. Interestingly, a meta-analysis of 34 publications including 41,578 patients at primarily academic medical centers in highly developed regions indicated that the rate of inappropriate or rarely appropriate testing with stress MPI was 15.7% using the 2009 appropriate use criteria (AUC) [83]. Therefore, barriers to testing in LMICs may lead to more prudent testing, although there is certainly room for improvement even in high-income countries.

In addition to identifying patients who need more sophisticated diagnostic testing, simplified cardiac imaging modalities can also be used to identify patients for medical treatment or surgery. This classification is especially important for the care of patients with CHD. Although prenatal detection is considered the standard of care in developed countries, diagnosis is frequently delayed in LMICs due to inadequately trained healthcare providers and socioeconomic barriers to care [84]. At the time of diagnosis, patients may already suffer from the consequences of untreated disease such as severe polycythemia, heart failure, fixed pulmonary hypertension, infective endocarditis, and stroke [85]. Devastatingly, some of these sequelae may preclude patients from being eligible for corrective surgery.

The results of the Heart of the Soweto Study, which followed individuals presenting with known or suspected CVD to a South African tertiary-care center, also highlight the need for early diagnosis by cardiac imaging or other means [86]. Of the 1593 individuals with newly diagnosed CVD, the most common conditions were hypertension (56.3%) and heart failure (HF, 53.0%), and more than one-third of patients with HF had an advanced stage of disease, as indicated by clinically significant dyspnea. Since 2006, a public health program has been implemented in regions of rural Rwanda so that nurses are trained to use portable echo and a simplified diagnostic protocol to diagnose and manage heart failure [87]. This program expands care to vulnerable populations and enables earlier diagnosis of disease with targeted therapy.

Once imaging has established a diagnosis, additional challenges emerge. While the optimal intervention for a newly diagnosed condition may be clear – for example, surgical repair of a rheumatic mitral valve – the availability of such an intervention may be highly limited, even in an urban tertiary-care center in an LMIC. Many LMICs depend almost entirely on foreign cardiac surgeons who are visiting as part of a humanitarian mission or on expatriate surgeons contracted to build surgical programs [88]. Based on a data obtained from surveys and the Cardiothoracic Surgery Network, there is estimated to be 1 surgeon per 3.3 million people in sub-Saharan Africa. Patients requiring surgical repair of pathology identified on echo may be placed on a waitlist for months to years [89]. A study in Brazil found that the mean wait time for coronary artery bypass grafting was 23 months and the mortality rate was 5.6 deaths per 100 patients per year [90]. For valvular surgeries, the mean wait time was up to 32 months, and the mortality rate was 12.8 deaths per 100 patients per year.

After a CVD event, rates of catastrophic health spending, defined as out-of-pocket health spending >40% of non-food expenditures, rise steeply among low-income individuals, and distress financing is most commonly provided by friends, family, and employers (Fig. 17.9) [11]. Especially with regard to surgical management of CVD, many families cannot afford the cost of treatment, and so cardiac defects may persist into adolescence and even adulthood. A study from Ghana's National Cardiothoracic Centre at the Korle Bu Teaching Hospital showed that only 20% of parents of patients under 15 years old with CHD requiring surgery could afford the operation within 1 year of echocardiographic diagnosis [91]. A large cohort study including over 2000 patients who underwent cardiac surgery by NGO-sponsored visiting surgeons operating out of two medical centers in Mozambique and Cambodia reported more favorable outcomes, with acceptable in-hospital mortality but high rates of loss to follow-up limiting long-term analysis [92].

Even medical management of CVDs diagnosed by imaging can be problematic. Essential medications, such as beta-blockers for systolic HF, are often inaccessible and too expensive for

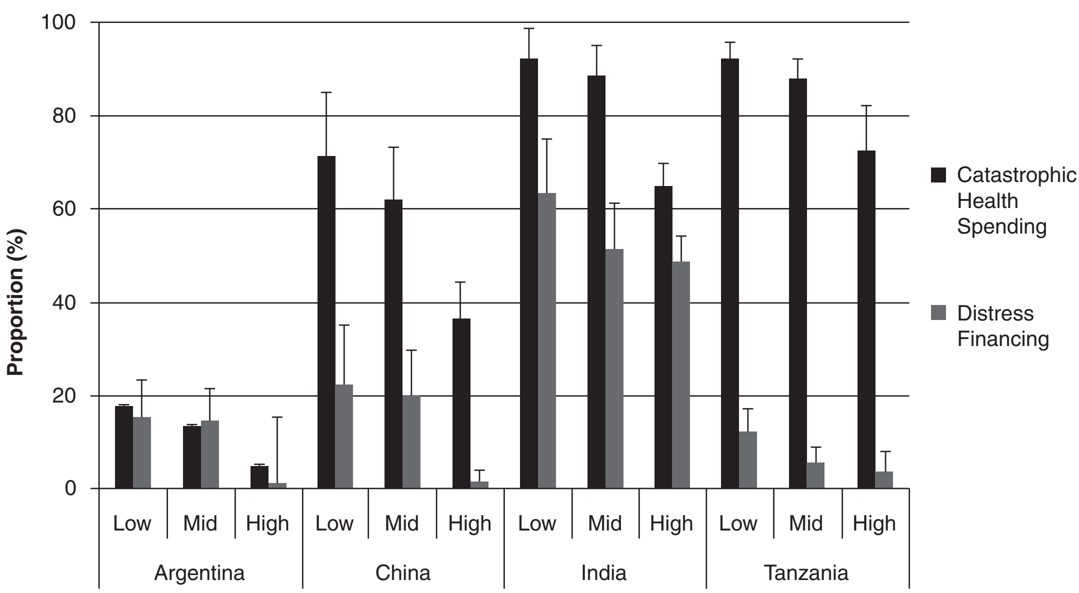

Fig. 17.9 Proportion of survey respondents who experienced catastrophic health spending (out-of-pocket health spending >40% non-food expenditures) and distress financing following CVD-related hospitalization, divided by income strata. Differences across income strata were considered statistically significant ($p < 0.05$) for China (CHS and DF), India (CHS), and Tanzania (CHS and DF) [11]. (Reprinted from Huffman et al. [11]. Copyright © 2011, Huffman et al.)

patients [93, 94]. One model for enhanced distribution of cardiovascular medicines in LMICs emphasizes the importance of increased availability of generic substitutions and both public and private efforts to limit cost [95]. Therefore, there is much room for improvement in a comprehensive model of care that includes accessible cardiac imaging services.

Future Directions for Cardiovascular Imaging in LMICs

Although many gains have been made spreading cardiac imaging globally, there remains a major discrepancy between what exists in developed regions and the rest of the world. As articulated in the White Paper Report of the 2013 RAD-AID Conference, as global poverty declines and technology improves, clinical models will maximize use of telemedicine and mobile equipment. Additionally, there will be increasing dependence on use of mobile devices with Internet-linked workstations to deliver cardiac imaging to extremely resource-poor areas [96]. As discussed in earlier sections, handheld echo is an indispensable tool in LMICs and can be combined with telemedicine to deliver expert care in areas with very limited resources. Telemedicine is promising as shown by the accuracy of remote interpretation of echocardiographic images transmitted via a secure mobile-to-mobile system [64].

Other clinical trials have evaluated similar technologies with satisfactory results, but the utility of these devices has not yet been validated in low-resource settings. For example, one group of investigators showed that remote interpretation of CCTA images using a mobile handheld device enabled the detection of lesions that occluded more than 50% of the coronary artery [97]. Remote operation by experienced individuals of CMR imaging equipment was shown to be successful as well, with excellent imaging quality in 90% of images versus 60% of images obtained locally by non-experts [98]. Further innovation must take place to generate cardiac-specific cameras and equipment that are both affordable and adaptable to limited-resource settings [76]. Easily maintained machines with on-site service would be preferable.

In order to implement new technologies and infrastructure for cardiac imaging, it is critical that local healthcare providers engage in efforts to influence policymakers [99]. However, leaders of LMIC economies have limited resources and many competing interests; as a result, directing funds toward improvement of cardiovascular health through diagnostic imaging is usually considered a low priority [100]. Financial factors play a major role in deciding which cardiac imaging facilities are available [75]. As governments in LMICs on a state and national level recognize the vital role of cardiac imaging in managing CVDs, finances will be allocated accordingly. International donation of equipment and pharmaceuticals is vital and should be encouraged. Additionally, some programs establish a sliding scale for cost based on need and ability to pay [76].

Cardiologists trained in cardiac imaging may informally disseminate knowledge during relief visits, but structured educational programs are most effective. Distance-assisted learning programs or web-based educational tools may be especially helpful in isolated areas [76]. A decentralized approach would create numerous regional centers of education for local physicians and training staff. Training programs within these institutions could be led by expert cardiac imagers [76].

Clinical models implemented in LMICs should be designed according to the needs of the patients in a specific region. Referral for cardiac imaging should be thoughtful to maximize available resources. Additionally, all efforts to streamline care after cardiac imaging diagnosis should be made. In the future, artificial intelligence-based diagnostic algorithms may help streamline referrals by dichotomizing imaging studies between normal and abnormal, allowing healthcare systems to focus additional diagnostic workup on the minority of patients that do not have normal studies.

Public policy initiatives to address cardiac imaging are very important but poorly developed or non-existent in many resource-poor countries. Most LMICs do not have health insurance systems in place, and so patients must pay completely out of pocket for cardiac imaging. As a result, there is significant need for a public program to reduce the expense of costly but necessary cardiac imaging tests regardless of an individual patient's ability to pay. Moreover, public policy programs to develop the infrastructure necessary for using cardiac imaging are essential. This includes facilities with reliable electricity, environmental control (e.g., temperature and humidity for sensitive electronic equipment), and appropriate personnel.

Conclusion

There is an epidemic of cardiovascular disease (CVD) in LMICs that is projected to be increasingly deleterious to economic development. Imaging is a vital component of accurate diagnosis and appropriate triage of patients with CVD. Access barriers include lack of equipment and appropriately trained personnel, but the versatility of ultrasound and other emerging technologies may provide increased access to necessary cardiovascular imaging. Improvement in local training will be critical with the concomitant expansion of imaging services to provide improved distribution channels for therapies.

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18 Pediatric Imaging in Global Health Radiology

Charles M. Maxfield, Sinisa Haberle, and Cheri Nijssen-Jordan

Introduction

Although there has been a significant improvement in child healthcare globally over the last two decades with a resulting decrease in the child mortality rate of around 50%, over 5 million children still die each year before age 5 [1]. These deaths occur in the neonatal period 45% of the time and are usually a result of prematurity, congenital conditions, and acquired infectious conditions. The remaining 55% occur in the postnatal period and are largely a result of common preventable etiologies like pneumonia, diarrheal diseases, other infectious diseases, and injuries. The United Nations (UN) Sustainable Development Goals for 2030 outline key relevant targets for diagnostic imaging in global health, which include the promotion of good health and well-being, industry, innovation and infrastructure, and reducing inequalities. Specific items which target pediatric imaging include decreasing preventable deaths of newborns and children under 5 years of age, limiting the impact of infectious diseases (AIDS, tuberculosis, malaria, neglected tropical diseases, hepatitis, water-borne diseases, and other communicable diseases), and finally halving the number of global deaths and injuries from road traffic accidents. Additional goals concerning training and retention of the healthcare workforce in low- and middle-income nations are also a critical issue in pediatric imaging [2].

It is important to note that children have unique disease manifestations and processes in comparison to adults. Additionally, familiarity with the variations and changes in the maturing child and adolescent is unique and necessary to care for this patient population. Development of the subspecialty of pediatric radiology was initiated in the first half of the 1900s and has now expanded to include all imaging modalities as well as interventional procedures [3]. The practice of pediatric imaging continues to face particular challenges in low-resource settings where imaging machinery, especially computed tomography (CT) and magnetic resonance imaging (MRI) are confined to major metropolitan areas, meaning access to imaging is restricted to many children in rural areas. Conventional radiography and, increasingly, ultrasound (US) are the workhorses of diagnostic imaging, but even their availability can often be limited. A lot of work is needed to meet the goals set by the UN, but with a collegial effort from radiologists around the world and some simple interventions much can be accomplished.

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Challenges for Pediatric Radiology in Low- and Middle-Income Countries

Specialty Expertise and Training

Pediatric radiology requires specialized knowledge of pediatric anatomy and pathology, dedicated imaging equipment, and a particular awareness of the risks of ionizing radiation and its effects on children. A major challenge that needs to be overcome, before diagnostic imaging can realize its full impact on public health, is the shortage of radiologists. One review estimated that there is 1 radiologist per 1.5 million in Tanzania, 1:1 million in Uganda, 1:400,000 in Kenya, and 1:100,000 in South Africa [4]. Furthermore, those radiologists from low- and middle-income countries who go elsewhere for additional training tend not to return. Radiologists with pediatric expertise are even scarcer in these areas, and as a result, less qualified healthcare practitioners perform and interpret most of the pediatric radiographs. Additional support from worldwide pediatric radiology societies through remote conferencing or educational partnerships focused on pediatric imaging may help to fill the gap in lack of onsite interpretation expertise.

Equipment

The World Health Organization (WHO) recommends that every hospital have basic imaging equipment and that simple radiographic and US equipment should be available to all children [5]. As pediatric care in low- and middle-income countries increases in volume and complexity, diagnostic imaging facilities must address equipment needs specific to children. This includes appropriate medications and supportive equipment [6]. Donation of old and used equipment is less than ideal as equipment arrives without a repair manual, service contract, maintenance records, or staff training. Thus, the upkeep and safety of old equipment may make it prohibitive for hospitals to accept old equipment [4].

Since 1995, the WHO has recommended the WHIS-RAD (World Health Imaging System for Radiography) unit, successor of the WHO-BRS (World Health Organization—Basic Radiological Services), as it has the highest possible safety profile and is therefore more suitable for children. The estimated cost of a WHIS-RAD unit as of 2016 is approximately $50,000 for an analogue machine and processing unit; digital units can cost twice as much [7].

Ultrasound equipment for children is readily available around the world at a reasonable cost and with acceptable imaging quality. When choosing machines for pediatrics, it is important to note that the appropriate probes must be chosen; as adult probes will often be of limited use on the small patient. Linear high frequency probes (10–16 MHz) should be used in the pediatric setting while still having curved high frequency (8 MHz) probes available for studies evaluating the deeper intra-abdominal viscera.

Techniques

Special consideration needs to be taken in the treatment of children when it comes to the radiation risk associated with radiographic image acquisition. Children are more radiosensitive than adults, which increases their risk of acquiring a radiation-induced malignancy. Physicians in low- and middle-income countries who are utilizing X-rays, fluoroscopy, or CT should understand the risks of radiation in order to use the technology safely and appropriately.

CT imaging has had a dramatic effect on the practice of medicine. Since its early clinical use in the 1970s, there has been a great increase in its utilization [8]. CT is a useful imaging modality and can save many lives when used appropriately [9]. Healthcare professionals should be judicious when ordering CT scans in children, and the radiologist and the technologist should inspect all CT requests in order to avoid unnecessary exams. CT exams should use a protocol to limit the area of exposure as much as possible and the responsible radiologist should use radiation parameters (kVp, mAs, pitch) to deliver the lowest radiation dose necessary to answer the clinical question. Any imaging professional performing CT scanning should be aware of the ALARA (As Low As Reasonably Achievable) principles and put them into practice [10].

The Alliance for Safety in Pediatric Imaging has formed the "Image Gently" campaign, which has set out to provide imaging guidelines for physicians. The Alliance was established in July of 2007 and its website was rolled out on January 22, 2008. The aim of the campaign is to "change practices by increasing awareness of the opportunities to lower radiation dose in the imaging of children" (www.imagegently.org). The Image Gently campaign advocates for child size appropriate kVp and mAs settings, for only one pass through the scanner (one phase), for only the indicated area to be scanned, and that one should scan only when necessary [11].

Other techniques for minimizing exposure time include ensuring patient compliance. Children the world over are fearful of strangers, new places, loud sounds, and big machines. When imaging children, it is important to ensure comfort and a sense of safety by having family members present when possible, using appropriate shielding and restraining devices, and utilizing fun distracting devices and methods [11].

These changes are a product of the Society of Pediatric Radiology's (SPR) ALARA conferences, multiple journal articles detailing the risks of radiation, practice guidelines from the ACR and CT accreditation programs, and manufacturer's protocols for pediatric patients. The lessons that radiologists have learned over the last few decades should be transferred to LMICs when providing imaging services. The radiology community should strive to minimize unnecessary exams, adjust the settings, replace exams by ultrasound or MRI if available, and educate future physicians about the effects of radiation [11].

Imaging Appearance of Common Pediatric Clinical Disease

This chapter will take a focused look at the most frequent and/or unique pediatric radiographic findings which are commonly found in low-resource settings around the globe.

System Approach

Head and Spine

CT and MRI provide valuable imaging information of the brain and spine. X-rays can evaluate for fracture or other bony abnormalities involving the calvarium. US can evaluate for hemorrhage or ventriculomegaly in the first months of life, before the fontanels close.

Diagnostic imaging likely makes its largest global impact in the evaluation of trauma. In children, the cranium is disproportionately large compared to the face with the fulcrum centered high in the cervical spine at C1 and C2 [12]. As such, head injuries are common in children while C spine injuries are infrequent and when they occur, they tend to be higher in the cervical area, which is associated with significant on scene mortality [13]. In the infant, the fontanels and sutures are open which allows for growth as well as accommodation of increasing cerebral pressure over a short term. These suture lines can often be confused with linear fractures [14]. In children, there is less myelin present and the cranial bone is thinner than in an adult skull; this puts children at an increased risk of skull fractures, brain injury, and developmental delay in the trauma setting. Perinatal infections such as Zika virus, and the TORCH infections, which are much more prevalent in low-resource settings, can lead to microcephaly and intracranial calcifications [15, 16]. Since many remote locations do not have access to CT scans, it is very important to have resources, which can assist in reading skull X-rays, which are commonly used in their stead.

The cervical spine in children less than 8 years of age has important differences from the adult cervical spine that must be understood when evaluating for traumatic injuries. These differences include C2–3 physiologic kyphosis, C2–3 pseudosubluxation, and incomplete fusion and ossification [17]. The entity of "spinal cord injury without radiological abnormality" otherwise known as

"SCIWORA" is more common in children than in adults and needs to be considered in the appropriate clinical setting [18]. This is a very challenging scenario to diagnose clinically in remote locations requiring transfer and consultation if possible.

Neck masses in children can be congenital or acquired, and they can be cystic or solid. Children have a large amount of lymph tissue, which has a low threshold for reactivity to infectious or inflammatory stimuli; in some cases, this can lead to life threatening suppurative complications especially in underserved communities [19]. There are many causes of lumps and bumps in a child's neck, some benign and some malignant. Lymphoma can cause cervical lymphadenopathy, neuroblastoma and rhabdomyosarcoma can present as a soft tissue mass, and cysts also commonly present in a similar fashion [20]. Ultrasound is a key imaging modality used in the diagnosis of neck masses in children. The differential of a neck mass, especially in the case of a cyst, when demonstrated on ultrasound, is largely dependent upon location. A midline cyst is likely to be a thyroglossal duct cyst, while off-midline cysts could be branchial cleft cysts (anterior) or lymphatic malformations (posterior), depending on their relationship to the sternocleidomastoid muscle.

US imaging of the thyroid gland can be used to evaluate for glandular enlargement or masses. Thyroid imaging is particularly useful in areas of iodine deficiency. The clinical exam in children remains difficult due to their shorter necks and possible behavioral cooperation issues. Due to the high frequency of thyroid enlargement in many parts of the world, ultrasound can be very useful in these challenging, resource poor areas [21].

Imaging modalities for the pediatric eye remain limited. In the context of pediatric ophthalmological trauma or congenital blindness, ultrasound imaging may be useful. Given how difficult pediatric eye exams can be, especially in the context of trauma, ultrasound techniques can be helpful [22].

Neurological

Common pediatric conditions in the neurological area include congenital hydrocephalus, intraventricular hemorrhages in the neonate, and various seizure disorders associated with tuberous sclerosis, neurofibromatosis, and Sturge-Weber syndrome. Parasitic infections, including those of the nervous system, will be covered later in this chapter.

US can be useful in confirming suspected hydrocephalus or intraventricular hemorrhages in an infant less than a year of age [23]. Once the anterior fontanel closes (between 6 and 12 months), CT and MRI are necessary to evaluate intracranial contents [24].

Respiratory

Children in LMICs are particularly susceptible to pneumonia especially bacterial pneumonia [25]. Predisposing factors include poor nutrition, low maternal education levels, increased exposure to tobacco smoke, and increasing use of institutional care (daycares, kindergarten). Children suffering from pneumonia in LMICs are also particularly prone to complications, including: pleural effusions, abscesses, empyema, and scarring [26]. X-rays are useful in the diagnosis of these complications and ultrasound-assisted aspirations can be used to help identify the organismal etiology as children are not able to provide adequate sputum samples. Naturally, in the areas where antibiotics are readily available there is increased antibiotic resistance, so it is extremely important to be able to access and identify causes of persistent fluid collections. Further comments on pediatric pneumonia are covered later in a specific disease section.

Cardiac

Cardiac lesions in children, both congenital and acquired, can be diagnosed and followed through the use of cardiac echocardiography (ultrasound) [27, 28]. Chest radiographs can be used to evaluate for cardiomegaly, pulmonary edema, and pleural effusions. Congenital heart disease presents later in low-resource areas due to the lack of these imaging technologies and low access to care [29]. These same areas also have high prevalence of acute rheumatic fever and endocarditis as a result of this low access.

The cyanotic newborn is also always a challenge for healthcare providers in LMICs and the bedside ultrasound can easily help with identification of cardiac lesions, which are amenable to surgical repair at various levels. Ultrasound would certainly help the clinician determine when and where to transfer a newborn with a heart condition as it provides functional and anatomical information. The identification of pericardial effusions and subsequent ultrasound-guided interventions can be lifesaving in the pediatric population especially when the patient is far from areas with advanced surgical assistance.

In select populations where thiamine deficiency is prevalent and which manifests as "wet beriberi" cardiomyopathy, cardiac ultrasound can help with management and follow-up of poor cardiac function [30].

Abdominal

Assessment of abdominal pain in children using ultrasound is considered standard of care throughout the world. The ability to screen for free fluid after blunt abdominal trauma with a FAST (focused abdominal sonogram in trauma) scan can be very helpful when a CT scan is unavailable especially since management of the pediatric patient is largely conservative for solid organ trauma including splenic and liver injuries [31].

Intussusception can be difficult to distinguish from hemorrhagic colitis (e.g., typhoid) on a clinical exam in the presence of bloody stools; however, the use of ultrasound can clearly identify the "target" appearance of the bowel leading to appropriate radiological or surgical management.

Abdominal complications of typhoid and dengue fever, such as perforation with free fluid, acalculous cholecystitis, and pancreatitis are common and should be considered in the pediatric patient who is not improving on medical management [32, 33].

Renal stones, with or without obstruction, are frequent in LMICs due to poor nutrition and hydration [34]. The urinary system is best imaged initially with ultrasound, and if necessary, by other modalities such as CT and VCUG [35]. In the setting of recurrent urinary tract infections diagnosed through point of care urinalysis, it is critical to have some imaging of the genitourinary tract to evaluate for hydronephrosis, reflux, and bladder calculi.

Liver and spleen pathologies are also common in low-resource settings especially related to tropical and other infectious diseases, but they are also commonly seen secondary to local genetic diseases such as thalassemia. Ultrasound can be useful in planning surgical intervention.

Musculoskeletal

Skeletal fractures in children are unique in two important ways. They can occur more often as incomplete fractures (pediatric bones are more elastic and can bend without breaking completely) or in the epiphyseal growth plates. Any injury or infection involving the growth plate can result in growth failure or excess leading to limb length discrepancies. This can be especially devastating in low-resource settings. Knowledge of the Salter-Harris fracture classification helps to ensure appropriate care and follow-up [36, 37] (Fig. 18.1).

Bone and joint infections are frequent in children living in low-resource settings. In addition, pyomyositis is common [38]. Ultrasound can be extremely helpful in determining location of infection as well as with assisting in draining local purulent pockets to relieve pain, provide diagnostic material, and guide further treatment.

Specific Common Pediatric Diseases in Low-Resource Settings

Tuberculosis (TB)

Tuberculosis (TB), due to *Mycobacterium tuberculosis*, is among the most prevalent causes of morbidity and mortality worldwide, particularly in LMICs. Overcrowding, poverty, lack of sanitation,

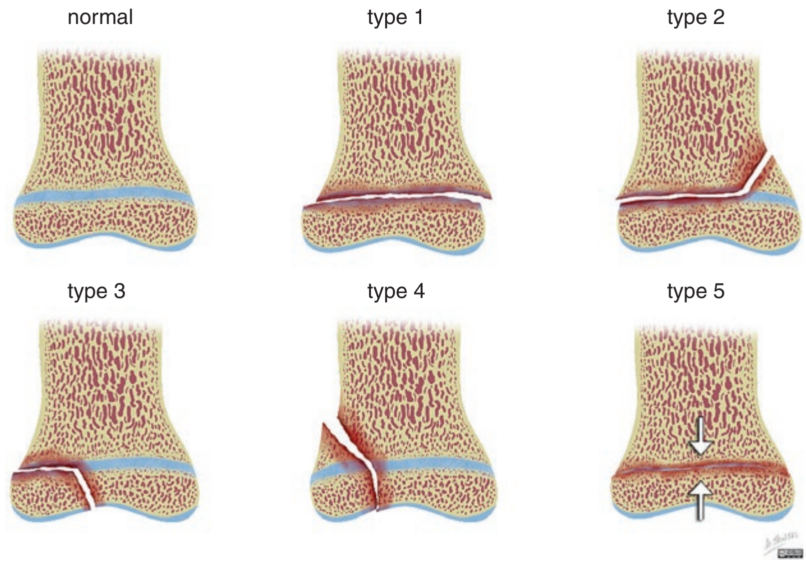

Fig. 18.1 Salter-Harris classifications. (Case courtesy of Dr. Matthew and Skalski [37]. Radiopaedia.org, rID: 27144; https://radiopaedia.org/articles/salter-harris-classification and https://radiopaedia.org/cases/salter-harris-illustrations-1)

and the HIV epidemic have all contributed to the resurgence of tuberculosis globally. The highest rates of tuberculosis are seen in sub-Saharan Africa and Southeast Asia [39]. Children are particularly susceptible to TB. Children are more likely to develop the disease after infection than adults and are also more prone to develop extrapulmonary and severe disseminated disease [40, 41].

TB infection is indicated by a positive tuberculin skin test (TST). Tuberculosis disease is also indicated by clinical symptoms and positive findings on chest radiograph. The risk of developing disease after infection has been estimated as 2% in children 5–10 years of age, 5% in children 2–5 years of age, 10% in children 1–2 years of age, and 30–40% in infants less than 1 year of age [42].

A definitive diagnosis of TB is dependent on many factors, including clinical history, symptomatic presentation, history of infectious contact, sputum smears, and the TST. Making the diagnosis of TB is difficult in LMICs due to lack of resources, and making the diagnosis is even more challenging in children for several reasons. First, children are less likely to manifest a cough productive of infected sputum for diagnosis [43, 44]. Less than 20% of children with proven TB will have a positive sputum or gastric aspirate as compared with 75% in adults [45, 46]. Moreover, the TST can be negative in a large proportion of children especially in low-resource areas as a result of a weaker immune reaction due to human immunodeficiency virus (HIV) or severe malnutrition [47, 48]. Diagnostic imaging, if available, could make significant contributions toward the diagnosis of this debilitating disease. If imaging can be used to limit the number of undiagnosed children, less will remain untreated and contagious to others around them.

Almost all cases of TB in infants and young children begin in the lung after exposure by inhalation. The initial, and sometimes only, manifestation of TB is often in the chest. Three different presentations are described: primary, reactivation, and miliary. Primary disease typically manifests as airspace opacities in one lobe with unilateral or bilateral hilar lymphadenopathy, and occasionally with unilateral or bilateral pleural effusions (Fig. 18.2). TB can present with lymphadenopathy alone, especially in very young children. Less common and less specific findings include segmental hyperinflation and atelectasis, effusions, alveolar consolidation, and interstitial densities [47]. Cavitation is rare in primary TB. These findings can be subtle on the chest radiograph. Thoracic CT, when available, can enhance visualization of small parenchymal lesions as well as mediastinal and hilar lymphadenopathy. CT, however, is scarcely available in LMICs and cannot be relied upon for diagnosis.

Ultrasound findings in pulmonary TB are being studied and further described, which may be useful in children living in low-resource areas [49].

Miliary disease, a complication of primary infection, is defined as the manifestation of disease that leads to discrete tiny nodules diffusely throughout two or more organs (Fig. 18.3). This form of TB is more common in very young patients and the immunosuppressed [39, 47]. When there is reactivation of primary TB, upper lobe predominant fibrosis and architectural distortion with cavitation are characteristic radiographic signs.

Children are particularly prone to extrapulmonary tuberculosis, which most often occurs in the abdomen, central nervous system, bones, joints, and skin [50]. The WHO Roadmap for Childhood Tuberculosis specifies that 30–40% of TB manifests as extrapulmonary disease [51]. Morbidity and mortality associated with TB are greatest when there is CNS involvement, especially meningeal (tuberculous meningitis), which can lead to blindness, deafness, intracranial calcifications, diabetes insipidus, and developmental delays. Of the patients presenting with meningitis, 80% are younger than age 4 years [52].

The abdomen is a common site of TB. Abdominal involvement can be seen with or without associated lung disease. Abdominal radiographs may demonstrate calcifications in the liver, kidneys, adrenals, or bladder. If available,

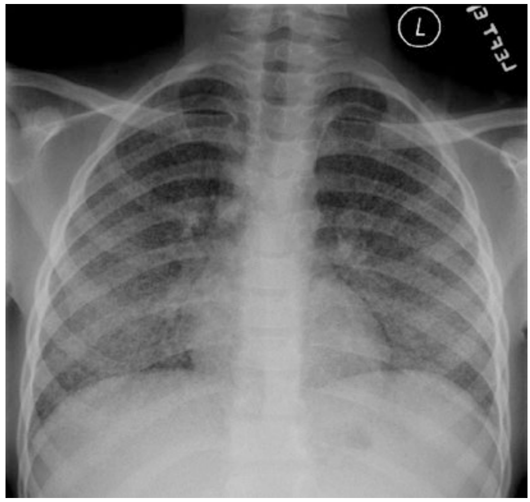

Fig. 18.3 Miliary tuberculosis in a 9-year-old male. Diffuse discrete tiny nodules are seen throughout the bilateral lung consistent with complication of primary infection. Miliary TB is a common manifestation in young and immunosuppressed patients

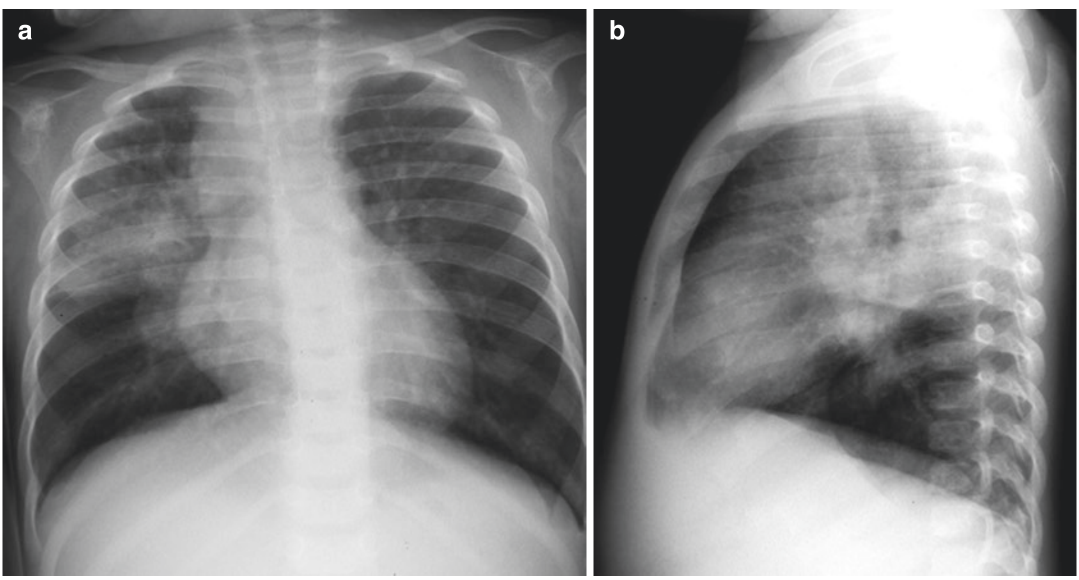

Fig. 18.2 Tuberculosis in a young boy. (**a**, **b**) Frontal and lateral radiographs of the chest demonstrate a right upper lobe opacity and associated right hilar lymphadenopathy

CT can demonstrate additional findings, including lymphadenopathy and changes affecting the ileocecal region of the bowel. When there is intestinal involvement, the ileocecal region is affected 90% of the time with the cecum and terminal ileum being contracted with wall thickening [50]. Enlarged lymph nodes may be seen in the mesentery and omentum, characteristically with hypoattenuating centers and hyperattenuating, enhancing rims. Renal involvement may present on CT, and occasionally on radiographs, as renal calcifications. Caliectasis and hydronephrosis may also be seen [50]. TB can also involve the adrenal glands. When bilateral, this can lead to adrenal insufficiency. Classic imaging findings include small adrenal glands with calcifications [53].

Musculoskeletal involvement is most often seen in the spine (50%). Tuberculous spondylitis most commonly affects the lower thoracic and upper lumbar spine [54]. The infection is due to hematogenous seeding of the vertebral bodies originating in the end plates. In children, the hematogenous spread may seed the disc instead which can lead to vertebral destruction and associated paravertebral soft tissue masses. Another musculoskeletal complication is septic arthritis leading to erosions and destruction of a joint (Fig. 18.4) [50].

Fig. 18.4 Tuberculous arthritis. Most commonly affects the hips and the knees. Reactive hyperemia leads to juxta-articular osteoporosis, erosions, and, ultimately, as in this 9-year-old boy, severe joint space narrowing

HIV/AIDS

HIV/AIDS has devastated children in LMICs in many ways. Currently about 1.8 million children are living with HIV and 150,000 are infected annually [55]. Most acquire the virus through vertical (mother-to-child) transmission, a combination of intrauterine, intrapartum, and postpartum exposures. Children can also be exposed during breastfeeding, which in most instances is the only form of nutrition that these children will receive [56].

Once infected, children with HIV in LMICs are particularly prone to complicating infections due to poor nutrition, lack of access to clean water and healthcare, as well as a high prevalence of gastrointestinal and respiratory pathogens in the community [57]. Opportunistic infections seen in HIV-infected children most often involve the upper and lower respiratory tract, the intestine, and the brain. Diagnostic imaging especially ultrasound can be very useful for diagnosis, assessment, and follow-up of many of these complications [58].

Although HIV/AIDS predisposes its host to unusual and opportunistic infections, the most common infections are community-acquired. In one study by Chakraborty, 58% of HIV-infected children died from pyogenic pneumonia [59]. The most common etiology of respiratory infections in this population is bacterial. Fifty percent are focal and consolidative, while the remainder are diffuse, nodular, or cavitary. Findings of bronchopneumonia in HIV patients have significant overlap with those of TB.

AIDS patients are predisposed to opportunistic infections such as PCP (*Pneumocystis* pneu-

Fig. 18.5 PCP in a HIV-positive young adult. Diffuse granular and reticular opacities in a perihilar distribution. The incidence of PCP has significantly decreased with TMP-SMX prophylaxis

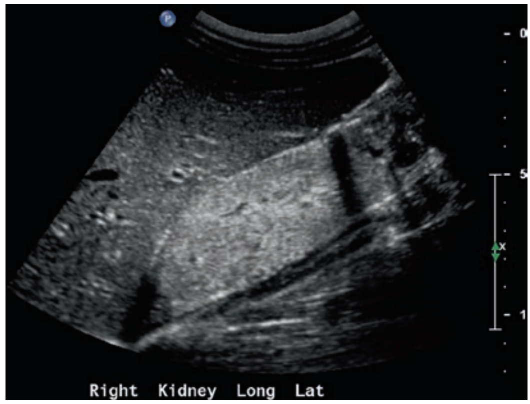

Fig. 18.6 HIV-positive male with diffusely echogenic right kidney consistent with HIV nephropathy. There is loss of corticomedullary differentiation junction and there is a clear increase in echogenicity of the kidney in relation to the normal liver

monia). Fortunately, its prevalence is decreased where HAART and prophylactic trimethoprim-sulfamethoxazole (TMP-SMX) are available [44]. Chest X-ray (CXR) findings can be normal in up to 40% of patients with PCP. Others will have bilateral perihilar finely granular, reticular, or ground glass opacities (Fig. 18.5) [60]. Other opportunistic fungal infections may demonstrate focal alveolar opacities or multiple pulmonary nodules.

HIV-infected pediatric patients may also suffer from dilated cardiomyopathy which is likely due to immune-mediated mechanisms, opportunistic infections which directly invade myocardial cells, or a primary infection of myocardial cells by HIV itself [61]. The CXR may reveal cardiomegaly, and in severe cases, signs of congestive heart failure. HIV-associated nephropathy may lead to proteinuria, hematuria, renal tubular acidosis, and end-stage renal disease. Sonographic findings include large, echogenic kidneys and decreased corticomedullary differentiation (Fig. 18.6) [62].

CNS involvement is common in HIV/AIDS. In Chakraborty's study, 18% of HIV/AIDS-infected children died from pyogenic meningitis [59]. Cranial CT findings of HIV infection include generalized (or frontally predominant) cerebral atrophy and basal ganglia calcifications [63].

Diarrhea

Although often thought of as simply a nuisance in high-income nations, diarrheal dehydration is one of the leading causes of death of children in LMICs. Lack of clean water is often the major cause, although other endemic diseases such as HIV are also significant contributors. Common pathogens causing diarrhea in children include rotavirus and *Escherichia coli* [64]. In the HIV population, they include cytomegalovirus, *Mycobacterium avium-intracellulare* (MAI), *Giardia*, and cryptosporidiosis [64, 65].

Imaging does not play a major role in the diagnosis and management of diarrhea in children; in particular, radiographs of the abdomen are rarely helpful as many of the imaging findings are not specific to any particular disease entity. Nonspecific findings include focal dilatation of small bowel loops, air fluid levels, or bowel wall thickening, primarily due to malabsorptive fluid loss [66].

If needed, the small bowel can be more thoroughly evaluated with an upper GI study with small bowel follow-through. This study requires fluoroscopy and barium (or another suitable oral contrast agent). In performing this study, transit time of contrast is worth noting, as normally barium passage through the small bowel usually occurs in 1–2 h. Note that in the diarrhea workup, in contrast, transit time can be normal, short, or longer than normal. This study may also reveal bowel wall thickening, particularly in the setting of CMV (thickened and edematous folds with deep ulcers and ulcerations), MAI (diffuse enteritis with thickened folds and a micronodular mucosal patterns), candidiasis (diffuse mucosal edema and linear filling defects), and cryptosporidiosis (secretory enteritis with thickened folds). Another common etiology of diarrhea is Whipple disease, caused by *Tropheryma whipplei* which preferentially affects the duodenum and proximal jejunum causing thickening of their mucosal folds [67].

Overall, contrast studies are not shown to help in discriminating between disease etiologies reliably. They rarely alter management and are rarely indicated in the workup of diarrhea [67–70]. If CT is available, it may show wall thickening of the colon or small bowel, and perhaps associated mesenteric lymph nodes [67]. In children with bloody stools, ultrasound may be very helpful in distinguishing between an enteric infection and intussusception in the appropriate clinical setting.

Malaria

Imaging plays little role in the diagnosis of malaria, as the diagnosis is made using peripheral blood smears and the clinical history. Imaging, however, may show findings concordant with the diagnosis of malaria. For example, ultrasound of the abdomen may reveal hepatosplenomegaly [69]. In fact, in children with acute abdominal pain, it is important to note that a life-threatening complication of malaria is splenic rupture, due to acute splenic enlargement and infarction. Emergent ultrasound in the setting of acute abdominal pain and malaria infection can help identify this complication [71].

Parasitic Infections

Echinococcus, the pathogen leading to hydatid disease, is still a frequent cause of liver and lung disease in many countries in LMICs. Hydatid disease is endemic in China, Africa, the Mediterranean, Balkan Countries, the Middle East, and South America, but it is now being seen more commonly worldwide due to globalization and migration [72].

The most common routes of infection are through ingestion of contaminated water or uncooked food, or from direct hand-to-mouth fecal transmission which often occurs in settings of low socioeconomic status and poor sanitary conditions [73]. Close human contact with dogs and livestock pose a particular risk. Serological tests can be used to confirm the presence of hydatid disease if available, but have variable sensitivity and are best used together with imaging techniques [74].

The liver is involved in 50–89% of cases of hydatid disease, more than the lung (10–30%) and other organs (10–20%) [75]. Most often, liver involvement takes the form of a solitary cyst although multiple liver cysts may also be seen [76]. Classic radiographic findings include hepatomegaly and scattered radiolucencies outlined by calcified rings. These findings are seen in up to 30% of cases on plain radiographs [77]. Densely calcified cysts are usually thought to represent inactive disease [78]. There is a predilection for involvement of the right lobe of the liver. Portable ultrasonography machines can be highly sensitive for cystic hepatic disease when available; ultrasound findings in unilocular hydatid disease include a smooth-walled cyst with anechoic fluid content and posterior acoustic enhancement. A cyst can also have mobile, dependent, echogenic hydatids, which are composed of brood capsules and free scolices [79]. Multivesicular cysts may demonstrate a honeycombing pattern with multiple septa representing the walls of the daughter cells. If CT is available, classic findings of *Echinococcus* show a mass with central necrosis and septations with a plaque-like rim of calcifications (Fig. 18.7) [80].

The radiologist should be aware of several important complications of hydatid cyst disease. For example, rupture of a hydatid cyst can occur in as many as 90% of cases and can often be clinically silent, but may lead to anaphylaxis due to release of antigens [77, 80]. Both US and CT can demonstrate a cyst wall defect with passage of cyst contents outside of this defect. Clinicians should be immediately notified and clinical anaphylaxis precautions arranged.

In addition to rupturing, hydatid cysts may become secondarily infected with bacteria, in which case the patient may present with right upper quadrant pain, leukocytosis, and fever. US findings of a secondarily infected cyst are nonspecific. US can demonstrate poorly defined margins with a solid appearance, mixed solid and fluid appearance, internal echoes, and air fluid levels. CT is more sensitive than US. CT findings include a poorly defined mass with a high attenuating rim suggesting that an abscess is surrounding the underlying cyst; gas and air fluid levels can also be seen [80].

Echinococcus infection may reach the lungs via hematogenous spread, which are the second most common sites of documented involvement. On plain radiographs, uncomplicated cysts appear as well-described masses and vary from 1 to 20 cm in diameter [81]. Cysts are usually multiple, bilateral, and located in the lower lobes in 60% of the cases [39]. Most of the cysts are acquired in childhood and remain asymptomatic. Cyst rupture may lead to sudden coughing attacks, hemoptysis, and chest pain [82]. Coughing may be productive of a large amount of clear fluid from the previously walled-off cyst. Organs less commonly affected by hydatid disease include the kidney, spleen, bone, and brain.

An additional parasite common in LMICs is *Taenia solium*. Humans are the definitive host of *T. solium* and acquire this intestinal tapeworm via ingestion of pork containing larval cysts. Humans can also become infected through the fecal-oral route from a tapeworm carrier which commonly occurs in close quarter environments. The most important implication of infection is the development of neurocysticercosis, which is one of the most common causes of acquired epilepsy in LMICs. It is thought to be the cause of over 30% of afebrile seizures in children in low-resource settings [83] . MRI is the most sensitive modality to detect neurocysticercosis but it is rarely available in LMICs; therefore, a combination of CT (if available) and serological testing should be used for diagnosis in these areas [84].

Neurocysticercosis has a propensity to affect, in decreasing order, the cisterns, parenchyma, and ventricles. CT findings depend on the stage of disease. During the early vesicular stage, the disease manifests as round or ovoid cysts which are solitary in 20–50% of cases (Fig. 18.8).

Fig. 18.7 Echinococcus (hydatid) disease. An 18-year-old male from Egypt with right upper quadrant pain. There is a large complex cystic mass within the right lobe of the liver. Numerous septations are also seen. Furthermore, the wall of the hydatid cyst is well-defined without definitive surrounding edema

Fig. 18.8 Neurocysticercosis. A 17-year-old male from South America with cystic lesion within the left middle cranial fossa and suprasellar cistern. Both of these cysts regressed with treatment

The classic finding of a hyperdense focus, the protoscolex, within the cyst makes the diagnosis of neurocysticercosis even more definitive. In the colloidal vesicular stage, hyperdense fluid with surrounding edema is seen as the larva are degenerating (Fig. 18.9). In the granular stage, mild edema is the predominant finding, while in the nodular stage, a small, calcified nodule may be seen [85]. It is important to note that lesions may be present in different stages in the same patient.

