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Matthew P. Lungren
Editors

Radiology in Global Health

Strategies, Implementation, and Applications

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To Libby -
There on the top of the down,
The wild heather round me and over me June's high blue,
When I look'd at the bracken so bright and the heather so brown,
I thought to myself I would offer this book to you,
This, and our children and my love together,
To you that have for miles with me driven,
With a faith as clear as the heights of the June-blue heaven,
And a fancy as summer-new
As the green of the bracken amid the gloom of the heather.

-Matthew P. Lungren

Dedicated to the loving memory of my mother, Gina Mollura, and my daughter, Nicole. To my wife, Laura, and our children, 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

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Foreword

I am honored to write a foreword for a book as important as "Radiology in Global Health: Strategies, Implementation, and Applications." As the global health community looks towards making real progress in addressing health care disparities in the developing world, the role of medical imaging has come to the forefront. Sitting in the academic institutions, private practices, and community hospitals of the developed world, we regard imaging as an essential part of high quality health care. In fact, we have faced the challenges of rapidly increasing utilization as our physician colleagues recognize imaging's role in coming to an accurate and rapid diagnosis, in many cases outweighing more traditional clinical data. Given the importance of imaging in our society's health care system, it is hard to imagine that much of the world's population cannot benefit from similar capabilities.

Looking at the tremendous chasm that separates our reality from that of the two-thirds of the world's population lacking adequate imaging services, our collective responsibility to address this disparity becomes clear. It is tremendously gratifying to see that I am far from alone in this belief: attending the conferences that Dr. Mollura and his organization, RAD-AID, have held at Johns Hopkins for the past 5 years, I have seen the passion that so many of our radiology colleagues bring to this challenge. Likewise, at several national meetings where global health care disparity has been a topic of discussion, I have been delighted to learn of the many academic departments, which are also attempting to address these issues through their own programs. Likewise, we at Johns Hopkins have provided educational programs for many years electronically to the developing world to help with Radiological education. However, up until now each individual department or NGO has had to "reinvent the wheel" as it develops programs from the bottom up. The guidebook that Dr. Mollura and colleagues have developed is a critical tool in this quest.

By taking a well-organized and thoughtful approach to the many issues and challenges surrounding improving global health and imaging services, this text will accelerate the development of solutions by chronicling past experiences and pointing the way to future involvement. The text will create a framework to understand the issues of radiology readiness, culture competency, ethics, economics, sustainability, and safety, to name a few of the topics covered, so that the reader can develop a personal or organizational strategy for global volunteering and philanthropic efforts.

I am both personally gratified and professionally appreciative to see Dr. Mollura and his colleagues, rising from the roots of RAD-AID developed during their residencies in our department, working with others in the community to create such an important academic work and practical guidebook. It is my hope that many of you, the readers of this book, will use it to learn, reflect, and feed your passion for making a difference in the world. Only through the dedication, passion, and efforts of many can we begin to address the very troubling health care disparities between the developed and developing world, and only by providing the right imaging services at the right locations with the right provider in a sustainable manner can we begin to truly move forward as a global community.

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An Important Discussion About Terminology Use in this Book from the Authors

As human civilization has progressed, language has expanded and adapted to allow society to label, express, and communicate its continuously evolving ideas, emotions, and discoveries. Unfortunately, despite the evolution of language, some concepts remain difficult to crystallize into a single word or phrase, whether due to their profundity, complexity, or socially charged nature. The terminology for the socioeconomic and resource-based disparity between nations falls in this category.

The early, controversial terms “First World countries” and “Third World countries” have rightfully fallen out of favor. They stand as relic terminology of the Cold War and, though not their original intent, carry the negative connotations of imperialism, colonialism, and paternalism.

In their place, terminology emerged that classified countries based on economic and social development, using a variety of indicators and metrics including nominal gross domestic product (GDP) per capita, gross national income (GNI) per capita, life expectancy, adult literacy rate, and other criteria, all of which have long been subjects of debate. Thus, we gained the phrases “developed countries” and “developing countries” (and other iterations including “undeveloped countries” and “least developed countries”). However, taken at face value, these terms are ambiguous and inadequate. What is the line between a developed and developing country and who decides it? Does any nation ever really stop developing? Do all “developing” countries develop at the same rate? Even the United Nations states it has no established convention for the designation of “developed” and “developing” countries.

Various other classifications have emerged as potential replacements in the global health lexicon, though without a perfect solution. For example, where “developed” and “undeveloped” deal in absolutes, the cumbersome phrases “most economically developed countries” and “least economically developed countries” introduce relativity, though they are not free of ambiguity. The World Bank classifies countries into low-income, middle-income, and high-income countries. Yet, even within high-income countries, there may be areas of poverty. The phrase “resource-limited countries” has gained popularity but is similarly vague. Which specific resources are limited? The Human Development Index (HDI), the Human Poverty Index (HPI), and other similar multifactorial indices have arisen to address some of these complexities but a single, ideal, universally accepted classification scheme remains elusive.