Amebiasis, caused by the intestinal protozoan *Entamoeba histolytica*, is endemic worldwide, and it is estimated that approximately 10% of the world's population is infected; however, only approximately 10% of infected individuals develop amebic liver abscess or colitis [86, 87]. The inflammatory changes within the colon are seen within the cecum and the ascending colon (Fig. 18.10) [87]. Hepatic infections occur as a result of colonic trophozoites which have ascended via the portal vein and invaded the liver parenchyma. As compared with patients with pyogenic liver abscess, patients with amebic liver abscess are usually younger and more acutely ill with high fevers. The ultrasound appearance of an amebic abscess is that of a rounded hypoechoic area within the right liver lobe with low-level internal echoes and an absence of significant wall echoes [86]. CT findings demonstrate a unilocular

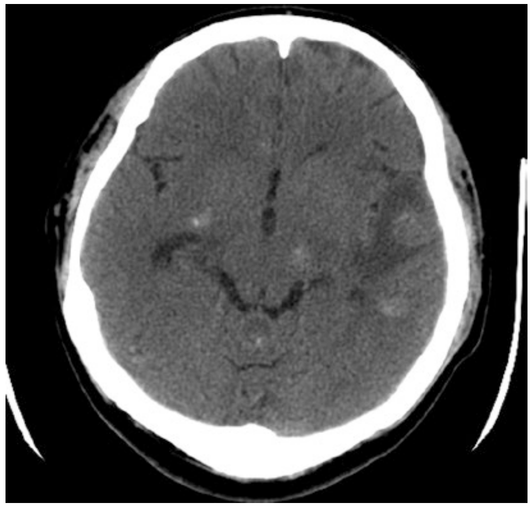

Fig. 18.9 Neurocysticercosis. An 18-year-old female with numerous areas of hyperdensity within the cerebral hemispheres. Furthermore, these hyperdense lesions are surrounded by areas of hypodensity likely consistent with surrounding edema

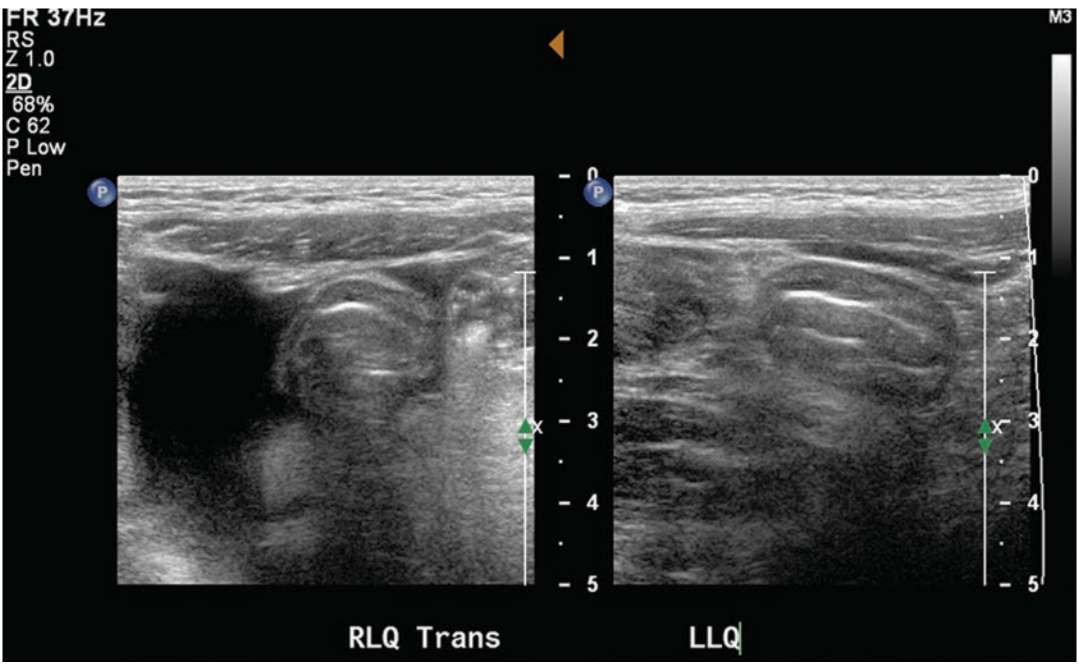

Fig. 18.10 Amebic pan colitis. A 10-year-old male from Peru with diarrhea. US shows diffuse mural thickening of the colon within the right and left lower quadrant consistent with pancolitis. There is an appearance of echogenic submucosa due to edema

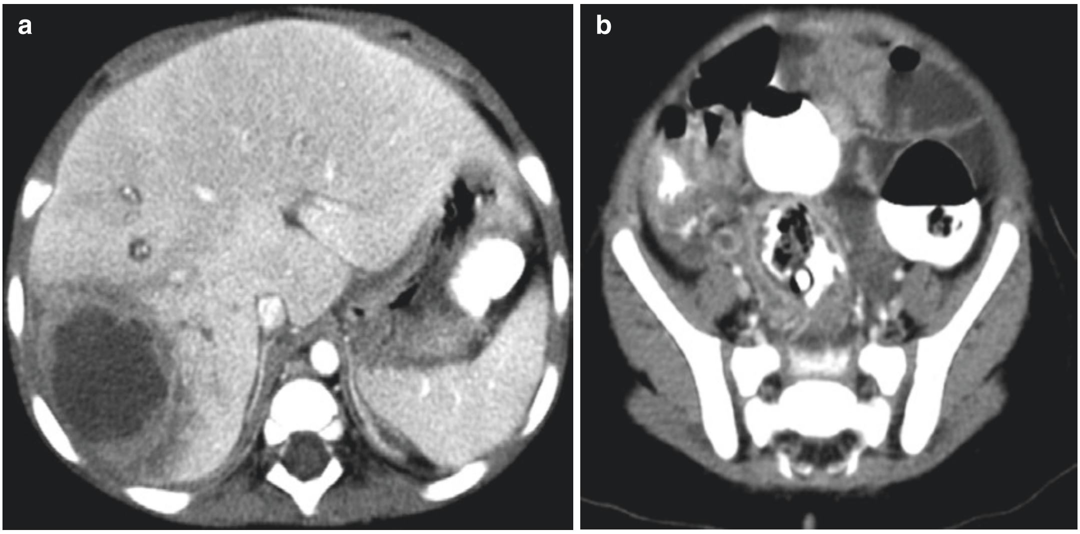

Fig. 18.11 (**a**) Amebic abscess. A 4-year-old male from Central America. There is a large amebic abscess within the right hepatic lobe with a shaggy internal wall and peripheral zone of edema. The abscess was treated with antimicrobials and a pigtail drainage catheter. (**b**) Amebic colitis. Patient also demonstrated diffuse right colonic thickening and inflammation on the same CT

or multilocular hypodense lesion made up of complex fluid (10–20 HU). Further findings include a hyperdense capsule and an area of peripheral low attenuation, due to marked edema, surrounding the abscess (Fig. 18.11) [86].

Neonatal Pneumonia, Meconium Aspiration, and Surfactant Deficiency

Infant mortality rates in LMICs are significantly higher than in high-income nations. Prenatal care is often lacking in LMICs, as is the capability to address acute perinatal problems. Because of the availability of conventional radiography, diagnostic imaging has the potential to impact pulmonary disease in these populations. Respiratory distress in a newborn may be secondary to meconium aspiration, neonatal pneumonia, surfactant deficiency disease (also known as hyaline membrane disease or HMD), or cardiac disease. A CXR can often distinguish among these possibilities.

Surfactant deficiency disease (SDD) is seen almost exclusively in premature babies. In high-income nations, exogenous surfactant is administered to premature infants at risk. This therapy can decrease the need for oxygen and ventilator support, the risk of intracranial hemorrhage, bronchopulmonary dysplasia, and overall morbidity. Exogenous surfactant, however, is expensive and not widely available in LMICs. The classic appearance of SDD is that of diffuse ground glass opacification with air bronchograms and low lung volumes on CXR (Fig. 18.12). When surfactant therapy is administered, there is a near complete, central, or asymmetric clearance of findings of SDD [88].

Neonatal pneumonia is an alternative, treatable diagnosis that must be considered in the neonate with respiratory difficulties. Pneumonia should be suggested when the opacities are linear rather than diffuse/ground glass, when lung volumes are preserved, and when there is persistent pleural fluid. Neonatal pneumonia is a major cause of morbidity and mortality, and it can be acquired via an intrauterine route, during birth, or soon after delivery. Many women in the high-income countries are tested and receive treatment for b-hemolytic streptococcal pneumonia. LMICs have a slightly different bacterial profile in neonatal pneumonia infections [89]. Premature infants are at greater risk for developing GBS

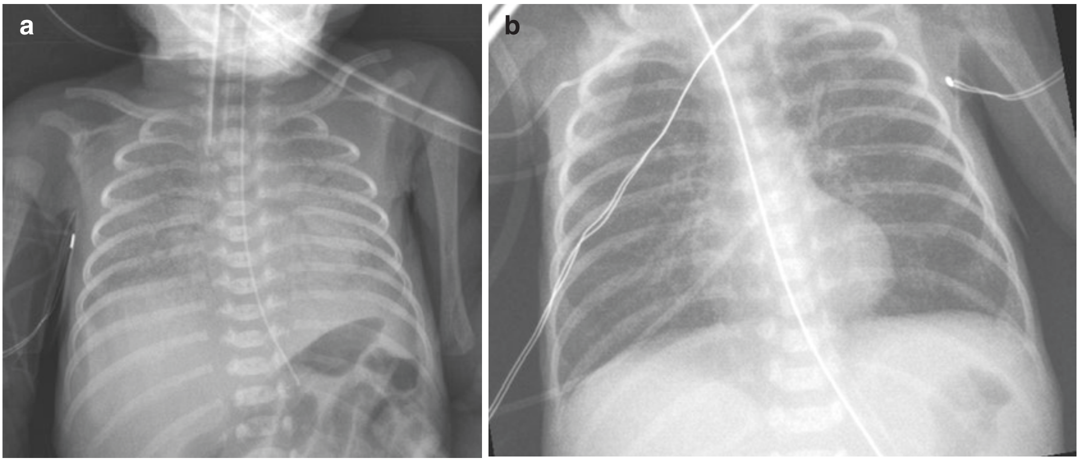

Fig. 18.12 (**a**) Surfactant deficiency disease in a premature infant. Diffuse ground glass opacities are seen with low lung volumes bilaterally. (**b**) Same patient after receiving surfactant therapy leading to complete resolution of the previously seen diffuse opacities

pneumonia after being exposed to the bacteria during delivery. The radiographic findings of group B streptococcus pneumonia can mimic SDD [88].

Meconium aspiration syndrome can have a similar appearance to neonatal pneumonia, although the opacities tend to be more heterogeneous, and the lung volumes can be dramatically increased. Pneumothorax complicates meconium aspiration in approximately 20% of babies (Fig. 18.13). The radiographic picture can be difficult to distinguish but the clinical history is often strongly suggestive. The delivering physician will suspect meconium aspiration based on meconium-stained amniotic fluid. If suction devices are available, meconium may need to be suctioned below the vocal cords in limited circumstances [90].

Fig. 18.13 Meconium aspiration. Heterogeneous bilateral opacities with normal to slightly increased lung volumes in a newborn infant. Furthermore, there is evidence of a right basilar pneumothorax

Non-accidental Trauma and Child Maltreatment

Injuries from maltreatment are seen throughout the world [91]. It is extremely important that healthcare providers are aware of diagnostic imaging findings that will help with identifying children at risk for this problem. While many of the findings including fracture patterns and head trauma which can be subtle and nonspecific, the possibilities of non-accidental trauma must always be considered [92]:

- Metaphyseal corner fractures (Fig. 18.14)
- Rib and sternal fractures
- Scapular fractures
- Spiral long bone fractures in on weight bearing children
- Skull fractures
- Multiple fractures of varying body parts and in various stages of healing

Fig. 18.14 An example of a metaphyseal fracture *(arrow)* seen in non-accidental trauma and child maltreatment

- Chronic subdural hematomas and subarachnoid hemorrhage
- Duodenal hematomas
- Pancreatitis
- Lacerations of contusions of intra-abdominal viscera

Conclusion

Ultrasound and conventional radiography are the workhorses of pediatric imaging worldwide. Community-acquired pneumonia and trauma are most prevalent, but the global health imager must be prepared to recognize rare infections and conditions commonly seen in LMICs, like *M. tuberculosis*, HIV/AIDS, parasites, and thiamine deficiency to which children are particularly susceptible.

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19 Maternal-Fetal and Women's Imaging for Global Health Radiology

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Introduction

The state of maternal-fetal and women's health in low- and middle-income countries (LMICs) remains appalling despite growing global attention. Every year approximately 350,000 women in the world die while pregnant or giving birth, up to two million newborns die within their first year of life, and there are 2.6 million stillbirths [1]. Each day 3500 women experience birth complications and 900 are likely to die. Since the adoption of the Millennium Development goals (MDGs) by the United Nations in 2000, deployment of resources toward Goals 3 and 4 (reducing child mortality and improving maternal health) yielded little improvement by the end of the target deadline of 2015. A renewal effort known as the Sustainable Development Goals (SDGs) replaced and expanded the original eight MDGs to include 17 distinct targets. Developed by a group of 190 world leaders, these goals focus on ending extreme poverty, fighting inequality and injustice, and repairing global climate change.

Examination of the published epidemiologic data from around the world reveals unique characteristics and dissimilarities of countries with high maternal mortality. This chapter examines the scope of morbidity and mortality for women of reproductive age and their offspring, with special attention to conditions that can be diagnosed by ultrasound imaging. An overview is presented on the impact of regional, legal, and sociopolitical customs in target communities on practice of prenatal ultrasonography and how obstetric imaging may play a crucial role in reducing maternal and perinatal mortality. Published outcomes of projects using trained indigenous healthcare providers in the use of ultrasound are promising. With increasing availability of ultrasound technology, the replication of these prototype projects (coupled with other social and educational changes) could lead to improved maternal-fetal outcomes and achievement of Sustainable Development Goal 3 – "Ensure healthy lives and promote well-being for all at all ages." [2]

The gap in healthcare outcomes between high-income countries (HICs) and low-income countries (LICs) is especially disparate in the field of maternal-fetal and women's medicine. While global maternal mortality rates have declined

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since 1980, they remain unacceptably high in low- and middle-income countries (LMICs). Of the nearly 287,000 reported maternal deaths in 2010, 99% were preventable and occurred in LICs [3, 4]. Despite accounts from the United Nations reporting a drop in maternal mortality by 50–60% since 1990 in parts of Asia and northern Africa, the maternal mortality ratio (those who survive compared to those who die) remains 14 times higher in high-income countries. Despite upward trends of increased prenatal care, only half of women in LMICs receive the recommended amount of care [2].

Similarly, neonatal mortality rates (death within the first 4 weeks of life) were equally disproportionate, as an estimated 99% of the reported four million global neonatal deaths per year occurred in low-resource areas [5]. Of these deaths, prematurity, low birthweight, and asphyxiation account for 52% [6].

High maternal-fetal death rates not only impact the affected individual, but also affect the local community and nation. The World Health Organization (WHO) submits that maternal-fetal health tragedies contribute significantly to "poverty and [inhibit] affected individuals' full participation in socio-economic development" [7]. The knowledge that most of these tragedies are considered preventable creates an incentive for further action.

This chapter reviews the epidemiological characteristics of disease in perinatal medicine as well as the impact of imaging, particularly ultrasound, on these disease processes. Unique sociopolitical and regulatory settings of different countries regarding maternal-fetal imaging are examined, as well as the variation in availability of resources affecting use of technology.

Background and Epidemiology

In the year 2000, 193 nations and other international groups met at the Millennium Summit and established eight Millennium Development Goals (MDG) to improve socioeconomic conditions in LMICs. Of these, Goals 4 and 5 were specifically targeted to reduce childhood mortality by 67% and maternal mortality by 75% by 2015. The maternal mortality ratio (MMR) for any given country is the number of maternal deaths per 100,000 live births during a given timeframe. Although some reduction in maternal mortality was achieved, 15 years later, Goal 5 remained elusive, with persistently high MMR in LICs. This rate is nearly 15 times higher in LICs than HICs, with sub-Saharan Africa and Southeastern Asia accounting for 85% of the global burden [3, 4, 8] (Fig. 19.1). In some African countries the maternal mortality ratio is 620 per 100,000 live births compared to 14 per 100,000 live births in HICs. Fifty-eight LIC countries are identified as contributing to 91% of the global burden of maternal mortality, 80% of stillbirths, and 82% of the neonatal mortality [1]. There are also disparities between urban and rural regions, with rural areas demonstrating worse outcomes [6].

Globally, over 70% of maternal deaths are due to the specific complications of pregnancy and childbirth of hemorrhage, infection, eclampsia, and obstructed labor. For perinatal mortality, the leading causes are infection, birth injuries, preterm births, and birth defects [5, 9]. Because these deaths are largely preventable, numerous publications have discussed potential strategies for intervention: increasing access to emergency obstetric services, increasing availability of skilled healthcare providers, increasing access to antibiotic treatment, employing safe abortion practices, and promoting disease prevention through hygiene-focused health education [10–12].

WHO in 2016 [13] published its priorities for reducing maternal and perinatal mortality, and stated that "effective prevention and management of conditions in late pregnancy, childbirth and the early newborn period are likely to reduce the number of maternal deaths, antepartum and intrapartum stillbirths and early neonatal deaths significantly" This group outlined the importance of quality of care based on best practices for identifying "essential interventions" such as treatment of pre-eclampsia. However, admittedly this requires availability and appropriate use of infrastructure and resources, as well as knowledge and attitude of providers. Quality measures and benchmarking were identified by consensus among experts from many countries. Operational

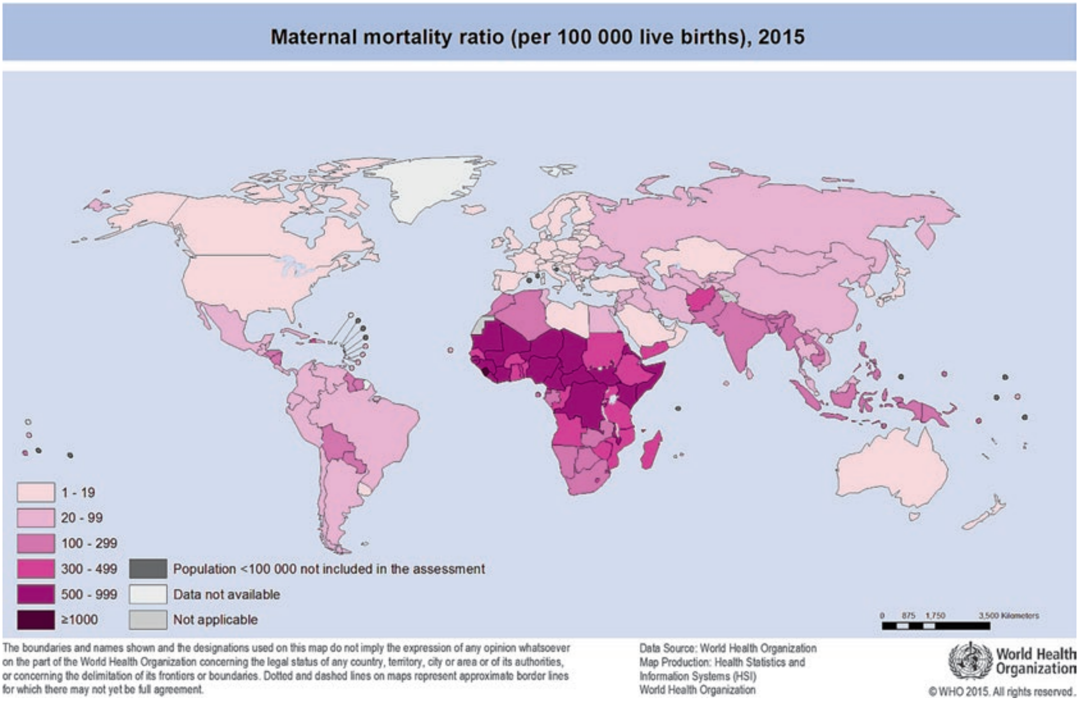

Fig. 19.1 Maternal mortality ratio worldwide in 2015. (Reprinted with permission from WHO Map: Maternal mortality ratio (per 100,000 live births), 2015, Health Stats and Info Systems, http://gamapserver.who.int/mapLibrary/Files/Maps/Global_mmr_2015.png)

definitions developed from these include very specific quality measures. One such measure specific to ultrasound is Quality Statement 8.3 defining availability of supplies and equipment needed for routine care and management of complications. It specified that each health facility should have in place "a functioning diagnostic ultrasound machine and trained health staff who can conduct a basic obstetric ultrasound examination to determine the number of fetuses present, gestational age, prenatal diagnosis of fetal anomalies or early diagnosis of placental insufficiency" [13].

Maternal mortality can also extend to the infant in LICs. For example, in some sub-Saharan African cultures, it is culturally unacceptable to wet nurse an infant born to a woman who dies in childbirth, so if a baby is not accepted into an orphanage, the infant is abandoned to starve to death.

Women who are not childbearing but of reproductive age still have an alarming mortality rate in LICs. A recent study from a tertiary care center in Nigeria (2013–2015) reported that of the 340 deaths of women of reproductive age (out of 2606 female admissions), 77.9% were from nonpregnancy-related causes. Of those, the primary causes of death were infectious disease (46.8%) and disease of the circulatory system (24.5%), followed by female cancers (total 19.25%), trauma (6.8%), and others. Maternal deaths accounted for about a fourth of the deaths of women in this center. Of those maternal deaths, 41% were due to hypertensive disorders, 27% due to puerperal sepsis, 20% due to hemorrhage, and 8% due to obstructed labor. By mode of delivery, 48% were by cesarean section, 36% were by vaginal delivery, and 6.7% died undelivered. It was thought that many of these women presented late with complications, which increased their risk of death [14].

Similarly, perinatal and neonatal mortality rates remain unacceptably high in LICs, with most of these deaths occurring in five countries: India, Nigeria, China, Pakistan and Democratic

Republic of Congo. Although global perinatal mortality rates have decreased by 28% between 1990 and 2009, this reduction was not sufficient to reach the target for MDG 4 by 2015 [15, 16].

Outcomes in Maternal Child Health are related to multiple factors, including healthcare delivery, socioeconomic, environmental, and cultural factors; therefore, no one technology or innovation can be expected to remedy all disparities. The utility of ultrasound imaging in the HICs has proven to be valuable in the early detection of common obstetric and gynecologic complications. Although research into its utility for use in LICs is not yet extensive, experience from HICs suggests that this technology may play a key role in early diagnosis and management of common maternal-fetal conditions. This review will address the potential value of ultrasound for the management of these conditions in LMICs.

Role of Ultrasound

Ultrasound (USD) is currently the most widely employed imaging modality for evaluating fetal well-being during pregnancy [17–19]. Its value for use in pregnancy has led most national and international organizations to recommend it as a standard exam for all pregnancies. The Federation of Gynecology and Obstetrics (FIGO) [20] has issued a recommendation that all pregnant women should be offered at least two ultrasounds in pregnancy.

Ultrasound has many advantages over other imaging modalities such as good image resolution, the ability of the operator to enhance images in real time, and immediate identification or diagnosis. The machines are portable and compact, allowing them to be used in most any location. They can also be programmed to be used for other clinical applications. Especially relevant for fetal imaging is that ultrasound does not use ionizing radiation for imaging acquisition.

While access to sonography may be limited in LMICs, the recent introduction of compact and affordable units may allow more widespread use of this technology [21]. These small units are not only portable, but they are sturdy; some offer unique features such as a rechargeable or solar battery, which are well-suited for areas with unreliable electricity. Many of the newer portable machines offer as standard the additional technology of color Doppler, improved image resolution, and DICOM (Digital Imaging and Communications in Medicine) or image transfer capabilities. There is early evidence that compact machines provide enough information to determine appropriate triage for patients with obstetric emergencies [22].

The field of teleradiology is expanding globally. One innovation includes the Imaging the World initiative. This program allows transmission of images from a portable ultrasound via mobile phone. Pilot programs now exist in sub-Saharan Africa, India, and China [6]. Other telecommunications platforms are also in use wherever cell or satellite service is available.

The impact of imaging on maternal-fetal outcomes in LMICs remains an ongoing area of research. Studies consistently demonstrate evidence of improved maternal/fetal management with the use of ultrasound [6].

Causes of Maternal Mortality and Use of Ultrasound

By knowing the causes of morbidity and mortality, inference of potential roles of imaging can be made. The impact of obstetric ultrasound may be seen in conditions specific to the mother, fetus, and a few syndromes when fetal illness affects maternal health.

Maternal Hemorrhage

Hemorrhage is the leading cause of maternal mortality in both low- and middle-income countries worldwide [23]. The utility of ultrasound in detecting causes of hemorrhage cannot be overstated – it is most useful for detecting abnormal placentation, uterine abruption, abnormal implantation, failed pregnancy, and retained products of conception (POC).

Ectopic Pregnancy

An ectopic pregnancy is a complication of pregnancy in which the embryo implants outside the uterine cavity. With rare exceptions, ectopic pregnancies are not viable. Furthermore, they are dangerous for the mother, since internal hemorrhage is a life-threatening complication. Hemorrhage secondary to ruptured ectopic pregnancy is an important and preventable cause of early pregnancy-related deaths in both HICs and LICs. Clinical diagnosis of ectopic pregnancy can be difficult as the typical signs and symptoms of irregular vaginal bleeding (tender palpable adnexal mass, and abdominal or pelvic pain) may not always be present. In patients presenting with a positive pregnancy test and non-specific signs and symptoms, ultrasound can be very useful in confirming or excluding an ectopic pregnancy. Typical sonographic findings in ectopic pregnancy include: an adnexal mass containing a yolk sac or embryo, adnexal mass without an intrauterine gestational sac (Fig. 19.2), large amount of free cul-de-sac fluid, or presence of a normal gestational sac in an ectopic location such as the uterine cornua or cervix (Fig. 19.3). A right upper

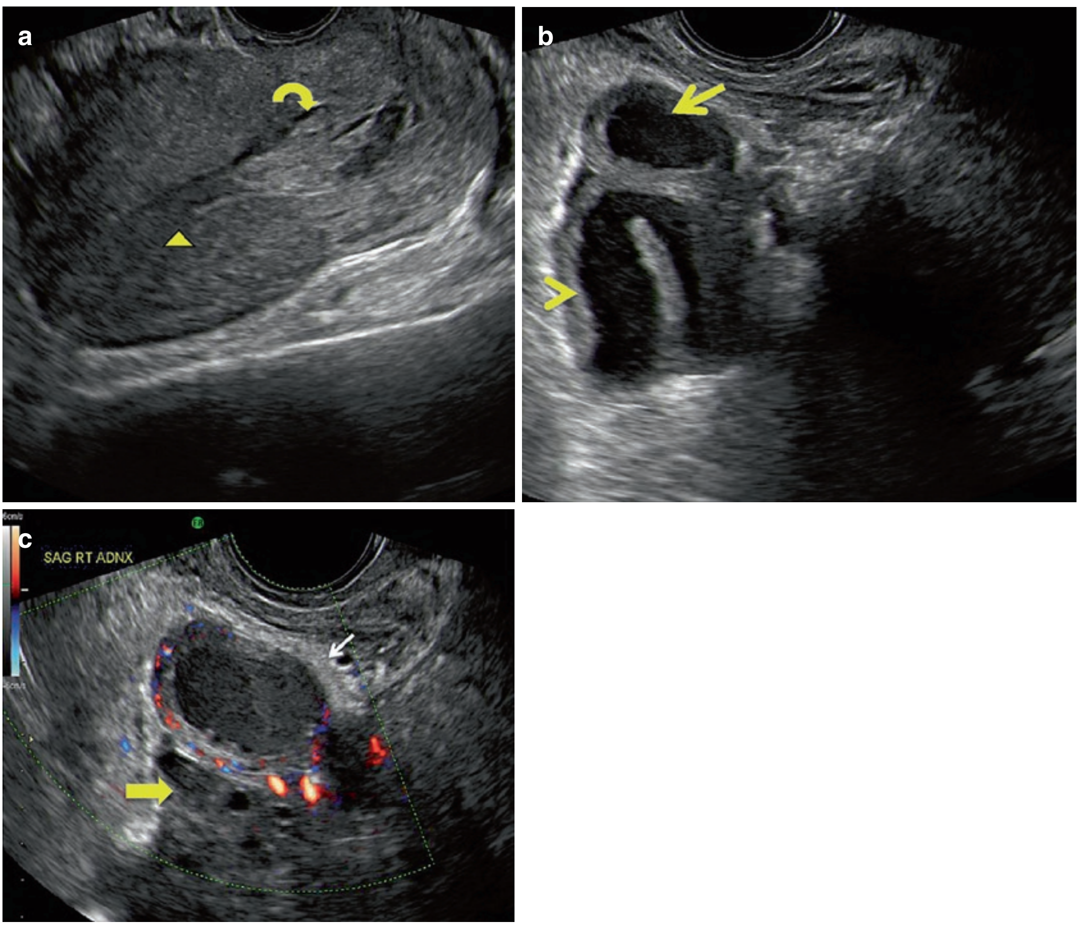

Fig. 19.2 (**a**) Sagittal midline view of the uterus on endovaginal ultrasound performed at 10 weeks of gestation by clinical dates. There is a thin endometrial stripe (*arrowhead*) in uterus without gestational sac. Note blood products in the lower uterine segment and cervix (*curved arrow*). (**b**) Sagittal imaging in the right adnexa in the same patient demonstrates a thickened, dilated fallopian tube (*arrowhead*). *Arrow* demonstrates a mass at the end of the fallopian tube, highly suspicious for a tubal ectopic pregnancy. (**c**) Sagittal Doppler imaging of the right adnexa in the same patient demonstrates further detail of the adnexal mass (*white arrow*) with peripheral blood flow (*ring of fire*). Note that this mass is separate from a normal ovary seen just inferior to it (yellow arrow). (Reprinted from Omonuwa et al. [24], Fig. 20.2, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

quadrant view looking for free fluid in Morison's pouch (below the liver) can aid in the diagnosis [23]. Early diagnosis may potentially allow urgent surgical intervention, thereby averting serious complications including death upon rupture.

While the incidence of ectopic pregnancy has increased in the United States, mortality from its complications has declined in recent years. Much of this decrease has been attributed to early detection by ultrasound imaging [25, 26]. Similarly, in LICs, where ultrasound has been utilized, diagnosis of ectopic pregnancy prior to rupture and subsequent intervention has resulted in the reduction of maternal morbidity and mortality [27, 28].

Abnormalities of the Placenta and Cord

Implantation Abnormalities

Ultrasound evaluation of placental implantation can provide valuable information concerning maternal risk in pregnancy. The placenta normally attaches to an intact endometrial lining within the uterus. With scarring from previous Caesarian section, prior instrumentation, or trauma, the placenta may invade to (accreta), into (increta), or beyond (percreta) the myometrium. Mild degrees of invasion (accreta) may not produce clinical symptoms, but could result in marked intra- or post-partum hemorrhage with severe cases resulting in hysterectomy or maternal death. With prior knowledge of an implantation abnormality, strategies for delivery may be planned to avoid serious complications. Although MRI is most accurate at determining degree of invasion and detection of posterior placenta accreta, recent studies have shown that USD is also reliable, detecting 50–80% of placenta accrete [29]. Sonographic findings of loss of the retroplacental clear space and presence of multiple lacunar spaces within the placental body may be suggestive of an implantation abnormality (Fig. 19.4). For women who are at high risk for an implantation abnormality, USD may be an effective, low cost alternative to MRI, particularly in LMICs where access to MRI may be limited [30].

Previa

Clinical symptoms of painless vaginal bleeding can be attributed to a number of causes including uterine fibroids, cervical polyps, placenta previa, or vasa previa. Of these, both placenta previa and vasa previa may result in significant maternal or

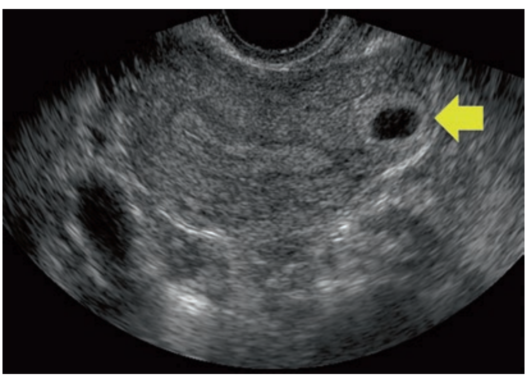

Fig. 19.3 Endovaginal ultrasound of another patient with positive beta-HCG. Transverse view of the superior uterus shows an eccentric implantation of the gestational sac in the uterine fundus with minimal myometrium surrounding it (*wide arrow*). The ovaries were normal (not shown). Findings are consistent with cornual ectopic pregnancy. (Reprinted from Omonuwa et al. [24], Fig. 20.3, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

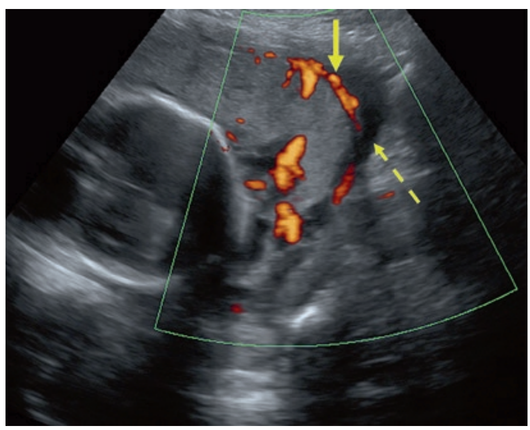

Fig. 19.4 A 32-year-old patient with history of prior Caesarian section, presented with hematuria. Color Doppler imaging demonstrates placenta (*solid arrow*) abutting the maternal bladder (*dashed arrow*) without intervening myometrium, suggesting invasion of the placenta to the level of the bladder wall. These findings are highly suggestive of placenta percreta. (Reprinted from Omonuwa et al. [24], Fig. 20.4, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

fetal blood loss during vaginal delivery. Placenta previa occurs when the placenta either extends to the margin of, partially covers, or completely covers the internal cervical os in the third trimester. With vasa previa, vessels from the fetal circulation may cross the internal cervical os (Fig. 19.5). During vaginal delivery, these vessels can tear and result in fetal blood loss. Vasa previa carries a fetal mortality risk of 33–100%. Early prenatal identification can lead to appropriate medical referral, preventing this outcome [30].

Gestational Trophoblastic Disease (Molar Pregnancy)

Early identification of GTD by USD and subsequent early surgical intervention may reduce the risk of maternal morbidity from severe hemorrhage, preeclampsia, thyrotoxicosis, or cancer [31]. In locations where sophisticated lab analyses such as Beta HCGs are not available, ultrasound may be the only method of diagnosing this serious, potentially malignant condition (Fig. 19.6).

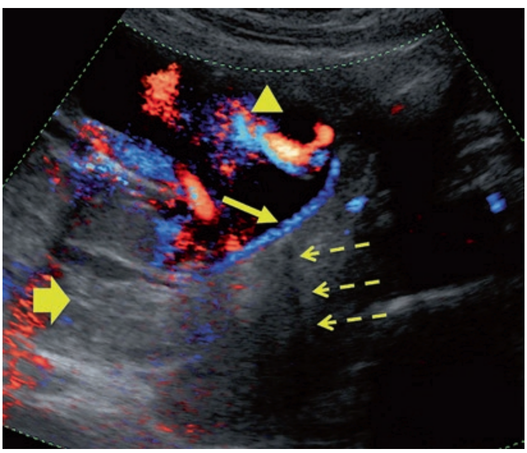

Fig. 19.5 A 25-year-old patient presented with painless vaginal bleeding. Color Doppler imaging of a gravid uterus at 20 weeks gestation demonstrates a posterior placenta (*wide arrow*) with velamentous insertion of the cord anteriorly (*arrowhead*). In addition, cord vessels (*solid arrow*) are seen crossing the internal cervical os (*dashed arrow*) consistent with vasa previa. (Reprinted from Omonuwa et al. [24], Fig. 20.5, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

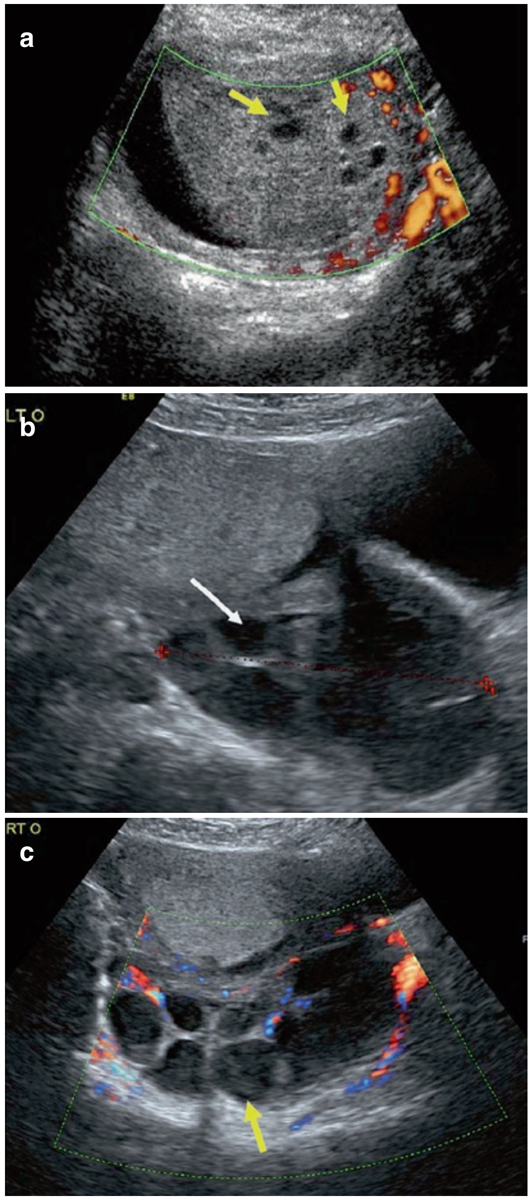

Fig. 19.6 (**a**) **A** 32-year-old patient with a positive beta-HCG presented with symptoms of hyperemesis. This is a thickened placenta with multiple cystic spaces (*arrows*). No fetal tissue or oligohydramnios are present. (**b, c**) Images of the ovaries in the same patient show multiple large cysts (*arrows*) consistent with theca luteal cysts. This constellation of findings is suspicious for a complete molar pregnancy. (Reprinted from Omonuwa et al. [24], Fig. 20.6, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

Abortion

The WHO estimates that approximately 13% of maternal deaths are linked to unsafe abortions, from procedures performed by unskilled practitioners with or without the use of sterile technique [32, 33]. Not every abortion is an elective termination of a live fetus; it can also include attempt to induce expulsion of a failed pregnancy, incomplete miscarriage, or fetal demise. The most common complications from these procedures are hemorrhage and infection (sepsis). In these situations, ultrasound may be helpful in determining the causes of hemorrhage such as retained products of conception (POC) or incomplete abortions. Findings suggestive of POC include gestational sac with or without an embryo, thickened or heterogeneous endometrial stripe with or without blood flow, or heterogeneous fluid collection within the endometrium. The use of ultrasound for definitive diagnosis may lead to earlier and more appropriate intervention for the condition. Timely detection and intervention are necessary as presence of POC can lead to sepsis, shock, hemorrhage, and maternal death [33–35].

In women who present with vaginal bleeding where a threatened spontaneous abortion is suspected, imaging may help differentiate nonviable from potentially viable pregnancies prior to surgical intervention. Ultrasound findings of irregular gestational sac without a yolk sac, absent cardiac activity, or too small gestational sac, can be diagnostic of a missed abortion or nonviable pregnancy (Fig. 19.7).

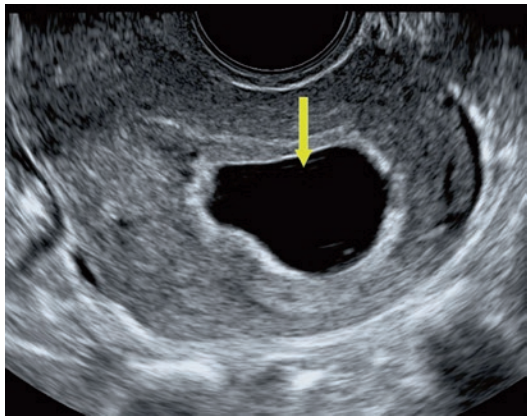

Fig. 19.7 Sagittal view of the uterus from endovaginal ultrasound performed for vaginal bleeding at 6 weeks and 5 days of gestation. *Arrow* denotes abnormally large, irregular gestational sac measuring 2.1 cm. No embryo or yolk sac is identified within the gestational sac. The findings are consistent with an anembryonic, nonviable pregnancy. (Reprinted from Omonuwa et al. [24], Fig. 20.7, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

Maternal Sepsis

Maternal sepsis, an uncommon but important complication of pregnancy, is responsible for 10–12% of maternal deaths in LICs [10, 29]. Clinical signs and symptoms of fever, chills, abdominal pain, or vaginal discharge in postpartum or post-cesarean section patients can indicate infection resulting from endometritis, chorioamnionitis, POC, or abscess [35]. Early diagnosis, broad-spectrum antibiotic therapy and treatment of the underlying cause of sepsis may prevent serious complications such as maternal death, secondary infertility, or long-term morbidity from chronic pelvic pain [36]. A diagnosis of sepsis is generally made based on clinical presentation of the patient. While USD may not be useful in diagnosis of sepsis, it may have value in detecting two important causes of sepsis: septic abortions or focal abscesses, both of which may require surgical intervention in addition to antibiotics for definitive treatment.

Causes of Maternal Morbidity and Use of Ultrasound

Obstetric Fistula

Ultrasound is likely to reduce the risk of obstetric fistula by identifying pregnancies that may result in obstructed labor and encouraging access to a birthing facility for delivery. It is estimated that two million women worldwide are living with an untreated obstetric fistula, contributing to a detrimental impact on quality of life. Gynecologic use of ultrasound is useful for detection of fistula and other consequences of birth trauma.

Gynecologic Infection and Disease

In addition to obstetric problems, bedside ultrasound can be used to evaluate gynecologic infections (tubo-ovarian abscess, complex adnexal masses, hydrosalpinx, and echogenic pelvic fluid). This has a high yield for diagnosis of gynecologic complications and potentially life-threatening infections for women [23]. It is useful for diagnosing disorders such as leiomyoma and uterine malformation, which can contribute to poor obstetric outcomes.

Causes of Perinatal Mortality

Fetal Growth Restriction

In women where menstrual history is unknown, such as with an unplanned pregnancy or failed contraception, first trimester crown rump length or second trimester biometry measurements provide an accurate and reliable estimate of gestational age as demonstrated by previous studies [37]. A precise estimation by sonography is necessary to avoid unnecessary pre- or post-date deliveries, which are important causes of perinatal mortality [38]. This accuracy decreases substantially by third trimester where measurements may have a much wider variation of normal. Accurate dating of a pregnancy theoretically allows early detection of fetal growth restriction (FGR), macrosomia, or post-date gestation; therefore, these measurements can potentially facilitate the timing and mode of delivery.

FGR, also known as IUGR (intrauterine growth restriction), is a complex condition, which may result in perinatal death from hypoxia, hypoglycemia, or meconium aspiration. There are two main types of FGR: asymmetric, from chronic fetal malnutrition, and symmetric, from diminished fetal supply later in the pregnancy. Asymmetric FGR is far more common and implicated in 90% of cases [39]. While FGR may be suspected clinically, sonography may be more accurate in predicting causes of and confirming presence of a compromised fetus [40]. Sonographic findings suggestive of symmetric growth restriction include low estimated fetal weight (<10th percentile for gestational age), decreased fetal abdominal circumference, or oligohydraminos. Ultrasound findings of fetal structural anomalies may be predictive of an abnormal karyotype, which may result in symmetric growth restriction, perinatal, or neonatal death. Other sonographic findings seen with both forms of growth restriction include abnormal umbilical artery cord Doppler ratios or waveforms, decreased fetal tone, movement or breathing. This diagnosis has implications for both maternal and fetal well-being. In the setting of preeclampsia/eclampsia, FGR is associated with severe placental disease and poor maternal and fetal outcome without appropriate treatment. Delivery is usually indicated in this context.

Pre- and Post-Term Pregnancy

Complications can occur from either pre- or post-term birth. Many women in LICs have irregular or unpredictable menstrual cycles due to malnutrition or peri-/post-lactation oligomenorrhea. Consequently, recall of last menstrual period is commonly inaccurate, giving an undetermined gestational age. One of the most important pieces of information that can be provided by an ultrasound is an estimated gestational age, and it is most accurate within the first trimester. Pre-term birth carries a risk of fetal lung immaturity and increased mortality due to respiratory distress of prematurity. Post-mature infants may succumb in-utero to placental deterioration.

Abnormal Lie and Malpresentation

Malpresentation can cause birth injury (maternal or fetal), umbilical cord compression, or prolapse during delivery, potentially resulting in perinatal death. Ultrasound can be used as an adjunct to physical examination to confirm the presence of malpresentation and potentially guide the maternal healthcare provider to determine appropriate delivery planning.

Causes Affecting Both Maternal and Fetal Health

Multiple Gestation Pregnancies

Twin pregnancies carry a higher maternal risk of pre-term delivery, postpartum hemorrhage, pre-eclampsia, and eclampsia [41]. Perinatal mortality is also approximately five times higher in twin pregnancies when compared with singletons [42]. While multiple gestations can be detected by careful physical examination and Doppler fetal heart rate monitors, the chorionicity and amnionicity can only be detected by careful ultrasound evaluation. This allows differentiating twin gestations with highest risk (monochorionic, monozygotic) from those at less risk. Monochorionic twin pregnancies have roughly 2.5-fold increase in perinatal morbidity and mortality compared with dichorionic twins [43].

In the first or early second trimester, dichorionic–diamniotic pregnancies can be identified by the presence of a thick, dividing membrane, separate placentas, discordant genders, or a "lambda" or "twin peak" sign [44, 45]. Monochorionic twins share placental vessels, which may lead to shunting of blood from one twin to the other. This twin–twin transfusion syndrome (TTS), a complication seen in up to a 30% of monochorionic gestations, is best identified by USD. TTS is a leading cause of fetal mortality. Early detection with careful follow-up and potential early delivery could lead to improved outcome [46].

Hydrops Fetalis

The classic definition of hydrops fetalis is the abnormal presence of fluid in two or more compartments [47]. The most common ultrasound findings include polyhydramnios, fetal pleural effusions, ascites, pericardial effusions, hepatosplenomegaly and skin edema (Fig. 19.8). Sources of hydrops fetalis may be broadly categorized into maternal (immune) or fetal (non-immune) causes. Rhesus isoimmunization is the primary immune-mediated source of hydrops. Non-immune factors contributing to hydrops include: fetal cardiac anomalies, arrhythmias, chest masses, peripheral shunts resulting from fetal or placental tumors, aneuploidy, infection, or TTS in multiple gestation pregnancies. The prognosis for the fetus can be variable depending on the cause. In cases where Rh-incompatibility is the underlying cause, early detection by ultrasound imaging is a critical first step, followed by close monitoring of the pregnancy and aggressive

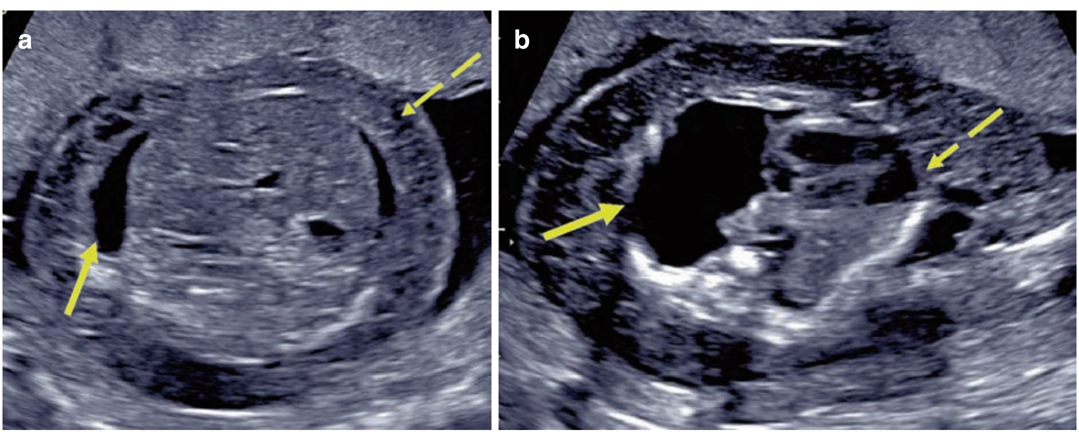

Fig. 19.8 (**a**) Axial view of the fetal abdomen demonstrates fetal ascites (*solid arrow*) and skin thickening (*dashed arrow*). (**b**) Axial imaging of the fetal thorax in the same patient demonstrates a large pleural effusion (*thick arrow*) with associated mass effect on the fetal heart (*dashed arrow*). (Reprinted from Omonuwa et al. [24], Fig. 20.9, with permission from SpringerNature. Image courtesy Sujata Ghate, MD)

medical treatment. Early delivery can often result in a favorable prognosis.

When maternal edema, preeclampsia, and proteinuria develop in association with hydrops fetalis, this condition is known as Mirror or Ballentyne syndrome. Studies have shown high rates of maternal morbidity and fetal intrauterine demise associated with this condition [47–49]. Early detection of fetal hydrops by sonography in conjunction with patient signs and symptoms may enable prompt surgical intervention or early delivery, potentially reducing maternal morbidity associated with this syndrome.

Overall Utility of Ultrasound

In reviewing literature from LICs, results conclude that most referrals for ultrasound of any kind are for OB/GYN (obstetric or gynecologic) reasons. One study in Liberia found 53% of patients coming for ultrasound required OB/GYN exams [50]. Similarly, in Cameroon 15% of referrals were obstetric and 32% gynecologic [51]; and in a Tanzanian refugee camp 24% were obstetric and 21.9% gynecologic [52]. The rate of obstetric exams was 30% obstetric in Rwanda and a majority in Botswana [53, 54]. These reports suggest that ultrasound is already being regularly used as an effective diagnostic tool.