In this textbook, you will encounter a multiplicity of terms that aim to express the complex classification of healthcare-related resource disparity in our world. And while there is no perfect terminology, we hope that you will understand our well-intentioned meaning: to advance the role of radiology and imaging in global healthcare through the initiation, implementation, amelioration, and sustainment of diagnostic and therapeutic radiology services in countries, communities, hospitals, or clinics that either lack such services or could benefit in their improvement. Radiology is a vital component of safe and effective healthcare that should be available to everyone, regardless of the terminology used to classify the place where they live.

Special Acknowledgment on Behalf of the Editors and Authors of this Book

Many of the clinical images presented in this text can also be found in the 1700 page, 2 volume textbook "The Imaging of Tropical Diseases, with Epidemiological, Pathological and Clinical Correlation" presented herein with the gracious permission of the authors Philip E.S. Palmer MD, FRCR, FRCP, and Maurice M. Reeder MD, FACR, and of the publisher Springer who previously held the copyright to the book.

Preface

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 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 its scarcity. Radiologic services common to the industrialized economies of the world are scarce in the poor and developing regions of the world [1]. 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 developed health care system, it is widely understood by both patient and provider that imaging plays a significant role in the diagnostic work-up: women routinely undergo breast cancer screening via yearly mammography; patients with heart disease receive angiography; trauma patients are evaluated by CT and radiography; the success of cancer therapy is monitored by CT and PET; expectant mothers are monitored by fetal ultrasound; and the list goes on and on. In the developing world, these technologies may be absent or inaccessible due to location, wait time, or inoperability, leaving patients with few or no options for diagnosis and care.

Who is the intended audience of this book? This is an important question because solution development requires dialogue with the correct diversified audience. This book is intended for a broad audience of health care providers, engineers, policy-makers, business leaders, academics, and health personnel 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. Perhaps you are a radiology resident 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 volunteer trying to make a difference in health solutions for the poor.

With such a broad audience in mind, this text has an interdisciplinary tone, mixing approaches and perspectives to describe and analyze solutions for radiology in global health efforts. This book integrates economic development, technology innovation, clinical model planning, educational strategies, and public health approaches to formulate a broad survey of international health care. For a long time, humanitarian aid organizations have emphasized "stethoscope medicine" which is the use of low-cost portable tools for simple diagnosis because more advanced technological resources were thought to be unavailable or impractical. One can imagine refugee camps or impoverished slums having poor infrastructure for medical imaging. This text, however, describes recent technological innovations such as solar-powered ultrasound, cell phone networks for digital images, and low-cost X-ray, which have created new opportunities to bring advanced medical technology into these impoverished under-resourced areas. Since the expertise required to acquire, implement, plan, and monitor these technologies is still multifactorial, this text attempts to comprehensively cover this planning process using an interdisciplinary approach. These technologies do not substitute for conventional medical methods, but supplement and advance medical care with complementary diagnostic and treatment resources.

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Introduction

1

Daniel J. Mollura and Matthew P. Lungren

Background

Historically, international radiology solutions for the developing world have been frequently dominated by hardware, since hardware (i.e., the imaging machine itself) is the most capital and cost-intensive component of radiology service implementation. In other words, if a group or institution had an ultrasound unit to donate, then it was an ultrasound solution offered to the hospital in need. This text, however, tries to reverse this thinking, by first assessing the clinical and epidemiological need (i.e., what diseases are prevalent in a community and how will they be treated) in order to then find the right hardware to address that need. The hardware is only identified after the full deficiency is measured.

In designing this text, we drew significant inspiration from our experience in founding and managing RAD-AID International, a nonprofit organization dedicated to increasing and optimizing radiology services in the developing world [1]. Much like this text, RAD-AID employs a multidisciplinary approach to radiology service assessment and implementation, and the overall approach is based on five key pillars, all of which are covered in this text: (1) economic strategies for financial sustainability; (2) public health radiology for population-based approaches (screening, safety, epidemic detection, and cancer prevention); (3) clinical model formulation tailored to the needs and resources of regions and communities; (4) technology innovation and optimization including hardware, software, and web-based strategies for radiologic data communications; and (5) public policy for healthcare system development at the government and international institutional level. The works of RAD-AID and many other organizational peers and partners were included in this text in order to demonstrate diverse strategic approaches, technical designs, and clinical models among very different regional and cultural contexts. The unifying underlying objective of the pages that follow is to address ways to achieve sustainable long-term imaging strategies for limited resource regions.

When it comes to developing nations, resources in health care are generally scarce, while radiology equipment and imaging services are relatively expensive and require a well-trained team with coordinated components. It makes sense to have other healthcare and infrastructural resources available before implementing radiology services in a medical or surgical context. This way, funds are not wasted on high technology

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placed in a setting without the basic infrastructure or complementary medical-surgical resources necessary to effectively use radiological imaging. Donated resources are optimized for the highest return to society. Asking questions in the context of the overall health system can help teams assess how effective radiology imaging services can be in the field. Does it make sense to have chest radiograph equipment for detecting pneumonias or tuberculosis if the clinic or country has no antibiotics for treating these diseases? What electric power is necessary for these advanced medical imaging resources to be used and maintained without interruption or breakage? Should a mammogram program be set up if there are no resources for doing biopsies of the masses found on abnormal mammograms, or if there are no surgeons to operate on the detected cancer?