Statistics for obstetrics and obstetric outcomes in LICs are generally unreliable, with only estimates available for most places. Up to 71% of births in sub-Saharan Africa are unregistered. Although ultrasound has been used in a number of these countries for some years, documentation on effectiveness or impact on outcomes has been made available only in recent years. Bussman performed 741 obstetric scans in Botswana, finding that the service was cost-effective, and improved patient management in 39% of cases [55]. The most common pathologies diagnosed were spontaneous abortion, fetal demise, low-lying placenta, and ectopic pregnancy. In Rwanda, obstetric scans were used primarily to determine fetal presentation, gestational age, and placental position [6]. These scans not only changed management in 43% of patients, but were considered affordable. In Liberia, a trial of 102 patients seen in a 5-week span, most were obstetric cases [6]. Pathologies most often seen were bleeding, fetal demise, gestational age determination, multiple gestation, and placenta previa, changing management in 62% of cases. In Northern Tanzania, a qualitative study reported that ultrasound helped delivery management, pre-procedural planning, and reduced pre- and post-term births [6]. Women also reported that knowing their estimated due date was helpful in planning a hospital delivery – highly significant since only 47% of Tanzanian deliveries occur in the hospital. A study in Malawi of 840 babies demonstrates the importance of diagnosing pre-term birth – in sub-Saharan Africa, a baby born at 32 weeks has a greatly diminished chance of survival, compared to one born in a HIC. Compared to babies born at term (confirmed by ultrasound), those diagnosed as pre-term were almost twice as likely to die in the first 2 years of life. Table 19.1 summarizes the above.

A review article by Harris and Marks summarizes anecdotal experience of ultrasound in limited resource settings [21]. The authors deployed donated units in Serbia, Vietnam, Nicaragua, Tanzania, Kenya, Mali, and Sierra Leone. The units had substantial impact on public healthcare, "particularly in maternal care." In Nicaragua, physicians reported maternal mortality reduced from 12 deaths per year to 5 deaths year [6].

In addition to detecting abnormalities for referral, ultrasound can reassure normalcy and reduce unnecessary intervention. A study in Cameroon showed that of 1119 scans, most were obstetric and gynecologic. Of these, 78% were normal. Geerts in South Africa scanned 3009 women in a low-resource setting, providing fetal anatomic scans. Results did not demonstrate improved outcomes, but it did significantly reduce the number of referrals to the regional medical center for increased surveillance. This was thought to be due to the accuracy of gestational age determination [57].

Safety and Efficacy of Obstetric Ultrasound

In consideration for widespread use of USD for standardized maternal and women's ultrasound,

Table 19.1 Review of existing literature in support of ultrasound use in the LMICs and training guidelines currently in use [23, 55, 56]

Year	Country	Number	Findings – significance
1998	Egypt	828	FGR/IUGR major contributing factor perinatal mortality and morbidity Mahran demonstrated 11.8% rate Detection by fundal palpation is 34.7% Detection by ultrasound 89.7%
1999	Cameroon	1119	78% of scans yielded abnormal findings – 68% judged to be useful for diagnosis 32% yielded diagnoses
2004	Ghana		Variety of settings 54% were abdominal and OB/GYN – 100% added to the clinical diagnosis 81% showed abnormal findings 40% influenced the outcome or treatment decision
2005	Malawi	512	OB scans prior to 24 weeks, providing EGA 20.3% delivered prematurely prior to 37 weeks. These infants were twice as likely to die as their full-term counterparts.
2008	Tanzania	542	Nurse-midwives trained in basic OB USD available to do scans 24 h per day; midwives had 100% agreement with sonographers in readings 542 suspected abnormal findings in 1 year; aided in dx of 39% Changed management plans in 22% Lessened workload of specialist
2010	Zambia	441	Rural area, 21 midwives, 6-month training program Main abnormal findings Non-vertex presentation (61%) Multiple gestation (24%) Fetal demise (8%) Prompted change in clinical decision-making in 17% of cases
2014	Kenya	271	5 midwives with extensive training 99.6% accuracy in interpreting scans done in remote areas 20 (7%) correctly labeled as high risk 25-minute turnaround time for transmission by cell phone to radiologist for interpretation

demonstration of safety is paramount. The American Institute of Ultrasound in Medicine (AIUM), the WHO, International Society of Ultrasound in Obstetrics and Gynecology (ISUOG), and other European Societies conclude that benefits of obstetric ultrasound outweigh the risks to the mother and fetus. In 2009, a meta-analysis of 61 publications conducted by the ISUOG-WHO found no association of ultrasound usage with adverse maternal or perinatal outcomes, presence of mental diseases in the child, impaired physical or neurological development, or decreased intellect. Although data from this study was mostly reassuring, there were limitations. The studies were observational, did not report on long-term bio-effects, and were mostly published before 1995 when the intensity of the ultrasound equipment was lower than in modern machines [58]. Nevertheless, the AIUM and other major international organizations consider ultrasound relatively safe during pregnancy.

To better regulate safety of obstetric ultrasound, the AIUM along with other international societies suggest the following general guidelines for clinical use [59, 60]:

- Keep USD exposure as low as reasonably achievable (ALARA) by performing ultrasound only when clinically required and minimizing scan time.
- Restrict use of color Doppler imaging in the first trimester as this technology may have potential to increase tissue temperatures.
- Comply with output display standards.
- Avoid non-medical use of ultrasound.
- Avoid use of ultrasound contrast agents in obstetric patients as risks to the fetus are not well-studied.

Ethical, Legal, and Regulatory Concern

Implementation of diagnostic obstetric ultrasound in LICs may face unique ethical and legal challenges. By far the most disturbing negative outcome of widespread prenatal imaging is the emergence of sex-specific abortion. In many parts of the world, there remains a preference for sons over daughters, resulting in a gender imbalance in these societies. The sex ratio of a given country is the ratio of males to females at birth. Without outside influences, the average sex ratio at birth should be equal to 105 boys to 100 girls. Any deviation from this natural sex ratio constitutes a significant shift. In Asia, ratios of male to female births have been increasing since the 1980s, particularly in China where in 2009, there were 120 boys born for every 100 girls [61]. Prenatal imaging is partially implicated in this phenomenon [62].

Historically Chinese culture encouraged parents to continue having children until a satisfactory number of sons were born. Obviously, this carried some economic burden, and there may have been preferential allocation of resources to sons over daughters. In 1979, the One Child policy was enacted which placed a legal limit on the number of children, and therefore, sons, a family could have. The result was a dramatic increase in "son preference" as evidenced by a rise in prenatal sex selection by ultrasound, as well as female infanticide [61, 63]. The Chinese government has since responded to this imbalance by criminalizing non-medical determination of fetal gender and imposing substantial penalties for offenders; however, this practice persists. Reports have shown some of the consequences, including increasing crime rates and decreased marriage opportunities for males in China, in addition to the ethical repercussions on women's welfare [64, 65].

Imbalanced sex ratios and sex-specific abortions are not isolated to China and have been reported in many parts of Asia and the world. In India, where there are 100 newborn boys for every 92.7 girls, abandonment of daughters, under-reporting of female births, and infanticide of newborn girls are serious issues [66, 67]. Although prenatal sex determination has been illegal in India since 1994, this law is difficult to enforce as it is nearly impossible to prevent unscrupulous sonographers from discretely alerting couples of fetal gender [68]. The Indian government is currently heading a strong initiative to limit sex-specific abortions in the 17 provinces with the most serious gender ratio imbalances. One state in India has recently started a policy of providing monetary compensation to parents giving birth to girls [69].

Illegal use of obstetric sonography in LICs may partially be due to the lack of government regulation and general oversight of these practices and practitioners. Many low-resource areas do not require formal training or licensure for sonographers, resulting in a few "entrepreneurs" who choose to perform scans for purely financial reasons while lacking the adequate technical skills. Furthermore, these practitioners may be more likely to break imaging-specific laws such as revelation of gender to expectant parents in regions of the world where this practice is illegal. Without appropriate healthcare infrastructure, it may be difficult to identify subpar or illegal practices [70–73].

Detection or suspicion of fetal anomalies Even in Western societies with state-of-the-art equipment and well-trained sonographers, definitive diagnosis of fetal abnormalities can still be difficult. In low-resource areas, where patient counseling and support is not as readily available, this uncertainty may be coupled with additional patient anxiety and insecurity. The choice of having a potentially disabled child versus enduring the stigma of abortion can be a difficult one for patients with limited resources as evidenced by one study in Vietnam [74]. While detection of fetal anomalies is an important role of screening obstetric ultrasound, appropriate support services should be available prior to implementation of such programs in LICs.

In LMICs, patient perception of obstetric USD may be influenced by education level, local culture, or religion. In a study that took place in Botswana, the act of "looking inside the womb" was perceived by some patients as invasive and inappropriate. For some women there is misconception that harm may come by looking at the unborn infant.

In some countries, like Tanzania, Botswana, Gambia, and Zimbabwe, the practice of witchcraft and spirits remains prevalent alongside the reliance of medicine. There exists a "medical pluralism" model of health where patients embrace both. Anecdotally, this author discovered a minor fetal anomaly while doing a third-trimester ultrasound in rural Tanzania. The woman was not advised of a minor detected fetal anomaly, lest the husband consider his wife to be cursed, causing him to abandon her. A similar fate might also happen to a woman told that she could not bear children.

For others, the ultrasound experience provided positive reassurance and the ability to plan ahead. Still others overestimated the technology; some even believing that ultrasound may help cure or treat fetal or maternal abnormalities. For the healthcare providers in this same study, the introduction of imaging sometimes replaced history-taking, critical thinking, and careful physical exams; all of these skills are essential for healthcare workers practicing in low-resource areas. These findings illustrate the need for specific guidelines on use of ultrasound and effective doctor–patient communication. Conversations about potential benefits and limitations may prevent the patient from having unrealistic or false expectations [75].

Sociopolitical Challenges

In formulating the MDGs, increasing the number of skilled birth attendants at delivery was identified by the WHO as a strategy for improving maternal-fetal health outcomes. The global shortage of trained health workers is estimated at more than four million [6]. Neonatal mortality and morbidity are inversely associated with coverage rates of skilled birth attendance – 60 million births occur annually outside of hospitals, 52 million without a birth attendant. One meta-analysis of three randomized trials showed no statistically significant reduction in maternal mortality when outcomes were compared with and without the use of trained attendants [76]. However, this might be mitigated by a definition of "skilled practitioner." A midwife trained in the UK, for example, has significantly different skill level than a "trained birth attendant" in Indonesia, for example. In South Africa, where about 86% of births were attended by skilled practitioners, poor maternal outcomes persisted; this result is likely secondary to a wide discrepancy in expertise of these "skilled practitioners" [77, 78]. In contrast, one study in rural Bangladesh demonstrated that the MMR significantly decreased in villages where trained midwives participated in home-deliveries [79].

Countries that have achieved greater success in the reduction of maternal mortality have generally been the ones implementing a combination of strategies such as increasing availability of free antenatal care and preventive care, increasing patient education (family planning, birth spacing, hygiene, sexually transmitted diseases), and providing skilled attendants. This is the case in both Malaysia and Sri Lanka where MMR was substantially reduced over four decades by improving female education, increasing attendance of midwives at delivery, as well as providing access to healthcare resources in emergent situations [76, 80–86].

Ultrasound Training

Prior to implementing an ultrasound program in a population, a detailed analysis of the local environment is needed. A generic approach is not practical; a program must be tailored to the local setting in collaboration with local stakeholders. Specific to each population are unique factors of geography, disease prevalence, availability of providers, physical infrastructure (electricity, Internet and availability of tele-radiology, transportation, etc.), ability to purchase a machine and supplies, and access to repair technology. Practical and logistical considerations include referral pathways, access to advanced medical care for referrals, clinical guidelines, image reporting, record keeping, quality assurance, and availability of appropriate patient counseling and support. Ability to pay for services is of concern to many without means. Culture must be understood fully so that best decisions can be made about abnormalities. Even consideration of a provider's gender must be considered. Availability of qualified providers for training is very important, as is the availability of training staff and access to educational media [6].

A cost–benefit analysis is reasonable for determining feasibility and depends on the ability of the planner to obtain resources either from government, NGOs, or charitable organizations to help with initial costs. This must be weighed against the burden/cost of the conditions that are likely to be avoided by use of ultrasound in that population. Initial outlay of cost is not the only consideration; determining sustainability is paramount to the success of a program. If the resources are lacking to continue ongoing training, quality assurance, equipment maintenance, and demonstration of effectiveness, the program is likely to be discontinued. If private entities assume ownership and make the service unaffordable to the poor, then the highest risk women remain underserved [6]. An entire chapter in this text is dedicated to ultrasound training and more information can be found there.

Conclusion

The state of maternal-fetal and women's health in LMICs remains a challenge. The benefits of diagnostic ultrasound in HICs are well-known, and its role in reducing maternal mortality in low-resource areas is being increasingly supported. With the implementation of new strategies, there is a potential for prenatal imaging, specifically ultrasonography, to have a significant impact given its potential for quick and precise detection of potentially life-threatening conditions. However, obstetric ultrasound must be employed in such a way as to stay within regulatory guidelines and should not contribute to technology-based malpractice. Nor should it add to economic or technologic burden or treatment inequities. Ultimately, effective prenatal imaging requires basic healthcare and national infrastructure including electrical power, sustainable equipment maintenance, low cost, trained personnel, available skilled birth attendants, and referral centers, all necessary to improve health outcomes in a sustainable manner. Large-scale trials are greatly needed to continue to validate the efficacy of this tool in improving maternal and infant outcomes in LICs. This will support the allocation of resources toward expansion of the use of ultrasound in global women's healthcare and solidify its contribution toward achieving the 2030 SDGs related to women's and infant's healthcare.

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20 Women's Imaging in Global Health Radiology

Lisa A. Mullen, Susan C. Harvey, Erica B. Pollack, Niranjan Khandelwal, and Tulika Singh

Introduction

This chapter focuses on screening services specifically for breast cancer and bone health; prenatal and maternal fetal imaging are discussed in a separate chapter.

Osteoporosis is a significant global public health problem. Osteoporotic fractures, particularly of the hip and spine, can lead to decreased mobility, disability, and loss of independence. Osteoporosis-related fragility fractures are associated with extensive social and economic costs. Since osteoporosis predominantly affects older women and men, the trends of an aging population related to longer average life expectancy will increase the number of people with osteoporosis, resulting in greater societal and economic burdens. There is likely to be a disproportionate burden from osteoporosis in low- and middle-income countries (LMICs) compared to high-income countries (HICs) because of resource scarcity and the rapid rate of increasing life expectancy in LMICs.

Breast cancer burden is increasing worldwide, particularly in LMICs [1]. This trend can be attributed, at least in part, to an aging population due to an increasing average life expectancy in LMICs approaching that of HICs. Breast cancer risk factors including a sedentary lifestyle, obesity, and delayed childbearing are also on the rise in LMICs [2–4].

There is a disparity in morbidity and mortality from breast cancer and osteoporosis in LMICs compared to HICs, which is secondary to limited access to early detection, diagnosis, and treatment services. Lack of available primary care facilities, misconceptions leading to fear and stigma of disease, and financial instability all contribute to suboptimal care. These are important factors to consider when planning and implementing programs intended to impact breast cancer and osteoporosis. Further, this implies that well designed programs to improve access to affordable radiologic screening for these diseases may decrease morbidity and mortality with the potential for positive healthcare outcomes worldwide.

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Osteoporosis

Epidemiology

Osteoporosis is generally defined as a decrease in bone mass with microscopic bone tissue deterioration, which greatly increases the risk of debilitating fractures of the hip, forearm, and vertebral bodies [5]. Osteoporosis affects an estimated 200 million women worldwide and causes more than 8.9 million fractures annually. Osteoporotic fractures account for 0.83% of the global burden of non-communicable disease [6, 7]. Fractures can lead to disability and loss of independence and are associated with large social and economic costs.

A meta-analysis of the literature was performed in 2012 to provide country-specific risk of hip fracture and the 10-year probability of a major osteoporotic fracture. The study showed prevalence of osteoporosis varies greatly by country and continent, up to tenfold [8]. Hip fracture rates are often used as a surrogate for osteoporosis rates due to the associated high morbidity and healthcare costs and the high probability that patients with hip fractures will require medical attention. The major countries at the highest risk are HICs including Denmark, Sweden, Austria, Norway, and Switzerland [8]. The World Health Organization (WHO) estimates that the lifetime probability of osteoporotic fractures in women at age 50 is over 40% in HICs. Men are at half the risk of fractures compared to women in many regions.

The WHO also predicts that the number of osteoporotic fractures will increase by threefold over the next 50 years as the world population ages. The rise in osteoporosis is thought likely to occur outside the USA and Europe, particularly in Asia and Latin America [7], and this theory is supported by statistics from the International Osteoporosis Foundation (IOF). The IOF also warns of the escalating costs of osteoporotic fractures, which place a large financial burden on healthcare systems. By 2050, one out of every two hip fractures worldwide will occur in Asia. China has experienced a 300% increase in osteoporotic fractures in the last 30 years [9].

Many of the risk factors for osteoporosis are environmental, rather than genetic, and this has been shown through the study of risk change in immigrant populations. Proposed risk factors include both low body mass index and obesity, low calcium intake, reduced sunlight exposure, early menopause, smoking, alcohol consumption, and decreased physical activity [8].

Screening Recommendations

The goal of screening for osteoporosis is to identify and treat at-risk patients prior to fracture, resulting in fewer fractures and decreased fracture-related healthcare costs. Although there are several methods for measuring bone mineral density, dual X-ray absorptiometry (DXA) is the most widely validated technique. Scans of the lumbar spine and hip are obtained, as well as the forearm in certain populations. BMD measurements are obtained for the total spine, total hip, femoral neck, and distal 1/3 forearm, and the BMD measurements are then compared to the young adult mean (using T-scores) or to an age-matched population (using Z-scores). The T-score indicates the number of standard deviations away from the young adult mean BMD, and the Z-score indicates the number of standard deviations away from the age-matched mean BMD. T-scores are used for diagnosis in postmenopausal women, women in menopausal transition, and men over age 50. Z-scores are preferred for children, premenopausal women, and men under age 50. The lowest T-score or Z-score is used for the overall diagnosis [10].

The World Health Organization (WHO) has developed diagnostic criteria for osteoporosis based on measurement of bone mineral density (BMD) as compared to the average bone density of young healthy women. Osteoporosis is defined as a BMD more than 2.5 standard deviations (SD) below the mean BMD for young adult women (T-score <−2.5). Osteopenia (also called "low bone mass") is defined as a BMD between 1.0 and 2.5 SD below the mean (T-score between −1.0 and –2.5). Normal bone density is defined as a BMD at or above 1.0 standard deviations below the mean (T-score of −1.0 or above) [6]. Pharmaceutical research targeted at osteoporosis treatment usually requires a diagnosis of low BMD and often uses DXA T-scores to provide thresholds for intervention.

For children, premenopausal women, and men under age 50, Z-scores are used for diagnosis. A Z-score of −2.0 or less is "below the expected range for age," and a Z-score above −2.0 is considered "within the expected range for age" [10].

The International Society for Clinical Densitometry (ISCD) Official Positions, most recently updated in 2015, include indications for bone mineral density testing of at-risk patient groups, as well as guidelines for diagnosis, quality control, reporting, and follow-up. Current indications for bone mineral density testing include the following: women aged 65 and older, postmenopausal women under 65 with risk factors for low bone mass (low body weight, prior fracture, high-risk medication use, or disease associated with bone loss), perimenopausal women with risk factors listed above, men aged 70 and older, men under age 70 with risk factors, adults with a fragility fracture, adults with a disease or condition associated with low bone mass or bone loss, adults taking medications associated with bone loss, anyone being considered for pharmacologic therapy for osteoporosis, anyone being treated (to monitor treatment effect), and anyone not receiving therapy in whom evidence of bone loss would lead to treatment. Children and younger men and women may need evaluation of bone mineral density if they experience low-trauma fractures, have known primary bone disease, or take medications or have known diseases which cause bone loss [10–12].

The frequency of BMD testing varies according to the patient's clinical situation and risk factors. For patients with normal bone mineral density or osteopenia at baseline testing, the interval for repeat BMD testing should be based on individual patient age, current BMD, and risk factors. Follow-up testing may be appropriate in 3–5 years, depending on individual factors. For untreated patients with low bone mass, serial BMD testing can be used to determine when to begin treatment. For patients on pharmacologic therapy, serial BMD testing can determine response to therapy. Testing 1 year after initiation or change of therapy would be appropriate, with longer intervals (usually every 2 years) once BMD is stable. More frequent testing may be needed for conditions associated with rapid bone loss, such as glucocorticoid therapy. Since bone loss or gain usually occurs slowly, follow-up testing should be performed when the expected change in BMD meets or exceeds the least significant change (LSC) [10, 13].

BMD measurement with DXA can be used to diagnose osteoporosis [10]. BMD measurement is also predictive of future fractures as the risk of fracture increases with decreasing BMD [14]. BMD measurement alone, however, does not detect all patients at risk of fracture. Evaluating BMD along with multiple other fracture risk factors such as age, gender, body mass index (BMI), prior fracture, and steroid use improves the ability to predict increased fracture risk [15–17].

Many fracture risk assessment tools have been developed to help clinicians identify patients at increased risk of fracture. The FRAX® tool is the most commonly used fracture risk assessment tool worldwide. The FRAX® tool was developed in 2008 at the University of Sheffield, UK, based on data generated from the WHO Collaborating Centre for Metabolic Bone Disease. It is based on patient models that integrate multiple clinical risk factors (age, gender, BMI, history of previous fracture, history of parental hip fracture, current smoking, steroid use, rheumatoid arthritis, history of secondary osteoporosis, and alcohol use) as well as the BMD at the femoral neck. Population-based cohorts on multiple continents were used to develop the models. The algorithm, which includes a digital or hard-copy questionnaire combined with BMD of the femoral neck, provides a 10-year probability of hip fracture and 10-year probability of a major osteoporotic fracture (spine, forearm, hip, shoulder). There are over 60 FRAX® tools available based on the country of patient origin due to a large variation in fracture risk worldwide [8, 18].

Other risk assessment tools are non-DXA based and include only a few risk factors, such as the Osteoporosis Self-Assessment Tool (OST) and Osteoporosis Self-Assessment Tool for Asians (OSTA), which consider only age and weight, and the Osteoporosis Risk Assessment Instrument (ORAI), which considers age, weight, and use of estrogen replacement therapy. These tools can be used to screen individuals for low BMD [19–21].

In most LMICs, the major impediment to screening for osteoporosis is the lack of access to imaging equipment for BMD measurement. Of note, the FRAX® tool can be used for fracture risk assessment with or without BMD. FRAX® without BMD has a predictive value for fracture similar to BMD alone [22, 23]. Therefore, it would be possible to use FRAX® without BMD to estimate risk and guide treatment. Alternatively, FRAX® could be used to determine which moderate- or high-risk individuals should undergo BMD testing. These options may be very useful in LMICs, where BMD testing is scarce [24].

Lack of data from LMICs makes osteoporosis statistics unreliable, and testing for BMD using DXA or other more portable methods is limited. According to the WHO, DXA and other forms of BMD measurement are highly specific but not sensitive, meaning that there is a risk of fracture even in setting of normal bone density measurement. The WHO suggests that patients should be evaluated for fracture risk using internationally applicable clinical risk factors together with BMD measurements rather than BMD alone [5, 7].

Program Quality Control

Program quality control efforts for DXA screening were published by the International Society for Clinical Densitometry (ISCD) and the National Institute of Standards and Technology (NIST) through a workshop held in 2006. The publication identified factors that limit DXA as a useful diagnostic tool, including discrepancy in BMD measurement across manufactures as well as between individual machines from the same manufacturer, requirements for training of technologists and interpreting physicians, and varying composition of the patient's soft tissues over time. Equipment and technology play an important role in the radiologic diagnosis of osteoporosis. Quality assessment and improvement programs in LMICs with osteoporosis screening programs must pay attention to equipment calibration using standardized phantoms, technologist training for accurate region of interest (ROI) placement, and standardization of treatment algorithms once a screened patient is appropriately diagnosed [25]. In 2016, the ISCD provided updated guidance regarding quality standards for BMD testing and interpretation at DXA facilities worldwide, as high-quality DXA testing is required for diagnosis, risk assessment, and monitoring [26].

Cost of Screening and Follow-Up Care

Clinical reference modeling has been used to predict the cost-effectiveness of diagnosis, treatment, and prevention of osteoporosis and the subsequent life-altering fractures that occur. Cost per fracture avoided is often used when the economics of osteoporosis screening and treatment is evaluated [27].

The FRAX® risk prediction tool can be used to identify individuals above a certain fracture risk threshold to facilitate cost-effective and efficient treatment [28, 29]. However, the thresholds for intervention should be country-specific [8].

Instead of offering DXA to an entire population over age 65, it may be more cost-effective in LMICs to use validated clinical risk factors such as age, sex, prior fracture, family history, and lifestyle to triage patients into a low-risk category unlikely to benefit from BMD testing, an intermediate-risk category where BMD results may affect the decision for pharmacologic treatment, and a high-risk category where patients are likely to be treated regardless of BMD results. The level of risk that merits intervention will likely need to be adjusted based on country or regional osteoporosis prevalence [7].

Referral Patterns and Outcomes

LMICs often have access to basic treatments for osteopenia and osteoporosis, including calcium and vitamin D supplementation. Some LMICs also have access to bisphosphonates at decreased cost, although the medications require a challenging level of adherence. Community health programs should be utilized to screen patients and subsequently refer them for BMD testing if available and affordable. Outcomes should also be monitored closely to determine if the screening program is effective.

Barriers to Care

According to the IOF and WHO, the main barriers to prevention, diagnosis, and treatment of osteoporosis are cost and lack of access to diagnostic equipment. DXA and FRAX® assessment are considered the gold standard, but a majority of the world population does not live within travel distance from a screening facility. Triaging screening populations using questionnaire-based risk assessment tools may facilitate BMD testing for patients at intermediate risk for osteoporotic fracture so that they can be prescribed appropriate therapy if needed [7, 24].

Breast Cancer

Epidemiology

Breast cancer is the leading cause of cancer deaths for women globally including LMICs [30], and the global burden of breast cancer is rising. Global health statistics published in 2012 have not been updated by Globocan, perhaps, in part, due to limitations in available data. The statistics published show that 1.7 million women were diagnosed with breast cancer worldwide, and 521,900 deaths occurred in 2012 [31]. This accounted for 25% of new female cancer cases and 15% of cancer deaths in 2012.

The incidence of breast cancer in LMICs has recently surpassed that of cervical cancer, which was previously the most common cancer affecting women worldwide. While breast cancer has a lower incidence in LMICs compared to HICs, women living in LMICs bear a disproportionate burden of the disease's mortality. Though the incidence of breast cancer is lower in LMICs, the death rates are the same for LMICs and developed countries [31, 32]. In 2012, HICs accounted for 50% of cases but only 38% of deaths from breast cancer [31]. In other words, close to 70% of worldwide breast cancer deaths occur in LMICs, which is overwhelming for resource- and physician-limited regions [33]. This mortality burden is multifactorial but is no doubt in part due to the typically late-stage presentation of disease in LMICs leading to poor prognosis and increased mortality. The majority of women in LMICs—up to 75%—have no access to screening programs and present with locally advanced breast cancer or metastatic disease (stages III and IV), while up to 70% of cancers in North America are stages 0 or I [4].

Importantly, it is well documented that information and structured data on cancer incidence and mortality are extremely limited in LMICs, and any discussion about incidence, treatment, and mortality must take this into account [34]. Breast cancer statistics in LMICs are from registries that track only a small portion of the population, in the order of 3%. Cancer registries in LMICs often reflect rates among women who are easy to reach due to their location in an urban environment or their socioeconomic status [3].

It has been suggested that women may be diagnosed younger with more aggressive tumors in LMICs such as India and in sub-Saharan Africa, where it is estimated that the average age at presentation is up to a decade younger than female counterparts in HICs [35, 36]. It is unclear if the earlier age is secondary to an average younger population overall or if there are genetic differences among these malignancies. More research on genetic and biologic influences and features is needed to better understand the reported early-onset, aggressive, estrogen receptor-negative cancers seen particularly in women with African heritage [37]. While there is limited access to immunohistochemistry, the data available show a high percentage of triple-negative breast cancers as well as estrogen and progesterone receptor-negative tumors. Importantly, the capability to test for human epidermal growth factor receptor 2 (HER 2) is very limited, and this may be related to the number of triple-negative cancers reported [38].

The rise of breast cancer incidence in LMICs is not fully understood but is likely multifactorial and may, in part, be related to some improvements in data collection. The trend toward increased life expectancy also contributes to higher rates of breast cancer, which is more common in the postmenopausal cohort. In addition, it has been suggested that "westernization" of lifestyle has had a substantial impact including dietary changes, delayed childbearing, greater availability of contraception, and a progressively sedentary lifestyle [39]. Increased autonomy over reproduction has allowed women to delay childbearing with overall decrease in parity and time spent breastfeeding. These trends decrease maternal mortality but increase the risk of breast cancer. The use of hormonal-based contraception may play a role as well [4].

Screening Recommendations

Many countries have not published breast cancer screening guidelines. HICs such as the USA are still actively debating breast cancer screening guidelines including appropriate age range for screening, exam frequency, and which screening modalities to use (particularly for women deemed to be at high risk of cancer or who have dense breasts). These recommendations vary based on the perspective of the authoring organization. For example, the US Preventive Services Task Force must formulate recommendations that focus on cost and resource use where professional societies, such as the American College of Radiology, focus on the earliest possible detection and recommendations that optimize imaging intervals and modalities to achieve this. The uncertainty regarding best practices has made it difficult for HICs and even more complex for LMIC governments and NGOs to formulate effective breast cancer screening and treatment programs where resources and physicians are scarce. In low-resource areas, the allocation of healthcare must be carefully considered, so the debate regarding screening in HICs has been used by some as a reason to delay implementation of breast cancer screening programs [30]. Those wishing to implement a breast cancer screening program in LMICs must also be wary of adapting guidelines designed for HICs because the specific barriers to care and solutions in LMICs are unique and documented results of screening programs in HICs may not translate to LMICs [40, 41].

The Breast Health Global Initiative (BHGI) was founded in 2002 in an attempt to create feasible guidelines for breast cancer detection and treatment in LMICs. The BHGI is a multidisciplinary panel of over 80 breast cancer experts from 40 countries and has published numerous consensus papers spanning prevention, early detection, diagnosis, pathology, treatment, healthcare systems, research agendas, and communication strategies [42]. Implementation of BHGI guidelines and recommendations according to the socioeconomic limitations of each country may have a significant impact on breast cancer mortality in the future. At this time, however, the guidelines are not substantive enough to be consistently deployed by governments or scalable programs. As a result, data remains insufficient to further inform programs, and progress is slow.

To summarize, the BHGI guidelines assess resource levels (basic, limited, enhanced, and maximal) and discuss potential or optional detection methods, program evaluation goals, and metrics to monitor the program for each resource level. Further details can be found through the BHGI library in the 2008 article entitled Consensus on Early Detection [43].

Basic Resources

According to the BHGI, all programs should be built upon a culturally sensitive public education and awareness platform, preferably supported by the local and national governments [43]. Teaching women the importance of seeking clinical evaluation after detecting symptoms associated with breast cancer may facilitate downstaging of disease. This may be effective if the possibility of breast-conservation therapy and improved survival are emphasized [44]. The goal is to increase the level of breast health awareness, which can be assessed by comparing the number of women in the targeted population who have had a recent general health visit versus the number of women who have attended an organized breast health program [44].

Limited Resources

In limited resource areas, public education and awareness remain key factors to breast health programs. Organized campaigns encouraging women at highest risk of breast cancer to undergo a CBE may be beneficial. Opportunistic offering of mammography or ultrasound detection may occur for targeted populations if feasible. The metric by which a limited resource program can be evaluated is the percentage of women with palpable abnormalities who undergo further diagnostic imaging [44].

Enhanced Resources

In LMICs where there are enhanced resources, opportunistic screening mammography may be offered. If no specific screening recommendations are available for the region, the BHGI suggests that mammography be offered to women between the ages of 50 and 65 every 2 years and that expansion of the screening program to younger women be offered after there is adequate coverage of the initial targeted population. The metric is to downsize and/or downstage asymptomatic disease in the highest yield target groups.

Maximal Resources

Organized screening programs should be implemented with performance and outcome metrics available.

Currently, only 2.2% of women ages 49–65 in LMICs have access to breast cancer screening [41]. In addition, as the BHGI attempts to address, women in LMICs face economic, cultural, religious, and empowerment barriers to screening for breast cancer. Improvements are being made on these fronts, however: Trupe et al. demonstrate moderate competency in education and understanding of breast cancer in rural South Africa [44].

It is critical to examine if capacity building using mammographic screening is appropriate for LMICs and if resource allotment and referral for abnormal findings and treatment are available. As described in the section on epidemiology, the age of onset of cancer, competing disease burdens, aggressiveness of disease, and overall life expectancy will impact decisions about how detection is performed [41]. For example, screening mammography before the age of 40 may not be ideal given assumed breast tissue density of young women and increased sensitivity to radiation at younger ages. In addition, a successful program requires high-quality imaging, programs for definitive diagnosis such as biopsy and pathology, as well as access to treatment, and these multidisciplinary teams are frequently unavailable [41].

Sustaining a mammography program brings considerable challenges (equipment maintenance, image quality control, training of technologists and physicians), and alternative detection methods such as clinical breast exam (CBE) and self breast exam (SBE) may be considered if these challenges are insurmountable. Recommendations for self breast exam and clinical breast exam remain controversial as reported impact varies over multiple studies in a wide variety of settings [45–52]. Teaching women the importance of seeking clinical evaluation immediately after detecting a lump or other symptoms associated with breast cancer may facilitate early treatment and downstage disease with only modest resource allocations [53]. The goal for meaningful downstaging of disease should be set at stage 2 or below. Stage 3 disease cure rates in the USA are in the order of 70%; however, in LMICs where chemotherapy, radiation therapy, and advanced surgical techniques are rarely accessible, a trend from stage 4 to stage 3 disease may add hope but little outcome improvement.

As ultrasound units become more portable and more affordable, screening breast ultrasound may be a more feasible option than mammography in some areas. A committee of RAD-AID-affiliated breast imagers conducted a review of the recent literature regarding breast ultrasound as a screening tool in order to consider its utility in low-resource areas where mammography is not available [54]. Because ultrasound yields improved cancer detection compared to mammography in young women with dense breasts [55], it may be a particularly useful detection tool in LMICs where breast cancer presents at a younger age. Hand-held ultrasound also offers advantages over mammography, such as portability, durability, lower cost, and ease of maintenance. A breast ultrasound-based detection or diagnostic program may be feasible in a low-resource region where mammography cannot be implemented due to cost and logistical barriers.

The use of breast ultrasound for detection could be combined with ultrasound-guided fine-needle aspiration (FNA) or core needle biopsy performed by generalist physicians for definitive diagnosis. This process traditionally utilizes cytology or pathology, however, which is also limited in low-resource regions. In the future, breast biopsy paired with rapid diagnostic techniques that are currently being developed may have an impact in regions with scarcity of pathologists. Both capacity building and innovation will be required to address the needs of a growing population of breast cancer patients.

Program Quality Control

Program quality assurance is critical to long-term sustainability of any opportunistic or organized screening exam. The quality metrics and logistics must be tailored to the program design and services provided as suggested by BHGI recommendations. Both film-screen and digital mammography are challenging exams to perform, and the quality of the images, challenges of interpretations, and the ability to refer women with abnormal exams for diagnosis and treatment are critical to program efficacy. Programs that deploy ultrasound as an imaging modality will find fewer technology challenges than mammographic screening programs, yet there remains considerable need for oversight of image quality and image interpretation for this tool as well.

Several of the larger HICs including the USA, Canada, Australia, and the European Union have published guidelines for radiographers, radiologists, and physicists in an effort to standardize breast imaging. In the USA, the American College of Radiology (ACR) offers a voluntary accreditation program that has become a national standard, and the Federal Drug Administration (FDA) and the Mammographic Quality Screening Act (MQSA) legislation oversee quality as well [56].

The International Breast Cancer Screening Network (IBSN) is a consortium of 23 countries that assesses the policies, administration, and outcomes of population-based breast cancer screening programs. The IBSN surveyed participating countries with screening programs. To date, external controls on quality assurance are limited to countries with national screening programs, none of which are located in LMICs. The IBSN also determined the importance of linking screening programs to cancer registries in order to define trends and program goals [57, 58]. These programs are mainly infeasible in low-resource regions, and, therefore, innovative ideas and quality programs are needed.

Implementation of quality control programs for breast cancer screening in LMICs is necessary to provide women with a high standard of care, yet the challenge of doing so may seem overwhelming. High-quality mammography and breast ultrasound are required to achieve the goals of early detection and reduction of breast cancer morbidity and mortality. In addition to image, program quality standards, and performance metrics, screening programs in LMICs also need to consider infrastructure and training [56]. Mammography equipment is sensitive to power fluctuations, vibration, dust, and extreme temperatures, and equipment calibration must be performed frequently to maintain image quality. This may render mammography infeasible in many regions. Training regarding equipment calibration is necessary to achieve consistent high-quality images, and the accreditation programs in HICs listed above can serve as models. Educational interventions geared toward mammography technologists in LMICs have demonstrated efficacy in the production of high-quality mammography, and continuing education at frequent intervals (<6 months) has a greater likelihood of producing a lasting impact [59]. The RAD-AID Learning Management System (LMS) is one solution to educational requirements for imaging quality and diagnostic skills required for accurate exam interpretations.

Image storage and transfer may be an important part of a screening program and should be considered. This may include file rooms for film-screen images and breast ultrasound stored on film, hospital-based picture archive and communication system (PACS), or cloud PACS with established connections between mammography units if full-field digital mammography is available [56].

Cost of Screening and Follow-Up Care

Screening programs, both opportunistic and organized, must be implemented only in the context of a committed complete program. Identifying early-stage cancer is important, but detection must lead to definitive diagnosis followed by feasible treatment. Cost-effectiveness analyses must guide breast cancer program development and allocation of severely limited resources. Most analyses have been performed for HICs, but several estimates for large LMICs have also been published. Groot et al. demonstrated that the most cost-effective breast cancer control programs were comprehensive (which often included mammographic screening and CBE in HICs) and targeted treatment of stage I cancers, while the least cost-effective option was treatment of stage IV cancers. This was measured as the cost-effective ratio (CER) per life-years adjusted for disability (DALY). For example, the CER for an extensive screening and treatment program in Africa or Asia was $75 per DALY and $915 per DALY in North America. Treatment of stage IV cancer demonstrated a CER of $4986 in Africa, $70,380 in North America, and $3510 in Asia per DALY [60]. This cost data bridges both HIC and LMICs.

Working to implement a cost-effective screening program targeting early-stage cancers is a possible first step for LMIC breast cancer programs. When soliciting government support for screening programs, the CERs may be used to demonstrate overall cost savings when disease is identified early. More comprehensive research on the lost resources and opportunities due to late detection of breast cancer and poor survival is necessary to better quantify the full economic impact and benefit of cancer screening. Although mammography is considered the gold standard in breast cancer screening, the economic and infrastructure barriers that LMICs face in implementing an organized screening program are daunting. Currently, only 5% of global screening dollars are used in LMICs [61].

Referral Patterns, Innovations in Care, and Outcomes

If medical and surgical treatment for breast cancer is not available, breast cancer screening programs, however effective, will not decrease breast cancer mortality [42]. After detection, it is crucial that women can be referred for definitive diagnosis with biopsy. Pathology services must also be available with adequate quality control to ensure accurate diagnosis and effective treatment planning. After appropriate diagnosis, patients need appropriate therapy which may include any combination of breast surgery, radiation therapy, oncology, and palliative care. Systematic tracking of referral patterns and outcomes to monitor the success of breast screening programs is critical to evaluate for effects on mortality. Barriers need to be addressed or alternatives put in place.

As new paradigms of breast cancer care are considered, detection could be combined with ultrasound-guided fine-needle aspiration performed by generalist physicians. Rapid diagnostic techniques that triage biopsies for pathologists make the work of specimen transportation and wait for available pathologist less onerous [62, 63]. In addition, rapid diagnostics can perform immunohistochemical (IHC) analysis without the cost and equipment requirements of standard IHC. Finally, treatment of breast cancer with non-surgical techniques such as ultrasound-guided cryoablation is currently being studied in HICs [64–77]. If proven effective and safe in HIC settings, these procedures may offer additional potential benefit in LMICs where access to surgery is limited. It is estimated that by 2020, the countries which have only 5% of the global resources will bear 70% of the cancer burden [32]. This will require a worldwide call to action for innovation and new cancer care paradigms.

Barriers to Care

A general lack of awareness and education is one of the greatest barriers to breast care in most LMICs, as well as many HICs [78, 79]. The BHGI emphasizes targeted screening population education as a key component to all breast care programs, with the level of education offered to women tailored to available resources [43]. An understanding of how information is best disseminated in a specific LMIC community is crucial, as community meetings and deployment of neighborhood healthcare workers may be more effective than the pamphlets and commercials that have been successful in HICs.

All educational outreach efforts should be developed in the context of the specific culture and history of the target community. Healthcare decision-making may be a group process on the part of the entire family, and educational materials may need to address potential concerns of the patient's spouse or children.

Financial and logistical barriers can be difficult hurdles to overcome. The financial considerations include not only the cost of care but the opportunity cost of missed work as an increasing percentage of women join the workforce outside the home. Healthcare centers may be located far from the homes of women who live in rural areas where walking is the primary means of travel. This issue becomes especially problematic following a cancer diagnosis when frequent follow-up visits may be required for treatment. Globally, LMIC governments often have scarce funding that requires balance among multiple pressing public health issues, and until recently, infectious disease has been prioritized over cancer due to the mortality associated with tuberculosis, HIV, and malaria [43, 80–83].

Patient navigators or trained healthcare workers, who can assist patients in understanding complex cancer screening services, have been incorporated into a multitude of HIC screening programs. It is important that the patient navigators originate from and maintain a connection to the community that they serve to fully understand and overcome common barriers [84, 85]. Inclusion of patient navigators in LMIC breast cancer screening and treatment programs will likely improve both initial program success and long-term sustainability.

Strategies to Increase Uptake of Screening Services for Osteoporosis and Breast Cancer: Mobile Imaging and Packaging Healthcare Interventions

In general, it is clear that women tend to utilize screening more often when it is convenient; a group of women surveyed in the United States preferred mammography performed in a retail setting rather than a hospital setting due to convenience, such as availability of parking and favorable operating hours [86–92].

Mobile healthcare solutions have been used in both LMICs and HICs to offer interventions to patients living not only in rural areas where access to care is difficult but also in urban areas to increase cancer screening participation rates. There have been several published studies from the USA that demonstrate successful mobile DXA screening in patient populations that are not able to travel to screening centers [93–96]. Published guidelines for a successful mobile DXA quality control (QC) program from the Third National Health and Nutrition Examination Survey (NHANES III) include a single center for review of all scans, continuous monitoring of daily QC procedures, reference standards for cross-calibration, longitudinal studies for assessment of instrument stability, monitoring of technologist performance, and technologist training [97]. Mobile DXA could be effective for screening intermediate- to high-risk populations in LMICs.

Mobile mammography can significantly increase the percentage of women screened in a community, and this has been well documented in HICs [98]. It has been suggested that mobile mammography units can increase screening rates among minority and low socioeconomic populations while reducing operational costs by capitalizing on economies of scale through high volumes and batch readings [99, 100]. Mobile mammography has been attempted in LMICs with varying success, and there is a paucity of published guidelines to improve mobile breast cancer screening programs. Successful mobile mammography programs have been implemented in India, Croatia, Uganda, Egypt, and Brazil [101–104]. Some breast cancer research groups have expressed skepticism about the ability of mobile mammography programs to screen large numbers of marginalized women in LMICs due to issues with scalability, lack of qualified physicians and technologists, quality control, and competing government priorities for funding [105, 106]. Patient surveys are an important source of data for program improvement. This allows program coordinators to better understand barriers to care and provide targeted, culturally sensitive community-specific interventions.

If a mobile mammography program is to be developed, imaging standards comparable to fixed-unit mammography must be attempted. Equipment on mobile units is subject to greater temperature, humidity, and vibration fluctuations, and machine calibration must be performed frequently. Given the increased need for equipment maintenance, consistent service contracts with vendors are critical in LMICs.

Use of portable ultrasound equipment can add value and improve efficacy by performing either targeted ultrasound for palpable masses or whole-breast screening ultrasound. As discussed above, the possible uses of ultrasound as a primary breast imaging modality should be explored for LMICs given the low cost of portable units, lack of radiation, durability, and a younger screening population with potentially increased breast density. The addition of breast ultrasound to mobile screening programs has been limited in some LMICs because of implications in using ultrasound to determine fetal gender, particularly in South and East Asian as well as in former Soviet Bloc [107].

Service uptake may also improve if breast cancer detection services are added to other well-established health services in LMICs. Gutnick et al. report cervical cancer screening services offered at established HIV clinics in Malawi [41]. This may be a useful strategy for breast cancer detection services in LMICs where there has been extensive investment in establishing infectious disease services, such as those to address TB or malaria. This would allow breast cancer screening to be offered through trusted community clinics or mobile facilities and leverage existing infrastructure and resources toward expansion of early breast cancer detection programs [54].

Several studies have advocated packaging multiple screening interventions targeted at a specific population to improve cost-effectiveness, compliance, and acceptance. It has been suggested that linking breast health education to education for maternal/child care enables a program to reach women in the age range for premenopausal breast cancer [108–110], which may be a good strategy in LMICs where breast cancer often affects a younger population compared to HICs. This approach, however, excludes the postmenopausal population, which accounts for the majority of breast cancer cases. Alternatively, linking breast cancer and osteoporosis screening to other interventions aimed at women 40 years and older may improve efficiency and decrease program costs while also improving patient acceptance. This is the approach employed in RAD-AID's outreach program in India, described below. In any screening package, culturally appropriate patient education regarding the targeted diseases should be included.

RAD-AID's Experience with Women's Mobile Imaging

Asha Jyoti

Beginning in 2010, RAD-AID and Project HOPE received funding from the Philips Foundation to develop and deploy RAD-AID's comprehensive radiology assessment tool (Radiology-Readiness™) in order to analyze the diverse needs for medical imaging in India. The RAD-AID team identified women's health services for the poor in semi-urban and rural areas as a key unmet need in India.

RAD-AID identified a local partner in the widely respected Postgraduate Institute of Medical Education & Research (PGIMER), a government medical center in Chandigarh, India. Since that time, RAD-AID has collaborated closely with PGIMER to develop a unique NGO–public–private partnership between a nonprofit nongovernmental organization (RAD-AID), government (PGIMER), and the private sector (Philips Healthcare). The resulting program *Asha Jyoti*, which means "ray of hope" in Hindi and Punjabi, is an innovative mobile women's healthcare outreach program that offers screening mammogram, DXA, and virtual colposcopy using inspection with acetic acid (VIA) (Figs. 20.1 and 20.2) and provides for follow-up care as needed based on the screening outcomes. This packaged service approach offers multiple public health interventions to a targeted population in order to improve cost-effectiveness and community uptake and has been employed in other public health efforts targeting women [112] (Figs. 20.3 and 20.4).