An excellent example of the primary multidisciplinary approach is Radiology Readiness, which was developed by RAD-AID in 2009–2010, with current efforts to continue upgrading strategies, adapting to different settings, and implementing projects in the field. Radiology Readiness is a framework for assessing the need, resources, utility, and feasibility of radiology service implementation in order to maximize the utility of radiology in developing countries. What does it mean to have radiology readiness or to be radiology ready? Radiology Readiness involves the deployment of resources around radiology that makes the medical imaging an effective part of the healthcare delivery process to make the whole system work better. With this basic concept in mind, some general criteria RAD-AID uses for assessing radiology readiness include:

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

When a country or region is not yet "radiology ready," RAD-AID works to find solutions so that resources can be implemented to achieve radiology readiness such as increasing access to medical-surgical personnel and supplies, improving basic infrastructure, and scaling up radiology training for local personnel so that vital imaging services can be effectively provided. Moreover, RAD-AID develops leadership programs for local entrepreneurs and emerging leaders so that they can build sustainable imaging programs to integrate with other patient care resources in their home countries.

While future efforts at assessing and planning radiology service deployment in the developing world may not always use the exact Radiology Readiness instrument, the message here and in the pages that follow is that using a multidisciplinary approach that aims to optimize the societal yield of radiology services will in turn maximize the value of donated resources, foundation grants, and institutional investments.

About This Textbook

In order to comprehensively explore the dynamics of implementing radiology for global health, this text is organized into two main sections: (1) Global Health Radiology Strategies and Implementation and (2) Global Health Radiology Clinical Applications.

The first section (Chaps. 1–11) explores the role of radiology in addressing healthcare disparities and addresses the challenges and strategies around radiology services project planning and implementation in low resource settings. Given the complexities of radiology services, diverse stakeholders, advanced technologies, education strategies, volunteer management, legal considerations, and the need for sustainable financing, this section aims to explore the features of each of these important components in designing tailored imaging solutions to improve public health and patient care outcomes in the long term. In addition, this section covers (1) needs-assessment tools for identifying strategic priorities in planning medical imaging services; (2) cross-cultural communication and ethics to implement global healthcare projects respecting cultural conventions; (3) economic development at the institutional and national levels for financially sustainable long-term solutions; (4) patient safety and legal issues; (5) equipment procurement, installation, and maintenance for software, hardware, and information technologies; and (6) approaches for managing educational training programs and volunteers. Again, the purpose of this section is to provide a range of tools in the planning and effective execution of imaging projects in the developing world.

The second section (Chaps. 12–21) of this book presents an overview of the clinical role of medical imaging in the developing world, including epidemiology and specific clinical models and applications. An example would be ultrasound for rural regions in maternal-infant care, mobile mammography for breast cancer screening outreach, infectious disease diagnosis (such as AIDS and TB), and portable X-ray for trauma evaluations among the urban poor, among others. This section also addresses clinical diagnostic challenges for recognizing and managing illnesses unique to the developing world and regions of limited resources. Further, among wealthier countries, some of the diseases presented here are sufficiently rare to be outside the usual domain of clinical training. Examples include parasites and other infectious disease that may not widely impact public health in the developed countries, but are still highly prevalent in poor, emerging, and developing healthcare systems. It would not be possible to include all disease entities in this text due to space limitations; however, we present some of the more common diseases and their radiologic findings in order to illustrate the role of imaging in diagnosis and treatment.

Summary

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 each country's healthcare system and their specific challenges and needs, we avoid any paternalistic overgeneralizations. Instead, this text is a starting point for global dialogue covering rapidly advancing imaging technologies and presenting novel ways to implement these tools in diagnosing and treating disease; however, with these innovations comes the complex task of implementing capital-intensive medical technologies in resource-limited regions. Through careful analysis and planning, as well as steadfast dedication to our patients' well-being, this text can be another step towards improving global health.

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Part I

Global Health Radiology Strategies and Implementation

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

Daniel J. Mollura and William W. Mayo-Smith

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 still apply to the radiology enterprise, 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 factor contributing to the failure of international radiology service deployment [1, 2]. 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, 2]. 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 treatments [3, 4]. The primary diagnostic imaging modalities 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, 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 equipment, servers, workstations) and software (computer-based applications). In the context of this text, the radiology enterprise may

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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 for 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.

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 this variation in scale, there are multiple processes common to all radiology enterprises which are critical to build appropriate delivery systems [4, 5, 6]. A breakdown in any one of these processes in the complex imaging chain will defeat the desired outcome. The common processes include (discussed in depth throughout the text):

1. Scheduling the patient for the appropriate test
2. Proper equipment to perform the test (includes stable reliable electricity, shielded room, equipment, etc.)
3. Appropriately trained personnel to operate the equipment
4. System to transmit and store imaging data and reports
5. System to visualize the imaging data
6. Radiologist (or 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 make sure all equipment is properly maintained and personnel are appropriately trained
11. Financial method of reimbursement to make the system viable and sustainable

Defining the Stakeholders (Personnel)

A radiology imaging service unit cannot operate well without a well-organized 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. 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 [5]. 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 IT capacities. Some radiologists will do their own nursing procedures (starting IVs, evaluating patient prior to imaging, etc.). It is important to recognize, however, that these roles must be represented in some way, either by specialized individuals or by multitasked individuals, because these capacities are all vital for effective and safe imaging [4, 5, 6].

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

Table 2.1 Stakeholders and responsibilities in radiology services

Stakeholder	Responsibilities
Administrators	• Schedule patients • Document insurance • Record payments • Manage human resources • Manage quality inspections • 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

Table 2.2 Relative expenses (investments) for imaging equipment

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

possibly present in an imaging organization, as well as relative expense. This wide variety of possible modalities, and the 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. 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.

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 breech of regulations or safety [5]. It is important to recognize this problem since one of the major safety concerns, radiation exposure, 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 towards the goal of matching the quality.

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 be overlapped with the radiologist's role. Technologists forming the images of patients on the imaging equipment will then either format the images digitally for transmission into the electronic servers, called picture archiving and communications (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 parts of the developing world. This topic is covered in greater depth elsewhere in the text.

Relationships Among Stakeholders for Service Delivery

The organized relationships among the stakeholders in radiology service implementation are critical [6]. 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, if an image is interpreted by the radiologist, accurate and timely communication of the result to the referring clinician is essential.

In developed healthcare settings, this may involve a cell phone call or a page indicating the results. In developing countries, 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, 2]; the proliferation of cell phone technologies in developing countries has made this mode of communication among the most stable for a communication structure among healthcare providers. Moreover, widespread utilization of tablets 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 on either cell phones or Wi-Fi to streamline these interconnections between radiology and other care providers [2].

Radiology Planning

In briefly reviewing the 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 developing countries. The integration of these parts is essential for (A) producing adequate care and then (B) communicating with the rest of the hospital or medical service so that imaging can be optimized in patient care. For example, if an abnormal finding is discovered on imaging, that result must be included in the other clinical information in order to arrive at the action plan for the 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, properly analyzing and planning radiology service can have a great impact on healthcare disparities worldwide. 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 will form 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 the Developing World

Nandish Shah

Introduction

Diagnostic imaging plays an important role not only in identifying pathology and tracking the progression of a disease but also in preventing disease via screening. In fact, health technologies (including imaging) are one of the six building blocks identified by the World Health Organization (WHO) as essential for all health systems [7, 16]. Missing even one of the six impedes a health system from functioning at a level necessary to improve the health of individuals and populations [7, 16]. However, according to the WHO, one-half to two-thirds of people in the world lack adequate access to basic imaging technology, such as X-ray and ultrasound [6, 10, 18, 20]. This figure remains unchanged from the WHO estimates from the late 1970s to the early 1980s [2, 5, 9–11, 19]. It is therefore essential to learn how to measure access in order to best improve it.

The Definition of "Access"

Before describing how the WHO assesses access to imaging, it is important to first understand what is meant by the term "access." The WHO defines it as an interaction of different factors, which include availability, affordability, accessibility, appropriateness, acceptability, and quality [12]. Thus, it is not enough for individuals to be geographically within reach of healthcare facilities that house imaging technologies as might be explained by "accessibility." A medical device or imaging technology must be scientifically valid, address local need, and be utilized in a manner that a country can afford. While these clear-cut components describe "appropriateness," "acceptability" is a more fluid term that incorporates cultural beliefs and individuals' attitudes regarding the use of various medical devices and imaging modalities. 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 [8, 12]. In light of the colossal nature of assessing world radiology, a proper understanding of the term "access," as outlined by the WHO, is necessary to provide both effective and equitable solutions to individuals in developing nations.

Essential Imaging Technologies in the Developing World

Interestingly, studies show that 80–90 % of the imaging need in developing countries can be met by X-ray and ultrasound alone [13, 18, 22]. X-rays are essential in the diagnosis and treatment for the large proportion of patients in developing countries presenting with pulmonary or orthopedic conditions among other things [13].

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This is true for acute conditions, such as pneumonia, pleural effusion, hemothorax, fractures, and osteomyelitis, as well as chronic ones, such as TB, asthma, chronic obstructive pulmonary disease (COPD), and occupational lung disease [13]. 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 screening and diagnosis of disease [13]. Additional conditions for which ultrasound has a critical role in resource-poor settings include deep vein thrombosis, cardiac valvular disease, cardiomyopathy, abdominal trauma (FAST), abdominal masses, abdominal sequelae of HIV/AIDS patients, ascites, neonatal cerebral hemorrhage or infection, and procedural guidance, such as for any type of fluid drainage (abscess, around an organ, in a joint), IV access, and difficult lumbar punctures [13, 21].

While applicability is useful, it is imperative to decipher the impact of these 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 developing countries around the world [21]. In addition, since presentation of a disease can vary drastically between developed and developing countries, ultrasound allows one to view a lesion in real time and from all angles leading to rapid intervention, procedural, surgical, or medical [15].