This mobile healthcare model relies on local sustainable support and infrastructure: The PGIMER radiologists, technologists, and public health staff are responsible for operating the van, implementing health awareness training, and collecting data from patients' experiences. The subspecialty medical and surgical departments based at PGIMER provide free medical care for women

Fig. 20.1 *Asha Jyoti* van arrived at PGIMER, Chandigarh, in April 2012. (Reprinted from Everton et al. [111], Fig. 22.1, with permission from SpringerNature)

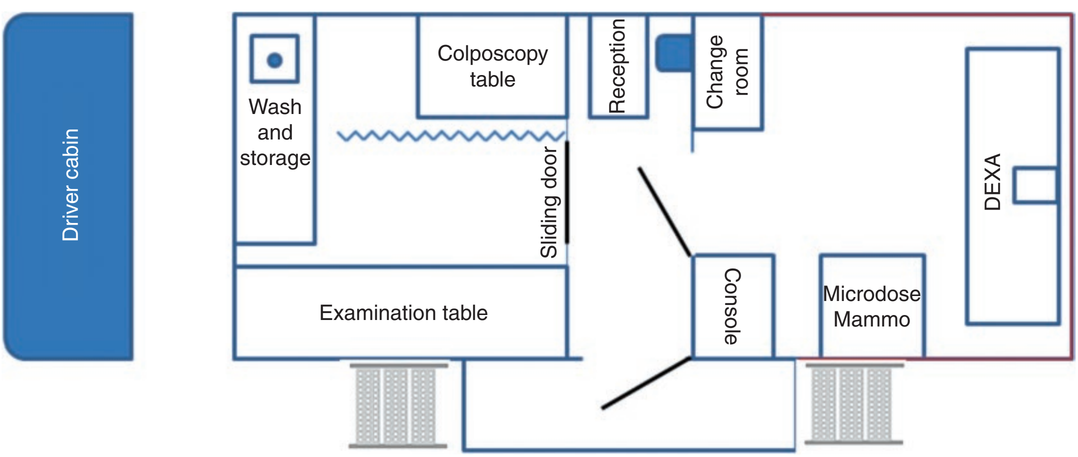

Fig. 20.2 *Asha Jyoti* van schematic. (Reprinted from Everton et al. [111], Fig. 22.2, with permission from SpringerNature)

Fig. 20.3 Asha Jyoti imaging room. (Reprinted from Everton et al. [111], Fig. 22.3, with permission from SpringerNature)

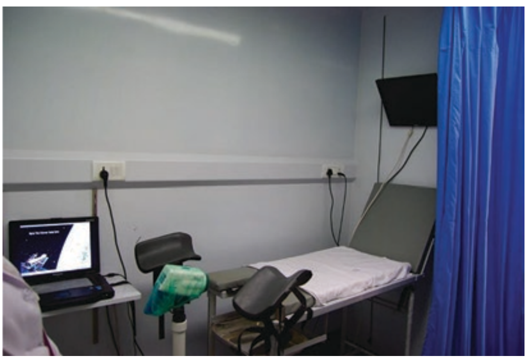

Fig. 20.4 Asha Jyoti colposcopy room. (Reprinted from Everton et al. [111], Fig. 22.4, with permission from SpringerNature)

below the poverty line (BPL) in accordance with local government policies (Fig. 20.5).

The goals of the *Asha Jyoti* program are to increase health awareness with education and to improve overall outcome of disease by screening for earlier detection and by providing a referral system for women into the public hospital system for treatment of breast cancer and osteoporosis. As of August 2018, 12,500 mammograms had been performed on the *Asha Jyoti* van, which has yielded approximately 60 cancer diagnoses. A total of 16,394 DXA scans have led to 2593 diagnoses of osteoporosis and 6348 diagnoses of osteopenia [113] (Figs. 20.6 and 20.7).

The extensive outreach efforts on the part of the PGIMER School of Public Health and involvement of social workers in tracking patients and guiding them through follow-up and treatment are critical components of Asha Jyoti, particularly for breast cancer patients. Of the patients with suspicious findings on screening mammogram for whom biopsies were recommended, there was an 83% compliance rate for follow-up leading to definitive diagnosis [113]. The majority of the remaining 17% of patients who failed to follow-up as recommended were identified in the beginning stages of the program, and processes were later optimized, which led to an increased rate of compliance for subsequent years [113]. The patients who received a definitive diagnosis were tracked through completion of treatment free of cost at PGIMER or, per patient preference, at an outside facility.

Prior to the program's launch, one anticipated hurdle identified based on research from previous mobile programs was a lack of public awareness or trust in a screening initiative. Perhaps due in part to strong local media support, patient turnout has been strong and utilization of the van screening services has remained high. An overall increase in regional awareness about breast cancer screening has also led to an increase in

Fig. 20.5 Former directors of RAD-AID India along with PGI physicians from the departments of radiodiagnosis, medical oncology, surgery, gynecology, pathology, public health, and endocrinology, as well as representatives from Philips Healthcare at an early strategy meeting for *Asha Jyoti* in January 2012. Establishing an accessible and affordable diagnosis and treatment referral network is critical for a screening program to result in decreased morbidity and mortality. (Reprinted with permission from RAD-AID International)

mammography screening rates at stationary sites in the region by two- to threefold, an impressive and unexpected positive impact [113]. A recent collaboration with the nursing school at PGIMER has led to increased staff available at the van. Nursing staff triage patients and optimize workflow, perform VIA, and provide education regarding breast cancer, cervical cancer, and osteoporosis (Fig. 20.8).

Outcomes of the *Asha Jyoti* screening exams and public awareness outreach are tracked by PGIMER's Department of Radiodiagnosis and the School of Public Health, respectively. RAD-AID and PGIMER meet biannually to assess program results and plan for future growth and improvements. The program features a breast imaging education exchange between PGIMER and the US clinicians, which encourages collaboration on best practices. PGIMER hosts an annual workshop for mammography technologists, which involves didactic lectures and hands-on practice sessions led primarily by RAD-AID technologists and breast radiologists for up to 100 technologists from Chandigarh, India, and surrounding regions [101, 114, 115] (Figs. 20.9 and 20.10).

Asha Jyoti demonstrates a model for integration of mobile health services into a large public hospital system, and although *Asha Jyoti* is a regional program focusing on locally sustainable growth, lessons from the program could impact other mobile screening programs in India and worldwide. Data is currently being collected and analyzed to report translatable findings to the international global health community. Plans are currently in the works to refurbish the original van and to expand the *Asha Jyoti* project to other parts of India.

Conclusion

As we continue efforts to improve healthcare in LMICs, better control of infectious disease has led us to consider how non-communicable

Figs. 20.6 and 20.7 Women in North India await their turn on the *Asha Jyoti* van. 20,000 patients were seen on the van between 2012 and 2017. (Reprinted with permission from RAD-AID International)

Fig. 20.8 Director of RAD-AID nursing with faculty at the PGIMER School of Nursing at a workshop focused on the role of nursing in breast care. *Asha Jyoti* employs a multidisciplinary approach toward community outreach and education in collaboration with the School of Nursing and the School of Public Health at PGIMER. (Reprinted with permission from RAD-AID International)

Fig. 20.9 (**a**) RAD-AID volunteers teach annual workshop in India geared toward mammographers. (**b**) Drs. Niranjan Khandelwal, head of Radiodiagnosis at PGIMER, and Tulika Singh, PGIMER Associate Professor of Women's Imaging present certificates to technologists who have participated in the workshop. (Reprinted with permission from RAD-AID International)

diseases such as osteoporosis and breast cancer will be detected, diagnosed, and treated in regions with scarce resources where there is fierce competition for available skills and tools. With regard to osteoporosis, detection of low bone mineral density can lead to changes in lifestyle and pharmacologic intervention. These interventions could decrease the risk of osteoporotic fractures, which in turn would decrease morbidity and healthcare costs while improving quality of life. Concerning breast cancer, earlier detection leads to less expensive and more effective treatment, which in turn allows for greater access to care and improves outcomes. Research is ongoing to design sustainable programs and low-cost devices that will provide scalable diagnosis and treatment. In the interim, providing access to affordable screening for early detection to avoid late-stage disease in close partnerships with diagnostic and treatment facilities, including mobile programs, is a step toward success.

Fig. 20.10 Directors of RAD-AID India and the *Asha Jyoti* technologists outside the Asha Jyoti van. (Reprinted with permission from RAD-AID International)

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21 Mobile Strategies for Global Health Radiology

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Since the dawn of radiology over 100 years ago, medical imaging has been mobile. Shortly after the discovery of x-rays in 1897, radiology was mobilized for outreach to populations that could not safely or easily reach fixed-site medical institutions. For example, among Marie Curie's many accomplishments in the development of radiologic imaging, she organized mobile radiology during World War I (1914–1918) to bring imaging to soldiers who were injured on battlefields far from stationary medical posts [1, 2]. The imaging was to be used for finding bullets and shrapnel in the wounded soldiers needing medical attention. With these efforts, Curie created a fleet of over 200 mobile radiology units during World War I (Fig. 21.1a), outfitted with onboard electrical generators for radiology equipment. This innovative radiology vehicle was nicknamed "little Curie" and launched the field of mobile radiology outreach in 1915. Additionally, during the influenza outbreak of 1918, mobile radiography was instituted as a means of getting medical imaging access to US military medical installations (Fig. 21.1b) [2, 3].

One hundred years later in the present, the challenges and goals of making radiology mobile are still inherent to the objectives of global health. With the advent of heavier and complex imaging technologies, such as computed tomography (CT), magnetic resonance imaging (MRI), positron

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Fig. 21.1 Early use of mobile radiology during World War I, including mobile units with x-ray capability developed by Marie Curie to find bullets and shrapnel in wounded soldiers (**a**) and vehicles built to provide imaging access to various military medical installations (**b**)

emission tomography (PET), and 3D breast tomosynthesis, the complexity of mobile outreach to underserved communities has more variables than ever before. For instance, can a truck safely transport a CT scanner over the mountains of Haiti to reach patients at a remote hospital? Can vehicle-based mammography provide breast cancer screening in Tanzania using the same strategies as mobile mammography in New York? Is it possible to incorporate aircraft into mobile radiology service delivery? With nearly 3–4 billion people lacking adequate access to radiology [4] and approximately 1 billion people living in remote regions without reliable infrastructure [5], the questions of how mobile radiology can serve global health objectives are paramount.

This chapter aims to address the goals, challenges, and strategies for optimizing mobile imaging for global health applications in reaching poor and underserved populations. How do mobile imaging strategies differ from fixed sites? What unique resources and technological constraints apply to the mobile context? What advanced planning may help optimize mobile health strategies? What data support the use of mobile radiology strategies? How can rapidly evolving imaging technologies, such as CT, artificial intelligence (AI), fused functional-anatomic imaging, and Picture Archive and Communications Systems (PACS), be integrated into newer mobile global health strategies?

These questions and others frame this chapter to focus on the following aims:

- Discuss the reasons for mobile radiology in global health.
- Review the unique challenges to mobile radiology strategies.
- Assess strategies for linking mobile outreach with fixed-site medical installations.
- Discuss efforts to innovate new approaches to mobile radiology outreach.

- Discuss how mobile imaging's opportunities, along with the inherent economic and technological constraints, achieve public health and clinical progress.

Why Is Mobile Radiology Important in Global Health

As of 2016, the World Bank estimates that 900 million to 1 billion people live without access to adequate road infrastructure, defined as living within 2 kilometers of an all-season road traversable by motored vehicles [6]. Moreover, this impaired access to infrastructure is viewed as a major impediment to economic development and health-care accessibility, in which poor transportation infrastructure contributes to sustained isolation and poverty. For example, approximately half the population of Nepal (10.3 million people) lives without access to reliable roads. Additionally, 33 million rural Tanzanians, 15 million residents of Mozambique, and over 75% of Ethiopian and Zambian populations have little-to-no access to road infrastructure.

Many studies suggest that the presence of quality road infrastructure is inversely correlated to the poverty in that region, along with higher rates of poor health-care outcomes and lower life expectancies [5–8]. However, it is widely recognized that identifying causality is difficult, primarily due to the many variables integral to poverty, economic development, and infrastructure. To improve the collection and analysis of infrastructure, poverty, and economic data, the World Bank recently enhanced its *Rural Access Index (RAI)* as a means of measuring infrastructure gaps and economic progress. These updated RAI statistics once again reinforce the widespread absence of transportation infrastructure in impoverished regions [5, 6]. Advancing technologies for measuring and analyzing infrastructure are enabling public health authorities to better deduce transportation impacts on health and economics, with ongoing efforts to significantly expand the RAI within the next several years.

As a technology-intensive and capital-intensive portion of the health-care system, radiology thrives on the interconnections that transportation infrastructure provides. For example, radiology can better reach populations when physically transported to the sites of need. Moreover, the market ecosystems for service inspections, maintenance, repairs, replenishment of consumables used in imaging (such as IV catheters, sterilizing agents, etc.), and access to spare parts for radiology equipment often rely upon stable cargo delivery and consistent mobility of personnel (including physicians, nurses, technologists, biomedical engineers, etc.).

To address this role of transportation infrastructure, the RAD-AID Radiology-Readiness Assessment tool, endorsed by the World Health Organization since 2012, has distinct infrastructure components to evaluate transportation accessibility as a major factor in determining appropriate radiology health solutions for under-resourced medical institutions. For example, if a CT scanner is to be donated to a site, it is critical to first evaluate whether the transportation networks will allow for the safe delivery and maintenance of a CT scanner. This is particularly true given that CT scanners can weigh more than 3 tons and have delicate electronics with gantry-alignment features that cannot withstand uneven and impassable roads often found in the interiors of low-income countries. Therefore, infrastructure and radiology must go hand-in-hand for effective planning and execution. Broadband connections and electrical power are other essential infrastructure constraints that contribute to long-term radiology sustainability.

Substantial data show that underserved populations can be reached via mobile radiology platforms. Most of the published data on mobile radiology is derived from mobile mammography in the context of expanding breast cancer screening programs. For example, multiple authors have demonstrated that mobile mammography increases screening rates over baseline levels at fixed radiology sites [9–12]. Moreover, research on mobile radiology outreach illustrates how populations receiving care from mobile providers are generally more likely to lack health insurance, have higher risk factors, come from minority demographics (such as African American and

Hispanic), and have more advanced disease diagnosed at presentation [12]. Even in the United States, where fixed-site mammographic services are accessible in many regions and states, the medical literature has documented that mammography is underutilized by lower-income women, those without health insurance, racial/ethnic minorities, and rural residents [13].

The central limitation of this research for generalizing mobile radiology's effectiveness in low- and middle-income countries (LMICs) is that most of these published trials were conducted with small populations using few mobile radiology vehicles in high-income countries, often associated with regional advanced health-care structures, with most of these studies focusing on breast cancer and mammography in single-modality service configurations. Additionally, the literature's published conclusions are limited in being able to deduce clear causation among the multiple contributing variables. For example, RAD-AID's program in India (covered in more detail in another chapter in this text) with Postgraduate Institute of Medical Education and Research (PGIMER) in Chandigarh has observed that health-care disparities among women in Northern India with high breast cancer mortality experienced an interplay of complex contributing variables, such as (i) infrastructure impeding patient transportation, (ii) high cost of travel over long distances, (iii) education levels of patient populations, (iv) personal health awareness, (v) family dynamics (such as not being able to leave the home for health care due to co-existing family responsibilities), and (vi) economics (including inadequate insurance, inability to pay fee-for-service, etc.). Therefore, it is essential to note these complex variables in mobile screening prior to attempting to infer causality in a mobile program's effectiveness. When analyzing whether radiology can be an effective mobile outreach tool for underserved populations, it is important to consider the relative benefits for the patients receiving mobile health care over fixed sites (hospitals, brick and mortar imaging centers, etc.). For example, if a patient has no means of transportation, or there is poor infrastructure limiting transit, mobile radiology overcomes those barriers by reaching the patients directly. Another value delivered by mobile imaging is the separation of common perceptions that hospitals and medical facilities are only for sick people, while mobile units are often viewed as screening facilities for the healthy and well, ultimately serving as an attractive distinction for those patients who do not want to be seen (by neighbors and families) as sick. This perceptual separation from fixed-site medicine may be particularly important in cultures within LMICs that still regard medical facilities as a sign of illness, which when used can often lead to cultural isolation. A mobile health unit can, therefore, serve as safe haven without the stigmas of illness, so that visiting patients can feel welcome to a place of wellness and prevention.

Another value in mobile radiology is the compact nature of the delivered care, through multiple service menus all within the vehicle's suite of rooms (Fig. 21.2). This simple vehicle-based layout can overcome the trepidation that patients may feel when trying to navigate complex layouts of medical facilities housed in large buildings. Moreover, mobile health can segment geographic regions to reach specialized patient populations by way of public messaging and vehicle designs matching the needs of particular at-risk populations, such as women at risk for breast cancer, homeless, uninsured, smokers, children, and other demographics that can be difficult to reach from a fixed-site installation for the general public. Lastly, by delivering care within the community, it may be possible to better triage populations to avoid more costly emergency department (ED) visits and ensure follow-up with patients through direct community engagement. Research has shown, both on the state and country level, that mobile health clinics significantly reduce unnecessary emergency department visits and associated costs to both patients and hospitals [14]. One large study showed that approximately 14 emergency department visits are avoided for every 100 mobile health visits, illustrating the vast impact that mobile health can have both on patient outcomes and health-care costs [15].

Due to these deliverable benefits of mobile health units (MHUs), there is ongoing growth

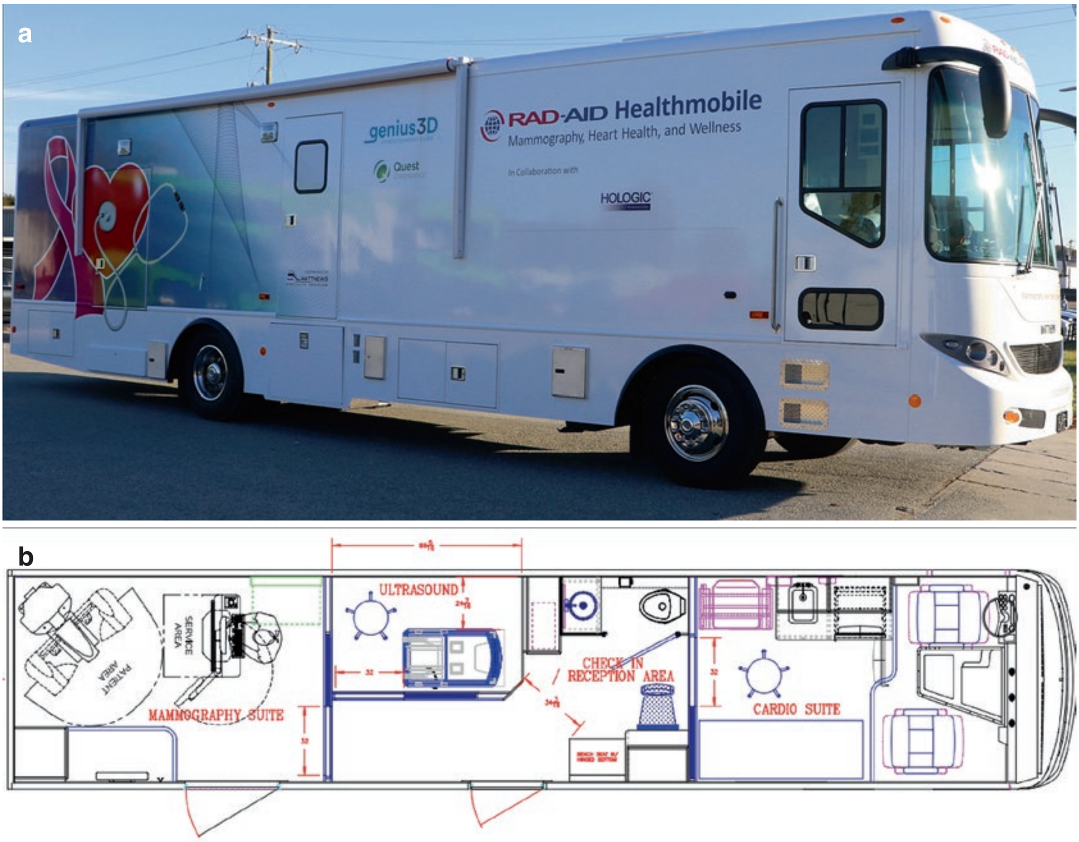

Fig. 21.2 The RAD-AID Healthmobile for mammography, heart health, and wellness, viewed from the outside (**a**) and schematic view (**b**) highlighting the capabilities of compact mobile radiology. (Reprinted with permission from RAD-AID International)

in mobile outreach. Although these figures change from year to year, to give approximate scales for this discussion, there were approximately 2000 MHUs in the United States in 2013, caring for approximately 6.5 million people, reporting an average of 3300 patient visits per unit annually [16, 17]. One regularly updated database, highlighting maps and activities of mobile programs throughout the United States, is available at www.mobilehealthmap.org. Given the important role for radiology in screening and medical care across many disciplines of medicine, surgery, obstetrics, and adult/pediatric health, it stands to reason that optimizing radiology for these growing mobile outreach efforts will continue to be an important strategic component of delivering care to underserved populations.

Economics of Mobile Radiology

A common question in mobile radiology for outreach to community-based populations is whether it is cost-effective or relatively sustainable in comparison with fixed-site radiology services. Similar to any industry involving different market segments, consumers, capital costs, and operational variables, there is a similar range of economic outcomes in mobile health services outreach. According to one survey study of US-based mobile mammography operations published in 1996, 46% of mobile facilities achieved breakeven or profitability [18]. Although some of the technologies relevant to that survey study have changed, many of the operational characteristics have stayed constant and are also relevant to emerging modalities of mobile radiology outreach, such as CT, ultrasound, and x-ray. For this chapter, it is helpful to review the features that drive the range of economic sustainability in mobile radiology outreach.

On the cost side of operating mobile radiology, one must consider the expenses of acquiring the vehicle (new or refurbished, purchased or leased, etc.), insurance, staffing, imaging equipment (hardware and software), medical consumables, vehicle servicing, vehicle operations (fuel, parking, etc.), telecommunications services, and compliance with regulations (licensing, inspections, etc.). A mobile health vehicle is generally depreciated over 5 years, with most truck-based platforms having a life cycle of 12 years before needing replacement. It is important to note that most of these costs are fixed, meaning that they do not change with utilization.

On the revenue side of operating mobile radiology, key contributors are percentages of patients covered by insurance, self-paying, or grant-supported philanthropic revenues to support services. This interface between revenues and costs is then framed by the number of days the vehicle can operate per year, the number of patients examined per day, and losses in operations due to downtime when the vehicle or medical equipment is not functional.

Similar to any economic entity that has high fixed costs that are overcome by maximizing utilization, a mobile radiology unit is optimized economically by maximizing the number of patient encounters (i.e. number of patients screened, diagnosed, treated, educated, etc.). This is similar to other high fixed cost industries such as airlines, in which airplanes can best cover their costs when planes are in-flight to transport passengers. Another example is hospital infrastructure having high fixed costs of personnel and equipment such as operating rooms, in which the returns on those investments are best yielded when utilization of the assets is highest. Idle assets not in use, while incurring high fixed costs, can drive steep deficits.

The high proportion of fixed costs in mobile health (such as personnel staffing, medical equipment, vehicle construction, and insurance) warrant higher utilization to lower the cost per patient. If a vehicle encounters many service outages due to inclement weather or repair needs, then the cost per patient is higher. If some services have higher proportions of patients with insurance or self-pays, then those revenues help offset losses of revenues from uninsured services. Many mobile mammography services report screening 20–30 patients per day at 150–250 days per year, with the balance of time needed for inspections, cleaning, replenishment of supplies, repairs, and travel between service sites [12, 18].

In the international context, this analysis has additional variables that have dynamic impacts on costs. The costs of manufacturing a vehicle may be lower in some countries, if the country has domestic automotive manufacturing capacity. Other regulatory costs are also lower than in the United States. On the other hand, infrastructure can be less reliable and contribute to more service outages in LMICs if there are more impassable roads affecting service routes.

Another significant factor impacting costs in the international setting is the need for multidisciplinary health vehicles. In the United States or other advanced health systems, it may be more plausible to have a single modality screening vehicle such as a mammography truck (“mammo van”). In a low-resource country or other underserved area, the need to maximize the range and value of patient encounters supports the addition of multiple services. For example, RAD-AID India supports PGIMER’s operation of Asha Jyoti by including breast cancer, osteoporosis, and cervical cancer screening within one vehicle (Fig. 21.3).

This interprofessional approach unites multiple themes and clinical workflows for women’s health into one mobile platform, which can simultaneously increase the workflow complexity of managing different types of patient visits and requiring more staff with specialized skills to match the different services on the vehicle. On the other hand, increasing the diversity of services on the mobile radiology vehicle can help attract a larger volume of patients, which in turn may drive up utilization and lower the cost per patient.

The economics of mobile radiology planning is also heavily impacted by the geographic

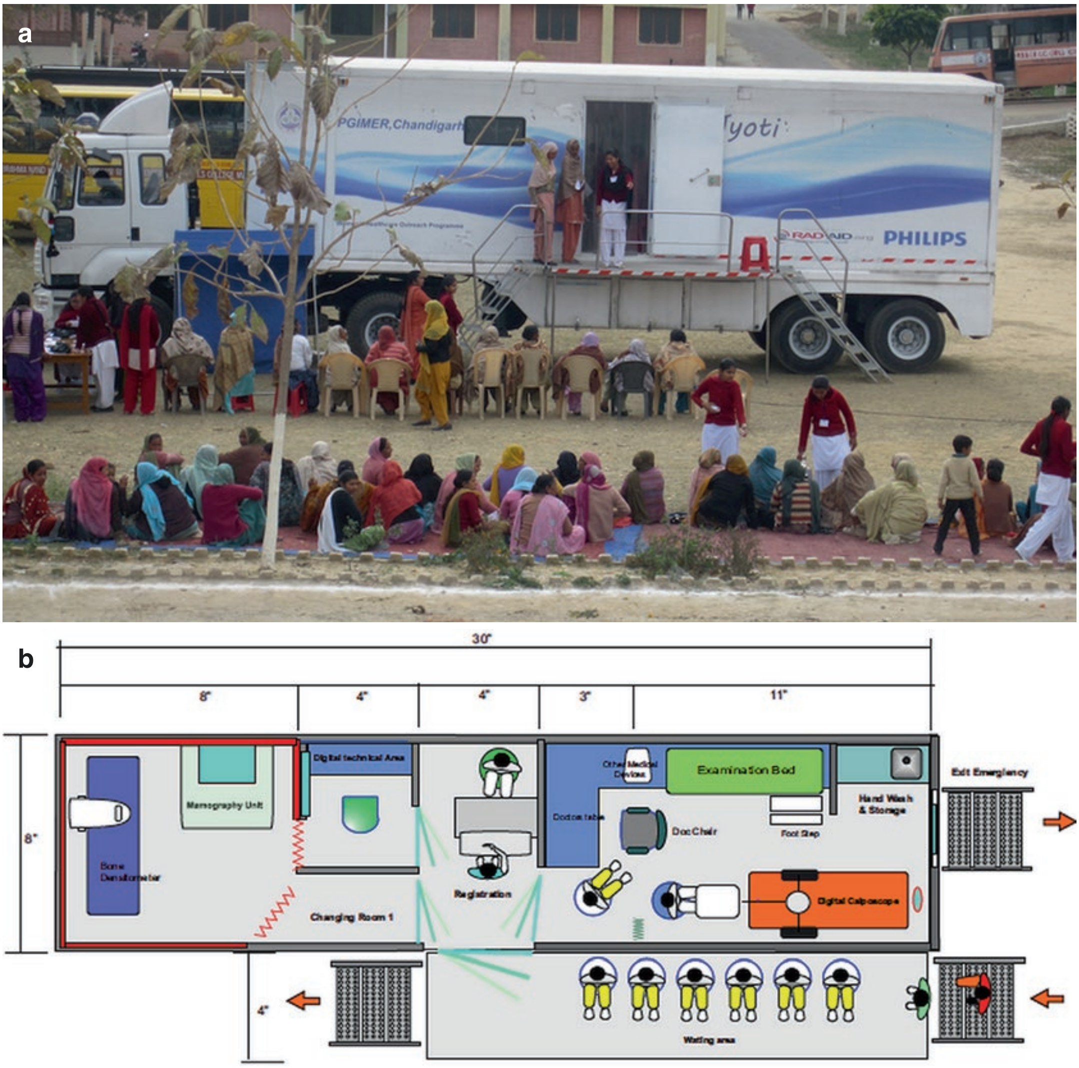

Fig. 21.3 RAD-AID India mobile health truck (**a**) and schematic (**b**) showing multidisciplinary capability to support women's health through breast cancer, osteoporosis, and cervical cancer screenings in a single vehicle. (Reprinted with permission from RAD-AID International)

service area that the radiology equipment needs to reach. A larger geographic range for the mobile health vehicle may require more transit time between sites (i.e., lower number of health service days) and increase operational costs from wear and tear on the vehicle. Such a larger geographic area may be necessary when the patients in an underserved area are in rural or marginalized zones lacking sufficient transportation infrastructure. Therefore, optimizing the routes (which is discussed below) can maximize the clinical site times and minimize the transit times to heighten economic sustainability.

Technology Choices in Mobile Health

As radiology and transportation technologies have evolved in the last hundred years, new opportunities have arisen for how radiology can better reach the remote and underserved populations. For the development of radiology technology on mobile platforms, there are several factors to consider:

- Compactness (size/weight) of the imaging equipment
- Ergonomic fitness of the radiology equipment for small mobile clinical spaces
- Sensitivity of radiology equipment to travel motion
- Power needs of radiology equipment
- Radiation safety in a mobile clinical space
- Mobile data network compatibility
- Clinical-social impact of workflow design

Compactness

The changing size dimensions of mobile imaging equipment afford new opportunities and trade-offs for radiology's role in community-based mobile outreach. For example, ultrasound units have become more compact, including handheld devices and laptops with footprints (floor space dimensions) that can fit well into a small space such as a mobile health vehicle (Fig. 21.4a). Easy storage of a compact ultrasound may be more space efficient than a full cart configuration, which may take up essential patient exam space. The transition from printed film to digital medical image archiving has made it easier to see images in mobile contexts and archive them permanently on PACS without use of valuable space in a mobile health unit. As a trade-off, mobile mammography (Fig. 21.4b) often requires uninterrupted power supply (UPS) units to sustain access to electrical power, which requires additional space in the mobile clinic. As these imaging technologies evolve, it may be possible to continue increasing the space efficiency of radiology equipment with fewer functionality trade-offs. Each selection of imaging equipment for a mobile unit must be careful to include not only the physical footprint of the hardware, but also the necessary wires for connectivity that limit hardware placement options, wireless configurations, ergonomic impact on clinical workspaces, and patient comfort.

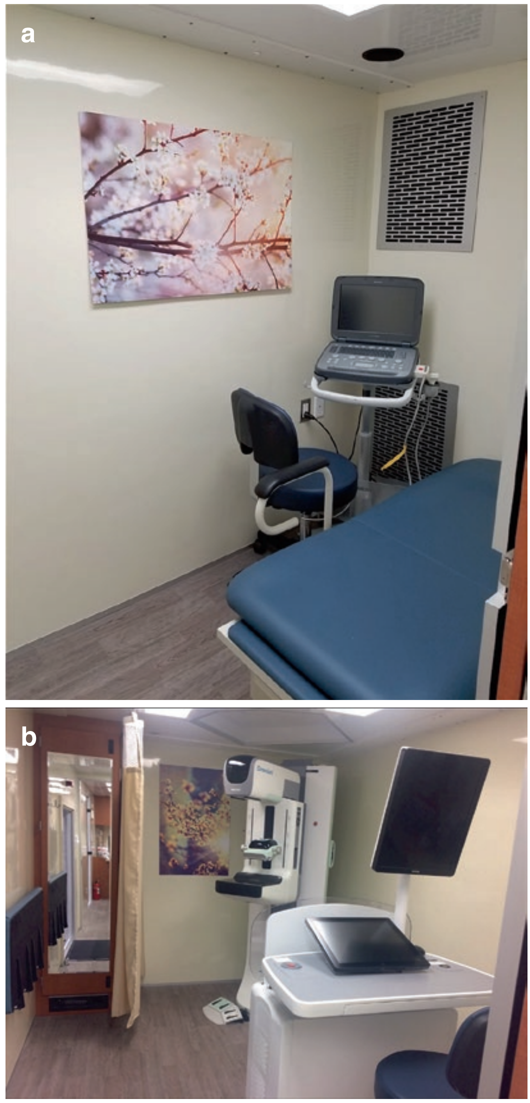

Fig. 21.4 RAD-AID Mobile Healthmobile illustrating compact design of an ultrasound room (**a**) and 3D mammography room with patient changing area (**b**). (Reprinted with permission from RAD-AID International)

Ergonomics

The field of ergonomics refers to how the design of systems interfaces with human use and experience, including elements of safety, productivity, and comfort. To maximize the space efficiency of mobile equipment on a vehicle, it is important to consider the impact of the machine on the safety, productivity, and comfort of the health personnel as well as the patients. For example, the position of the patient exam table/bed in a mobile health unit can limit the ergonomics of a sonographer, such that only left-handed or right-handed sonographers may have good use of the equipment and ample access to the patient if there is a tightly apposed wall along one side of the bed in a mobile imaging suite, which not only impacts the workflow of patient care, but also alters the risk of repetitive strain by the sonographer. Even a beveled ceiling in a mobile mammography suite can add more height range to the mammography for the imaging of taller patients (Fig. 21.4b).

Wheelchair accessibility of a mobile health unit also fits into the ergonomic design of the mobile clinic space, by requiring extra width of doors and passable space for patient transport (Fig. 21.5). Therefore, if a mobile health unit is planned for targeting patients who are more likely to be in wheelchairs, keeping these additional design parameters in mind is essential.

Privacy is an additional paramount ergonomic feature of a mobile clinic, such that the privacy of a changing room or a secured consultation room aboard the mobile health unit must include the provision of barriers (curtains, walls, etc.). These ergonomic considerations may also need to account for whether patients are accompanied by family or friends or are expected to appear alone for the mobile clinic encounter. Accompaniment by friends or family may be important in some cultures or may be an absolute requirement in pediatric settings and therefore must account for the increased number of people present in the clinical workspace.

Optimizing the number and types of personnel for a limited workspace is impacted by ergonomic design. Operating with fewer staff can better use the space but may lead to missing skill sets that are essential for quality health care. However, adding more personnel for specialized skill sets can put a strain on the workspace. These challenges can be overcome by a better ergonomic

Fig. 21.5 Mobile health unit with wheelchair-accessible entrance. (Image from Matthews Specialty Vehicles. Reprinted with permission from RAD-AID International)

design of the space and careful workflow planning so that patient and staff traffic are better coordinated.

Travel Motion Sensitivity

Radiology is uniquely sensitive to travel motion, such as uneven roads, bumps, and other physical travel impediments, because radiology equipment has integrated radioactive and electronic configurations. Sensitivity to motion is a clear challenge for CT and MRI. Weighing more than 3 tons, having a relatively large footprint, and using delicate electronics, this equipment can make an uneven road or steep hill descents treacherous for mobile radiology. Classically, CT scanners that are mounted on trucks are not for mobile stop-to-stop community imaging, but instead are for providing an extension trailer-based fixed site in the parking lot of a hospital or imaging center. As CT scanners become more compact with designs more tolerant of bumps, potholes, and other road attributes, it is possible that CT can be more fully utilized in the community-based outreach strategy. This sensitivity to travel motion requires balanced appraisal between the intended terrain of the mobile outreach and the intended imaging modalities, so that transported radiology hardware remains safely intact.

Power Needs, Water Supply, and Ventilation

Since mobile units cannot always connect to fixed electrical supplies, transportable power sources are usually needed for mobile health outreach. For example, outfitting the mobile health unit with a generator enables continuous access to electrical power. Moreover, some imaging hardware also requires uninterrupted power supply (UPS) units to provide continuous electricity to the imaging unit. One example is mobile mammography units, which have site plans requiring the UPS to be positioned at a certain distance from the imaging hardware. Therefore, power supply needs to be carefully considered for the mobile design so that the appropriate access points and backup connections to electrical power are included.

Along the same lines, use of water on the mobile health clinic raises questions about whether the vehicle can plug into an external source or must carry its own tank of water until reaching a refill station. The use of water in the workflow must be considered, such as for washing or for an onboard lavatory, and whether washing requirements include only simple hand sanitation or a broader need for cleansing of clinical spaces (such as in onboard laboratory or phlebotomy stations).

Ventilation may also be uniquely designed for certain mobile outreach strategies. First is the issue of climate control for patient comfort/safety and also for the maintenance of temperature-sensitive equipment. Radiology equipment can often require temperature control, as do many advanced types of computer hardware/software. Ventilation is also an important feature of infection control, such that well-ventilated areas can be safer against respiratory pathogen transmission. Under very specialized conditions, some mobile health units treating highly transmissible and pathogenic droplet or airborne diseases, such as tuberculosis, would include a negative pressure ventilation system. Therefore, the ventilation strategy for the mobile health unit should be designed to accommodate the patient population, onboard equipment, and expected range of infection transmissions.

Radiation Safety

Radiation safety for mobile units can follow different regulations compared to fixed-site designs, due in part to the small spaces and the absence of concrete walls. When planning a mobile health vehicle, there are space requirements (minimum room size standards) for radiation-emitting imaging devices and lead shielding for protecting patients and health-care workers. As technology progresses in radiation safety and lower-dose scanners come into production and use, these innovations may further facilitate the mobility of radioactive imaging modalities. Radiation safety planning for fixed sites often has more stable assumptions because the location of the radiation source does not change relative to the general public. For example, a CT room near a hallway is not going to change significantly over the course of time in the building. However, a CT on a mobile unit may change locations relative to the public, by parking in an isolated parking lot one day and a full parking lot the next day, leading to different exposure profiles. Therefore, the mobile unit must often be planned for radiation safety with the assumption of highly occupied adjacent public areas in order to ensure the greatest protections. Additionally, a fixed site may benefit from having concrete in the walls and other structures that reduce scatter and incidental exposure. Mobile units are not likely to have concrete, and the thinner walls and materials may increase requirements for shielding. It is therefore important to have a physicist involved in the planning and design of a mobile unit so that these exposures, barriers, and protections are carefully analyzed for the protection of the public, patients, and staff.

Mobile Data

Mobile data is an essential technological component of the mobile health architecture. Now that scanners are transmitting more data than ever before to PACS, there are questions about how to best send such data to a cloud or fixed site for storage, retrieval, and interpretation. Sending data from a mobile health truck can encounter cost issues, as wireless data can increase costs when using satellite or cellular data over Wi-Fi networks. If immediate interpretation of imaging is not essential (such as with mammography breast cancer screenings), many mobile health vehicles utilize nightly data transfers by connecting to a local access network (LAN). The workflow implication here is that mobile units that do not offer immediate interpretations may have increased risk of patients lost to follow-up when they need to be contacted days after the exam. If such immediate image review is essential, requiring transmission to the interpreting physician or health worker, then the data may need to be transmitted by cellular and satellite networks, which can be costly and slowed by bandwidth limitations. This is a trade-off that will likely be affected by evolving marketplace and technology capabilities of the telecommunications systems. As data moves faster and more cheaply in advancing telecom systems, then perhaps more real-time radiology interpretation can become more cost-effective.

Mobile Health Services, Referral Networks, and Radiology Stakeholders

The workflow implications in mobile outreach are also changing with the frequent output of new radiology technologies. Most mammography vehicles by 2017 were offering 2D mammography, but some “mammo vans” are adopting 3D tomosynthesis. For 3D tomosynthesis, the exam is longer and produces more images than 2D, which then changes the workflow. As stated above (in the economics section of this text), such a change in workflow may impact the number of patients seen. Moreover, while the additional images may lengthen interpretation time and increase data requirements, the advancing technology may produce progress in clinical outcomes as a result. Along similar lines, if CT becomes more compact and resistant to motion-based breakage, these imaging modalities may limit the scope of diagnoses to specific applications, such as head CT, cardiac CT, or orthopedic CT, which again impacts workflow operations.

A central element in workflow of mobile radiology is the referral network. A referral network is the means by which patients having initial encounters on the mobile unit can then be referred on to a fixed site for more comprehensive follow-up and management. As care has become more digitized with electronic medical records, such mobile outreach now necessitates electronic data links to the fixed-site referral centers so that there is care continuity. Telemedicine can also reinforce these referral networks so that the data from a patient encounter is still housed at the same institution where the initial mobile screening occurred.

Since the mobile strategies are based on bringing frontline medical screening and basic care to underserved communities and remote populations, definitive care and more advanced follow-up medical and surgical services remain based at fixed-site medical facilities ranging from primary care, emergency departments, and tertiary care referral centers. Therefore, it is essential that each mobile health service has pre-planned referral systems for following up with patients to ensure that the patients needing more advanced care are successfully referred for further evaluation.

In many cases, the mobile program is formulated as an outreach service of a hospital, so that the mobile program operates like any other hospital service fully integrated with the rest of the hospital operationally. In this arrangement, the mobile unit is just like any other clinic from the hospital, except that it has the ability to move from site to site. Once patients visit the mobile unit, they essentially become outpatients of that hospital.

In other configurations, the mobile program is independent of the hospital from a legal and operational standpoint, and the referral systems are arranged via the mobile program and the fixed-site referral centers. This independence can facilitate referrals to many different hospitals (based on locations and clinical expertise) as an integrated regional network but can also be more complicated in arranging additional stakeholders from various institutions with diverse referral protocols, clinical strategies, and financial/legal operations.

RAD-AID, for example, has taken the approach of designing and coordinating mobile programs with multiple partner stakeholders. In India, RAD-AID's Asha Jyoti Program provides mobile breast cancer, osteoporosis, and cervical cancer screening in camps and sites in northern India. Asha Jyoti's mobile program patients are referred to the partnered tertiary care center PGIMER Chandigarh. In this way, RAD-AID helps support program design, workflow, education, fund-raising, personnel training, and research, while the PGIMER Chandigarh leads the clinical services, deployments, onboard patient care, research, and referrals.

This stakeholder management is also essential for selecting mobile sites of patient outreach and patient recruitment. Informing the communities that a mobile clinic is coming to their region or community is vital for ensuring full utilization of the service. Forms of public messaging include social media (Twitter, Facebook, etc.), emails or text messages (if the program administration has a running list of patients who signed up for such communications), printed signs or brochures, a publicly available website describing the service, advertisements on television or radio, oral announcements at community-based social institutions, and street volunteers handing out materials to the public. It is critical that the outreach message clearly stipulates what services are available and how the program operates. Additionally, if there is a research component to the mobile program's services, it is vital that such research objectives are clearly disclosed to patients, and the appropriate IRB approvals outlining patient recruitment and management are acquired in advance.

This recruitment of patients and management of follow-up is vital for mobile programs because lower compliance with follow-up recommendations is a common challenge in mobile outreach [12]. It is important to invest in a system for letting patients know their results in a timely manner and give assistance to patients who need referrals to the fixed-site health center.

Managing diverse stakeholders is critical for mobile outreach. Different medical specialties may have very diverse approaches to outreach. The use of limited space and resources onboard a mobile medical unit warrants high degree of coordination among the participating specialties. Using a mobile unit for single-modality outreach may be easier in coordination, such as "mammo van" approaches deployed from radiology departments alone, but the integration of other services (such as primary care, non-radiologic cancer screening, and patient education resources) would necessitate coordinating with other departments.

Security, Disaster Response, and Care Delivery Models

A mobile program bares the risk of security, such as vandalism, terrorism, and other forms of armed conflict that may impact the safety of patients, personnel, and the public, as well as the security of the vehicle, regardless of whether that vehicle is a truck, ship, or aircraft. One central aspect of planning a mobile program is taking into account the safety issues so that these objectives are met early on. First, while site selection may be driven by safety concerns for some programs, others may address safety as integral to the mobile unit's objectives, particularly if the aim of the mobile unit is to address patients in a conflict zone, or care for refugees affected by regional armed conflict. A second approach to safety is how the unit is designed. In many cases, mobile units have been designed to look nonmilitary by baring clear logos, flags, and emblems of neutrality, in order to avoid being targeted by armed groups. This has been particularly important for mobile outreach efforts that may have collaboration with the military but are overall separate from military operations. Misinterpreting a health-based outreach service as a military infiltration unit is a particular risk that must be governed when organizing a mobile unit that will operate in a conflict zone.

Another aspect of security stems from the type of care that is being delivered by the mobile unit. Acute care models are likely to have different workflow patterns on a mobile unit than models emphasizing health-care screenings and chronic care strategies. Moreover, disaster response methods for mobile outreach can also influence safety parameters, as natural elements and destabilization of community infrastructure can create uncertainties and exposure risks for the mobile unit. Therefore, safety management comes into play for organizing a mobile unit by carefully strategizing a unit's appearance, structure, service model, service area, and sites.

Innovating Mobile Health: Opportunities for Advancement

Radiology Software Innovation: Health IT and Artificial Intelligence in Mobile Health

As radiology has become more digital, replacing printed film over the last 15 years, the storage and retrieval of imaging in PACS have become widespread in high-income countries, while these advanced health IT applications and data networks have remained scarce in low- and middle-income countries. This disparity impacts mobile health outreach in LMICs because PACS-enabled radiology systems on a mobile health vehicle cannot send data to a hospital that is still using printed film or lacks PACS, RIS, and other EMR applications. Therefore, an important assessment for a mobile health strategy in a low-resource region is to consider how imaging data will be temporarily stored on the health vehicle and how it will then be transmitted to the affiliated fixed-site hospital or imaging center for long-term storage.

The emergence of artificial intelligence applications is greatly impacting the development of health IT. As a definition, *artificial intelligence* (AI) refers to software applications that organize and process data and information and simulate human learning to adaptive simulations of human decision-making. *Machine learning* is the mechanism by which artificial intelligence applications create cognitive computing to enable simulations of human learning and decision-making.

Mobile health outreach could potentially utilize AI to impact workflows and clinical patient care in contexts where personnel are scarce. Such integration of AI into mobile health could help triage normal from abnormal imaging cases, provide preliminary interpretations of images and provide immediate feedback recommendations to patients at the vehicle, alert remote caregivers to emergent findings discovered, aid processing of images with other variables to immediately compute risk factors, and expedite referrals of patients from a vehicle that is still in the field. Although there are many challenges and opportunities from AI, there is large-scale investment and research efforts being placed in AI that will potentially impact low-resource regions and mobile health with the focused aims of streamlining mobile health vehicles' workflows and patient management.

Geographic Information Systems and Mobile Health Planning

Another current field of innovation and research impacting mobile health outreach planning is geographic information systems (GIS) research. In general, GIS is a tool that presents geographical data in a way that can be managed and manipulated for the purpose of useful analysis. By taking data about the world and dividing it into multiple layers, or "data slices" (Fig. 21.6), the GIS model enables users to select data sets that are applicable to the user, varying from topographical and infrastructure data to population and health-care statistics. As a result, these information systems can be used for numerous applications and industries, ranging from engineering and telecommunications to business and health care.

Conventionally, mobile radiology and mobile health vehicles determined routes of outreach based on anecdotal knowledge of the communities and populations needing specific services. Satellite imagery began to change the nature of mapping by providing images of locations and geographic sites, such as Google Earth and Google Maps. By 2017, applications incorporating GIS became available to extract information from multiple data sets to produce overlaid maps of data. For example, with GIS, integrating multiple layers such as population distribution, poverty levels, and disease incidence can highlight populations at risk for disease in poor economic zones with health-care disparities (Fig. 21.7).

By integrating additional data sets such as topography, hospital or clinic sites, and various infrastructure qualities, these location-driven GIS maps can also better inform the strategy for improved access to those populations (Fig. 21.8).

Other examples of GIS mapping could include levels of vaccinations in a region or cancer death rates of a target population, which can then be used to optimize strategies for vaccine delivery and cancer screening. Regardless of which data sets are chosen, these layers can be superimposed to create a severity index to highlight populations with the most need for mobile health outreach (Fig. 21.9).

By identifying these locations and populations, a data-driven method is possible for creating a mobile outreach route for each particular mobile health vehicle. Such GIS strategies can increase efficiency of mobile routes by interconnecting sites that have the highest yield of clinical impact.