As per the most recent "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 [23]. In addition, they rank fourth in terms of projected causes of death globally in 2030 with the top 3 being cardiovascular disease, cerebrovascular disease (stroke), and COPD [23]. Furthermore, the burden of maternal conditions, while almost entirely confined to low- and middle-income countries, is so great that they, alone, make up one-fifth of the leading causes of disease among women aged 15–44. Of note, almost all of this loss of healthy life years is avoidable [23]. In light of the WHO findings and the utility of X-ray and ultrasound technology in these disease processes, it is clear that both technologies have a vital role in the practice of medicine in developing nations. What remains is achieving adequate access.

Measuring Access to Imaging Technology

The WHO has been involved in aggregating world data on medical imaging since the late 1970s. In fact, 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 (Fig. 3.1) [2]. 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 developing nations after taking into account various infrastructure factors [20, 24].

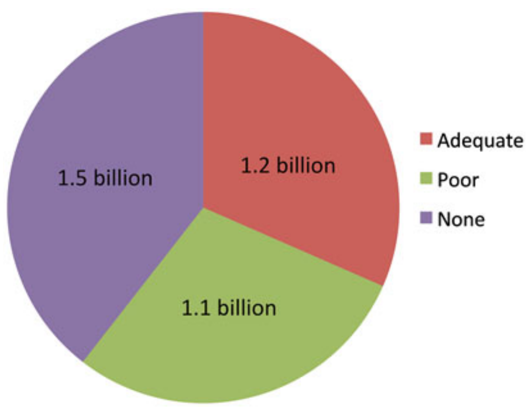

Fig. 3.1 World access to imaging technology, 1979 survey

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 developing nations [17]. 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 [3, 4]. It was administered to the ministries of health in 145 WHO member countries. Seeming to build upon the survey in 1979, the questionnaire allows one to understand the various factors that make up the term "access." For example, low- and lower middle-income countries, as defined in the World Health Statistics report from the WHO, had fewer than 1 mammography units per million people compared to 23 per million in high-income countries [25]. In terms of 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 [3]. This disparity between the developed and developing world is the same, if not worse, when looking at access to MRI, PET, and nuclear imaging devices as per the baseline survey.

While the report on the baseline survey breaks data down by nation, the annual World Health Statistics report and Global Health Observatory Data Repository complied 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 [14, 25]. 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 [7]. 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.

Understanding Adequate Access

It is evident from the data collected that disparity exists between developed and developing countries. However, disparity in access to health care and medical technology also exists *within* developing nations, specifically between the private sector and the public sector. While the private sector has the resources to offer needed imaging services, it is inaccessible to many in a country due to cost and its location in 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 [1, 9, 13]. With this in mind, the most important next step in understanding access to diagnostic imaging technology is the Needs Assessment for Medical Devices, 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 [17]. In its simplest form, it is meant to assist a nation in cataloguing 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 [17].

Clearly, a thorough definition of the term "access" by the WHO 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 [20]. Using this barometer, it is easy to see that developing countries have not reached the capacity to provide appropriate access to both X-ray and ultrasound technology [2, 5, 9, 15]. Therefore, what remains to be seen are other benchmarks devised by the WHO to aid nations in understanding adequate access.

Conclusion

In light of the pervasive presence of imaging technology in the United States, it is easy to take for granted a technology that forever has been so difficult to provide in much of the world. The first step in attacking this problem is to understand the various factors that contribute to the definition of "access" as outlined by the WHO. Next, looking at the various surveys conducted by the WHO, it is easy to see a disparity in the access to medical imaging technology, among all modalities, between the developed and the developing world. Now, with the needs-based assessment in place, the WHO has laid the foundation for uncovering the overall gap in adequate imaging technology. With this information, all parties involved, whether it is radiologists, radiologic technologists, sonographers, NGOs, ministries of health, or developing nations, will be able to join forces to close this gap.

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Radiology Readiness™, Research and Relationship Development

4

Ezana M. Azene

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 the developed world have come to expect access to readily available radiology services. It seems radiology has become so ubiquitous that most of us living in developed 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 developing world. This disparity in access to radiology services has been termed the "radiology divide" [2–4]. Governments, 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.

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 developing nations, particularly low-income developing 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 developing countries.

The second broad category underlying the radiology divide is a lack of appropriate device procurement and planning. Unfortunately, well-meaning groups and individuals often bypass the necessary steps required to ensure the sustainability of radiology improvement projects in developing nations. 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

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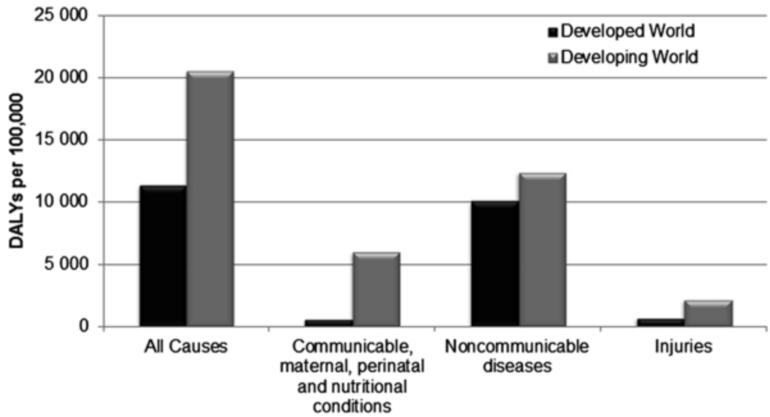