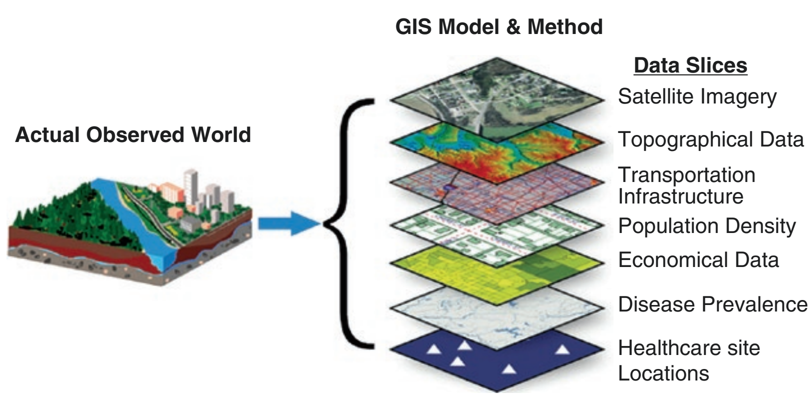

Fig. 21.6 Illustration of how geographic information systems (GIS) extracts and organizes geographic and population-based data as individual layers for segmented analysis, to produce fused geographic and navigational planning for optimized mobile radiology outreach. (Reprinted with permission from RAD-AID International)

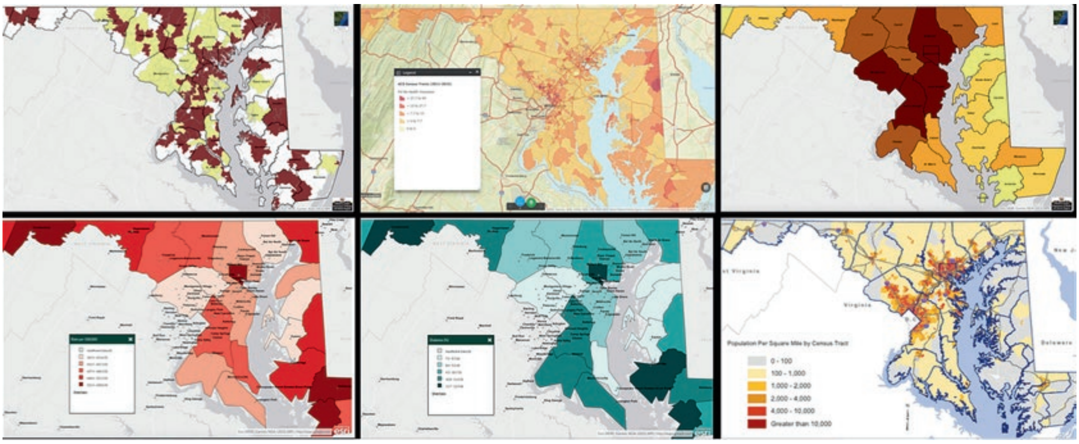

Fig. 21.7 Examples of population-driven GIS data layers of Maryland, United States. Information from Maryland State Health Department. Maryland State Health Department: Enterprise Zones: https://maps.health.maryland.gov/phpa/hez/. Maryland State Health Department. Cancer Indicators: https://maps.health.maryland.gov/phpa/eh/epht/cancer/

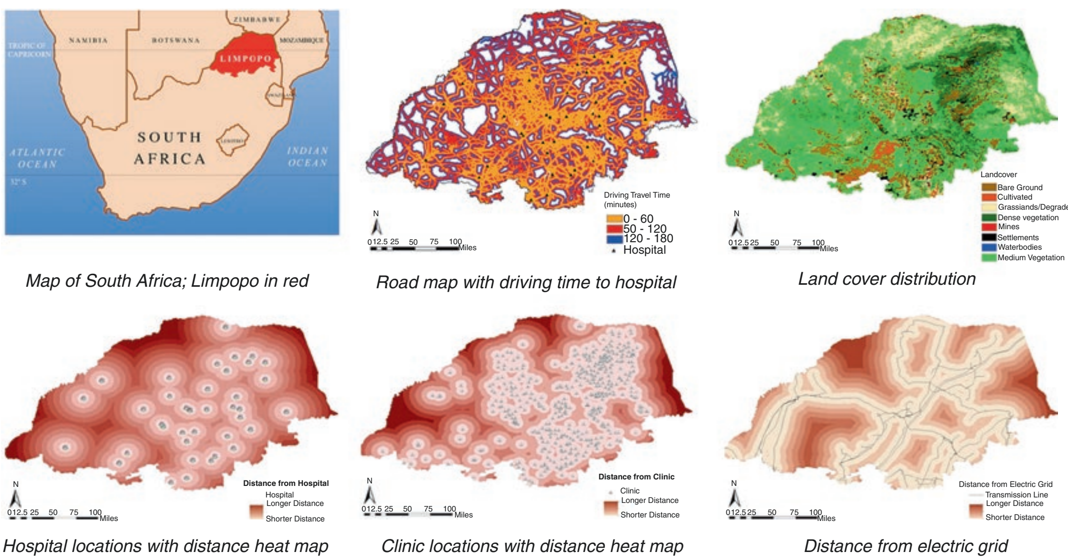

Fig. 21.8 Examples of location-driven GIS data layers of the Limpopo region, South Africa. GIS maps throughout this book were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. More info on publishing GIS maps from ESRI software is available at https://support.esri.com/en/technical-article/000012040. (Reprinted with permission from RAD-AID International)

Transportation Strategies and Service Innovation

Transportation strategies for mobile health programs come in many forms: by air, land, and sea. This section looks at innovation in the context of these different transportation strategies. Each modality offers a different range of opportunities and challenges for health-care delivery, with ongoing innovations that may create change in the future for how these efforts are delivered.

Seagoing mobile health outreach is well known as a means of deploying traveling hospitals. One strength of this approach is that approximately

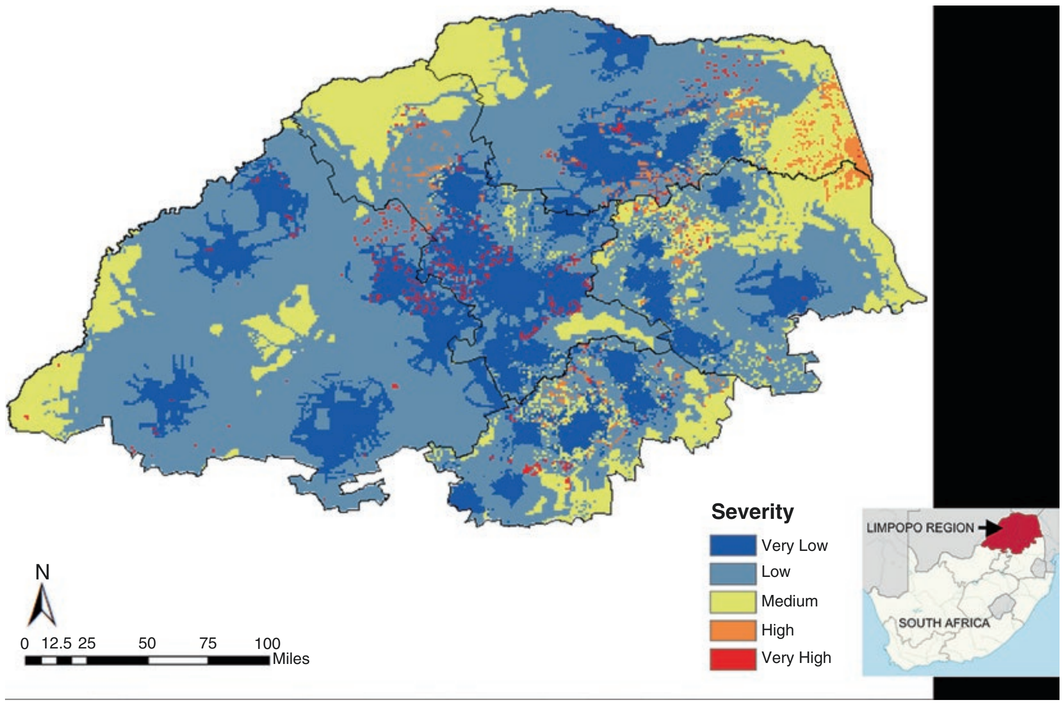

Fig. 21.9 Severity index map of the Limpopo region, South Africa, highlighting locations of greater (orange and red) or lesser (blue) need for mobile health outreach based on GIS analysis. Maps throughout this book were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. More info on publishing GIS maps from ESRI software is available at https://support.esri.com/en/technical-article/000012040. (Reprinted with permission from RAD-AID International)

40% of the world's population is within 60 miles (100 kilometers) of the coastline according to the United Nations. Some examples include Mercy Ships and Project HOPE. Project HOPE began ocean-based mobile health in the 1950s by working with the United States Navy to convert the USS Consolation (AH-15) to be the first peacetime hospital ship (SS HOPE), which was later retired from service in 1974 [19]. Another example is the USNS Comfort (T-AH-20), which has been in service since 1987, owned by the United States Navy and operated by civilians within the Military Sealift Command (MSC). These are noncombatant health vessels and operate separately from military operations (Fig. 21.10).

The key advantages of ship-based health outreach include the ability to move large amounts of heavy medical equipment and cargo while at the same time having large space for patients, treatment areas, and supplies. The principal limitation, then, is restricted access to coastal regions, which is offset in part by the larger populations living near the coast, and the potential for ports to serve as hubs for transporting medical outreach services inland. The costs and knowledge requirements for seagoing medical outreach have also raised the need for partnership between nonprofit medical service organizations and military naval entities, which serve as a significant barrier to entry among those nonprofits not having such organizational relationships.

Automotive-based mobile outreach is widespread and has several advantages and disadvantages as well. The pros of automotive mobile outreach are the accessibility of automobile technology, lower costs than naval and air, and the flexibility of scaling vehicle-based outreach through incremental acquisition of trucks and cars. Truck-based medical outreach can be limited by poor road infrastructure, small space, and

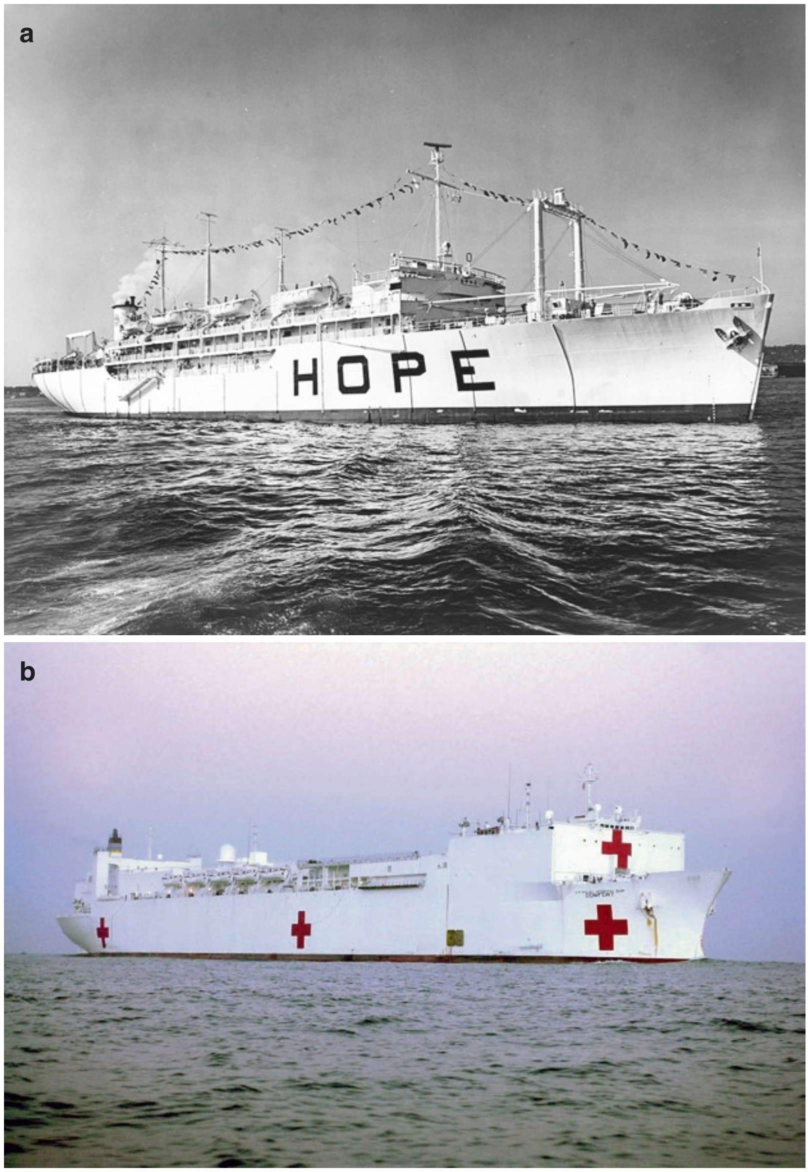

Fig. 21.10 (**a**) SS HOPE (Project HOPE's hospital ship) and (**b**) USNS Comfort (T-AH-20) are examples of seagoing mobile health outreach. (Source: United States Library of Congress and United States Navy, available on Wikimedia Commons)

complex power needs for sustaining refrigeration of medical supplies or temperature control for temperature-sensitive medical equipment.

Automotive technologies are continuously advancing. From basic fuel combustion engines, there is now the recent arrival of hybrid engines and electric automotive vehicles. While this may seem to not impact mobile health, these advances are greatly shaping the way fuel efficiency is managed in mobile outreach, and these vehicles traveling long distances may need extended charge times after switching from fuel combustion to electric platforms.

A very relevant innovation in automotive transportation in mobile health outreach for radiology is air ride or air suspension. As an advance from conventional steel coil suspension systems, air suspension systems are powered so that a compressor pumps air into flexible bellows for improved shock absorption. This system is important for mobile health transportation because sensitive electronic equipment and

Fig. 21.11 An example of aircraft-based medical outreach as shown by the United Nations Humanitarian Air Service (UNHAS) Mi-8 transport helicopter delivering aid supplies for the World Food Programme to Nepal in May 2015. (Source: United States Marine Corps, Photo by Staff Sgt. Jeffrey Anderson)

hardware with fragile moving parts can be easily damaged by rocky, uneven, or potholed roads.

The use of aircraft for mobile health outreach has been a long-standing effort. For example, the United Nations operates the UN Humanitarian Air Service (UNHAS) for using aircraft-based medical outreach (Fig. 21.11). To refine this discussion, it is important to distinguish the use of aircraft to transport medical supplies and personnel, versus the direct use of aircraft for medical service deployment. Although many organizations use air transportation to move personnel, equipment, and cargo, most air-based operations do not have the aircraft serve as a medical facility for communities and populations. Helicopter and small aircraft-based transport are akin to flying ambulances in providing emergency care to patients en route to tertiary care facilities. Similarly, many commercial airlines make humanitarian contributions via pro bono flights of passengers and medical personnel to health-care sites. These uses of aircraft for transporting personnel and patients are distinguished from aircraft-based mobile facilities that land and deliver community-based health services to local populations.

The integration of radiological service delivery into aircraft is currently very limited. Transporting radiologic equipment by airplanes is subject to safety regulations to prevent interaction between radiation and electromagnetic fields with aircraft equipment. Limited space, high cost, and heavy cargo weight have historically limited the use of radiologic health services being deployed directly from aircraft. In addition, the need for specially trained imaging personnel may not be practical in aircraft having limited personnel and passenger space.

Moving Beyond Infrastructure: The World's First Hybrid Medical Airship

As stated before in this chapter, a significant limitation of mobile health outreach is the need for passable, reliable, quality transportation infrastructure, such as roads, railways, airports, and harbors. The World Bank's Rural Access Index (RAI) estimates that 900 million to 1 billion people live without access to reliable transportation infrastructure, thereby greatly limiting health-care resources and economic development [5, 6]. Patients in these regions often cannot travel to a hospital due to poor road conditions, and the travel time may be prohibitively increased by long detours by car or long alternative distances on foot. Studies have shown that increased travel time to a health-care facility is inversely proportional to clinic usage: while nearly 100% of the population will utilize a clinic that is within 0–60 min of travel time, usage drops sharply after this point and reaches less than 10% by the 120-min mark (Fig. 21.12) [20]. With poor infrastructure in low- and middle-income countries, there is a significant population not receiving health care either due to the patients being unable to travel to a facility or due to mobile health vehicles being absent or unable to reach these populations.

To overcome the impact of infrastructure limits on health-care disparity, RAD-AID partnered with Lockheed Martin and Straightline Aviation (SLA) to develop the world's first hybrid medical

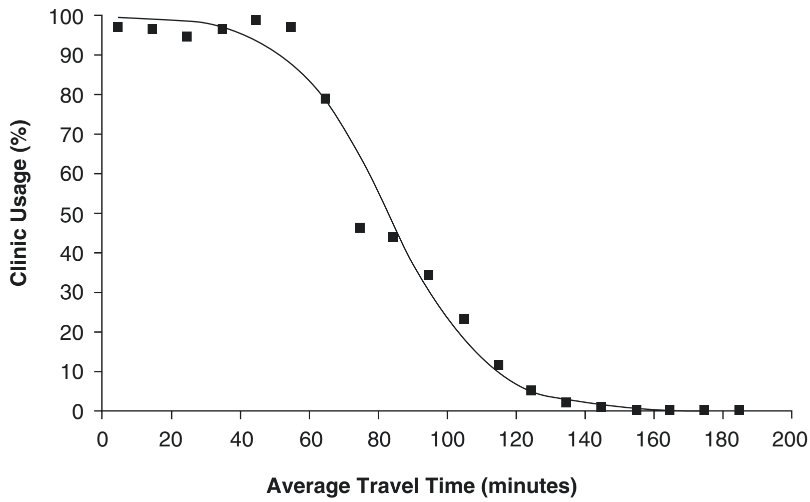

Fig. 21.12 The percent of clinic usage has been shown to be inversely related to the average travel time to that clinic, exemplifying the impact of poor infrastructure and increased travel times on a population's health care. (Reprinted from Social Science and Medicine, Tanser et al. [20], Copyright 2006, with permission from Elsevier)

airship, which is designed to provide clinical assistance to the most remote areas of the world without the traditional constraints of infrastructure. The hybrid airship, such as the LMH-1, is able to take off and land on any flat, unprepared surface, including grass, dirt, snow, ice, and water (Fig. 21.13), enabling transportation of freight, personnel, and medical services to underserved remote regions.

With ongoing development from 2017 to 2020, the hybrid airship is an aviation advancement that uses a trilobed envelope for buoyancy and engine-based propulsion for achieving ranges of over 1500 miles, along with a low-carbon footprint that offers 1/10th the fuel consumption of a heavy lift helicopter [21]. Approximately 80% of the lift is derived from buoyant helium within the envelope, and 20% is from the aerodynamic lift generated by the shape of the hull and vectored thrust from the craft's four rotatable engines, which altogether enables a cargo capacity of up to 20 tons, with higher cargo capacity planned for future models. Along the underside of the airship (Fig. 21.14) are several hovercraft-type air cushions that are used not only for landing on any unprepared flat surface (including grass, dirt, ice, snow, and even water) but also can be reversed in flow to enable the airship to have a suction grip on the landing surface, which eliminates the need for external mooring or paved airstrips.

For navigation and outreach site planning, GIS is being utilized for strategizing airship operations by identifying unprepared flat areas (using topographical and land feature data) to serve as potential landing zones for mobile health outreach (Fig. 21.15). GIS extracts layers of map-based health, economic, and infrastructure data that are then superimposed on topographical data for selecting landing sites with highest clinical utility and aircraft maneuverability.

To further expand the innovation strategies for mobile health, RAD-AID is designing several architectures with Lockheed and SLA. Once the airship has arrived at a location, there are multiple options for approaching medical outreach for that population, which will be driven by the medical mission for that particular area. One approach is to design the 60′ × 10′ internal cargo space of the airship as a medical clinic, in which patients can be examined and treated within the hull, and the entirety of the medical infrastructure is integral to the cargo space of the airship (Fig. 21.16).

Another approach under design is to create deployable container-based clinics (or "pods"), measuring roughly 20′ × 10′ that can be transported by the airship to various landing sites and

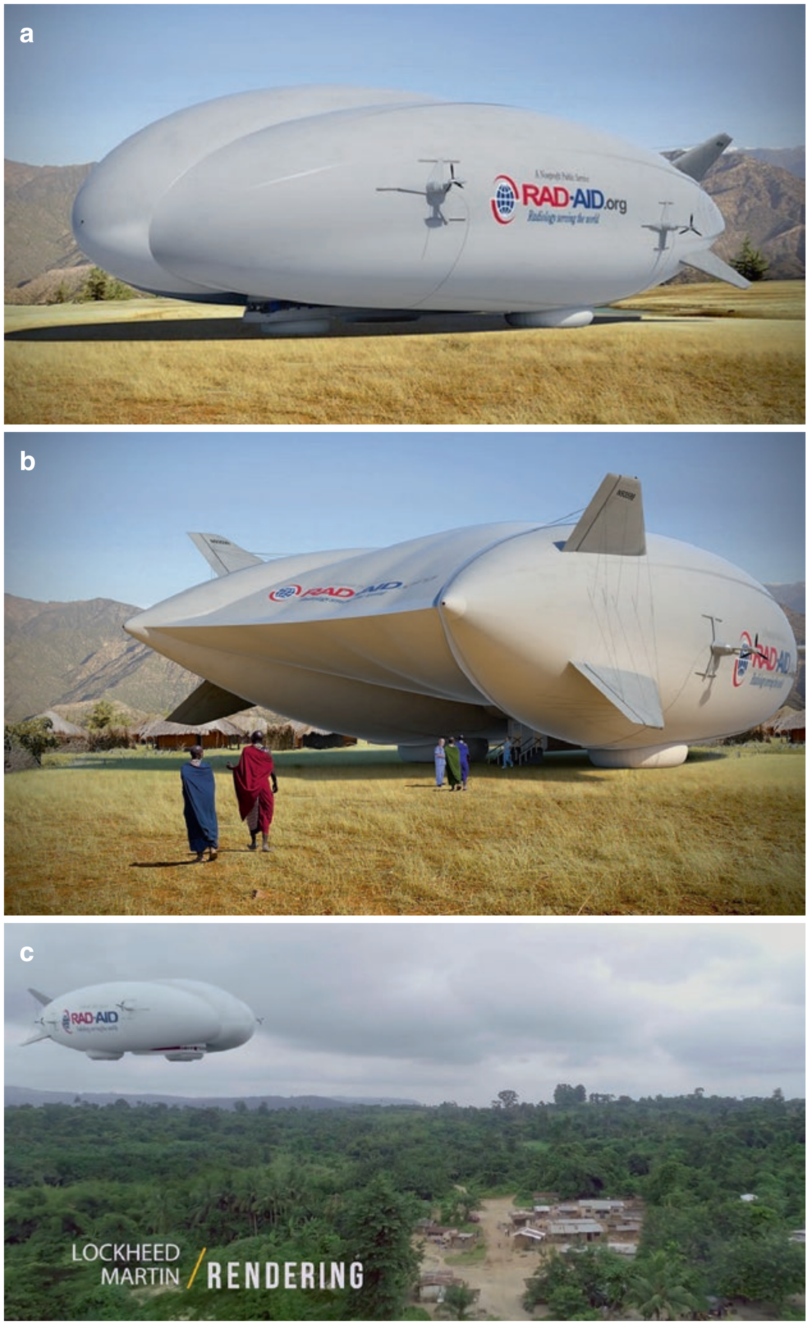

Fig. 21.13 RAD-AID hybrid medical airship renderings as seen from the front left (**a**), rear right (**b**), and depicted airborne over Ghana (**c**). (Images from Lockheed Martin, Hybrid Enterprises, and Straightline Aviation with permission. Reprinted with permission of RAD-AID International)

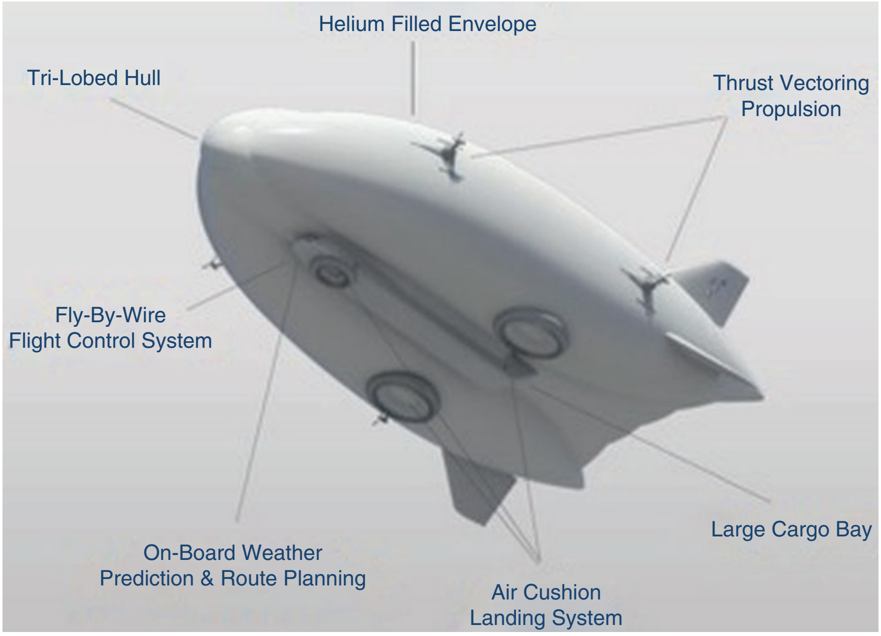

Fig. 21.14 Hybrid airship underside view highlighting the location and relative size of the cargo bay and air cushion landing system. (Image from Lockheed Martin, 2017, with permission. Reprinted with permission of RAD-AID International)

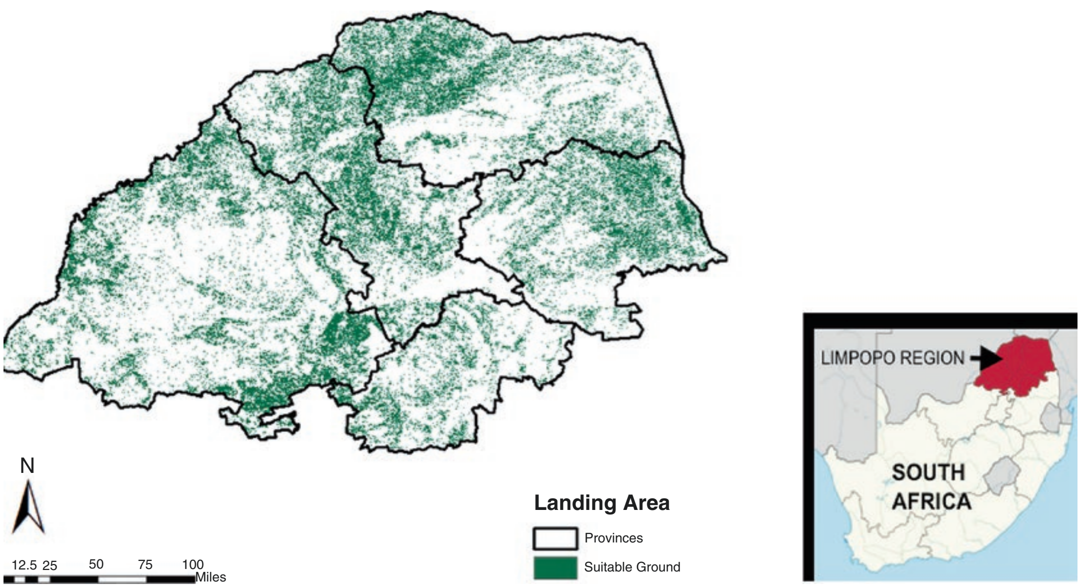

Fig. 21.15 GIS-produced map of the Limpopo Region in northern South Africa, highlighting 23.4% of the region (green) as suitable for hybrid airship operations, which includes land slope less than 3° and a land cover of either bare ground or sparse vegetation that spans at least 3000x1200 feet. GIS maps throughout this book were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. More info on publishing GIS maps from ESRI software is available at https://support.esri.com/en/technical-article/000012040. (Reprinted with permission from RAD-AID International)

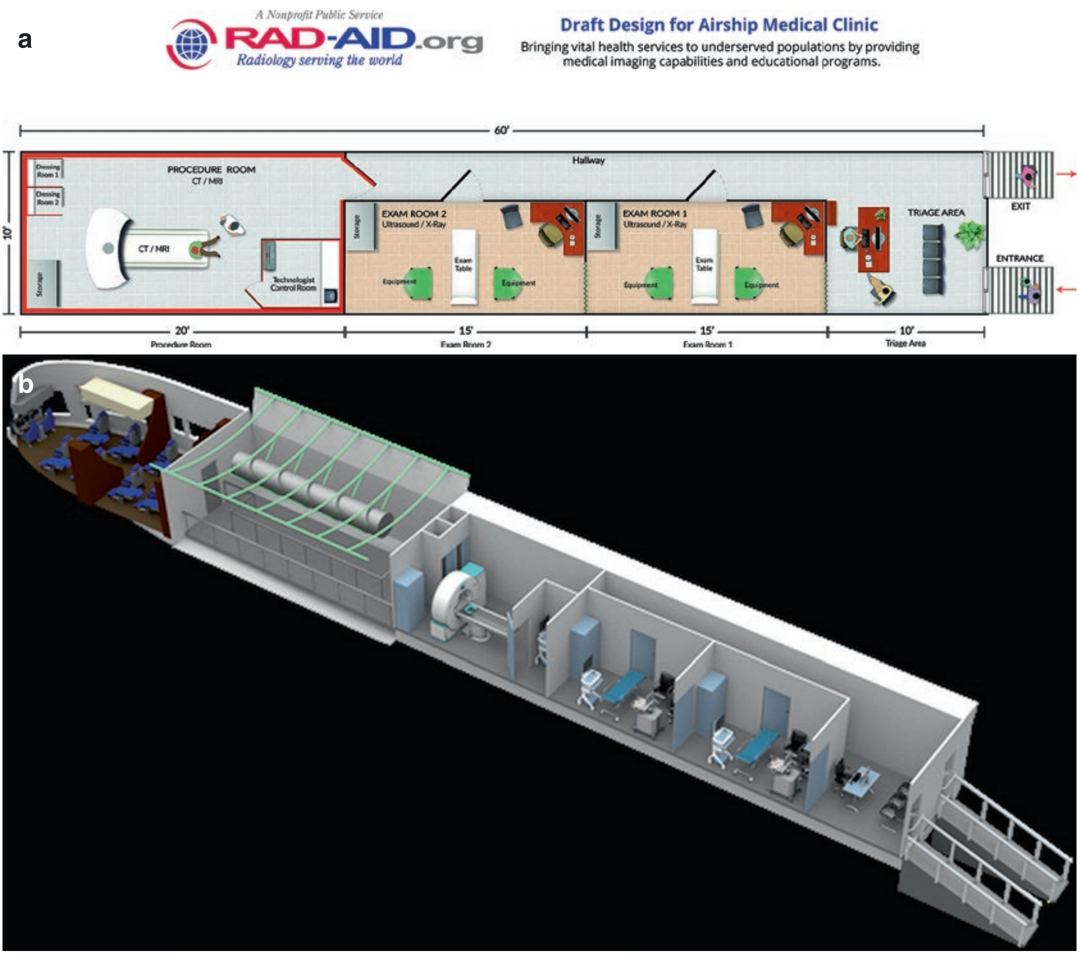

Fig. 21.16 Draft design for RAD-AID's hybrid medical airship internal clinic with (**a**) floor plan and (**b**) 3D rendering highlighting CT scan and exam room capabilities housed within the cargo area of the airship. (Reprinted with permission from RAD-AID International)

deployed temporarily at those locations for patient care (Fig. 21.17).

Using a hub strategy based out of a central location (Fig. 21.18), the airship can service and rotate the container-based clinics for maximizing efficiency, and each pod can be designed for specific medical needs such as maternal-infant care, cancer screening, interventional radiology, disaster response, vaccinations, primary care evaluations, or ambulatory surgery. This strategy also leverages the airship's unique 24–7 (day/night) and all-weather operation capabilities for delivering and servicing mobile facilities in after-hours to maximize the utility of these modular clinical services.

Conclusion

This chapter has aimed to present an overview of mobile radiology as an emerging spearhead of global health for addressing health-care disparities. Beginning with the historical context, we can see that radiology has consistently served as a mobile health platform since the early 1900s such as truck-based radiography units in World War

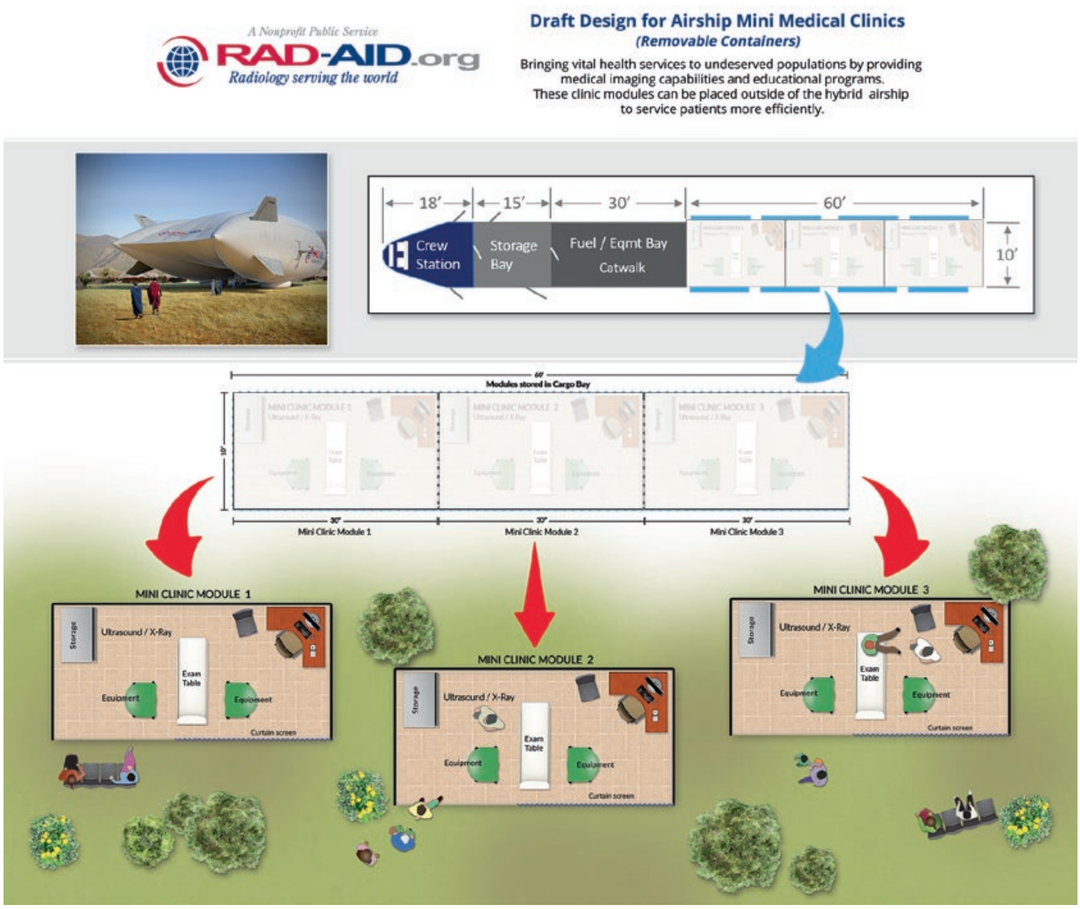

Fig. 21.17 Draft design for RAD-AID's hybrid medical airship mini-medical clinics (deployable containers), which can be placed outside the airship to service patients more efficiently. (Reprinted with permission from RAD-AID International)

I. Since radiology involves a complex set of health-care equipment, the evolution of mobile radiology has sought to address the intricacies of high fixed costs, electrical power requirements, data management, medical referral systems, patient and personnel ergonomics, topographical constraints, and infrastructure elements. By addressing these variables, it is hoped that this chapter conveyed how these elements can be analyzed, planned, and implemented to achieve measurable and concrete results for populations in need of radiology. Since medical imaging is a vital part of health service delivery, ranging from ultrasound in maternal-infant health, mammography in breast cancer screening, CT for trauma and cancer staging, and MRI for neurologic and musculoskeletal diagnostics, it is imperative that mobile imaging be an integral part of reaching marginalized populations who cannot otherwise reach a medical facility. As the future continues to develop new imaging and transportation technologies, it is exciting to envision how we can better integrate air-, land-, sea- based transportation modalities with advancing medical imaging methods to improve the quality and accessibility of health care.

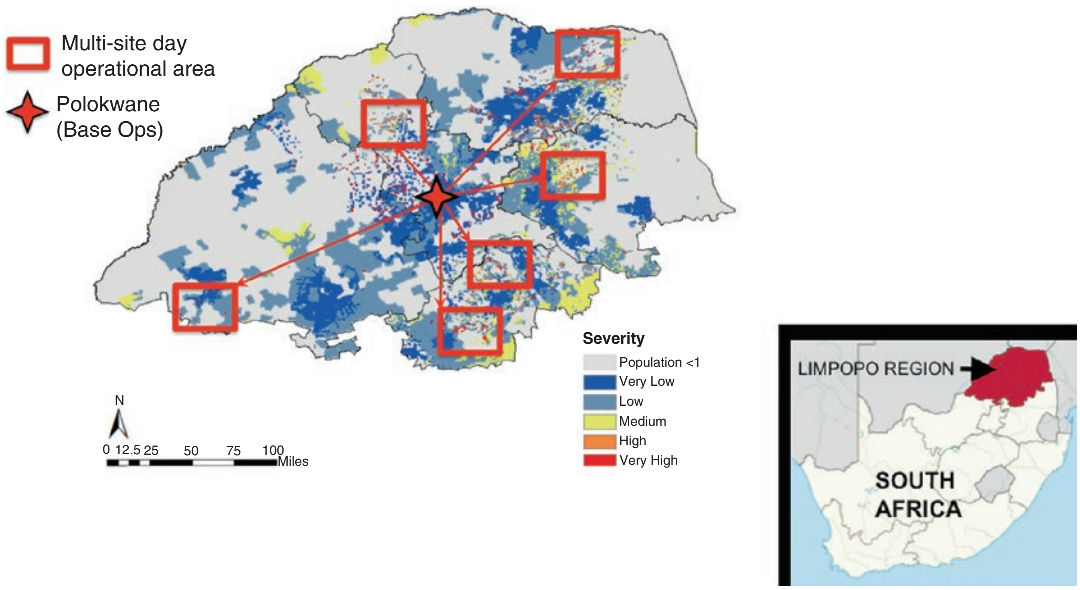

Fig. 21.18 Example of a hub-based, multi-site operational flight plan based out of Polokwane, South Africa, with overlaid GIS-produced severity index map of the Limpopo Region used to identify areas in need. Maps throughout this book were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. More info on publishing GIS maps from ESRI software is available at https://support.esri.com/en/technical-article/000012040. (Reprinted with permission from RAD-AID International)

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Disaster Response

22

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Introduction

Disasters and mass casualties may be natural or human made, and their onset, duration, and scale are variable. Earthquakes, floods, tsunamis, outbreaks, bombings, conflict, and war have all impacted humanity with large losses of life and immense economic setbacks. Due to the interconnected nature of the world's economies and populations, accurate death tolls and economic costs of these disasters are difficult to determine. In 2015 alone, natural disasters caused the deaths of 22,773 people, at an economic cost of 66.5 billion US dollars. The definition of "disaster" provided by the United Nations Office for Disaster Risk Reduction emphasizes a level of disruption that "exceeds the ability of the affected community or society to cope using its own resources." Because disasters involve disruption of order on a grand scale, disaster relief and humanitarian aid efforts require a tremendous degree of organization [1].

The medical response to disasters is well described; although the literature is still dominated by case studies and anecdotes, many aspects of best practice remain unresolved. The role of radiology in medicine is also well described, with data demonstrating its ability to accurately and quickly diagnose and guide treatment. What is not well described, and often not fully considered, is the complex role of radiology in disaster response [2]. As the disaster relief paradigm evolves with new technology and

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challenges, medical imaging is becoming increasingly accepted as a crucial component. For example, radiology played a vital role in disaster relief efforts following the Indian Ocean tsunamis of 2004 and the 2010/2015 earthquakes in Haiti/Nepal and currently continues to be vital to the care of casualties from the Syrian War. As a specific example, in the 2011 series of massive tornadoes that hit Alabama in the United States of America (USA), 176 X-rays and 151 CT scans were performed at one pediatric hospital within a 12-h period [3]. Medical resources, a key component of disaster preparedness and management, must be properly allocated and triaged to deliver the best possible care for a potentially large number of victims. As a fast-evolving field, diagnostic imaging has been increasingly relied upon to make rapid noninvasive diagnosis and triage/care decisions for patients. The continual need to adapt to new threats and gaps within the field of disaster medicine poses a moving target, necessitating constant adaptation among the radiology community.

Natural catastrophes such as the tsunamis beneath the Indian Ocean in 2004 resulted in approximately 230,000 deaths across 14 different countries, and the 2010 earthquake in Haiti yielded a death toll of 316,000 [4]. Ironically, the cost of such disasters both in terms of human life and economy is expected to rise as low- and middle-income countries (LMICs) become more advanced. This is because industries and cities flourish along coastlines and rivers, areas that are particularly vulnerable to natural disasters. Increased urbanization also leads to additional challenges related to communicable diseases, sanitation, and resource deficiencies in the post-disaster setting, as seen with the devastating cholera outbreak following the 2010 earthquake in Haiti [5].

Man-made disasters include armed conflicts, terrorist incidents, bombings, nuclear disasters, and transportation accidents. The 9/11 terrorist attacks on the USA in 2001, in particular, marked the beginning of the twenty-first century, in which there has been a heightened impact, both of terrorism and the war against it. Within the field of military combat and warfare, there have been modern generations of engagement and destructive methodology utilizing technology and weapons that often transcend the boundaries of international diplomacy. As will be evident in specific case examples new to this chapter, the effect of these modern day man-made catastrophic elements on global health has particular consequences for radiology. In the face of such tremendous humanitarian and economic hardship, the necessity of well-organized medical relief efforts is clear. Diagnostic imaging and minimally invasive, image-guided procedures have become essential to modern emergency medical care; consequently these services should not be considered luxuries in the setting of disaster response, regardless of the affected region's economic status.

In March 2017, the UBC Vancouver Department of Radiology published its bibliometric analysis, which verifies the significant contribution by radiological sciences in disaster medicine. Over 177 original research articles have been published on this topic since 2000. Focused analysis of the top 100 of these clearly demonstrates the increasingly recognized value of imaging in the disaster paradigm (Box 22.1). The most studied disaster types were disease outbreak (55 articles), armed conflict (23 articles), terrorist incident (10 articles), and earthquake (7 articles). The most studied disasters were the H1N1 influenza outbreak in 2009 (28 articles); SARS outbreak in 2003 (24 articles); war in Afghanistan,

Box 22.1 2017 UBC Vancouver Department of Radiology Bibliometric Analysis [1] of Top 100 Disaster Radiology Research Articles (Numbers in Parenthesis)

Most studied disaster types	Most studied disaster incidents
Disease outbreak (55)	H1N1 outbreak 2009 (28)
Armed conflict (23)	SARS outbreak 2003 (24)
Terrorist incidents (10)	Afghanistan war 2001–2014 (8)
Earthquake (7)	Iraq war 2003–2011 (6)
	Sichuan earthquake (China) 2008 (6)

2001–2014 (8 articles); Iraq War, 2003–2011 (6 articles); and Sichuan earthquake (China) in 2008 (6 articles). Among the first authors, 59 were primarily affiliated with radiology [1].

Certain elements of radiologic technology, such as portable ultrasound (US) and robust, mobile digital radiography (DR) units (Figs. 22.1, 22.2 and 22.3), are ideal for use in environments with limited resources and potentially damaged infrastructure. Other technologies, including computed tomography (CT), magnetic resonance imaging (MRI), fluoroscopy, and standard/stationary radiography, are challenging to transport and implement in this setting and, in some cases, may be considered inappropriate. Again, it is very clear in the humanitarian disaster relief community that more is not always better—rather emphasis should be placed on the most appropriate technology.

Fig. 22.1 Handheld ultrasound units used for FAST scanning for bomb blast victims of the Syrian War adult victim. (Photo courtesy of Syrian American Medical Society (SAMS))

Defining the Mission

To fully understand the role of radiology in disasters, it is necessary to examine the setting of these events, including the conditions on the ground and the populations in need of aid. It is also important to have an understanding of the disaster relief paradigm currently implemented by aid organizations across the globe. The role of radiology can then be explored within this contextual framework, and conclusions can be drawn about steps that might be taken to maximize the effectiveness of radiology in future catastrophes.

Aid efforts can generally be categorized as either humanitarian assistance or disaster relief.

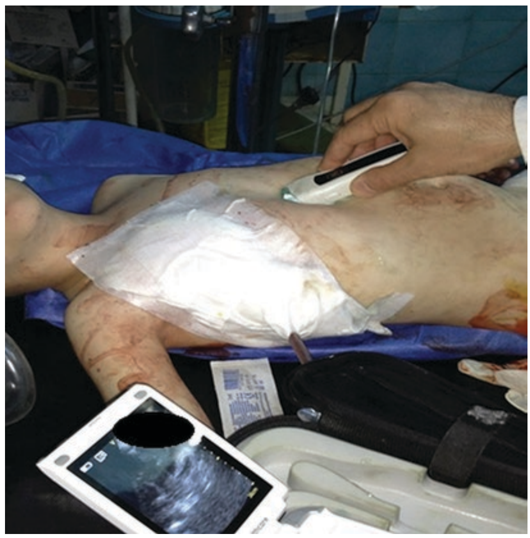

Fig. 22.2 Handheld ultrasound units used for FAST scanning for bomb blast victims of the Syrian War child victim. (Photo Courtesy of Syrian American Medical Society (SAMS))

Fig. 22.3 Digital radiology unit used by the field workers in Haiti after the 2010 earthquake. (Photo courtesy of MinXray, Inc.)

Box 22.2 Phases in Disaster Events

	Phase 1: acute	Phase 2: intermediate	Phase 3: long term	Phase 4: disaster preparedness
Time frame	Day 1–6 months	Day 1–2 years	Month 5–15 years	Ongoing
Goal	Short-term triage	Stabilization	Rebuilding	Emergency risk reduction and prevention
Services provided	Rescue, medical attention, food, water, temporary shelter	Food, water, long-term shelter, sanitation, Healthcare	Engage local population in planning and reconstruction	Training, policy and procedure creation, relationship building among service providers and communities
Media	Extensive coverage; high emotional pull	Coverage declines as first emergency efforts dissipate	Coverage continues to decline	Little coverage; no emotional pull

In order to adequately prepare for and execute a successful mission, it is crucial to first understand the integral components of disaster relief and humanitarian assistance. Disasters may result in humanitarian emergencies when the community's status quo has been disrupted, often severely. Fundamental components of infrastructure such as potable water, electricity, food, and shelter are often devastated. In addition, human resources such as healthcare providers, engineers, and law enforcement may have been lost to injury, death, or displacement. The population's health is far from baseline, with numerous acute injuries and illnesses as a result of the disaster.

The widening scope of disasters necessitates varying approaches to intervention. During 2017, the Yemen acute watery diarrhea (AWD)/cholera crisis left the country on the verge of famine—with more than 1.8 million children (400,000 under 5) and 1 million pregnant and lactating women expected to suffer from acute malnutrition and likely other infections such as pneumonia and tuberculosis. Since child protection and refugee management are major concerns, UNICEF/UNHCR would be the responsible UN authorities. As another example, since March 2011, the crisis in Syria has been described as the worst humanitarian disaster of this era with more than 13 million people in need of assistance and has caused untold suffering for Syrian men, women, and innocent children. The UN is officially still the mandated authority but may not have capacity in a war zone [6].