Fig. 4.1 Age-standardized disability-adjusted life years (DALYs) per 100,000 adult women stratified by development status. Data was obtained from the World Health Organization Global Burden of Disease summary for 2004 [10]. In the developing world, noncommunicable diseases like heart disease, cancer, 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

> 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 developing nations, 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 the developing world, 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. 4.1). 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 developing nation 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 the 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 [6].

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 [7]. 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

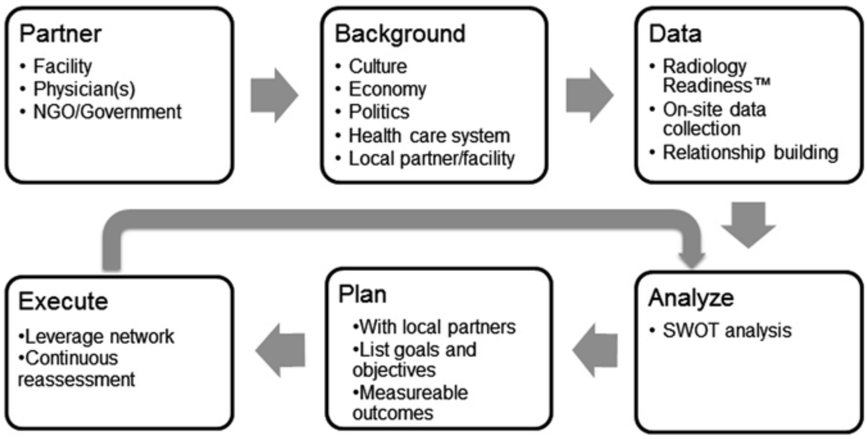

Fig. 4.2 Summary of the RAD-AID approach to assessment and program development

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.

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. 4.2) 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. We 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.

Table 4.1 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
United States 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 4.1). 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 also useful. RAD-AID and other organizations involved in radiology projects in developing countries 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. The RAD-AID PubMed catalogue of peer-reviewed publications is available on the Internet and can be viewed by anyone [8].

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 also 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 analysis method [9]. SWOT analysis forces the project team to identify the inherent Strengths and Weakness 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.

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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Economics of Sustainable Radiology in the Developing World

5

Frank J. Lexa and Sarah Iosifescu

Introduction

As we enter 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 Somalia and Afghanistan at 53 deaths/1,000 live births. The lowest infant mortality is in Japan at 1.1/1,000, an approximately 50-fold difference [1]. 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 Chad at 48.69 years, while Monaco has a life expectancy almost twice this number (89.68 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 5.1 and 5.2).

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 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.

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 that are related to regional differences 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 homogenously poor nations; in fact, economic inequality also exists among developed countries, including the United States according

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Table 5.1 2008 WHO rank of top 20 countries by ratio of healthcare expenditure to national GDP

Country	GDP
United States	15.2
Nauru	14
Marshall Islands	14
Timor-Leste	13.9
Maldives	13.7
Niue	13.5
Federated States of Micronesia	13.3
Sierra Leone	13.3
Burundi	13
Kiribati	12.5
Cuba	12
Liberia	11.9
France	11.2
Belgium	11.1
Palau	10.8
Switzerland	10.7
Moldova	10.7
Portugal	10.6
Germany	10.5

Table 5.2 2008 WHO rank of bottom 20 countries by ratio of healthcare expenditure to national GDP

Country	GDP
Equatorial Guinea	1.9
Turkmenistan	1.9
Qatar	2
Kuwait	2
Oman	2.1
Burma	2.2
Brunei	2.3
Indonesia	2.3
United Arab Emirates	2.5
Gabon	2.6
Pakistan	2.6
Mauritania	2.6
Congo, Republic of	2.7
Libya	3
Syria	3.1
Eritrea	3.1
Papua New Guinea	3.2
Singapore	3.3
Angola	3.3

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 that are currently classified as middle-income rather than low-income nations and 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 that may not appropriately reflect this need.

Sustainability

One of the key challenges for building radiology services in the developing world 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 in designing a wide variety of enterprises in the 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 as well as on a longer trajectory toward self-sufficiency in the future, rather than perpetuating a state of dependence upon 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 innovative technologies and services that can help meet these goals.

Radiology services are currently paid for in a wide variety of ways around the world, ranging from full coverage by the state, private pay for service, donated services by religious organizations and other NGOs, and mixed systems with elements of two or more of the above. All nations must manage both 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 lower costs in the near 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. This will be discussed in greater depth elsewhere in the text.

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 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. 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.

[1] An *accountable care organization* (ACO) is a healthcare organization characterized by a payment and care delivery model that seeks to tie provider reimbursements to quality metrics and reductions in the total cost of care for an assigned population of patients.

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 developing nations, 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 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 of trying to balance commercial sustainability while attempting to adjust interest rates that may be feasible for the "very poor" clients they are designed to serve.

Despite that Muhammad Yunus and the Grameen Bank of Bangladesh have often been credited with popularizing microfinance in the twentieth century, the actual practice of community financing has been in place in developing nations alongside private-sector economies for hundreds of years. The term MFI refers to the institution providing financial services to the poor including credit, loans, bank accounts, and basic insurance. MFIs often offer financial products through two schemes, group lending and individual lending.

The MFI group-lending model involves assembling a group of borrowers together to borrow money as a unit as follows: 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 which in place of 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.

Many MFIs select loan officers who live and know the area in which they are working to help the MFI learn about the local community in addition to facilitating communication when there are language barriers. These loan officers are the individuals who train the groups, monitor repayments, and communicate with individuals as issues arise. They have unique insight and access to the client, which can prove beneficial when starting to promote new services.

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 possessing an often 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 pay back 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. Traveling to a hospital or medical center in developing nations requires extensive travel as well as time spent waiting for services. Individuals lose valuable time, time in which they could be working, as they spend days and sometimes weeks seeking medical attention [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 sicknesses, 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 (Table 5.3).

The Freedom from Hunger study found that the primary demands for health services include health education, health financing, and health products and services (Table 5.4).

As currently structured, the challenges MFIs may face in trying to incorporate radiology equipment would include corporate governance, capital investment, maintenance, and training. While some MFIs have reached a point of sustainability and have even gone public, many are in development stages and may not have the resources or management in place to take on a project of this magnitude. In addition, implementing a radiology program at an MFI would require medical technicians to either work at the MFI to maintain the equipment or train current staff to manage the equipment. The ongoing equipment maintenance costs, increased staff costs, and availability of doctors may all be challenges the MFI would have to overcome.

Table 5.3 Health expenditures according to market research and official data

MFI	Reported average monthly income of respondents (in US dollars)	Reported monthly average expenses for health services and % of income	Private health expenditure as percentage of total national healthcare expenditure (WHO 2004) (%)	Out-of-pocket expenditures as percentage of total private spending on health (WHO 2004) (%)
Bandhan (India)	$60–$100	$12–$20 (20 %)	78.7	98.5
CARD (Philippines)	$25–$250	Not reported	61	45
CRECER (Bolivia)	Not reported	Not reported	40.2	81.3
PADME (Bénin)	<$95	$24–$31 (33 %)	53.5	90.3
RCPB (Burkina Faso)	Not reported	–40 %	54.1	98.9

Data from Metcalfe M, Sinclair M. Enhancing the Impact of Microfinance: Client demand for Health Protection Services on Three
Continents. April 2008. Freedom from Hunger website. https://www.freedomfromhunger.org/sites/default/files/EnhancingImpactMicrofinance.Final_.pdf. Accessed April 20, 2012. Table 2, page 12

Table 5.4 Most common illnesses reported in focus group discussions and individual interviews

Country (MFI)	Most common routine (low-impact illnesses)	Most common serious (high-impact illnesses)	Diseases with most impact on women and children
India (Bandhan)	Cold, cough and fever, skin diseases, diarrhea, gastric (hyperacidity)	Cancer, stroke, cardiac disease, appendicitis, kidney problems gynecological problems, childbirth complications, gastric ulcers, gall bladder disease, asthma, typhoid fever, jaundice (liver disease), tuberculosis	Women: gynecological problems, childbirth complications Children: appendicitis, jaundice
Philippines (CARD)	Cough, cold, fever and flu, diarrhea, amebiasis, UTI, hypertension, skin diseases, rheumatism (arthritis)	Cancer, diabetes, stroke, lung problems, asthma, typhoid fever, tuberculosis	Women: female cancers; children: amebiasis, typhoid fever, diarrhea
Bolivia (CRECER)	Cough, cold, fever, skin diseases (scabies), diarrhea, UTI, gastric ulcers, dental problems, anemia, infectious childhood diseases (measles, chicken pox, etc.), rheumatism	Pneumonia, gall bladder disease, kidney problems, female cancers (breast, cervix, ovarian), accidents/ trauma, rabies, appendicitis, gastric ulcers	Women: anemia, gall bladder problems, cancer, complications of pregnancy and child birth, vaginal infections Children: pneumonia, developmental problems (teenagers), skin problems (scabies), anemia
Bénin (PADME)	Malaria, anemia, coughs, diarrhea/vomiting, high blood pressure, glaucoma, gastric ulcers, measles	Malaria, anemia, cholera, HIV/AIDS, complications from childbirth, typhoid fever, glaucoma, gastric ulcers	Women: complications from pregnancy and childbirth, anemia Children: malaria, stomach illnesses, anemia, measles
Burkina Faso (RCPB)	Malaria, coughs and whooping cough, high blood pressure, stomach pain, diarrhea, eye pain, skin diseases, dental problems, typhoid fever	Malaria, HIV/AIDS, meningitis	Children: malaria, meningitis, coughs, stomach pains, eye pain

Data from Metcalfe M, Sinclair M. Enhancing the Impact of Microfinance: Client demand for Health Protection Services on Three Continents. April 2008. Freedom from Hunger website. https://www.freedomfromhunger.org/sites/default/files/EnhancingImpactMicrofinance.Final_.pdf. Accessed April 20, 2012. Table 2, page 25

In addition, addressing the issues of how clients will be able to pay, whether by setting up insurance schemes, providing scaled fee services, or providing health loans, will be another hurdle the MFI would have to address. Other potential solutions would be hybrid efforts by MFI and corporations that provide mobile networking solutions, that could deliver health-care information as part of infrastructure development.