Both of these examples are disasters of immense proportion without imminent timelines. Diagnostic radiology expertise might be welcomed in a partnership with UNICEF in Yemen refugee camps (outside active war zone); however, the presence of hostile combatants within the needy areas in war-torn Syria often results in targeting of diagnostic medical technology, which makes any medical partnerships with WHO authorities/institutions inside these territories vulnerable. One situation is outside the zone of combat and can be engaged traditionally. The other is within the combat zone and is in a state of lawlessness. Both are still the responsibility of the disaster outreach community. This revised understanding of the scope of disaster outreach has broader implications for radiology which is a technology-based specialty and potentially a vulnerable target.

There are four phases in disaster events: acute, intermediate, long term, and disaster preparedness (Box 22.2) [7].

The Four Phases of Disaster Response

The *acute phase* has the most emotional audience pull and results in an outpouring of relief efforts. The first priority of the response is to both provide immediate lifesaving medical care for those with acute, disaster-related injuries and illnesses and improve the health of a population through

Box 22.3 Patient Populations During Acute Disaster Relief [9]

- Those acutely injured or ill because of the inciting event
- Those with acute illnesses unrelated to the event (e.g., pneumonia, appendicitis, etc.)
- Those with chronic illnesses that have lost access to care due to loss of infrastructure
- "Special interest" patients

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primary care services and public health initiatives. Care should be taken not to neglect the group of patients with acute non-disaster-related ailments, such as pneumonias or acute abdominal conditions, and the patients with chronic ailments such as diabetes and heart disease who need regular checkups and repeat medications. "Medical Diplomacy Healthcare" for local leaders and their families might be a necessary step in establishing and maintaining a good rapport with the leadership as they help facilitate the delivery of care to the populace (Box 22.3) [8].

During the *intermediate phase*, the days and weeks give way to months and years, and the true extent of the disaster unfolds away from media attention—in the throngs of displaced survivors within regional camps and tent cities or with refugees of war in foreign countries. Damaged and destroyed health infrastructure and medical equipment remain unusable depriving communities of vital resources. Because of sewage and water challenges, communicable diseases like measles, malaria, and cholera may become pandemics. Mental health and physical well-being of victims and rescuers may continue to be impacted. Rehabilitation post-disaster also includes the planning of reconstruction surgeries, manufacture of prosthetic limbs, and repeated plastic surgeries for burn victims.

As the phases of disaster relief progress, the emotional appeal of the situation fades. During the *late phase*, the need to rebuild local capacity becomes priority as foreign organizations leave for other events. Arguably, the most important phase is that of *disaster preparedness*, which is never ending and requires constant investment and resources in order to be relevant and appropriate during future events.

Coordination of Disaster Relief Efforts

Disaster relief and humanitarian assistance efforts demand significant amounts of human resources, organization, equipment, supplies, and other resources. Initial challenges include performing timely and accurate needs assessments with gap analyses, financing needed resources, mobilizing those resources, and coordinating deployment or distribution of those resources.

Within the USA, disaster response may fall under the jurisdiction of federal, regional, state, local, or tribal authorities depending on the scope and scale of the disaster. When a disaster occurs, the affected area may require assistance from multiple sources, including the state government, the federal government, or neighboring cities or states. At the federal level, the Federal Emergency Management Agency (FEMA) is part of the Department of Homeland Security (DHS) and serves as the lead in domestic disaster response. FEMA utilizes the National Incident Management System, which includes the Incident Command System (ICS). The ICS is used across all disciplines and at every level of government. According to the Emergency Management Institute [10], "The ICS is a management system designed to enable effective and efficient domestic incident management by integrating a combination of facilities, equipment, personnel, procedures and communications operating within a common organizational structure, designed to enable effective and efficient domestic incident management." The ICS is used to coordinate and mobilize resources in a domestic disaster response. Among the components of the ICS are Disaster Medical Assistance Teams (DMAT), which are composed of medical professionals designated to provide medical care during a disaster as part of the National Disaster Medical System (NDMS).

Disaster response in the USA is generally well structured, financed, and coordinated, requiring little to no assistance from outside the country. The challenges faced by FEMA tend to be administrative and authoritative rather than resource related. In contrast, disaster response efforts in resource-poor countries are complicated exponentially by lack of infrastructure, healthcare facilities, human resources, clean water, and other essential commodities. Such relief efforts generally require assistance from governmental organizations, nongovernmental organizations (NGOs), the United Nations (UN), and other international organizations.

In the USA, response to international disasters is coordinated by the US Office of Foreign Disaster Assistance (OFDA) at the United States Agency for International Development (USAID). Disaster relief efforts in LMICs have had highly varying degrees of success over the years. In comparison with high-income nations, such as the USA, disasters in resource-poor countries are more likely to result in significant destruction of vital components of local infrastructure, including buildings, power supply, roads, water and waste management facilities, and communications networks. There may be disruption of public health programs, destruction of healthcare facilities, and loss of key personnel including healthcare providers and other professionals. For the global community, the sheer scale of many of these disasters causes profound logistical challenges. Factors such as insufficient coordination, poorly defined roles, ambiguous leadership, inconsistent protocols, and misappropriated or inadequate resources frequently amplify these logistical challenges.

In 2005, a UN review of the global humanitarian system identified several inadequacies and generated several recommendations. These included strengthening the humanitarian coordination system; ensuring an emergency response fund capable of providing timely, adequate, and flexible funding; and adopting a "lead organization concept" by UN agencies and partners to cover critical gaps in providing protection and assistance to victims of conflict and natural disasters. In response, the UN Inter-Agency Standing Committee (IASC) established the "cluster system" for humanitarian relief efforts. There were initially nine clusters, including (1) *protection*; (2) *camp coordination and management*; (3) *water*, *sanitation*, *and hygiene*; (4) *health*; (5) *emergency shelter*; (6) *nutrition*; (7) *emergency telecommunications*; (8) *logistics*; and (9) *early recovery*. Two additional clusters, (10) *education* and (11) *agriculture*, were added later. In a disaster, each cluster is led by a designated agency charged with coordination and oversight of activities within that cluster (Box 22.4).

Similar to the ICS, the cluster system is designed to provide structure and coordination to improve the effectiveness of disaster response. For example, there may be numerous organizations within one disaster response effort that focus on the delivery of clinical care, ranging from large NGOs like *Médecins Sans Frontières* to small organizations with only a few members. It is important that these organizations coordinate not only with each other but also with organizations with a focus on public health initiatives

Box 22.4 Overview of the Cluster System [9]

UN Inter-Agency Standing Committee (IASC) established the "cluster system" for humanitarian relief efforts.

Clusters:

1. Protection
2. Camp coordination and management
3. Water, sanitation, and hygiene
4. Health
5. Emergency shelter
6. Nutrition
7. Emergency telecommunications
8. Logistics
9. Early recovery
10. Education
11. Agriculture

Reprinted from Sydnor et al. [9] Box 15.2 with permission from Springer Nature such as vaccinations, water, sanitation, hygiene, and vector control. All organizations with a focus on health are encouraged to register with the health cluster and send a representative to health cluster meetings to receive up-to-date information, share experiences and knowledge, learn from each other, minimize duplication of efforts, and identify and respond to gaps in services.

Even with appropriate coordination, funding, and resources, many challenges remain. Depending on the individual situation, there may or may not be a functioning government as well as other groups with various missions and political agendas. Some of these groups may be corrupt or have agendas based on culture, religion, or ethnicity. There may also be differing missions among the various relief organizations involved in a single relief effort, often reflecting the agendas of their constituencies. Such differences can lead to conflicts that delay recovery efforts and harm no one more than the victims these organizations are supposed to be helping.

Effective disaster response begins with a timely and accurate assessment of the situation followed by a response that is well coordinated, adequately funded, appropriately resourced, and culturally appropriate. While each disaster is different, lessons from each relief mission should be reviewed and utilized to improve the response to subsequent disasters.

The Role of Radiology in Disaster Relief

The goal in both disaster relief and humanitarian assistance is to provide the highest quality of care possible to those in need, as appropriate for the given context. As mentioned previously, ultrasound (US) and digital radiography (DR) are ideal modalities for use in resource-poor environments, and they should be considered "must-haves" on the immediate deployment list. These technologies are portable, robust, and relatively inexpensive and can provide useful diagnostic information. With US, ionizing radiation safety concerns are also avoided. Example applications of US in the acute setting include focused assessment with sonography in trauma (FAST) scans, evaluation of obstetrical and gynecologic emergencies, pediatric abdominal emergencies, identification of soft tissue foreign bodies, fractures, and diagnosis of deep vein thrombosis or abscesses. Radiography may be used in the acute setting for diagnosis of orthopedic injury, intraperitoneal free air, bowel obstruction, pneumothorax, airway obstruction, pneumonia, aspiration, and pulmonary or mediastinal hemorrhage.

Returning to the concept of providing the best care possible, physicians in high-income countries often use additional imaging modalities in the evaluation of complex pathology. Computed tomography (CT) is logistically more difficult to establish in low-resource settings due to its cost, transport challenges, need for consistent maintenance/repair/robust power supply, inherent radiation safety risks, and requirement of advanced operator training. When feasible, however, CT can dramatically elevate the level of care provided, allowing identification of pathology that would be difficult to evaluate or entirely invisible with DR or US (e.g., most forms of intracranial pathology). In the disaster response setting, CT plays more of a role in acute diagnosis and management than in primary care. Deployable/portable CT is fast becoming a reality for civilian outreach programs and has been a standard of care in military disaster response missions. Its role in triage could be the key to more effective health resource distribution for all affected populations as described later.

Interventional radiology (IR) is another service that can have tremendous beneficial impact but may not be feasible in certain settings. Similar to CT, this largely relates to cost, relative lack of mobility, maintenance issues, the need for an appropriately designed imaging suite, and the requirement for specialized training of both radiologists and technologists. With relatively simple interventional procedures, the radiologist can contribute to a dramatic improvement in patient outcomes, offering excellent alternatives to surgery in many cases and the only feasible treatment in others. One example is percutaneous drainage of abdominal or other deep abscesses. Another interventional service that can yield profound improvements in patient outcomes is the placement of peripherally inserted central catheters (PICCs) and other vascular access devices, which give clinicians the ability not only to stabilize and treat in the acute setting but also to provide long-term intravenous antibiotic care while minimizing risk of catheter infection. In the setting of trauma or other cause for internal hemorrhage, the bleeding vessel can be coiled or embolized without the need for potentially life-threatening surgery. Examples of other services that may be offered by an interventional radiologist in the disaster relief setting include chest tube placement/thoracentesis, percutaneous nephrostomy tube placement, paracentesis, pericardiocentesis, and occasionally foreign body retrieval.

Of course, before radiology services of any type or complexity can be delivered, various cultural factors must be considered. The most obvious of these is language. Radiologists, like all healthcare providers, need to be able to communicate effectively and without ambiguity, both with patients and with other physicians. Communication is crucial in order to ensure that the correct imaging study or procedure is performed, particularly in a setting where local physicians may not be accustomed to having radiology services available. The language barrier can be minimized through the use of skilled, trusted interpreters and simple aids such as pictures or drawings. In societies with openly discriminatory policies and customs, cultural differences related to interactions between genders can also cause challenges for medical relief teams. For example, a Muslim patient population is likely to have beliefs about gender roles and appropriate doctor-patient conduct that differ significantly from those of a non-Muslim team of medical aid workers. Another commonly encountered challenge is that of delivering Western-style medicine to populations that are accustomed to seeking traditional sources of treatment (e.g., Voodoo in Haiti). It is important, therefore, for healthcare workers to develop a strong cultural knowledge base prior to going abroad and to adapt their practices appropriately. Beyond the role of clinical radiology in the management of patients, its impact on the broader diagnostic and therapeutic cycle merits attention.

The nature of disaster medical response may be small and ad hoc, with independent groups traveling to the site of a disaster equipped with minimal supplies. Alternatively, they may be more substantive with large international organizations collaborating with local healthcare systems to design a sustained response. Whatever the footprint, the basic capabilities of that response can be quantified by its ability to stabilize, triage, treat, and evacuate patients [11]. This metric, called a STEP rate, provides a valuable insight into the role of radiology in a disaster response.

Radiology services act as a catalyst for a hospital STEP rate by improving the sensitivity and specificity of diagnosis, which enables more effective triage and treatment of patients. To the extent that radiology services are deployed and utilized appropriately, they can significantly improve the efficiency of a hospital's activity. The critical capabilities of a hospital include resuscitation, blood products, operating rooms, intensive care units, and ventilators. These capabilities are unique to hospitals, and they are the most resource intensive and therefore vulnerable to depletion. Considering that many disaster responses are in remote and austere regions with little or no infrastructure of their own, these hospital resources must be used wisely.

Triage is the act of sorting casualties by their severity with the intent to treat the most seriously wounded first, but there is an aspect to triage that is often forgotten in settings that are rich in medical resources. Triage is intended to balance priority of treatment against likelihood of survival in a resource-constrained environment. Omitting this corollary may lead to the misconception that the purpose of triage is "to do the most good for the most people." If resources are truly constrained, the purpose of triage might be understood "to do no more than is necessary to assist survival until more resources become available." In this way, overtriage, the act of assigning a higher priority of treatment to a patient than required, will deplete resources unnecessarily.

Overtriage has been shown to result in higher critical mortality rates in mass casualty incidents [12]. Overtriage results in delays in diagnosis and treatment of more critically injured patients. It also depletes resources. Radiology's essential role in accurate diagnosis may be taken for granted during routine operations in mature healthcare environments, but its value is sometimes overlooked when designing a healthcare response to disasters. By reducing overtriage, the initial logistical investment in radiology resources will pay off in the critical moments of a disaster response by accurately selecting the most appropriate patients for the allocation of limited resources.

When incorporating radiology resources into a medical response to disasters, it is important to select the appropriate tools to fit the requirement. The logistical trail for radiology is often greater than expected by most non-radiology medical planners, and a subject matter expert should be included early in the process [13]. If the medical footprint is to be small, ultrasound provides an easy, portable, and low-cost capability that can diagnose hemoperitoneum and pneumothorax, essential trauma triage capabilities. For larger footprints and more sustained responses, X-ray and CT are recognized as essential to providing emergency care. CT has the capability to rectify errors in prior triage by reducing the burden on resource due to overtriage. In remote or austere environments, these modalities will be challenging to deploy, and if done incorrectly, they will not perform in a way that meets the standard of care [13, 14].

Case Studies

Case Study 1: Indian Ocean Tsunami 2004

On December 26, 2004, a massive (> 9.0 magnitude) earthquake occurred in the Indian Ocean off the coast of Sumatra, Indonesia. The subsequent cataclysmic tsunami devastated the coasts of 14 countries on two continents. The most severely affected region was Banda Aceh, the capital of Aceh province on Sumatra. The US Navy deployed a combined civilian/military relief force aboard the *USNS Mercy*, one of its two hospital ships, to Banda Aceh to participate in the relief effort. In addition to its 1000 hospital beds (including 100 ICU beds), 12 operating rooms, full lab, and blood bank capability, *Mercy* also has a highly functional radiology department (Box 22.5). With a large, multinational land-based medical response effort underway in multiple tent facilities, *Mercy* was well suited to fulfill the role of tertiary care center for the sickest patients or patients who needed more advanced diagnostic workups, such as lab and imaging studies. *Mercy* also sent field teams ashore each day, where they provided multiple services including primary care, preventive medicine, specialty consultation, education, and civil reconstruction, among many others. The *Mercy* mission provides insight into two models for radiology implementation in the disaster relief setting: a "standard" model utilizing portable, mobile equipment and an "advanced" model utilizing imaging and image-guided procedural capabilities including CT, interventional radiology (IR), fluoroscopy, and US [15].

Box 22.5 Imaging Capabilities of USNS Mercy and Comfort [9]

(1)—64-slice CT scanner
(1)—Angio suite
(2)—Fixed CR diagnostic rooms
(2)—Fixed combined CR diagnostic/fluoro rooms
(3)—C-arm units
(5)—Portable X-ray units
(4)—Field use portable X-ray units: 2 DR, 2 CR
(3)—Portable ultrasound machines
(2)—High-end ultrasound machines
(1)—Full PACS with voice recognition dictation

Reprinted from Sydnor [9] Box 15.3 with permission from Springer Nature

The "Standard" Model

The *USNS Mercy* deployed with three portable ultrasound units (SonoSite, Bothell, WA) that were sent ashore each day with different clinical teams. Depending on the anticipated number of patient encounters and the number of providers, one or two units were dedicated each day to women's health (primarily obstetrical care), with the other unit going with an emergency medicine, family practice, or gastroenterology provider. To maximize use of personnel, an ultrasound technologist always accompanied the women's health team. He scanned the patients in advance and created concise, handwritten reports for the provider to reference when he/she evaluated the patient. This enabled the team to see large numbers of patients each day, thereby providing high-quality clinical service and engendering positive feelings among the local population—critical elements of a successful mission. The alternate team employed their ultrasound unit to examine patients for pathology such as hepatic abscesses, empyemas, pericardial effusions, hydronephrosis, and gallbladder disease. Fluid collections such as abscesses and empyemas could then be treated in the field with ultrasound-guided percutaneous drain placement. These drains can save lives yet are easily managed with minimal clinical resources (Fig. 22.4).

While portable digital radiography was not available on the Indonesian tsunami mission in 2005, it has been extensively utilized in follow-up missions with great ease and success. One of the first encounters each patient has with the healthcare system consists of a portable chest radiograph. This is read at the point of care on a laptop computer and enables the healthcare team to rapidly screen for tuberculosis prior to the patient's entry into the treatment facility. Standard methods of tuberculosis screening using patient questionnaires have not been found to be reliable, likely due to factors such as language differences and fear of care being withheld because of a positive response.

The "Advanced" Model

The ability to provide advanced imaging capability and image-guided procedures elevates the level of care to that of "first-world" medicine. During the Asian tsunami relief effort, CT was used to treat the sickest patients hospitalized aboard the *USNS Mercy*; it was used to assist with diagnosis and treatment planning for patients who were failing to improve using empiric clinical methods but were not so critically ill that they could not be cared for in a field hospital. The additional information provided by the CT scan was often sufficient to set the patient

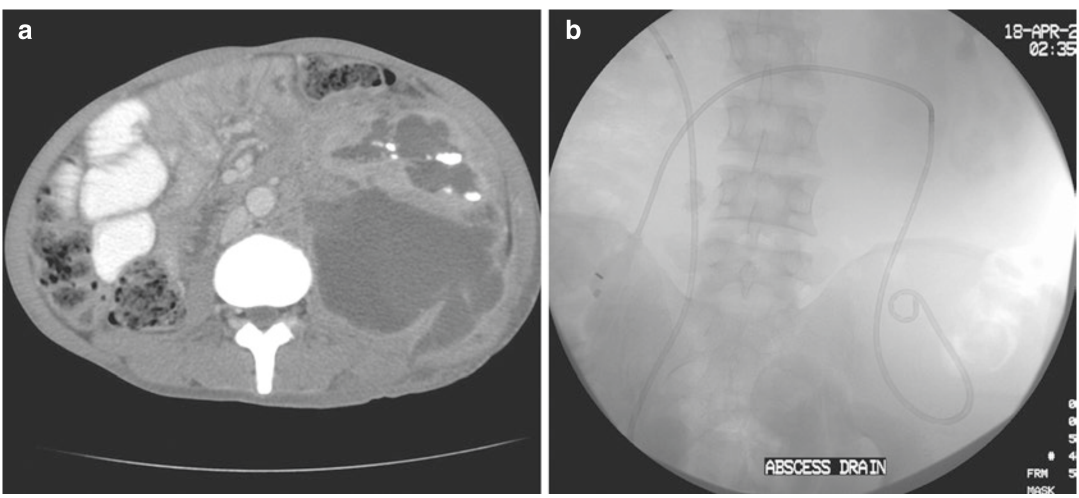

Fig. 22.4 (**a**) Contrast-enhanced CT of the abdomen in a patient with sepsis demonstrates a large left retroperitoneal abscess. (**b**) Spot fluoroscopic image following placement of two percutaneous drainage catheters [9]. (Reprinted from Sydnor et al. [9] Fig. 15.3, with permission from Springer Nature)

on the path to complete recovery. It was also used to perform more complex image-guided procedures including biopsies and drainages.

While the number of patients who underwent CT scans vastly exceeded the number treated by interventional radiology procedures, IR procedures provided some of the most dramatic benefits. Embolization procedures saved the lives of multiple trauma victims and patients with gastrointestinal bleeds. Septic shock was relieved with nephrostomies, thoracostomies, and abdominal drains. Less dramatic but equally beneficial procedures included PICC placement, prophylactic inferior vena cava filter placement in polytrauma victims, and thoracenteses in hypoxic children. It is important to note that among the variety of cases performed, many of the most beneficial required only a portable ultrasound unit and a modicum of ingenuity (Fig. 22.5).

Case Study 2: Haiti Earthquake 2010

On January 12, 2010, the island nation of Haiti was devastated when a 7.0-magnitude earthquake struck near the crowded capital city of Port-au-Prince. As the nation's already tenuous healthcare system was overwhelmed by the magnitude of destruction and number of casualties, the USA responded by sending a combined civilian/military aid force aboard a hospital ship called the *USNS Comfort* (similar to USNS Mercy pictured in Fig. 22.6). With the addition of a massive civilian volunteer contingent, the *Comfort's* capacity

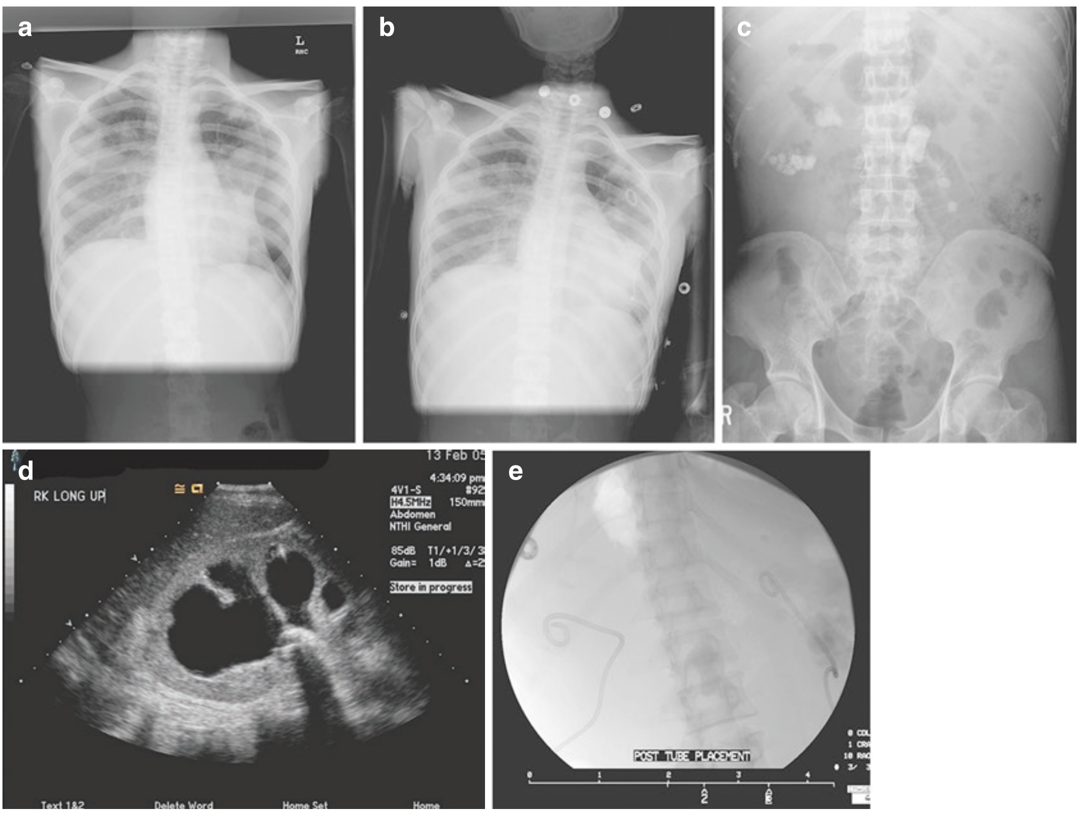

Fig. 22.5 (**a**) Frontal portable chest radiograph in a patient with "tsunami lung" reveals left pneumothorax with air space consolidation and cavity formation [16]. (**b**) Frontal portable chest radiograph following left pigtail tube thoracostomy placement. (**c**) KUB reveals multiple bilateral uroliths. (**d**) Ultrasound demonstrates right-sided hydronephrosis secondary to large pelvic urolith. (**e**) Spot fluoroscopic image following placement of bilateral nephrostomy tubes [9]. (Reprinted from Sydnor et al. [9] Fig. 15.4, with permission from Springer Nature)

Fig. 22.6 The US Navy hospital ship, *USNS Mercy* (*similar to the USNS Comfort deployed in Haiti during the earthquake*) [9]. (Reprinted from Sydnor et al. [9] Fig. 15.5, with permission from Springer Nature)

could be expanded to 1000 beds, including 880 ward beds, 80 intensive care unit beds, and 20 post anesthesia care unit beds. *Comfort* was equipped with the same advanced surgical and imaging capabilities as was *Mercy*. Additional services on board included a blood bank; hemodialysis; laboratories for chemistry, hematology, pathology, and microbiology; a morgue; physical therapy; two oxygen-producing plants; and a generator capable of producing 300,000 gal of potable water per day. The ship also featured a helicopter deck and side ports for accepting patients at sea.

Deployed on January 15, the *USNS Comfort* was stationed in Port-au-Prince harbor and began accepting patients within 7 days of the earthquake. The *Comfort's* staff cared for patients aboard the ship while simultaneously deploying healthcare teams and mobile technology on the ground. The initial flux of patients onto the ship consisted primarily of victims of high-force trauma, who benefited most from advanced imaging, interventional radiology, and surgical services. These patients were identified by the US Navy triage officers and transported to the ship via helicopter [17].

As described above in the context of the 2004 Indian Ocean tsunami, both "standard" and "advanced" radiology services were delivered during the crisis in Haiti. As with radiologists serving on the *USNS Mercy*, those aboard the *Comfort* had to practice with a degree of ingenuity and flexibility rarely required in their regular careers. At the same time, the ship's advanced clinical and technological capabilities allowed them to accomplish far more than they would have even in the most advanced Haitian hospital. RAD-AID has a country program in Haiti that has developed and been shaped by the earthquake, although it is not specifically geared toward reconstruction efforts.

Case Study 3: Nepal Earthquake 2015

On April 25, 2015, Nepal was struck by a deadly earthquake measuring 7.8 on the Richter scale. This was followed by numerous aftershocks and a second 7.3-magnitude earthquake on May 12th. Over 9000 people were killed, and more than 20,000 people were injured in the main earthquake. Previously, RAD-AID established a relationship in Nepal during 2014 when a Radiology-Readiness survey was conducted at the 50-bed Tribhuvan University Teaching Hospital (TUTH) in Kathmandu that indicated a need for a Radiology PACS system. The earthquake struck a few weeks before a RAD-AID team was due to undertake a follow-up mission.

After establishing safety of the area in conjunction with RAD-AID partners on the ground in Nepal, a decision was made to expand the mission's goals to include disaster response. The focal points of the mission were to evaluate the current role of imaging in disaster response and to address educational and PACS needs within the main teaching hospitals in the Kathmandu area as determined by the Readiness survey. A delegation of six personnel traveled to Nepal. This included two radiologists, three radiologic technologists, and one sonographer. The team assisted with physical examination, first aid, and transporting patients, in short whatever was necessary beyond any radiological commitments that had been made. RAD-AID therefore had a presence on the ground just after 2 weeks post disaster. The team was present for 3 weeks on a rotating basis.

RAD-AID partners in Nepal were Project HOPE and the Gorkha Foundation. These organi-

Fig. 22.7 (**a**, **b**) Temporary shelters built on hospital grounds to help with the surge of trauma victims

zations were very helpful with logistics, hospital site visits, and integration with the WHO health cluster meetings and access to the Ministry of Health. While the epicenter of destruction was about 100 miles outside Kathmandu, all the local hospitals, which were referral centers, became quickly overburdened. The rural areas most affected had been largely cut off from cities with most roads being destroyed by landslides and mudslides. Many of the villages were only accessible by air transport/helicopter. Given the overflow and safety concerns, many temporary hospital facilities were constructed on the grounds of hospitals and referral centers (Fig. 22.7).

A red, yellow, and green sticker system was used for triage which radiology embraced for its workflow. Red was positive, green negative, and yellow indeterminate. FAST scan ultrasound was the main radiological tool of triage particularly in the chest, abdomen, and pelvic trauma. CT scan was the mainstay of imaging. It was notable that because imaging access to portable equipment was scarce in the field, trauma surgeons could not always differentiate surgical fracture cases from nonsurgical cases, and this often resulted in overtriage of cases [18]. The other face of tragedy was the lack of resources in affected areas necessitating air transfer to referral centers, which were effectively cut off from the rural areas by the landslides. This was compounded by the altitude and hostile mountainous terrain. Portable equipment even in referral centers was very much a scare resource.

It is always challenging to create a support structure beyond the acute phase of the disaster. In the aftermath, RAD-AID has established a dedicated country program in Nepal. The main benefit post-earthquake was in establishing relationships with local technologists and radiologists in order to continue a program of support to the radiology community. Educational resources were delivered that helped local radiology students to graduate and take their expertise to other areas within the healthcare system [19].

Case Study 4: Improvised Explosive Device-Related Trauma in Today's Unconventional Warfare

During the Iraq War of 2003–2011, improvised explosive devices (IEDs) were commonly placed along roadways and walking paths to create as many casualties as possible. From 2001 to 2005, head, face, and neck injuries accounted for 30–50% of all injuries with the majority of these secondary to IEDs (Figs. 22.8 a, b, and 22.9a–c). Chest trauma accounted for approximately 5–10% of all combat-related injuries during 2001 to 2005. Abdominal injuries were relatively uncommon accounting for approximately 3–10% of injuries. Advances in body armor meant to protect the torso from firearm injuries resulting in

Fig. 22.8 (**a**) A training improvised explosive device lies on the ground at the site where Polish coalition forces instruct Tribal Mobilization Force members how to safely counter potential effects of IEDs" (Baghdad, Iraq) January 06, 2018. (Photo by Maj. Craig Savage, Combined Joint Task Force – Operation Inherent Resolve). (**b**) An explosive ordinance team member prepares a training improvised explosive device outside Fort Belvoir Community Hospital in September 13, 2016 as medical personnel and emergency response teams ensured preparedness for a mass casualty incident. (Department of Defense photos provided by Reese Brown)

fewer injuries to the torso [20–22]. Urogenital trauma accounted for approximately 5% of sustained injuries and was most often due to fragmentation-type injuries [20–23].

In 2006, the Joint Forces Mine-Resistant Ambush Protected (MRAP) vehicle program was initiated. This program sought to create a blast-resistant armored vehicle and decrease injury rates due to IED attacks [24]. The rate of head, neck, face, and extremity injuries remained relatively constant [25]. However, increasing numbers of spinal fractures were encountered by coalition troops in these new armored vehicles. The primary blast of the IED is absorbed by the underside of the vehicle with rapid upward displacement of the floorboards. This initial impact results in severe injuries to the "point of first contact" in over 75% of soldiers being concentrated at the thoracolumbar junction, leading to what was named as "combat burst fracture" (Fig. 22.10) [26–28].

In 2010, coalition forces announced the deployment of additional soldiers to Afghanistan, known as the surge [25]. With the additional soldiers, an increased number of dismounted patrols were performed. This shifting of patrol tactics also led to a change in IED construction with a change in injury patterns known as the dismounted complex blast injury. The dismounted complex blast injury was characterized by high-energy injuries to the bilateral lower extremities. Radiology plays a critical role in the diagnosis, management, and treatment of these injuries.

Case Study 5: The Field Role of Medical Imaging in Evolving Asymmetric Warfare

What is the role of radiology in the contemporary asymmetric and hybrid warfare? In the latter half of the nineteenth century, Western nations started equipping their armies with weapons capable of firing high-velocity steel-jacketed bullets instead of the soft lead balls typical of early wars. Radiology became an extremely valuable adjunct to battlefield care and behind the line surgery in locating and localizing bullets lodged in soft tissues. The second-generation warfare of the First World War legitimized the role of radiology as an established combat medical specialty and an integral part of battlefield medicine. The concept of second-generation warfare is defined as massed firepower and was utilized during WWI. This evolution led to radiology's increased presence in the form of mobile X-ray vehicles behind frontlines and fixed radiography units in the rear. The third generation of warfare, armored-maneuver warfare, was conceptualized by the Nazi Wehrmacht before and during WW2. Rather

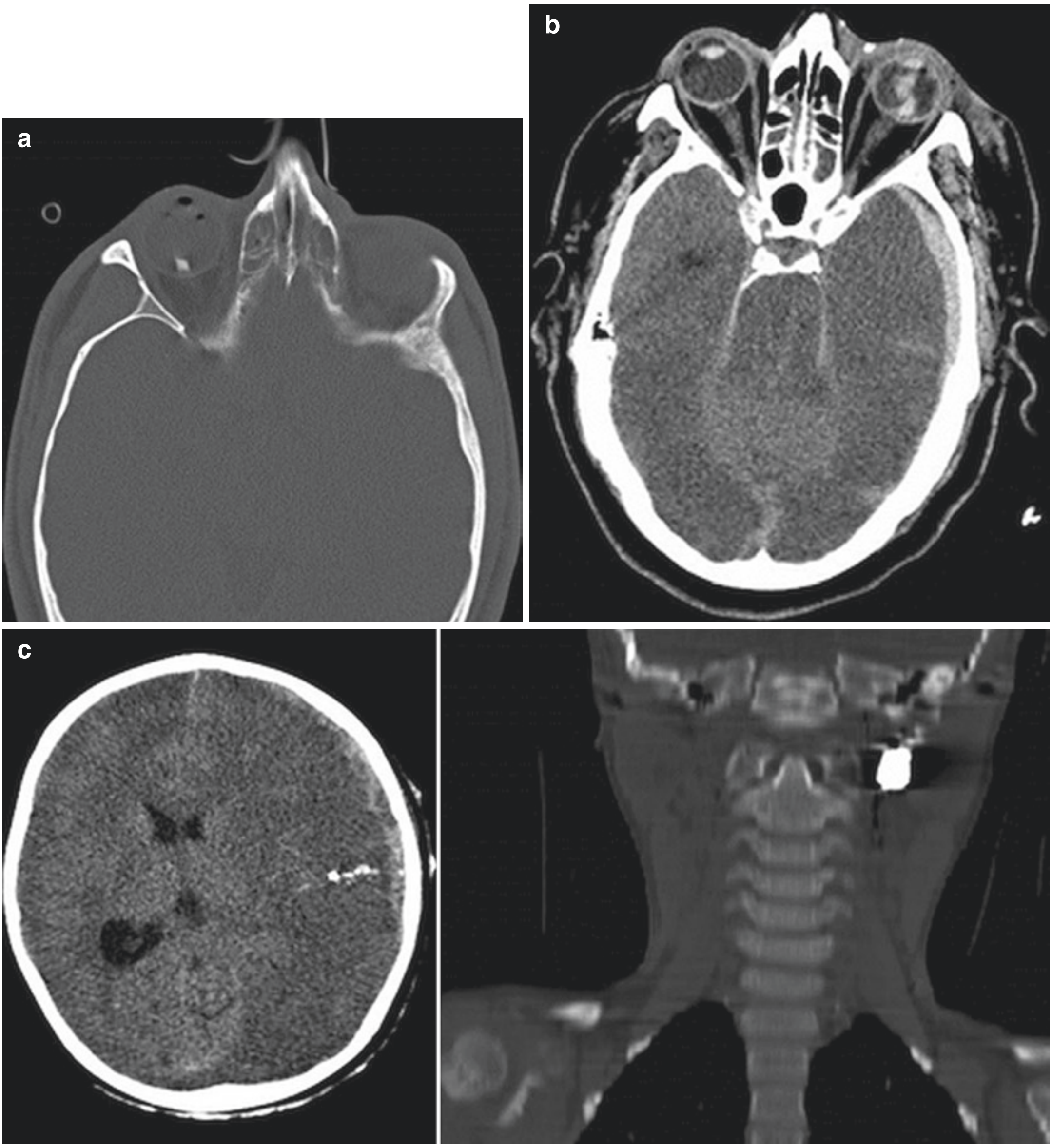

Fig. 22.9 (**a**) Axial CT image demonstrating shrapnel in the right globe with subsequent collapse and subcutaneous emphysema. (**b**) Axial CT image demonstrating a left retinal hemorrhage. (**c**) The image on the left is a noncontrast axial CT slice that demonstrates hypoattenuation of the left cerebral hemisphere, secondary to embolization of an IED fragment within the left internal common carotid. The CT image on the right is a coronal reformation, demonstrating an embolized IED fragment within the left internal carotid artery. (Photo courtesy Farhad Ebrahim, MD)

than facing the enemy along a rather static line of battle, one would bypass the enemy, attack from the rear or the flank, and destroy the enemy by attacking its command and control infrastructure. Mobile and portable radiology units in field surgical hospitals moved with the maneuver units providing invaluable imaging support and guidance to the surgeons.

Over the past 20 years, warfare has entered into its fourth-generation, asymmetric warfare, faced by coalition troops in Afghanistan and Iraq for the past 16 years. This warfare involves

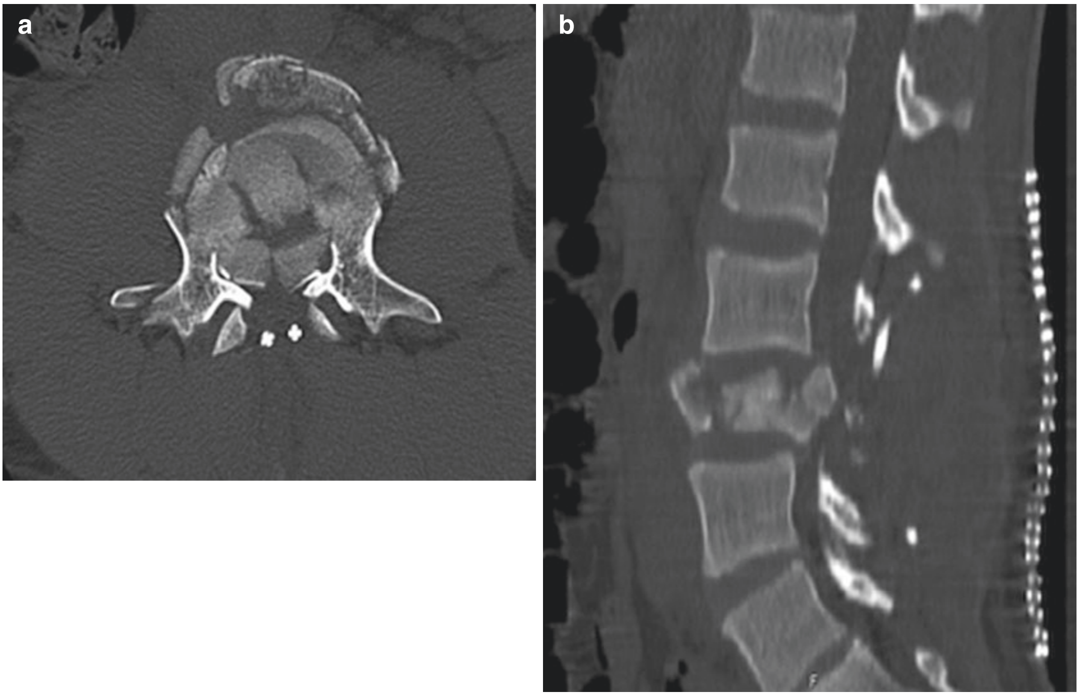

Fig. 22.10 Axial CT image (**a**, left) of L3 demonstrates a three-column combat burst fracture. Sagittal reformation (**b**, right) demonstrating the same L3 three-column combat burst fracture

nation-states fighting a long, protracted, low-to-medium intensity war. This type of warfare does not always distinguish between combatants and civilians. The signature weapon of fourth-generation warfare is the IED, which has been dubbed in medical literature as the fourth weapon of mass destruction [29, 30]. On the battlefields of Iraq and Afghanistan, military radiology played a vital supportive role in the almost 98% survival rate of IED-related and other battlefield casualties [31]. The forward deployment of 64-MDCT scanners in theaters of war and the development of high-speed broadband teleradiology networks letting military radiologists stationed in Germany or Alaska read and interpret images performed in Iraq and Afghanistan accurately diagnosing primary, secondary, tertiary, and quaternary effects of blast-related trauma explosively revolutionized the specialty of battlefield imaging.

While the fourth-generation warfare is evolving, a fifth generation is emerging. This involves "super-empowered" individuals who have the ability to wreak havoc on state assets and infrastructure. In fifth-generation warfare, or unrestricted warfare, a single individual or a small group of individuals with appropriate financial and technological resources can inflict the same degree or greater damage on a nation state, which previously only another nation state could inflict, an example being the anthrax mail letters in 2001. This almost paralyzed the legislative branch of the US government for 12 days, and the cost of cleanup and decontamination was approximately a billion dollars. Radiology played a critical role in suspecting and suggesting anthrax on chest radiographs and CT scans of anthrax victims by noticing widened mediastinum, necrotic lymph nodes, and hemorrhagic mediastinitis [32] (Fig. 22.11).

Finally, the sixth and seventh generations of warfare are distant no-contact warfare and cyberwarfare. It is noteworthy that the US Department of Defense has declared the cyberspace as the fifth domain of warfare in addition to sea, air, land, time, and space. These new generations of

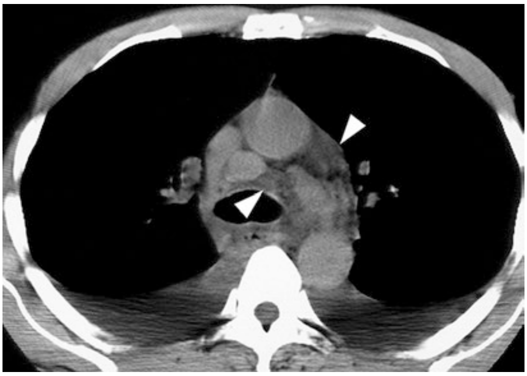

Fig. 22.11 CT scan [33]. (Reprinted with permission from Earls et al. [33], Fig. 2b)

warfare have the capability of bypassing the formal militaries and military defenses of a country and directly attacking and paralyzing the infrastructure and military-industrial complex of the enemy. This puts a tremendous responsibility on the civilian disaster response community, as they will be at the forefront of tackling the aftermaths of damage to civilian infrastructure.

In May 2017 a global cyberattack using hacking tools crippled the National Health Service (NHS) in the United Kingdom. Hospitals and family medicine surgeries in England and Scotland were among at least 50 NHS trust service organizations hit by a "ransomware" attack using malware called Wanna Decryptor. The radiology PACS and RIS were integral targets of this cyberattack. MR/CT and PACS systems were unable to operate as their digital platforms were corrupted with an inability to access images and reports. Given that the radiologist's functionality is integrated into the digital world, the field is particularly susceptible to advanced generation warfare strategies.

Hospitals and their staff who are very accustomed to preventing the spread of biological infections must now apply similar levels of caution when addressing the spread of cyber infections. The medical industry is not alone in fighting this threat—they do not have to invent new techniques for preventing cyber infection; they simply need to adapt the proven strategies employed by other industries. Simple solutions like instituting an air gap networking security system that isolates secured computer networks like PACS from unsecured networks like local area network would provide a point through which data flow and hence "cyber infection" is carefully controlled, much like putting a scrub room before the OR.

Case Study 6: The Syrian Case: The Targeting of Medical Facilities and Health Workers

Over 250,000 people have been killed and over 1 million injured since the onset of the Syrian crisis in 2011. More than half of all Syrians have been forced to leave their homes, often multiple times, making Syria the largest displacement crisis globally. Human rights violations and abuses continue to occur in the context of widespread insecurity and in disregard of international law, international humanitarian law, and human rights law. Children are the most innocent victims of the tragedy [34]. Health facilities in Syria are systematically targeted on a scale unprecedented in modern history. There have been over 454 attacks on hospitals in the last 6 years, with 91% of the attacks perpetrated by the regime and its supporters. During the last 6 months of 2016, the rate of attacks on healthcare increased dramatically. In April 2017 alone, there were 25 attacks on medical facilities.

The fortification of medical facilities is now considered a standard practice in Syria. Field hospitals have been driven underground, into basements, fortified with sandbags and cement walls, and into caves. The Syrian American Medical Society (SAMS) is a nonpolitical, nonprofit medical relief organization that has treated approximately 3 million patients in 2016. They have hundreds of highly skilled volunteers. In October 2015, SAMS M10 Hospital, the largest trauma center in East Allepo, was destroyed by bombing. This forced operations underground. SAMS provides numerous ancillary services which include teaching programs and supporting the large refugee camps in neighboring Jordan, Turkey, and Lebanon especially the Zaatari Camp in Jordan. SAMS includes radiology services

Fig. 22.12 SAMS underground facilities, Syria. Currently SAMS has two complete underground facilities and four partial underground facilities. (Photo courtesy of Syrian American Medical Society (SAMS))

such as teleradiology interpretation services, FAST scan ultrasound courses held in Jordan and Turkey with over 150 handheld ultrasound units disseminated to field hospitals, and a mobile cardiac catheterization lab. In 2016 alone approximately 8000 telemedicine services were provided [35] (Fig. 22.12).

Case Study 7: Mega Scale Disaster Response—An Idyllic Futuristic Model for Imaging

As the world response to large-scale disasters becomes more sophisticated, the need for proportionately capable advanced imaging is increasing. The United States Military Combat Support Hospitals (CSH) often have CT scanners in addition to point-of-care (POC) ultrasound and X-ray equipment. Multiple specialty physicians can be deployed within a CSH hospital including trauma surgeons, orthopedists, anesthesiologist, and intensivist. The need for advanced imaging is naturally growing to support these specialized clinical services. Advanced imaging generally includes CT, MRI, and PET; however, CT is the only realistic advanced imaging modality that can be quickly operationalized in a disaster setting.

A concept introduced at the World Association for Disaster and Emergency Medicine (WADEM 2017) in Toronto, Canada, is the strategic advanced imaging reserve (SAIR). This comprises imaging equipment and resources that are stored in strategic locations and made available emergently to global mass casualty events. The SAIR would augment the existing capabilities of the deployed teams especially during the resource-intensive surge phase. The SAIR would likely include CT scanners, point-of-care ultrasound (POCUS), PACS, satellite uplinks, diesel generators, and IV contrast. Command of the SAIR would logically fall to a multinational organization such as the WHO. Deployment decisions would need to be transparent, expeditious, and data driven. The massive increase in imaging needs during the surge phase will also require a concomitant increase in technologists and physician image interpretation capability. Without optimal interpretation, medical beneficence is compromised, and the resource cost of deploying CT as well as the risk associated with medical radiation is difficult to justify. A timely radiologist interpretation would offer optimum benefit from this exam, as well as for radiographs and ultrasound use.

Even a moderate-sized global disaster event might have tens of thousands of cases in the surge phase, and few organizations have the interpretation capacity to meet this level of need. The creation of a large pool volunteer on-call registry that has technologists and radiologists who are available through teleradiology technology to serve a large-scale disaster will be crucial to advancing care. This global disaster radiology team (GDRT) would be available to offer imaging assistance to any medical team that responded to a disaster such as the Red Cross or an international military goodwill medical team. Likewise, the GDR could serve the needs of a SAIR deployment. The GDR would include a selected group of available technologists that have flexible working circumstances and appropriately skilled radiologists who are committed to being available for disaster imaging interpretation (Box 22.6, Box 22.7, and Box 22.8).

Box 22.6 Future Elements of Disaster Preparedness

- Establishing radiology subcommittee/special interest group at WADEM
- Exploring the role of ASER as a lead organization in radiology disaster outreach planning
- Working group on radiology equipment prestaging
- Performing feasibility for a radiology disaster response protocol such as SAIR
- Performing feasibility for global disaster radiology team
- Creating a volunteer registry for radiologic disaster outreach missions
- Working group on portable CT
- Developing network with biomedical engineering
- Establishing best practices guidelines
- Establishing relationships in geographic areas of need
- Education program on cyber threats in radiology and imaging role in IED attacks

Box 22.7 Essential Components for Successful Radiology Implementation in Acute Disaster Relief

- Robust radiology equipment in place prior to disaster
- Replacement and repair of existing technology
- Portable ultrasound
- Mobile digital radiography
- Advanced imaging (e.g., CT and fluoroscopy) at a nearby off-site location
- Well-trained individuals

Box 22.8 Essentials Intermediate- and Long-Term Phase

- Continue to foster relationships with local partners and institutions.
- Investing resources in building local capacity of needed skill sets.
- Develop specific areas of education support such as fellowships or visiting lecture programs.
- RAD-AID Radiology-Readiness tool performs gaps analysis to establish priorities, such as PACS implementation.
- Develop supportive radiology program for planning reconstruction surgeries.
- Engage with UN support agencies like UNICEF to gain support for dedicated radiology disaster coordination response in accordance with Sendai Framework.

Looking Forward

Perhaps the greatest challenge to achieving disaster preparedness will be the process of ensuring that crucial technology, infrastructure, and expertise are in place before disaster ever strikes. Ideally, hospitals in vulnerable regions should be equipped with at least portable US and DR, and they should have reliable generators on-site to accommodate disruptions in the local power supply. CT and fluoroscopy should be made available at tertiary care centers. In certain regions, the use of mobile imaging services (generally DR and US) may also be feasible and highly effective. Of course, in order for all of this imaging technology to go to effective use, a number of infrastructural elements must be in place, including communications networks, well-devised standing protocols, reserved space and medical supplies, surgical and other acute care services, and reliable patient transportation.

In reality, all of these components are rarely going to be in place when disasters occur. Of all available resources in this setting, people are by far the most valuable. Brilliant plans and state-of-the-art technology are of little benefit in the hands of inadequately prepared individuals. Both local and foreign volunteer radiologists and technologists must be fully prepared to step outside of their comfort zones or specific areas of expertise and to integrate themselves into a cohesive medical care team. This often means utilizing physical exam skills and other potentially dormant elements of one's medical training, and it means collaborating with other members of the care team to devise novel solutions to clinical problems using the resources available. Radiologists must go abroad prepared to get involved in patient management and to use forgotten tools such as stethoscopes, otoscopes, ophthalmoscopes, blood pressure cuffs, IVs, and even endotracheal tubes. Each individual must be prepared to act first and foremost as a *physician* rather than a specialist or subspecialist.

It is clear that radiology has a unique and critical role to play in the setting of disasters, particularly in the developing world. The fact that radiology has historically been underutilized in this setting can be largely attributed to a general lack of understanding of this role and failure to make appropriate preparations. Experts and professional organizations in the field of radiology must strive to implement vital technology and training programs in vulnerable regions. They must insist on having a place at the table in the planning of disaster relief programs. As described previously, there is light developing at the end of this tunnel; there are increasing signs that other specialties in the frontline of disaster response are recognizing the need to have formal incorporation of radiology opinion into their planning. The radiology profession armed with its tools must now seize this window of opportunity to increase its efforts; otherwise it risks remaining the constant weak spot in the disaster relief paradigm.

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23 Trauma Imaging in Global Health Radiology

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Introduction

The World Health Organization (WHO) reports that 16,000 people die from traumatic injuries every day, and for every person who dies, several thousand more are injured, many of them with permanent disabilities [1]. As the world continues to undergo an epidemiological transition toward increased socioeconomic development and urbanization, the worldwide costs of trauma are expected to significantly increase. In 2012, trauma ranked as the ninth leading cause of worldwide morbidity and resulted in five million deaths annually, accounting for 15% of years of life lost (estimated toll of premature death) [2], with more than 90% of global deaths from injuries occurring in low-income countries. Yet trauma is expected to increase from the ninth to the third leading cause of worldwide disease burden by the year 2020 [2]; this will ultimately disproportionately affect poorer, less developed countries [3].

Much of the global burden of trauma-related injuries and fatalities can be correlated to an increasing worldwide dependency on motor vehicles as a means of transport [4]. Motor vehicle accidents kill 1.2 million people and injure or disable tens of millions more worldwide every year, with most traffic-related deaths occurring in low- and middle-income countries (LMICs). One study has reported that more than 85% of all deaths due to road traffic and 96% of all children killed in road crashes occurred in LMICs [5]. Accidents also disproportionately involve men aged 15–44 years old, with pedestrians, cyclists, passengers on public transport, and riders of motorized two-wheeled vehicles being those most commonly harmed [6]; these demographics also highlight the societal burden, particularly in patriarchal cultures in which young adult men are the primary wage earners for families. The overall costs from these accidents in LMICs exceed US$65 billion per year, a sum greater than the total amount of developmental aid/assistance received in all of these countries combined.

Despite these staggering statistics, investment in trauma prevention worldwide is disproportionately low. For example, in 2006–2007, the WHO allocated less than 1% of its annual budget to

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work-related injuries and physical violence worldwide [7]. Other studies show that in the 1990s, the Disability Adjusted Life Years (DALY) value of external assistance provided was more than $50 for leprosy, $6.90 for blindness, and $4 for HIV/AIDS and other sexually transmitted diseases, compared to $0.11 for accidental injuries/trauma (per affected person per event per year) [8].

The disproportionate rise in traumatic injuries and deaths in LMICs is further complicated given the endemic disparity in post-traumatic outcomes between LMICs and high-income countries. One recent study found that persons with life-threatening but salvageable injuries are six times more likely to die in a low-income setting (36% mortality) than in a high-income setting (6% mortality) [9], while another study compared outcomes for adults in low-income, middle-income, and high-income countries and found that the mortality rate rose from 35% in high-income settings to 55% in middle-income settings and to 63% in low-income settings [10]. While the causes for the improved survival and functional outcome among patients injured in trauma in developed countries are multifactorial (e.g., proximity and availability of travel to hospitals and organized trauma care services), a significant portion is related to the lack of access to high-cost medical equipment and technology, specifically diagnostic imaging.

The predominant diagnostic imaging modalities used for trauma/emergency services in LMICs are X-ray and ultrasound [11]; in fact, these two modalities alone meet over 90% of the imaging needs of the population [12]. Rapid ultrasound may effectively screen for significant thoracoabdominal trauma including pneumothorax, cardiac tamponade, and abdominal organ injuries [11]. For the large number of patients who present with significant pulmonary or orthopedic conditions, radiography is critical to diagnosis and treatment [13].

Unfortunately, in the majority of cases in which radiograph and ultrasound are not readily available, the necessity for long-distance patient transportation to facilities with adequate diagnostic capability can significantly delay treatment and lead to increased morbidity and mortality [11]. One group reported that in western Nepal many patients must travel over 10 h and others over 2 days, to reach an X-ray facility; transportation costs alone for this may exceed an average monthly wage [11].

Clinical Considerations in Trauma

Traumatic Brain Injury

Traumatic brain injury (TBI) is a major cause of death and disability among the trauma patient population worldwide [14]. While exact statistics are lacking, TBI is a particular problem in LMICs [15], in part due to limited access to appropriate screening imaging tools. In certain trauma populations in LMICs, the incidence of TBI has been reported to be as high as 74% [16]; according to the WHO, head injury is one of the major causes of trauma-related disability and death worldwide [1].

While guidelines [17, 18] established for the management of severe TBI have shown to improve survival and functional outcome after severe head injury in high-income countries [19], these protocols require expensive resources, including computed tomography (CT) imaging. For example, post-traumatic extra-axial hemorrhage, diagnosed by CT, can require neurosurgical decompression for decreased morbidity and mortality. Even when CT scanners are present in low-income countries, many factors often render them unusable, including prohibitive maintenance costs and consequent long periods of breakdown [20]. If CT scanning is available in the setting of head trauma, the WHO has recommended that basic quality improvement programs should assure that all patients warranting CT scan of the head (generally Glasgow Coma Scale of 8 or less) can be imaged within 2 h of presentation [1]. It is important to consider that while current treatment strategies for TBI have been validated in the western medical literature [21], their effectiveness is unknown in the setting of inadequate infrastructure, absence of advanced medical imaging, lack of emergency medical services, and/or limited ICU availability [3].

Given limited access or in some circumstances outright lack of advanced imaging modalities in

LMICs, it is desirable to have objective screening measures in place to determine appropriate allocation of resources. A recent multicenter validation study compared the accuracy of several clinical decision tools including the Pediatric Emergency Care Applied Research Network (PECARN) mild pediatric TBI scoring system against experienced physician clinical judgment; the results demonstrated a high sensitivity (99–100%) and negative predictive value (100%) of the PECARN tool. However, the results also showed overall increased number of CT scans when PECARN was applied compared to clinical judgment alone [22]. These findings were largely corroborated in a prospective cross-sectional study from Tehran, Iran, which also showed high sensitivity (92.3%) in identifying children with clinically important TBI. Interestingly, the Iranian study showed a 5% decrease in the number of CT scans performed when PECARN criteria were used [23]. These differences may reflect inherent differences in patient populations, experience, and/or practice patterns of physicians or some combination thereof. While currently unsettled, it is possible that such clinical decision tools may be useful in resource-limited settings by helping to identify patients at high risk for TBI and ensuring timely imaging whenever possible.

Traumatic Spinal Cord Injury

Like TBI, traumatic spinal cord injury (TSCI) is an increasing health-care challenge in LMICs. The overall incidence of TSCI in LMICs is measured as 25.5/million/year [24]. The average age of patients with TSCI in LMICs has been reported to be below 35 years old [24, 25], a devastating statistic given the high morbidity associated with TSCI. There is generally a high male-to-female ratio in TSCI, with reported ratios as high as 7.5:1 having been reported in the literature [26]. Currently, the leading causes of TSCI in LMICs are motor vehicle collision (41.4%) and falls (34.9%) [24].

The management of TSCI is challenging, even with a full complement of diagnostic and therapeutic resources available. While several studies have assessed short- and long-term survival rates after TSCI in high-income countries, very few long-term outcome studies exist in LMICs. One study from Zimbabwe reported a 1-year survival rate of approximately 51% [27], a significant improvement from earlier unpublished data from the same group. A separate study from Sierra Leone reported an in-hospital mortality rate of 29.2% in the setting of TSCI [28], which was approximately three times higher than a similar series from Brazil [29]. Recognition of the presence of risk of spinal injury is essential at all levels of the health-care system.

While clinical evaluation is the first critical step in the evaluation of suspected spinal cord injury, radiographs are a very helpful adjunct and are considered the minimum requirement for imaging evaluation. The incidence of TSCI, like TBI, is likely to increase as the prevalence of motor vehicles continues to increase in LMICs. Many authors have advocated for a more comprehensive spinal injury response system in LMICs, including environment modification, vocational rehabilitation, and caregiver education [28].

Thoracoabdominal Injury

In addition to TBI and TSCI, post-traumatic thoracic and abdominal injury (both blunt and penetrating) is an increasing cause of morbidity and mortality worldwide. As with TBI and TSCI, while physical examination and clinical evaluation of trauma patients are the first steps in evaluation, these methods are significantly augmented in the acute setting with ultrasound or CT capabilities. Ultrasonography is the primary method of screening patients with blunt abdominal trauma worldwide [30, 31]. Focused assessment with sonography for trauma (FAST) is a rapid bedside ultrasound examination which can be used to screen for the presence of free fluid in the abdomen or pelvis [32], the presence of which suggests traumatic solid organ or gastrointestinal tract injury and has important clinical and management implications in the post-traumatic setting. According to previous reports, the morbidity of gastrointestinal tract injury is mostly related to delays in diagnosis [33].

Because of the much wider availability of ultrasound in LMICs, FAST is a very important diagnostic application in the setting of trauma. A Cochrane systematic review found that the sensitivity of FAST for detecting hemoperitoneum in trauma patients was 85–95% [34]; the average specificity of FAST for intra-abdominal blunt trauma has been reported as 90–99% [34–36], with one study investigating FAST in LMIC settings reporting a specificity of 100%, regardless of mechanism of injury [37]. FAST scanning expedites the appropriate triage of trauma patients, decreasing time to definitive care and reducing demands for CT scanning, which is particularly important in low-resource areas [37]. Repeated scanning has been shown to increase the sensitivity of FAST to above 90% for detection of the presence of free intraperitoneal fluid [38, 39]. FAST is often considered less sensitive than other methods of determining the extent of post-traumatic intra-abdominal injury such as diagnostic peritoneal lavage (DPL) or CT. However, a direct comparison of FAST and DPL showed FAST scans to be a good alternative, with a similar specificity and a much lower complication rate [40]. While CT remains the gold standard for assessment of intra-abdominal traumatic injury, FAST is an acceptable alternative in resource-poor facilities, where CT is often unavailable [41, 42]. Despite the high negative predictive value of FAST in blunt trauma, reported as 91.6% in one study [37], it is important to remember that the absence of free fluid on FAST scanning does not exclude intra-abdominal injury, with one study revealing the presence of visceral injury on CT in 34% of patients with no evidence of hemoperitoneum on FAST evaluation [43].

Within the last two decades, the standard FAST examination has been augmented to include evaluation of thoracic injury in trauma patients, termed extended FAST (EFAST) [44–46]. In the EFAST exam, the thorax is scanned anteriorly to assess for pneumothorax as well as along the bilateral flanks to assess for the presence of hemothorax [44]. Pneumothorax is a common complication in major blunt trauma and can be found in more than 20% of cases, with supine chest radiography still considered a primary diagnostic tool for pneumothorax detection [44, 45, 47]. Sensitivity for pneumothorax with supine radiography is reported at or below 50%, with a majority of studies demonstrating EFAST superiority in the trauma setting [44, 45]. Ianniello et al. reported sensitivities near 80% in ultrasound detection of pneumothorax in over 350 unstable trauma patients [48]. A prospective study consisting of 225 trauma patients reported sensitivities of EFAST around 50% versus 20% in chest radiography, with a specificity of 99% and positive predictive value reaching 88% [47]. Regarding hemothoraces, supine radiographs require approximately 175 mL of fluid to be visualized, compared to ultrasonography which can detect as little as 20 mL of pleural fluid [44]. Given this efficiency coupled with rapid availability, the additional ultrasound evaluation of the thorax to traditional FAST has become a useful and widely accepted adjunct in the point of care paradigm for the trauma patient.

Ultrasound is an excellent but heavily operator-dependent modality, and optimal use of ultrasound for assessment of trauma necessitates an effectively trained team of sonographers and/or other clinically based professionals, including physicians and nurses. Strategies seeking to incorporate clinical ultrasound in LMIC for trauma evaluation require an effective clinical education component for effective implementation.

Extremity Injury

Traumatic injury of the extremities is a significant worldwide cause of morbidity. Socioeconomic change within LMICs, as described at the beginning of this chapter, including an increased dependence on motor vehicles, has resulted in a significant increase both in the number and in the complexity of injuries of the extremities [49, 50]. Resources are often in short supply to address such injuries. This has led, as one author described, to the dilemma in LMICs of attempting to manage what can be termed “first-world injuries using third-world facilities” [4]. Untreated fractures, many of which are the result of road traffic accidents as previously described, are a major burden of disease.

Musculoskeletal disabilities can be greatly reduced if promptly recognized and corrected [1]. X-ray facilities are generally designated as essential by the WHO for the diagnosis, treatment, and successful management of skeletal injuries. In addition, portable X-ray capability greatly facilitates the diagnosis of skeletal injury and the management of patients in traction and during operative procedures. C-arm fluoroscopy is also a very important component of many orthopedic interventions in the setting of trauma, as it reduces operative time, can decrease radiation exposure, and allows for closed, rather than open, procedures [51, 52].

It is estimated that two thirds of the world has no access to orthopedic care as the majority of the world's orthopedic surgeons are found in high-income countries. In countries with poor access to resources, nonoperative treatment is often offered for fractures, despite the fact that operative repair would result in a better functional outcome. The reasons for this include the unavailability of implants, deficiency of equipment and imaging capability, and lack of surgical training. While the majority of fractures will heal whether or not formal treatment is undertaken, the problem is that healing may not occur in the desired position or alignment, thus compromising function [4]. In general, extremity trauma continues to constitute a major trauma-related problem in the LMICs and proves to be multifactorial.

Evidence-Based Strategy for Treatment of Trauma

Trauma Teams

Organized trauma teams have proven to be a vital adjunct to medical imaging in the successful treatment of trauma patients in high-income countries. One study reported that in the presence of an organized trauma team, resuscitation time was reduced by 54% [53]. This was interpreted to be a result of task allocation and the adoption of simultaneous rather than sequential resuscitation. The involvement of an experienced senior trauma team leader, who was not actively involved in the physical aspects of the resuscitation, was found to help shorten resuscitation times [54]. Compared to resuscitations without a designated team leader, resuscitations that had a team leader had an increased proportion of completed secondary surveys and formulated definitive plans. A different study evaluating pediatric trauma care found that the improved organization of a dedicated trauma team resulted in shorter times to CT scanning for head-injured patients, shorter time to surgery when necessary, and decreased times in the ER [55]. It has been reported that the establishment of organized trauma teams can be accomplished at very little cost [56].

While organized trauma teams have significantly impacted morbidity and mortality related to trauma in high-income nations, such organization is often lacking in the care of trauma patients in LMICs. Preliminary studies evaluating the utility of organizing trauma teams in LMICs have been conducted [57, 58]. One study in Thailand, for example, demonstrated that improving the trauma team in the emergency department constituted a vital component of efforts to improve trauma care at the hospital. A study from Turkey demonstrated that the establishment of an organized trauma team at an urban trauma center resulted in a decreased mortality rate from 33% to 23% [59]. These and other studies from high-, middle-, and low-income countries indicate that improvements in dedicated trauma team organization can be a cost-effective way of reducing trauma-related morbidity and mortality. Efforts to improve trauma management should include a system for ongoing evaluation, including methodology to accurately track data on the incidence of trauma-related injuries and deaths. Resources must be devoted to efforts to augment existing sources of data about injury and to assure the quality and timely availability of data [60].

World Health Organization Essential Trauma Care Project

While medical imaging and organized trauma teams are important components in the delivery of effective trauma care in the LMICs, there are many more components which are beyond the scope of this chapter. A comprehensive review and compilation of recommendations regarding trauma treatment worldwide has been undertaken by the WHO in the form of the *Essential Trauma Care Project* (EsTC). The EsTC project seeks to define what essential trauma treatment services should realistically be made available to almost every injured person worldwide [1] and then seeks to develop ways of assuring the availability of needed resources, both human and physical. The EsTC project serves as an excellent comprehensive resource addressing the delivery of trauma care in LMICs and can be downloaded (at no charge) at the following link: http://whqlibdoc.who.int/publications/2004/9241546409.pdf [61]. In 2016 the WHO *Trauma Care Checklist* was introduced, a simple tool designed as the result of an international collaborative effort to ensure a systemic approach to the evaluation of trauma patients and that life-threatening conditions are identified in a timely manner. This checklist can be downloaded (at no charge) at the following link: http://www.who.int/emergencycare/publications/trauma-care-checklist.pdf [62].

Conclusion

Trauma-related morbidity and mortality continue to rise as LMICs undergo an epidemiological transition related to socioeconomic development and urbanization, with trauma expected to become an increasing cause of worldwide disease burden in years to come. It is important to understand the socioeconomic and demographic data as related to trauma in LMICs and to evaluate how the implementation of medical imaging and organized trauma responders can minimize post-traumatic morbidity and mortality in low-income countries. Given persistent resource limitations across large segments of the global population, it is likely that both optimizing current trauma imaging protocols as well as developing new applications of the most readily available modalities (radiography, ultrasound, and CT) are the most meaningful ways to improve trauma care worldwide.

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24 Interventional Procedures for Global Health Radiology

Mark L. Lessne, Andrew Kesselman, and Paul V. Suhocki

Introduction

While the impact of diagnostic imaging has revolutionized modern medicine, its availability in low- and middle-income countries is often limited, of reduced quality, or nonexistent [1]. Paralleling the importance of imaging to diagnosis, the evolution of minimally invasive interventional radiological procedures has allowed these often lifesaving therapies to minimize or obviate the need for potentially morbid open surgeries. While the challenges of modernizing diagnostic imaging capabilities in LMICs are great, there is little doubt that greater hurdles must be overcome to safely and practically implement technologically demanding interventional radiological procedures. In some cases, even middle-income countries with relatively developed primary healthcare systems find the implementation of highly specialized or interventional procedures difficult [2, 3].

This chapter will discuss the financial and educational challenges involved in establishing an effective IR service in LMICs. It will also outline practical approaches to current IR techniques that may make them more accessible to technologically devoid or low-resource areas. It is expected that with the emerging interest in and increased ability to provide minimally invasive therapies to a wider global population, many of the challenges addressed below will be mitigated, while others will be newly discovered. However, with the dedication of interventionalists and colleagues all over the world, even the most seemingly insurmountable obstacles can be overcome. The ultimate goal is to provide the best care to even our most vulnerable patients.

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The Cost-Effective Approach

The equipment used by interventional radiologists for diagnosing and treating patients may be capital-intensive, but not exclusively so. When implementing an interventional program in LMICs, the value of care (defined as outcomes per dollar spent) must be carefully considered. While the subspecialty is highly technical, innovative, and integral to modern western medicine, a value-based perspective must be used to determine the precise role interventional radio-

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logical procedures can play in resource-limited countries. Treatments considered "optimal" in high-income countries, but that come at a prohibitive cost to poorer regions, may be altered or truncated while remaining beneficial to the patient—albeit with potentially unequal efficacy compared to the original therapy. For example, percutaneous thermal ablation of hepatocellular carcinoma has become a mainstay of treatment, but it requires a capital investment that may be unfeasible for poorer countries; however, minimally invasive ablation with ethanol can be used in LMICs at a much lower cost [4].

The World Health Organization (WHO), a United Nations agency, provides guidance on health policy and resource allocation for improving the quality of human life worldwide. The WHO acts as a broker and arbiter, helping to shape the rules of engagement between governments, development agencies, and civil society while promoting equitable and sustainable health for all. In bringing radiology services to countries where resources are limited, the WHO has stated that the majority and most marginalized should be prioritized. The WHO estimates that roughly 90% of countries with basic or no medical care access would, in terms of radiology services, benefit most by standard plain film radiography and ultrasound. The remaining patients who would benefit from more advanced and expensive equipment are given a lower priority for resource allocation. In fact, the WHO recommends that fluoroscopy, CT, angiography, MRI, nuclear medicine, and advanced ultrasound should not be installed unless radiologists and fully trained technologists are present at the facility to use it. Paradoxically, very expensive imaging equipment is often seen in hospitals that lack even the most basic healthcare essentials such as chest tubes, cardiac monitors, pulse oximeters, drugs, staplers, suture material, gloves, and lubricating gel. In many of these instances, the root cause can often be traced to political corruption, resource misallocation, or ill-prepared outreach and donation efforts [5].

The WHO recommends that imaging equipment in low-income regions be "available, accessible, appropriate, and affordable," as stated in their 2010 publication *Medical Devices: Managing the Mismatch*. This report points out that medical devices may not be able to withstand hot and dusty climates or run on the insufficient electricity supplies commonly seen in low-income settings. Oftentimes, generators break down, equipment does not get serviced, and there are no service engineers in the country. Replacement parts can take months to arrive and then require additional costs of transporting and housing an engineer to complete the repairs. Sometimes, even if the representative is present, there may not be a full service and maintenance contract between manufacturers, suppliers, or maintenance companies and users; this disconnect leads to long periods of inactivity and frustration. Therefore, an emphasis on interventional procedures that rely on low-cost, low-maintenance equipment is vital to sustaining a valuable interventional service [5].

Furthermore, one must consider the expense of the traditionally disposable tools required to perform interventional procedures. Although the expense of items such as catheters, needles, and wires may seem minor at first, their cumulative cost may prove to be a powerful obstacle to the ongoing function of an IR lab. One of the more obvious—and common—ways to mitigate this hurdle is to recycle and reuse interventional tools [6, 7]. While the safety of this practice is controversial, in many centers worldwide this option is necessary and routine. The main concerns rest not only on the risk of infectious complications from catheter reuse but also on the risk of instrument malfunction or fracture; the impact and frequency of these complications are uncertain. Some centers will screen patients for human immunodeficiency virus (HIV) and viral hepatitis, disposing of the instruments in those cases where the patient tests positive [8]. One pediatric cardiology catheterization lab in India has described >32,000 catheterization procedures with no cases of procedural-related sepsis or endocarditis where hardware is often reused after ethylene oxide sterilization. Although the center reported occasional cases of catheter breakage, fragments were successfully removed [7].

Interventional Radiology Training and Education

Meeting the financial requirements of image-guided interventions may arguably be less of a challenge than satisfying the human resource and education requirements. Unlike diagnostic radiology, in which telemedicine allows for "outsourcing" of practitioners competent in imaging interpretation, minimally invasive procedures demand that a skilled provider be physically present. While teleconferencing is an established and inexpensive method to share expertise, it is often unavailable during a procedure, requiring the operating interventionalist on site to be competent enough to perform the procedure and manage potential complications independent of a remote expert.

Though medical volunteerism and international health rotations may provide interventionalists from other parts of the world with the required procedural expertise, their numbers are insufficient to match global demand; effective training of local providers should be the ultimate goal in establishing an IR practice.

Medical volunteer programs must be cognizant of their role in the specific community. This is especially true when offering advanced services such as IR procedures: a program emphasizing treatment of diseases must be integrated with programs focusing on the preventative component to that disease. Otherwise, there is a risk of undermining local community health programs, creating a culture where patients shift responsibility to the treating volunteer program and away from the already in place preventative local health programs [9].

Additionally, procedural competence must be matched by a provider's cultural competence specific to the region. Morally difficult scenarios present real challenges and are often unique to the procedural radiologist in LMICs; the overseas interventionalist is likely not only unaccustomed to such problems but may also be unaware of their existence and untrained to handle them. In a perspective essay on overseas medical experience, Henderson delineates these moral dilemmas that may arise in impoverished nations:

> However, clinical moral dilemmas remain: do we give life-saving blood known to be contaminated by hepatitis B? Do we re-use a spinal needle as it is the only one available and the child, if not the mother, will die without a Cesarean section? Do we give the Taliban a sterile surgical set to cut off hands of thieves? [10]

A dedicated training program involving domestic experts should consider these issues and train staff appropriately. Along the same lines of ethical concern is the involvement of trainees from high-income nations—residents and fellows—occupying a trainer role in LMICs [11]. It is essential that good intentions do not lead to medical malfeasance—teaching trainees that international patients do not require or deserve the same attending level care than do patients back at home [11]. Constrained resources further limit the ability of the physician to manage iatrogenic or avoidable complications and thus necessitates that optimal medical care be delivered on first attempt [12]. However, with appropriate supervision, critical appraisal of resident or fellow skills, managed expectations, and well-delineated guidelines, trainees can help initiate and support an interventional service with appropriate supervision.

A newer option emerging for training—both domestically and abroad—exploits the great technological advancements in medical simulation training. In a procedure-based specialty such as IR, there is little substitute for experience; however, the opportunities for interventionalists to practice their skills are far less readily available than for their diagnostic colleagues, who have the ability to review vast teaching files to hone their diagnostic abilities. Simulators may play an expanding role in procedural training both domestically and in resource-restricted areas as technology is becoming more accessible worldwide. Simulators can be model-based, computer-based, or a hybrid of the two; while model-based simulators may be inexpensive, there is usually little objective feedback that can be provided from the model [13]. The hybrid-type simulator can combine physical models with a computerized interface to allow for a more robust, tailored, and interactive experience [14]. Recently, the concept of telesimulation was introduced by Canadian physicians in order to teach laparoscopy to African surgeons [14]. This distance learning technique relies on the computerized linking of medical simulators at the trainers' and the trainees' sites and on computer video conferencing for didactic communication. This novel technique utilizing the most advanced pedagogical tools in a relatively low-resource manner has been shown to be effective in increasing the trainee proceduralist's confidence, comfort level, and skill in performing procedures [14, 15].

Even more recently, social media has infiltrated medical education with the development of free online access medical education (FOAM) [16]. This powerful tool may facilitate the rapid dissemination of value-based interventional techniques, not only from high-income countries to LMICs, but among LMICs themselves, in a "peer-to-peer" fashion. Challenges including management of sensitive information, vetting of users to ensure dissemination of exclusively medically sound information, and widening of social media access in remote regions remain.

Regardless of the mechanism, once the decision has been made to train providers from LMICs, the stakeholders must choose the types of procedures that warrant implementation and the skill level of the trainee required to perform them. Surgical operations may be categorized according to the extent of training required: operations within the competence of any qualified doctor or physician extender; operations that could be performed by a doctor or an advanced practice provider specifically trained for the procedure; operations normally performed by someone with higher qualifications and training; operations that require subspecialty training beyond the scope of the general practioner [17]. A similar organization hierarchy could be applied to interventional procedures, ranging from paracentesis to transjugular intrahepatic portosystemic shunt (TIPS) to complex embolization procedures. In this way, educational resources may be distributed more efficiently and practically. Practitioners in very rural settings may gain expertise and resources to perform medically necessary procedures with lower skill level requirements and leave the more difficult procedure training to the hospitals in relatively major centers who can "fly solo" with regular support [17, 18].

A final consideration critical to the implementation of an IR training program in LMICs is periprocedural care. In the USA, the shift away from the interventional radiologist as an isolated proceduralist relegating medical care of the patient to referring physicians has largely been accepted as necessary, inevitable, and appropriate [19]. While the reasons for this paradigm change in the USA are multifactorial, this model of the interventional radiologist as clinician may be even more important in a resource-scarce area. Given the potential for the infusion of locally novel, minimally invasive procedures into a healthcare system unfamiliar with the equipment used, the procedure itself, or the periprocedural medical care needed, the foreign interventionalist occupies the most appropriate role to be proficient in all these areas rather than relying on local medical colleagues. In fact, IR programs that have recently emerged in China have already begun embracing this concept, allowing the interventionalist to assume responsibility for the entirety of periprocedural care and follow-up [20].

Beyond redesigning training programs, there have been many innovations that modify how procedural treatments are both accessed and conducted. The need for creativity to limit resource requirement is essential to the development of an economically feasible IR service in LMICs. It is crucial to reevaluate the necessity of the technologies and techniques that have become standard in high-income nations. For instance, whereas percutaneous nephrostomy for obstructive uropathy is typically performed with a needle, wire, dilator, and catheter, the feasibility of a direct puncture technique using only a low-cost trocar catheter drainage set has been reported with good outcomes—this is a good example of the creativity needed to eliminate extraneous equipment and additional expense [21]. Reports describing gastrostomy tube placement, foreign body retrieval, and vascular malformation treatment under ultrasound guidance provide a few examples of therapies that may be offered without the traditional technological demands of fluoroscopy [22–24]. Additionally, there exist some procedures conventionally outside the scope of the interventional radiologist that may be introduced to an area with ultrasound capabilities: ultrasound-guided incarcerated hernia reduction represents such an intervention [25]. Other diseases for which the proceduralist traditionally offers image-guided therapy may be replaced completely with medical management, for example, using only tPA in the treatment of cerebrovascular accidents [26].

Innovative Strategies for Interventional Radiology Outreach

As noted above, a relative lack of resources and expertise can make translating the practice of IR in LMICs challenging. Broadening the availability of structured training in project development and novel interventional techniques has increased access to procedures previously confined to high-income nations [27]. The purpose of this section is to look at ways IR has been practiced in resource-constrained environments and to develop strategies that can bring these concepts to LMICs. Return on investment analyses have quantified the value of these services in terms of quality-adjusted life years saved and avoidance of other medical expenses [28].

Fluoroscopically and CT-Guided Interventional Radiology

In an extraordinary initiative by Drs. Nestor Kisilevzky and Henrique Elkis, uterine artery embolization was offered to women in underserved, impoverished areas of Brazil. They used a small truck to transport a mobile C-arm and angiographic supplies among four hospitals. They rotated among the hospitals every week for a total of 6 weeks [29]. All equipment and supplies were moved into either an operative suite or obstetric suite in the hospitals to help protect them from damage. They were able to achieve fluoroscopic times within an acceptable range, and outcomes and complications were similar to published results from conventional facilities. While these authors reported that all embolizations were performed under epidural anesthesia without complications, those wishing to treat patients with the help of local operating room staff should do so with caution. Sustainability of such a project in other applications has yet to be explored.

On a much larger scale are two 1000-bed hospital ships, the USNS Mercy and USNS Comfort, which provide medical and surgical services afloat and ashore in support of US disaster relief and humanitarian operations worldwide. They each have 12 operating rooms, including an IR suite, 80 intensive care units, and 20 post-anesthesia care units. They are fully equipped with CT, ultrasound, and MRI. Working on a ship can present unique challenges to an interventional radiologist [30]. Heavily pitching seas can affect the ability to manipulate catheters and guide wires, requiring the ship's captain to either redirect the ship into calmer seas or reposition it in a more favorable direction.

Following the destructive 2004 Asian tsunami, the USA deployed the USNS Mercy. On board the Mercy was a dedicated angiography suite, a CT scanner suite, and C-arm and ultrasound capabilities. During that time, in 2005, approximately 300 minimally invasive, image-guided procedures were performed. Of note, only 85 of these procedures were done in the angiography suite, and 20 were done in the CT suite. Nearly two-thirds of the interventional procedures were done with ultrasound and/or fluoroscopy [30]. This example of IR practice in a disaster relief situation illustrates how the most basic and widely available imaging modalities could be more easily utilized in the most resource-scarce of environments.

In Ethiopia, CT-guided fine needle aspiration has been explored for early diagnosis of infectious etiologies as well as lung cancer to aid in determining appropriate therapy and improving survival rates. Over a three-week training period, local staff radiologists at a resource-limited facility in Addis Ababa performed CT-guided thoracic FNA procedures under direct supervision using locally available equipment with good results. This experience highlights the potential for collaboration through longitudinal partnership, needs assessment, use of local resources, and in-country training [31].

Combat necessitates the need to provide high levels of acute care in unique and varied situations. In wartime-US medical bases, IR has been used for arterial embolization, IVC filter placement in patients with complex trauma, diagnostic evaluation of extremities, percutaneous abscess drainage, nephrostomy tube placement, percutaneous chest tube placement, and central venous access [30]. Even the most advanced endovascular treatments such as endovascular aortic repair are now performed in combat—these examples serve as a blueprint for efforts applying these procedures in LMICs [32].

Angiographic embolization for hemorrhage control after trauma has been explored in low- and middle-income healthcare settings. At the Aga Khan University Hospital in Pakistan, a retrospective review of 36 patients who underwent embolization for trauma-related hemorrhage demonstrated technical success in all cases. Pre-intervention CT images were obtained in 31 of the patients. The authors note that the results of this study demonstrate that availability of CT, radiologic interventionalists, and a dedicated IR suite can make the implementation of angiographic embolization for trauma possible in the low-middle-income healthcare setting [33].

Access to the latest technology and appropriate expertise will always be a relative challenge in the practice of IR in LMICs. Examples of IR in the austere environment illustrate how basic equipment and skill can act as a framework for establishing the practice. As the practice becomes more established, focus will move from emergency situations to long-term care of patients [34]. As imaging modalities become more ubiquitous, expertise in the application of these modalities will grow also. Finally, recent trends demonstrate declining communicable disease burden worldwide and rising prevalence of non-communicable diseases within LMICs indicating that interventional oncology may play a larger role in outreach endeavors in the future [27].

Ultrasound-Guided Interventional Radiology

One consideration that offers high-value and low-resource requirement is to concentrate on the use of image-guided procedures which rely heavily on the use of ultrasound. The utility of diagnostic ultrasound in modern medicine extends far beyond maternal/fetal healthcare. Ultrasound exams account for 25% of all diagnostic imaging studies performed in high-income countries. There is growing evidence for its effective use in LMICs where it is widely used in the diagnosis and management of many tropical and parasitic diseases, including echinococcosis, schistosomiasis, amebiasis, filariasis, ascariasis, river blindness, loaiasis, leprosy, lung-fluke infections, larva migrans visceralis, gnathostomiasis, anisakiasis, oesophagostomiasis, tuberculosis, and HIV infection [35–41]. Additionally, ultrasound guidance allows for direct administration of antibiotics into an abscess [42]. The "injection jet sign" can confirm correct needle position using ultrasound [43]. Ultrasound-guided core lymph node biopsy has been shown to be an important tool for the diagnosis of tuberculous lymphadenitis [44].

The procedure likely to be the most immediately beneficial if implemented in remote, resource-limited regions is image-guided percutaneous drainage of infected fluid collections, first described in 1977 [45]. As specified by the Society of Interventional Radiology Standards of Practice Committee, percutaneous aspiration and drainage of a fluid collection are indicated when there is suspicion of infection, if there is a need for fluid characterization, or if there are related symptoms [46]. Importantly, these procedures can often be performed with local anesthetic, obviating the need for sedation or general anesthesia. The enormous benefit of having image-guided percutaneous drainage capabilities further extends to diagnosis and treatment of symptomatic or infected joint effusions, pleural effusions, ascites, renal obstruction, and biliary and gallbladder obstruction. However, some abscesses, renal drainages, and biliary decompression may require catheter drainage and moderate sedation, which adds to the cost and resources required.

Ultrasound is being used more in increasingly complex procedures including biopsies, vascular access, urologic surgery, orthopedic surgery, and regional anesthesia [47–51]. Its use endoluminally by cardiologists, gastroenterologists, interventional radiologists, pulmonologists, and vascular surgeons for guiding procedures is also increasing [52]. The WHO has already recognized the utility of ultrasound in guiding interventions in LMICs, having distributed guidelines for its use in the transcutaneous treatment of echinococcal cysts, an endemic disease with high morbidity. Use of an ultrasound-guided biopsy simulator allows a trainee to practice prior to performing a procedure on a patient. However, simulators are prohibitively expensive for use in LMICs, costing between $100,000 and $200,000. Fees for annual maintenance, which can be difficult to procure in this setting, range between $10,000 and $16,000 [53]. Healthcare workers are typically trained using the apprenticeship model. In a study on the bedside use of ultrasound in rural Tanzania, medical students were able to perform basic ultrasound scans that can identify ultrasonographic markers of parasitic infections after only 10 hours of training [54]. Adler et al. also reported their experience in training healthcare providers in the use of ultrasound in a refugee camp in Tanzania [55]. They conducted a 4-day ultrasound training course for healthcare providers on a donated SonoSite Titan ultrasound unit. Four physicians and 6 nonphysicians were supervised while conducting at least 20 examinations of the abdominal aorta, hepatobiliary system, soft tissues, and kidney, echocardiographies, pregnancy examinations, and ultrasound-guided procedures. They returned 2 years later to review the logbook and to assess the status of the ultrasound machine. Five hundred and forty-seven ultrasound studies had been performed on 460 patients, 3–85 years of age. Trainees reported that the use of ultrasound improved the care of their patients.

Spencer et al. reported results of a smaller study in which portable ultrasound units using linear and curved linear phased array transducers were placed in two primary care sites in Ghana [56]. Sixty-seven ultrasound examinations were performed. Eighty-one percent of these were noted to have added to the diagnosis and 40% to have influenced medical care.

With the costs of installing and maintaining fully equipped angiography suites and interventional CT rooms lying far beyond the reach of LMICs, a shift in focus to the use of ultrasound technology in these countries may best meet their public's needs. As noted above, ultrasound offers a relatively inexpensive, efficacious, and portable modality to facilitate interventional procedures [57–59]. For these reasons, a WHO study group has advised that ultrasound be disseminated to LMICs as part of a radiology system initiative [60].

Fortunately, there are inexpensive ultrasound units that are well suited for use in remote areas: the compact or handheld unit. They are highly portable and can be carried in a backpack. Although new units are ideal, refurbished first-generation units can be obtained for a fraction of the cost. They are simple to operate, robust, and have rechargeable batteries [61]. In the Philippines and Honduras, these units have allowed for a 360% increase in scan times. They have a 5-year warranty and are highly reliable. The small size of the handheld units makes them easy to transport to service sites when necessary. Batteries have a life span of 1–2 years and cost $200.00 to replace. Where grid power is unreliable, alternative recharging sources that can be used include wall mains (120 and 220 Hz), cigarette lighter plugs, solar energy, and gas generators. Solar recharging time takes 4–6 hours at 45° latitudes.Ultimately, despite the versatility of ultrasound guidance for invasive procedures, there remain many valuable interventions that still require direct visualization under fluoroscopy. These include some procedures that are lifesaving and eliminate the need for surgery such as embolotherapy for hemorrhage, esophageal and enteric dilation and stenting, TIPS placement, and thrombolysis and thrombectomy. For those regions with the resources to establish a permanent, functional angiography suite, maintain required equipment, and stock needed supplies, the availability of such procedures would certainly be of substantial benefit to patients within reach. Of course, outside of major cities, few areas in LMICs possess the ability to accomplish such a feat; however, novel and creative strategies have been employed to bring such technology to the rural setting.

Conclusion

The intellectual barriers to safe, ethical, and effective procedural training for practitioners in LMICs are neither insignificant nor insurmountable. The challenges and considerations in this chapter represent only a part of the planning, creativity, and ingenuity required to maintain an effective IR practice in LMICs. Other important factors, such as anesthesia requirements and radiation safety, while not discussed here, must be considered.

The shrewd physician will critically appraise the risk to benefit balance of offering novel interventional treatment versus conventional therapy that is locally available, or alternatively, no therapy at all. While the dedication of many motivated, thoughtful practitioners may build an international healthcare system that serves its citizens well, it takes only a few wanton individuals to leave the community worse off for their deeds.

With careful consideration, planning, and monitoring, local providers in LMICs can be trained to offer comparable lifesaving, minimally invasive procedures that currently benefit so many patients in high-income nations. Finally, with the assistance of international humanitarian organizations, and by modifying traditional approaches to basic procedural techniques, radiologists can make significant contributions to the global community.

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Radiation Oncology in Global Health

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Introduction

Radiation oncology is one of the three main therapeutic disciplines of clinical oncology, along with medical and surgical oncology [1]. As in radiology, the team members in radiation oncology work together in patient care. Radiation oncologists are physicians who work closely with a multidisciplinary team of oncologists and radiation therapy staff to treat mostly cancer (and some benign conditions) using ionizing radiation.

At the time of consultation, a radiation oncologist assesses the need for additional diagnostic evaluation or clinical interventions. Then, they integrate their knowledge of the patient's diagnosis, diagnostic studies, natural history of disease, and general medical condition with their understanding of medical physics, radiobiology, and radiation safety to answer the following questions to guide therapy [1]:

1. Indication for treatment: local control, symptom relief, improving quality of life or cure in

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the context of available data, the patient's clinical condition, and personal goals
2. Intent of treatment: palliative vs. definitive with use of single or combined therapies (e.g., systemic agents, surgery, oxygen, heat)
3. Target delineation: identifying the volume of tissue to be irradiated using understanding of anatomy, radiology (i.e., X-rays, CT, MRI), knowledge of disease
4. Method of delivery and treatment techniques: teletherapy vs. brachytherapy, 3D conformal vs. intensity-modulated radiation therapy, radiosurgery, stereotactic body radiation therapy, and particle/energy used for treatment delivery (e.g., photons, electrons, protons)
5. Prescription: total dose to target, fractionation (number of treatments), and dose per fraction
6. Normal tissue tolerance/toxicity: balancing treatment benefit with acute and chronic toxicity to maximize the effect of local treatment while minimizing the risk of damage to normal tissues

Treatment duration may range from 1 day to over 8 weeks; during this time, the radiation oncologist manages treatment-related adverse effects and coordinates care of the patient with other involved disciplines. He or she serves as leader of the radiation oncology team, working closely with all members.

While patients rarely meet medical physicists, their work is critical for safe, accurate delivery of the highest quality radiation therapy and monitoring staff safety. Their work requires close partnership with physicians, dosimetrists, and therapists while applying knowledge of radiation physics, radiobiology, and radiation safety. Physicists perform routine quality assurance (QA), investigating equipment and imaging system performance as well as quality for treatment; they work closely with IT and engineering staff ensuring that all equipment (machines, computers, software) functions optimally and is compliant with international/national standards. They perform accurate measurements of radiation output from radiation treatment machines as well as output from radioactive sources used during therapy, confirming that the planned dose is actually delivered to the planned target during treatment.

For new machines and equipment, they perform calibration, commissioning, and installation of radiotherapy equipment ensuring accurate delivery of radiation therapy. Research is a vital role of physicists; their fields of study include but are not limited to the application of new technology, high-energy machines, and development of new methods of treatment delivery and radiation measurements [2, 3].

The medical dosimetrist is a member of the radiation oncology team that works closely with radiation oncologists, medical physicists, and therapists to design radiation treatment plans applying knowledge of radiation treatment machines, physics, radiology, anatomy, and radiobiology.

Prior to treatment planning, dosimetrists assist during simulations (e.g., clinical setups, CT, PET, MRI) to ensure optimal immobilization for the patient and treatment delivery. Plan design requires use of computer software planning systems or manual computations to optimize beam geometry such that dose to the target is maximized and dose to critical structures is minimized as per the radiation oncologist's prescription; they also use beam-modifying devices (such as wedges or blocks) to manipulate the beam and achieve this goal. For cases that require the use of PET scans or MRIs, the dosimetrist registers these images to the treatment planning software so that these images can be used to delineate the treatment target. For brachytherapy cases, dosimetrists perform planning and dose calculations needed prior to treatment delivery. Once planning is complete with approval from the physician, dosimetrists perform calculations for accurate delivery of the prescribed dose and verify calculations prior to treatment delivery [4].

A patient referred for radiotherapy first meets radiation therapists during the time of treatment simulation when the patient undergoes imaging (clinical setup, CT, MRI, PET) in the treatment position. Therapists assist in choosing this position and designing an immobilization device that would be most comfortable for the patient as well as most reproducible for daily treatment delivery.

Therapists see the patient daily during the course of treatment. They are trained in administering therapeutic doses of ionizing radiation to a target via teletherapy (typically linear accelerators or Cobalt machines), using their knowledge of physics, radiology, patient anatomy, patient care, and radiation safety [5–7]. They must accurately reproduce the patient's position for treatment by lining up the patient using a system similar to coordinates on a grid system; this process often requires evaluation of imaging (X-ray, CBCT, MRI) and changing patient position such that treatment position closely resembles position at the time of simulation. Therapists monitor patients while operating the teletherapy unit to accurately and safely deliver treatment [5–7].

Radiation oncology nurses play a critical role in patient care and advocacy; they have daily interactions with patients and their families while working closely with the radiation oncologists, therapists, and clinical social workers [8]. Prior to the start of treatment, nurses assist with patient assessment in multiple domains (health, physical, mental, emotional) at the time of consultation and teach patients and family members about treatment-related adverse effects and management.

Nurses assist with procedures such as brachytherapy, invasive examinations, drug administration, and the simulation process. During the course of treatment, nursing staff are critical providers of patient support, helping patients and their family members navigate through complex medical systems while coordinating care with other specialties (oncologic and nononcologic) and coordinating any additional work-up. They also manage treatment-related toxicities closely with patients [8].

Radiation oncology nurses serve as essential intermediaries for patients and physicians, while building their own rapport with patients. They often inform physicians of the patient's current condition and need for additional management; for patients, they answer many questions while providing physical and emotional support before, during, and after treatment.

To provide comprehensive medical, physical, emotional, and psychological care for radiation oncology patients before, during, and after treatment, there are additional members of the radiation oncology team. Patient care is enhanced by a number of other individuals including but not limited to clinical social workers, psychologists/psychiatrists, nutritionists, speech-language pathologists, dentists, nurse practitioners, physician assistants, and research staff [1].

Gaps in Radiotherapy

The global demographic and epidemiological transitions predict an increase in the cancer burden in the next few decades [9, 10]. A 53% increase is predicted from 2014 to 2030 with more than 20 million new cancer cases expected annually [10].

Radiotherapy is an essential component in the management of cancer that can be used with a curative intent, either alone or in combination with surgery and/or systemic treatments. Also, it can be used with a palliative intent to alleviate symptoms in patients with incurable disease. Radiotherapy is estimated to be required in 50% to 60% of newly diagnosed cases [11].

In recent years, a large body of evidence has emerged on the demand and supply of radiotherapy worldwide [12–19]. Gaps to radiotherapy access have been identified, but in particular in low- and middle-income countries (LMICs). Initiatives that address the gaps must take into consideration quality and safety of radiotherapy [20]. Resources, including those from the International Atomic Energy Agency (IAEA), are needed to support radiotherapy activities; careful planning is essential to avoid compromising safety and quality [21, 22]. Financial resources for equipment must be coupled with an understanding of the advantages, disadvantages, and limitations of available technologies [23, 24]. In addition, an accurate assessment of the radiotherapy condition on the ground and in-depth knowledge of the unique local needs is essential to make appropriate equipment recommendations.

Radiotherapy is cost-effective as a key treatment modality for cancer with substantial positive economic returns associated with the expansion of access to radiation oncology in LMICs [17]. Bridging the gap in global access to radiotherapy is both affordable and feasible. Disparities to meet the demand for radiotherapy arise from gaps in access to equipment and gaps in health workforce.

Gaps in Access to Equipment

The status and the total needs to provide full access to radiotherapy by region are detailed in Table 25.1. It shows the currently available resources and the related costs (annual operational costs and average cost per course) calculated for the status of equipment to date. In addition, it presents an estimate of the total number of courses needed to obtain full access, with the related projection of total resources needed. Finally, it gives the total investment costs, based on capital investment and training, needed to optimize access, as well as the operational costs and cost per course projected for this optimal situation. As can be observed, the coverage in Africa is only about one-third of the optimal, whereas coverage nearly reaches two-thirds in Asia Pacific. In Europe and Latin America, coverage hovers around 90%. Conversely, North America seems to be significantly over-resourced, when using the same operational model of 12 h/day that is commonly used when calculating needs in other regions. Thus, this finding is likely due to a combined effect of real excess in available equipment together with different operational models used in clinical practice.

Figure 25.1 shows the current number and additional needs of megavoltage units by region and income group. By absolute numbers, the needs of Asia Pacific are clearly the greatest. However, as a percentage of what is already available, Africa needs additional resources in the order of 200%, and Asia Pacific around 40–70%. Figure 25.2 shows the additional investment needed to close this gap by region and income group, in absolute numbers. Half of the additional investment needed in low-income countries is needed in Africa.

There are around 40 countries without radiotherapy services. Focusing on LMICs, there are 4221 teletherapy machines installed, representing between 38% and 49% of the machines

Table 25.1 Actual status and total needs to provide full access to radiotherapy

	North America	Latin America	Africa	Asia Pacific	Europe
Population and RT courses					
Population (million)	350	601	1070	4108	893
Total RT courses needed	934,746	573,385	437,624	3,277,387	1,884,893
Resources					
Actual MV machines	4243	968	277	3894	3751
Total MV machines needed for full access	2175	1106	813	6406	4098
Actual coverage of the needs	195%	88%	34%	61%	92%
Costs					
Additional investment needed to reach full access (million USD)	1558	918	2118	10,497	2573
Actual operational costs/y (million USD)	6151	975	182	4638	5868
Total operational costs/y (million USD), assuming full access	6588	1192	571	6968	6573
Actual cost per RT course (USD)	6581	1939	1226	2423	3428
Total cost per RT course (USD), assuming full access	7048	2079	1306	2126	3487

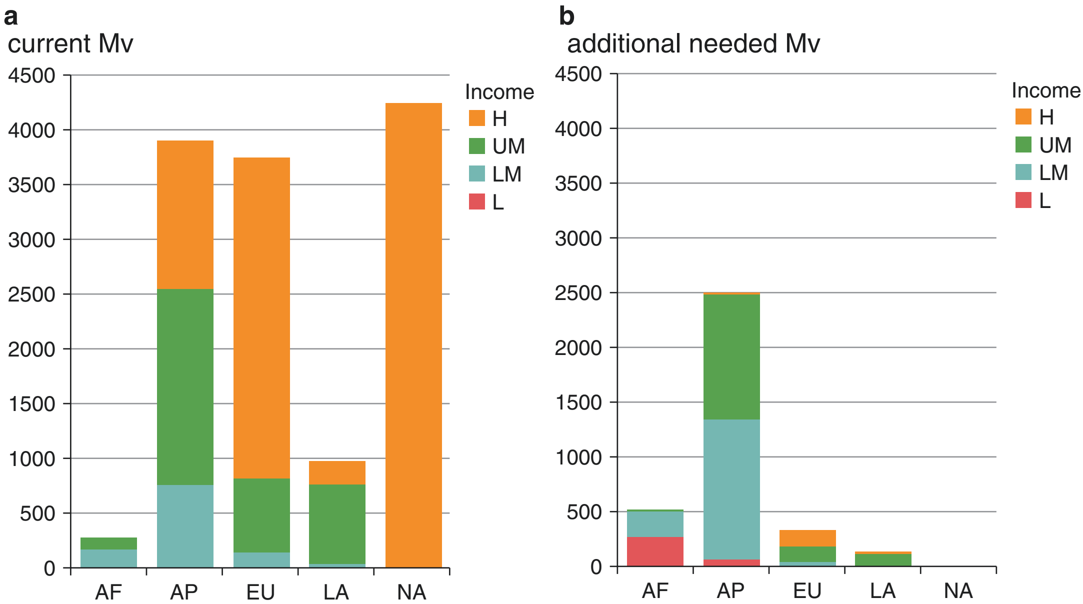

Fig. 25.1 Current (**a**) and needed (**b**) equipment, by region and income group

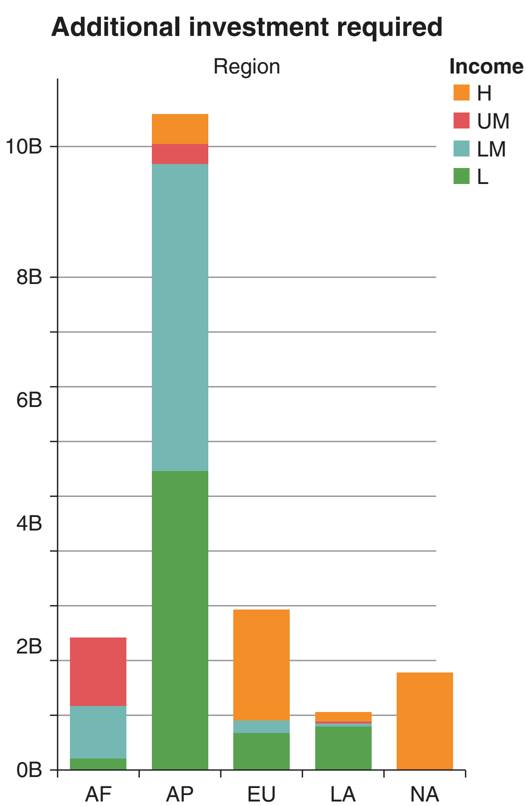

Fig. 25.2 Additional investment needed to close the gap by region and income group

needed, depending on the benchmark used. Between 4320 and 6958 additional units are required to meet these needs [18]. The Global Task Force on Radiotherapy for Cancer Control (GTFRCC) has proposed a call for action to increase by 25% the 2015 radiotherapy treatment capacity in LMICs by 2025 [17].

Gaps in Human Resources and Education

While the radiotherapy gap in low- and middle-income countries (LMICs) is usually measured in terms of equipment, human capacity for treatment delivery is in severely short supply also [16]. Meeting the demands for radiotherapy depends not only on the supply of radiotherapy equipment but also on the availability of qualified professionals to run this equipment. Furthermore, competency-based educational programs should be considered for capacity building activities [25]. In addition, novel approaches need to be used to continue to close the gap in the availability of skilled personnel that has been identified by several authors [16–18].

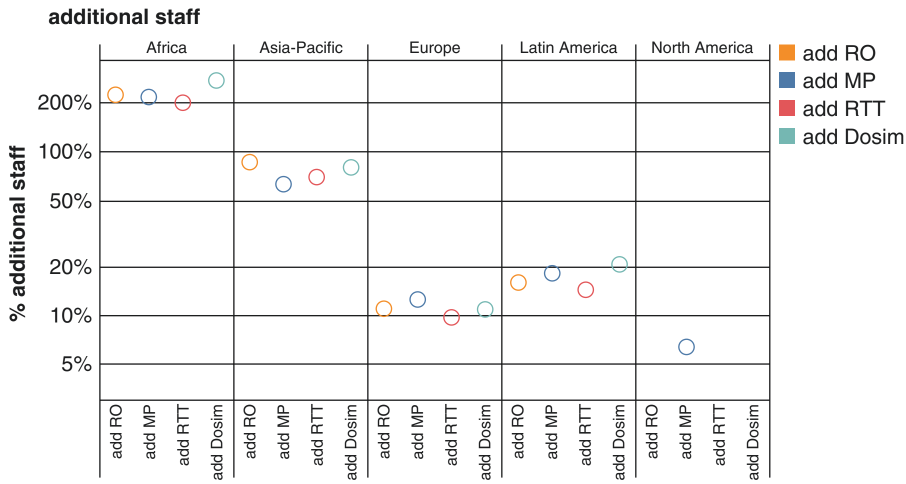

Fig. 25.3 Additional staff needed by region

To fill the gap in human resources required in LMICs, a total number of additional professionals needed will be 12,960 radiation oncologists, 6480 medical physicists, 3240 dosimetrists, and 20,520 radiation therapists [18]. In this regard, the GTFRCC has proposed a call for action to train 7500 radiation oncologists, 20,000 radiation therapists, and 6000 medical physicists in LMICs by 2025 [17].

With regard to additional staff needed by region, Africa's additional need in human resources is around 200%, and Asia Pacific around 70% (Fig. 25.3).

Because of the increasing disease burden and the gap in trained personnel, it is critical that LMICs develop adequate training programs [26]. Traditionally, high-level trainees from LMICs commonly emigrate to high-income countries for specialized oncology training but then choose not to return to their home country. This has led to "brain drain," an unfortunate phenomenon that propagates imbalances in the global cancer workforce.

Multiple stakeholders are required to engage if there is hope to make significant progress in training the necessary workforce. Established in 1957, the IAEA is the multilateral international organization with the longest track record for developing human capacity for radiotherapy in LMICs. As part of any Technical Cooperation (TC) project to establish radiotherapy services, the IAEA always includes the training of a full team, including radiation oncologists, medical physicists, radiation therapists, and occasionally maintenance engineers and nurses [11]. Typically, training options in the home country are limited, so training is sponsored abroad on a country-specific basis. The first choice for a partner training site is typically within the same world region.

To supplement international training efforts, there is growing interest from radiation oncologists in high-income countries to support colleagues in LMICs. Such assistance can prove vitally important to developing sustainable human capacity and infrastructure for clinical care, research, and education. Presently, there are successful examples of "twinning" partnerships, such as those between the University of Pennsylvania and Massachusetts General Hospital in Botswana, the University of California at San Diego in Senegal, and Duke University in Tanzania, among others [27–30]. These partnerships are challenging to sustain, and there is no established pathway for trainees interested in global oncology to become global oncologists [31–33]. For radiation oncology trainees interested in global health, there are opportunities for rotations abroad to gain exposure and to develop partnerships to enhance human capacity. Some current examples of training options include the American Society for Radiation Oncology's (ASTRO)/Association of Residents in Radiation Oncology's (ARRO)'s Global Health Scholar Program and the American College of Radiology Foundation's Goldberg-Reeder Resident Travel Grant.

To attempt to bridge the human capacity gap in a more transformative fashion, the International Cancer Expert Corps (ICEC) is developing a novel global mentorship–partnership model to address workforce capability and capacity [34]. The ICEC twinning program is a collaborative relationship between a university department or cancer program (or private practice) in an upper-income country (an ICEC Hub with ICEC Experts) and a cancer program/facility in an LMIC (an ICEC Center with ICEC Associates). The ultimate aim is for the ICEC Centers and Associates to progress to become ICEC Hubs and Experts for their specific regions.

Clearly, the human capacity gap for radiotherapy in LMICs is profound, and it will take a tremendous effort to close the gap. As roughly 50% of cancer cases can be prevented, investing in prevention programs could reduce the required human capacity for radiotherapy services [35]. The creation of effective radiotherapy treatment programs in LMICs requires a multipronged approach. Such an approach could include the following:

- Individual LMICs dedicating efforts and investments towards comprehensive cancer control plans
- The IAEA's continued investment in human capacity for LMICs to develop a sustainable local workforce
- International societies (e.g., ASTRO, ESTRO) providing consensus guidelines on best radiation therapy practices that are stratified for available resources [36]
- Radiotherapy device manufacturers developing radiotherapy equipment that requires fewer man-hours, reduced QA requirements, and reduced maintenance demands

Novel Approaches

Novel approaches are needed to fill the gaps in access to radiotherapy worldwide. These novel approaches fall into three different categories: alternate models for radiotherapy centers, use of new technologies, and new tools for scaling-up the human workforce.

The traditional model of a fully independent stand-alone radiotherapy facility is unlikely to expand to meet the demands in large regions of the world. The implementation of alternate models could reduce the current shortfall. Alternate models include (1) central/satellite configuration, where satellite centers rely on support and direction from a central institution; (2) networks of small departments that share some processes or equipment; and (3) small departments that outsource complex activities such as contouring, planning, or quality assurance.

Automation in radiotherapy will play a major role in the future and will help fill the gaps in equipment and process management. Automated contouring and treatment planning and automated QA will streamline the radiotherapy process, especially in low-resource environments. Enhancing the use of internet and communication technologies (i.e., the internet of things) to routine radiotherapy workflow will enable remote equipment diagnosis and assistance, presumably reducing downtime and increasing cost-efficiency, safety, and efficacy.

The human workforce should benefit from novel approaches. Virtual tumor boards for peer review of clinical cases, radiotherapy indications, and plans are one example. The development of sophisticated e-learning tools and the creation of virtual communities or hubs for discussion and twinning partnerships are other examples of novel solutions. New models of education are also needed, as the demand for health professionals is unlikely to be filled through traditional models. The redefinition of traditional roles in radiotherapy and task shifting can also promote a more efficient use of the available human resources. This approach should only be done after extensive consultations, study, and evaluation of the effect on patient care to ensure that quality is not compromised.

Mobilizing Resources to Finance Global Access to Radiotherapy

Full access to radiotherapy could be achieved for all patients in LMICs by 2035 for as little as US $97 billion [17]. Despite this "investment case" for the global expansion of radiotherapy and the growing political commitment to reducing global mortality from noncommunicable diseases (NCDs) reflected in the UN Sustainable Development Goals (SDGs), programs aimed at increasing access to quality cancer services in developing countries remain woefully underfunded.

Whereas high-income countries devote an average of 3–7% of total health spending to cancer control, most LMICs allocate far less; cancer accounts for about 1% of domestic health spending in Brazil and India, and only 2% in China and Mexico [37]. The majority of low-income countries in Africa and Asia are spending much lower amounts. Achieving adequate and sustainable funding levels for the expansion of radiotherapy in developing countries will require blending multiple sources of financing and applying innovative investment approaches.

Major Financing Sources

Domestic Funding

In all LMICs, most of the financing for cancer care and control will continue to be from domestic spending on health. Sources for this funding consist of government allocations and social health insurance schemes, and out-of-pocket spending by patients, including through private health insurance.

Overall, domestic funding for health is expected to increase rapidly in the next decades, driven by continued economic development and higher rates of government social spending. If current trends continue, overall global health expenditures will grow from US $9.2 trillion in 2014 to US $24.5 trillion in 2040. The rate of increase, however, will vary greatly across countries, with health spending in low-income countries (LICs) expected to remain low at US $195 per capita in 2040 [38].

Out-of-pocket (OOP) spending, on the other hand, is the least equitable and efficient means of financing health systems and often leads to impoverishment. OOP payments are highest in low-income countries representing more than 50% of total health expenditures [39]. A diagnosis of cancer is associated with some of the highest rates of out-of-pocket expenditure of any health intervention, with the poor and disenfranchised at greatest risk. State spending on health and in particular on cancer care should be boosted. This can also be achieved through the reallocation of existing funds and raising new revenue by enhancing the tax base and improving tax compliance.

Another very promising avenue for raising additional funds is the introduction of excise taxes on unhealthy products, that is, on tobacco, alcohol, and certain foods and beverages. Raising taxes on tobacco, for instance, is seen as the most important single cancer prevention intervention, and a tripling of the excise tax on tobacco would mobilize an extra US $100 billion worldwide in annual revenue, which, in turn, could be invested in expanding cancer diagnosis and treatment services [40].

In addition, a major target of the Sustainable Development Goals aims at achieving Universal Health Coverage (UHC) by 2030. As more and more countries adopt UHC policies, it will be important to ensure that high-impact, cost-effective cancer treatments, including radiotherapy, are included in all iterations of any UHC coverage plan to expand affordable and equitable access for patients in need.

Development Assistance for Health

Although domestic resources are the primary means of closing the financing gap globally over time, significant additional resources are needed to meet, by 2030, the SDG target to achieve a third reduction in premature NCD deaths, including from cancer. It will be important that high-income countries provide more and higher quality resources to the countries in need to complement domestic resources. A potential funding source is international development assistance for health (DAH). However, noncommunicable diseases (NCDs), including cancer, receive only 1.7% (or US $643.8 million) of an estimated total US $37.6 billion DAH spent by international funders in 2016 [41]. DAH, development bonds, and concessional loans can be leveraged to build capacity and catalyze cancer service delivery in resource-poor settings.

Major global health financing institutions have identified opportunities for stronger synergies and investment opportunities linking programs geared towards infectious diseases with NCD interventions.

The Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM), for instance, is collaborating with beneficiary countries to integrate human papillomavirus (HPV) screening and early treatment into well-resourced HIV programs. The Global Alliance for Vaccines and Immunization (GAVI) has spent US $39 million for HPV vaccinations to prevent cervical cancer in LMICs in 2011–2015 and is further expanding these activities [42].

The IAEA has for many years provided support in setting up and upgrading radiation oncology infrastructure and training the necessary professionals. Between 1980 and 2016, it has spent €305 million on cancer-related technical cooperation projects in LMICs.

Development banks are playing an important role in making substantial funding available to expand cancer diagnosis and treatment capacities in LMICs. In 2016, over 20 NCD-related loans worth hundreds of millions of dollars have been supplied by lenders such as the World Bank and the Inter-American Development Bank [43].

Also, the IAEA has partnered with the Islamic Development Bank (IsDB) to jointly support countries in accessing cancer-related funding. Since 2013, the IsDB has committed US $100 million to strengthen cancer diagnostic and treatment services in several common member states, including Côte d'Ivoire, Djibouti, Niger, Sudan, and Uzbekistan [44].

In addition to providing access to much-needed financing, international development assistance also provides ample opportunities to build much-needed cancer control capacity in LMICs through offering mechanisms for sharing experts, expertise, and approaches that are suitable to bolster national cancer control efforts in resource-limited settings.

Private Sector and Innovative Financing Mechanisms

The final element of the financing agenda for expanding cancer control services, including through investments in radiation oncology, is the contribution of private sector solutions and ways to align private capital with national health priorities, including through public-private partnerships and innovative financing.

Private sector entities are key players in the national cancer control arena. They provide goods and services that have a profound impact on health outcomes and inequalities and in many countries are major healthcare providers. The private sector brings to the table innovative methods and strengthened mechanisms for research and development partnerships, knowledge-sharing platforms, technology and skills transfer, and infrastructure investment.

Future Steps in Global Radiation Oncology

Future steps in global radiation oncology are as diverse as the "gaps in care" are wide. These efforts will continue to be guided by multiple goals centered on tackling the many limitations to advancing global radiation oncology care in low-resource settings. Advocacy by organizations to increase awareness about the global burden of cancer and the staggering conditions of cancer care is critical; this step will mobilize radiation oncology resources (human, equipment, monetary, etc.) to tackle these limitations.

Partnerships between developed programs, developing programs, international organizations, industry, local healthcare workers, and governments can continue to provide avenues for training physicians, physicists, and therapists to create self-sustaining treatment, education, and research programs while respecting cultural sensitivity. While a variety of initiatives exist to advance safe use of equipment, few initiatives exist to provide radiation therapy units in low-resource settings; this limitation is an enormous roadblock to increasing access to radiation therapy care. Lack of electrical/technological infrastructure to sustain technical radiation treatment equipment is a huge impediment to providing radiation therapy in LMICs; understanding local government and customs is the cornerstone to establishing infrastructure suitable to foster radiation therapy. The shortage of trained individuals, shortage of equipment, and lack of infrastructure can be addressed by novel approaches and "thinking outside the box" by designing software that would automate treatment planning/quality assurance steps or by creating a quality teletherapy unit that is affordable, user friendly, "reliable, self-diagnosing, is insensitive to power interruptions and has low power requirements," as was designed by an ICEC-hosted workshop at CERN [45].

Numerous organizations have invested in advancing oncology care worldwide – AMPATH, GlobalRT, IAEA Expert Group on Increasing Access to Radiation Therapy, ICEC, industry, International Organization for Medical Physics, Istituto Scientifico Romagnolo per lo Studio e la Cura dei Tumori, Medical Physics for World Benefit, RAD-AID, Radiating Hope, UICC, and so on. Global Oncology Map has created a website to form a directory and create a platform to unify current global oncology efforts and continues to make this resource more robust. All of the abovementioned limitations, steps, projects, and organizations will continue to need financing through the multitude of methods listed previously. While manuscripts and task forces on global radiation oncology identify the need of a number of teletherapy units or human resources by a specific time, the question of how to meet this need as a global community remains to be answered. Many organizations are answering this question and working to meet the global need in cancer care, individually. Formulating this response and creating a paradigm for the future will require global collaborations to align together and focus on a common goal of advancing radiation oncology care worldwide.

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Appendices

Appendix 1: A Kenyan Perspective into the Journey of Obtaining a *Career in the* Field of Radiology

Rose Ndumia

High School

During the final year of high school, it is required that the students in Kenya fill out forms on the choice of university courses they would want to study and in which university. The courses are categorized by the subjects one should have studied and the minimum grades that he/she should have scored. There has been little or no career guidance in the past, but in 2012 a body called Kenya Universities and Colleges Central Placement Service was formed that, among other roles, is charged with the responsibility of coordinating the placement of government-sponsored students to universities and colleges [1]. It has a website where a list of public universities and colleges and the courses available as well as career guidance is offered [2]. Such a website offers a great platform for one to provide career advice on the field of radiology and its allied fields such as biomedical engineering. Medical physics is not offered in any of the Kenyan universities [3].

Medical Schools

Ten years ago there were only two medical schools in Kenya, which have now increased to nine. Six of these are public universities and accept both government-sponsored students and self-sponsored students [4]. Most of the bright students would go into the field of medicine, but even by the time they are in the fifth year of training, few would opt to join radiology and may only choose it based on the perceived controllable lifestyle of a radiologist [5]. Radiology rotations in medical school are for only 2–4 weeks out of the 6 years of training; this is in the two oldest medical schools where the number of radiologists is more in comparison to the newer universities. With this limited exposure to the field of radiology, it comes as no surprise that few would choose this as their first career choice. In global health radiology education, supplemental radiology education for medical students can be one of the initiatives that can be pursued and more so in the newer medical schools which have a lower number of radiologist faculty.

Technologist Training

The Kenya Medical Training College has 38 colleges spread out in various towns throughout the country and offers certificate, diploma, and higher

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diploma courses in various medical fields [6]. Amongst these is a 3-year diploma course in medical imaging sciences conducted in six of its colleges in major towns in the country which trains radiographers in various imaging modalities except ultrasound, which is taught separately as a 1-year higher diploma course to those who have already completed the diploma in medical imaging sciences [7, 8]. A 2-year certificate course in medical engineering is also available at the colleges with training in a variety of medical equipment inclusive of imaging equipment [9]. These medical colleges are located adjacent to or within major public hospitals in order to provide practical application of knowledge acquired. One public university recently started a Bachelor's degree course in radiography which takes 4 years to complete, but those with diplomas in medical imaging sciences can bridge and take a shorter duration to complete the course [10].

Radiology Residency Training

There are few universities that offer radiology residency training programs in the developing world. For example, in Kenya there are three universities that offer radiology residency programs, while in a country like Malawi there is no such program. In Kenya, the oldest of these programs is at the University of Nairobi, a public university which started training radiologists in 1977 and whose capacity sometimes gets stretched to accommodate the demands from the government to train more radiologists [11]. They have also trained radiologists from other countries including two who graduated in 2012 from Tanzania and Malawi where there is a limited number of radiologists. By 2015 they had eight foreign residents, five of whom were from African countries and three from Asia [12]. They have also had partnerships for foreign students who do not have residency programs in their countries to be trained at their institution [13]. The Aga Khan University Hospital in Nairobi is a private university which started residency training programs in 2005 in various specialties with radiology being one of the programs offered and is a 4-year training program. The residency programs were initially free of tuition fees for a 10-year period and residents had a monthly salary. In 2015, tuition fees were introduced and the residents continued to receive a monthly salary; the tuition fees can however be refunded to varying degrees depending on the academic performance of the resident. The initial intake was two residents but that has now increased to four residents who can obtain external sponsorship to cover their monthly salaries and tuition fees. The third is Moi University in Eldoret town which is a public university and started its radiology residency program in 2010; the training takes 3 years and has had challenges in terms of equipment and few number of faculty.

National Need for Radiologists

According to Kenya's Ministry of Health strategic report on the health sector human resource strategy, the required number of radiologists in the country is 576 and for the duration of the report (2014–2018), they needed to train 41 radiologists, while the current number of radiologists in Kenya is under 200 [14]. To meet this requirement, the current capacity to train radiologists has to be increased, but that is not feasible on a short-term basis with only three universities that offer radiology residency training.

Fellowship Opportunities

There are no radiology fellowship trainings available locally [3]. Those who have pursued 1-year fellowship trainings have mostly come from the private university in Kenya where they have had collaborations with universities in the USA, Canada, and Europe. Two radiologists were able to pursue fellowships in the USA through a collaboration that came about with the University of Virginia who prior to this had conducted interactive webinar sessions with the residents [15]. Those who pursue fellowships in the USA have to sit the USMLE examinations which require time and money and it therefore helps to motivate one to go through these exams when there is a collaboration with an institution that assures the resident of fellowship position. Additionally the Kenyan private university has a fellowships committee, which through a contractual agreement sponsors radiologists to pursue fellowships abroad, which upon completion return to the institution. One radiologist from this institution was the first in the country to pursue a fellowship in Interventional Radiology through sponsorship by Israel's MASHAV program and now works and trains radiologists at the University of Nairobi and has inspired more to pursue the same. Areas of fellowship training obtained abroad and now locally available include body imaging (2), cardiothoracic imaging (1), neuroradiology (1), breast imaging (1), nuclear medicine (1), interventional radiology (1), and fetomaternal imaging (1). As more radiologists obtain fellowship trainings abroad and return to their home countries, they can be pioneers of fellowship training programs in their home country, albeit with the collaboration from global health radiology partners or those institutions where they obtained their fellowship training. Some sub-specialties in radiology are not yet available and these can be areas where short-term efforts such as online lectures and elective terms can be offered to residents in training for a short duration of time as happens with residents at the Aga Khan University Hospital in Nairobi who go for electives to a hospital in the UK. Through this elective period, contacts can be established which charts the path for future fellowship training, as has happened with three radiologists who in this way have been able to get fellowship positions in the UK in the fields on oncologic imaging, neuroradiology, and nuclear medicine.

Impact of the Residents Trained

At the Aga Khan University in Kenya, out of the 23 graduates, 7 have set up their own private radiology practices including teleradiology services, 11 have gone for fellowship training abroad, and 13 have served as faculty in the radiology department at various points in their careers. This has strengthened the provision of radiology services in the country including the remote areas through teleradiology as well as strengthening the residency training program which at its inception relied on expatriates and few local radiologists. The University of Nairobi trained one radiologist from Malawi who then returned to offer the much needed radiology services as the only radiologist in the country. Local collaboration exists where residents from the University of Nairobi rotate at the Aga Khan University for a few months in the course of their residency training.

Opportunities of Radiology Global Health Programs

In view of these insights into the journey of a career in radiology in Kenya, it is clear to see the benefits of formal training, yet it seems to be a career that one stumbles upon or chooses out of convenience yet it is so key in the practice of medicine. Global health radiology education initiatives thus have an opportunity to first create more awareness in the various career opportunities in the field of Radiology from high school, university, medical college to residency level. Once the awareness is built then those students interested can chart the appropriate career path and the global health radiology education team would then work with the training institutions to identify the most suitable means to boost their radiology education be it in the short or long term.

Short Term

This may include assisting in writing curricula for new programs or review of programs that train radiographers, radiologists, and biomedical engineers. On-site visits, faculty exchanges, and online resources such as webinars, teaching files, and free online journal access can also be used to enhance already existing programs. Provision of elective terms in developed countries, where residents rotate in radiology specialties not comprehensively covered in the developing country due to few cases encountered or lack of specialists in the field, such as pediatric radiology, would be a consideration for global health radiology programs.

Long Term

This would aim at increasing the number of well-trained radiology professionals in the developing countries. In countries where no healthcare human resource report exists with targets of various professional required in the country, global health teams may collaborate with the governments to facilitate the compilation of such reports such as the Kenyan Ministry of Health did by collaborating with Emory University [14]. Once the number of radiology professionals required is known, then an assessment of the capacity of the available training institutions would then be carried out to establish how many can be trained in a given period of time. The existent training institutions may be found to be too few to train the required numbers in a given duration of time or they may have a limited capacity. The global health radiology education programs can then partner with various universities and colleges to set up new radiology training programs and to increase the capacity of already existent programs.

In countries where no training programs exist, the global health radiology education team can work at helping those interested in obtaining training positions in other countries and assisting them in obtaining training scholarships with emphasis for them to return to their home country thereafter. Alternatively, through bilateral or multi-institutional collaboration faculty from developed countries can take an extended period of time, for example during sabbatical leaves, to train the students in the developing country at institutions that are already training radiology professionals. Such courses may be for a 1-year duration in order to be comprehensive as in the case of fellowship training programs with formal certification provided at the end of the course and would then need one dedicated radiology professional or more than one who would then operate on a rotational basis. This worked at the inception of the Radiology Residency Training Program at the Aga Khan University Hospital in Nairobi where a seasoned radiologist and newly qualified radiologists from the partner university in Pakistan were amongst the first faculty members alongside two local radiologists. These foreign faculty members have since left and most of their faculty is now composed of the alumni of the training program some of whom have also pursued fellowship training abroad.

Assisting the training institutions in sourcing and maintenance of their medical imaging equipment would offer an indirect method of providing educational support since the functionality and availability of equipment is core for the success of a radiology training program, be it for radiographers, radiologists, medical engineers, or medical physicists. The biomedical engineers and medical physicists in the global health radiology team, when on the ground installing the equipment and conducting maintenance checks, would have an opportunity to provide practical training to those pursuing training in this field.

Other than setting up new training institutions, which may be costly, conversion of existing medical colleges into universities where they can offer more comprehensive degree programs can be a consideration that would require collaborative efforts with global health radiology partners. For example, the number of medical colleges in Kenya training radiographers is six and exceeds those training radiologists which are three with a lower capacity for the number of residents they can train, and as such there are fewer radiologists compared to radiographers [14]. Global health radiology education teams can then assist in streamlining the process, and with goodwill created from this ground-breaking effort would have more opportunities to have ongoing educational activities at the institutions. A collaboration of this nature would help improve the confidence of new students enrolling in such an institution to be confident of the quality of training that they will receive. This worked in the Kilimanjaro Christian Medical College that initially offered a 2-year radiology course to medical officers with the goal to deploy them to the rural areas and that is now training radiologists for a 3-year duration [16]. The commission for university education in Kenya was formed in 2012 to address the need to regulate, coordinate, and assure quality in university education as a result of growth and expansion of the university subsector in Kenya [17]. It would serve as a good assessment tool for global health radiology education teams to research on various Kenyan universities and the programs they offer which would hopefully make their collaborations more fruitful.

Appendix 2: An Example of an Educational Collaboration in Global Health

Sheryl Gillikin Jordan and Anthony Charles

Global public health has become a bonafide discipline in many specialties in medicine, though radiology's role has yet to be fully realized and lags other disciplines. The traditional model of investing in expensive technology has not proven sustainable, and teleradiology does a disservice to the development of indigenous physician talent. The time is ripe for us to change the paradigm of radiology in global health and explore rational and sustainable models steeped in the triad of education, clinical care, and research, so as to advance and support clinicians at the frontline of healthcare in low-resource settings.

Infectious disease has led other medical specialties as the primary United States driver in global public health in low-income countries to this point, specifically devoting decades to understanding and treating human immunodeficiency virus, tuberculosis, and malaria. More recently, we are reminded of the value of infectious diseases and global health with the Ebola and Zika outbreaks in Africa and Latin America, respectively [18].

Neither surgery nor radiology as disciplines has been considered part of larger global health initiatives because of their perceived expense. As a result, these disciplines have participated little in necessary investments in education, training, and technology transfer. The traditional model in surgery is exemplified by "mission trips," usually disease-specific, e.g., cleft lip and palate, and is often criticized as being unsustainable and better for the surgeons' operative experiences rather than those people served. More importantly, this model does not build local capacity, and outcomes are often unknown.

More recently, academic medical centers have begun to engage in global surgery in meaningful manner with an emphasis on building programs that (a) expand surgical education of local physicians, (b) increase clinical care by improving surgical access, and (c) increase global surgical research. Fast becoming the standard, these emphases feed the desires of surgical trainees from high-income countries (HIC) to participate and learn side by side their international colleagues [19].

Radiology lags behind other disciplines in global health discourse in part due to its need for expensive and even cumbersome technology; however, among current undergraduate and graduate medical trainees in high-income countries, there is well-documented keen interest in global health, to include global radiology. A 300% increase in Accreditation Council for Graduate Medical Education (ACGME)-accredited institutions offering global health radiology training in the past 5 years has been reported [20]. Organizations, like ACR Foundation, RSNA, and RAD-AID International, have worked diligently to define global imaging needs and strategies with published educational strategies and technology adoption guidelines [20, 21]. For existing, new, and planned global radiology training tracks, these publications prove to be invaluable; we cannot overstate the importance of offering to ACGME institutions proposed foundation, framework, checklists, and reference libraries for international rotations.

Among the published educational radiology global strategies are models describing care in Tanzania, Ethiopia, Botswana, Malawi, Ecuador, and Uganda [22–28]. Common to most of these reports is the emphasis on interdisciplinary collaboration with the postulate that institutional team-based volunteerism works best, to include focusing on educating global radiology partners in radiography, sonography, CT, mobile mammography, and radiation safety.

To illustrate the World Health Organization's report of alarming global health workforce shortages and estimates that two-thirds of the world's population lack diagnostic imaging medical care, one need look no farther than our institution's partner country Malawi. A landlocked country of 18 million in southeast Africa, is the sixth poorest country in the world [29]. As is the case in many African countries, Malawi's healthcare system is tiered and based on the legacy of British colonial rule. The first tier health facilities are Primary Health Centers, located in mainly rural areas minimally equipped to deliver basic care in the absence of a physician. Second tier facilities are District General Hospitals, better equipped and headed by physicians, and lastly Central Hospitals are tertiary referral centers with modest specialty care capabilities. There are four Central Hospitals serving the whole of Malawi.

HIV, tuberculosis, malaria, schistosomiasis, and typhoid are endemic diseases, and due to success of the President's Emergency Plan for AIDS Relief program that changed the outcomes of the HIV epidemic in sub-Saharan Africa, HIV-related cancers to include Kaposi's sarcoma and lymphoma are increasingly prevalent. The high burden of injury also consumes limited healthcare resources. Significant healthcare workforce shortages impact physicians at large, with a physician density of 2/100,000 as compared to 255/100,000 in the USA [30]. The radiologist shortage is extreme, with only two radiologists currently employed by the country's Ministry of Health. Malawians' direct access to radiologists is extremely limited; due to workforce shortage, the bedside clinician must evaluate most radiographs, while ultrasounds are performed and interpreted in contemporaneous manner by trained sonographers. The radiographs are processed in hard copy film manner and are given directly to the patient or the patient's clinician, and stored thereafter with the patient or a family member. Regarding ultrasounds, the results are handwritten in each patient's medical passport, and there are no retained images. Only CT scans are consistently interpreted by radiologists, and a backlog of cases inevitably occurs. The backlog sometime spans weeks [25].

Our institution has veered in important manner in implementing an approach to global radiology that is at once collaborative, sustainable, and novel. Pillars in our model are dual emphases on interdisciplinary collaboration and scholarship, while building on strong foundation in the newly-implemented ACGME 2017 Common Program Requirements (CPR). Through our partnership with the local institution, we are working with local colleagues to address gaps in radiology sustainably by (a) educating local clinicians on appropriate use and integration of radiology and (b) building local human capacity in the department of radiology by working with the on-site consultant radiologist on this goal.

Specifically, we advocate embedding interested radiology residents within a preexisting global health infrastructure (in our case, general surgery and infectious disease training programs) in a manner that positions radiology trainees (and faculty, where able) in both patient- and clinician-facing manner. Participating onsite in interdisciplinary meetings, actively rounding with clinicians in both surgical and medical specialties, offering daily consultation services to clinicians who perform radiology rounds with their patient's radiographs in hand, reviewing CT scans at the workstation monitor with medical teams, taking call in casualty by scheduling shifts alongside teams covering the emergency department, offering imaging interpretation-intensive courses for clinician colleagues and then following those courses in short order with the clinician teams on the wards, transducer or film in hand – all provide unique experiences in imaging education, interpretation, and advocacy. In short, at this stage in global radiology, our model offers remarkable opportunity for engaged radiologists to genuinely make a difference. This can be especially impactful for global radiology destination sites with marked shortages in radiologists.

Our interdisciplinary collaboration is ideal for upper-level radiology residents who rotate on site for 4 weeks or longer at a global destination, be it

Africa or elsewhere. Since 2013, diagnostic radiology residents sit for the American Board of Radiology (ABR) Core examination in early June of their third year of radiology residency, as a post graduate year four resident [31]. The comprehensive test requires diligent preparation and practice; these residents become treasure troves of knowledge thereafter as fourth year residents. Add in the opportunity for senior electives many residencies now offer that enable post-Core elective blocks chosen by the resident in manner tailored to his/her areas of interest, and also the fact that fellowship spots have already been secured. Many residency stressors have been relieved. Fourth year resident knowledge and discretionary time combine with the self-replenishing nature of residency training to assure this model is uniquely sustainable. Though US radiology faculty schedules may necessitate shorter or less frequent global radiology onsite presence, the availability of many fourth year residents in renewable manner per year per engaged residency sets the stage for success. A local radiologist provides valuable introduction and oversight, and insight and expertise is exchanged daily, in turn passed along to more and more trainees. Attendings from the home institution overlap with resident travel and are able to view cases for educational consultation at the site via server connection between institutions.

A recent survey of the Association of Program Directors in Radiology (APDR) confirms the nascent status of US radiology residencies' formal global health outreach with low subscription reported; further only a few programs participate in research while onsite internationally [32]. We have adopted a more robust approach to clinical and educational scholarship in our model. The very nature of interdisciplinary collaboration lends itself nicely to valuable exchange of knowledge and ideas, which in turn lends it to further study, then reporting in manner to contribute in meaningful way to the existing body of knowledge.

For many low- and middle-income country (LMIC) destinations, there are significant challenges to the delivery and reporting of diagnostic radiology beyond human resource limitations. These include larger infrastructural issues to include the lack of reliable electricity, lack of maintenance contracts and service agreements, poor understanding of supply chain management tenets (not infrequently, weekend shifts run out of film), limited record-keeping of patient procedure logs per modality, variations in radiograph quality, and lastly poor track record of radiation safety.

Topics such as these in global radiology lend themselves to quality improvement initiatives that can be published also. The synergy and added knowledge that ensues when colleagues from different disciplines discuss disease presentations, care algorithms, and outcomes not only expand knowledge and improve patient outcomes but invite scholarship. To encourage scholarly output, we assign residents academic days during the international block. Thus far, these days have been devoted to focused assessment with sonography for trauma (FAST) course administration and follow up, teaching file development to include readapt correlation (via scheduled consultation in pathology and laboratory), and tropical diseases case study reporting. Our institution's recent scholarship examples include needs assessments, FAST, role of radiology in acute care surgery, and early results of breast cancer clinic development; these topics reflect merely the early efforts as others continue to make their way through the needed steps toward publication [25, 33–35].

Accreditation Council for Graduate Medical Education-Common Program Requirements (ACGME CPR): In February 2017, the ACGME approved substantial revisions in the Common Program Requirements (CPR) affecting all residencies effective July 1, 2017. CPR Section VI underwent meaningful consequential change, with the Learning and Working Environment directives far more prescriptive in the areas of patient safety, professionalism, and well-being [36, 37]. Section VI has expanded with greater attention to patient safety and resident and faculty member well-being; specifically prescripted is a "program structure that promotes safe, interprofessional, team-based care" VI.A.1.(a).(1).(b), as well as "policies and programs that encourage optimal resident and faculty member well-being" VI.C.1.d [37].

Further, the CPR now details the increased risk for burnout and depression in the current US healthcare environment that residents and faculty members alike must acknowledge and admonishes programs that physician self-care is a skill that must be learned and nurtured in like manner to other educational components of residency training. The message to trainees must be that psychological, emotional, and physical well-being are critical in the development of the competent, caring, and resilient physician:

- "On multiple levels, I found the experience integral to my growth as a human being and a radiologist." [27]
- "For myself, the experience felt as if it allowed me to at least temporarily live up to the rhetoric I put down on my medical school application." [23]
- "Spending time in casualty department is yet another eye-opening experience. Two young interns virtually run the show in there, making all decisions in admission/consult/discharge, and also performing small procedures; it's pretty impressive. Most of my time was spent interpreting x-rays and lending a hand when needed. It was a good opportunity to teach a bit about plain film interpretation, one-on-one with the interns, who do a good job but have little radiology experience." [Personal communication with Ryan Embertson MD PGY5 onsite Kamuzu Central Hospital Lilongwe Malawi, October 9, 2017.]

The future of global radiology is bright and rests largely within the domain of academic medical centers. We believe it can be sustained best if built on an interdisciplinary educational model with radiology resident integration model that emphasizes collaboration, bidirectional education and scholarship, and is in synergy with the newly implemented ACGME 2017 requirements. Embedding upper-level radiology residents in existing clinical services on rotations that are no less than 4 weeks in length enhances education with local radiologists and clinicians. With an increasing pool of interested and qualified residents and with unequivocal support for global radiology from departmental leadership, we believe this model to be applicable in today's global radiology paradigm.

Appendix 3: Examples of Discussion Questions

Melissa P. Culp

Part I Global Health Radiology Strategies and Implementation

1. From your practice and experiences, why do you believe that radiology is important in global health? Why does the topic of global health radiology interest you?
2. Discuss a situation in which you were faced with an ethical dilemma in radiology. How did you handle the situation?
3. What are some ethical dilemmas that might be faced in global health radiology initiatives? How should we approach those situations?
4. Why is the process of learning from failure important? Have you experienced the benefits of such analysis in your own life or work? If so, how?
5. What is an example of how cultural competency is important in your role as a radiology professional?
6. Why are the cultural dimensions from the textbook important to consider in global health radiology? Give a hypothetical or real example.
7. Why do you think Radiology Readiness Assessments are important for sustainable global health radiology initiatives?
8. Why is it important to have measureable target objectives in global health?
9. How does the concept of partnership apply in global health radiology? What is your vision for partnership in the context of your goals for global health?

10. Why does economics matter for sustainability in global health radiology? In your opinion, what are the pros and cons of microfinance?
11. Based on the text, what are your suggestions for best-practices in addressing equipment needs in low-resource nations?
12. The authors mention “dose creep,” a radiation safety concern that can arise in the transition from analog to digital imaging systems. How might these considerations apply with partner sites making the transition from film to digital currently? What educational initiatives would be important to include within these partnerships?
13. What are ethical situations that might arise with radiation protection within the context of a limited-resource setting? For patients? For providers? Within room construction? How would you address these issues in your global health initiatives?
14. What is the role of the medical physicist on the global health radiology team?
15. In your work as a healthcare professional, what are the different types of professional roles that must work together in radiology to achieve quality patient care? Why is it important that representatives of those occupations are all part of a radiology global health team?
16. What barriers prevent you from interacting with team members from other backgrounds in radiology within your current setting? What are actionable items that you can feasibly implement to come to know other professional groups in the field? Why would this prep be useful before initiating a global health radiology partnership?
17. What should be considered (logistics and ethics) if information technologies are going to be integrated into a global health radiology initiative?
18. How are global health radiology initiatives a potential educational experience for you?
19. Why is local human capacity development important for sustainability in global health?
20. What are legal considerations within global health radiology that you should consider within your work?

Part II Global Health Radiology Clinical Applications

1. Describe the role of radiology in public health programs. How may the implementation of these programs vary among low, middle, and high-income nations?
2. There are many considerations an imaging department should implement in order to properly satisfy ethical and safety concerns that could arise in the department with patients, staff, and the public. Among those considerations is the proper use of personal protective equipment to prevent the spread of infection within the department. Why is this relevant in global health radiology?
3. In its origin, global health had emphasis on primary care, trauma, and infectious disease. Data suggest that non-communicable diseases are increasing worldwide. How can you integrate imaging and radiology education for non-communicable diseases in global health?
4. How might community health, screening, and patient education become part of your global health initiative to comprehensively address this issue?
5. How might an interdisciplinary approach with other clinical services, like internal medicine, surgery, etc., contribute to addressing non-communicable disease in global health?
6. In your work experience, what special considerations do your pediatric patients need? Give specific examples considering different modalities and pathologies.
7. What special considerations might pediatric patients need in global health radiology planning? Give specific examples considering different modalities and pathologies.
8. The text mentions ethical considerations for medical imaging in obstetrics. If your global health radiology initiative included a focus on prenatal, fetal, and maternal health, then how you would address these issues?
9. In your perspective, why is the Radiology Readiness tool important in the creation of a program like Asha Jyoti or for other mobile health initiatives?

10. What special challenges do you see for radiology global health initiatives focusing on breast health? What considerations must be made for the sustainability of women's imaging programs in global health initiatives?
11. How is providing aid in disaster response different than other radiology global health programs? What considerations should be made in the disaster response setting?
12. How does radiology improve trauma outcomes based on your experience and/or what you have read from the text? In your experience working in healthcare, how is radiology integrated by the trauma team? How might the relationship of radiology and trauma care be integrated into global health?
13. What are considerations for the integration of interventional radiology into global health initiatives? Legal and ethical? Procedural?
14. How might a global health partnership address supply chain issues sustainability?
15. How can radiology work with radiation oncology to reduce the global burden of cancer?
16. Based on the text, why is radiology important in global health?

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