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 minicomputers, 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; consider that while using a mobile-based radiology services would require maintenance and training, the capital investment would be significantly reduced [15].

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

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 in great need. 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].

Maintenance and repair are two areas that are often neglected with donation of medical equipment. Considering many developing world hospitals have no trained technicians, and even fewer of those technicians may be trained in the maintenance of X-ray equipment, the required maintenance and repair may be challenging. Indeed, nearly 40 % of all medical equipment is out of service in the developing world, with a significantly higher rate (nearly 50 %) for X-ray equipment [3]. In other words, donating X-ray equipment usually does not guarantee an improvement in patient care. There are many alternatives to donation that might better serve the recipient hospital or clinic [4].

When considering a donation of imaging equipment to a resource-poor hospital, steps can be taken to improve the chances that your donation will be effective. This paper reviews the major considerations for donation 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 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 of these are often in limited supply in the developing world. In many cases, maintenance schedules are programmed into the machine, meaning that a service contract is required to keep the machine running, even if there are no repair issues. Electrical power and physical plant infrastructure will often exceed the capabilities of all hospitals outside of the capital, in many developing world nations. In short, donated MRI machines rarely,

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if ever, function for 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 highly resource-poor settings such as refugee camps and rural clinics with few problems [5]; however, this is not to say that donations of the 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 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 the 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 they 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. A 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 special 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, making maintenance very difficult.

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 a limited IT infrastructure and annual maintenance visits. So, a service contract is still required or advisable. 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) health-care equipment donations 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 surveyed donate broken medical equipment [10]. No American physician would consider the quality of an expired drug acceptable, yet 90 % of surveyed donors gave expired goods as donations [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 is 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 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 for a $1.5 million purchase price [3]. Extrapolating this to the developing world suggests that donating a $100,000 piece of imaging equipment gives the recipient hospital a $100,000 burden in terms of maintenance and repair. Even if the 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 (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 over a 10-year period (about 10.1 % of the purchase price per year).

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 (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 pieces 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 three 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, so the equipment's functionality is generally not restored.

Even a donated working unit may fail to reach the patient. Without technicians 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 more 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. Even for reliable equipment, such as mobile X-ray and ultrasound, at least a visit once per year by a qualified technician should be considered necessary.

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.

The donation of a working piece of medical imaging equipment from one US hospital to another US hospital would only save the recipient 50 % of the total cost of ownership. In the developing world, the cost savings is probably much less. In fact, the costs of shipping may wipe out all the cost savings from donation. 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, 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 at a minimum setting the machine to the frequency and power typical 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 putting 14–19 % of donated medical equipment out of service [6, 18].

With the exception of the smallest pieces of medical imaging equipment, shipping complexities and adaption preclude the direct donation of medical imaging technology from an individual, physician's 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, the hospital will need to be prepared to receive the equipment. This 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 completed history of 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 unit, the cost of maintenance of the equipment will exceed the cost of the equipment donation manyfold. 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 are no biomedical technician training programs in Cambodia at this writing. 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 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 in the medical use of the device. Unfortunately, training the technician on the maintenance of the equipment is a much less common adjunct. 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 service which is 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. Most donation coordinators should not expect the partner

NGO to provide service support. Likewise, older equipment may no longer be supported by the manufacturer, leaving the recipient hospital with nowhere to turn.

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. The effective clinical value may be nearly equivalent. Mobile imaging machines enjoy a lower cost of shipping and much lower costs of installation, and the units are more reliable and robust in a developing world.

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. A donation of an imaging system is a long-term commitment to financial and intellectual operation of a distant hospital's infrastructure in collaboration with that hospital's technical staff.

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7 Medical Imaging Safety in the Developing World

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Introduction

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 observed 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 "cook-book" 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 developing world context. 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*

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procedures refers to techniques that are generally available in most locations and includes projection X-ray imaging and ultrasound. *Advanced procedures* 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.

Context for Considering Medical Imaging Safety in the Developing World

There are several features of operating a healthcare facility in the developing world that present particular challenges regarding safety that might not be experienced in more developed regions. While this list is not exhaustive, such challenges include the following: (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 indications 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 that is 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 still other settings, ultrasound equipment had been donated but stood unused due to inadequate training on operating the probes or even a lack of acoustic gel to use with the device. Thus, in certain settings in the developing world, 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. Clearly, a lack of resources is a major issue confronting imaging in the developing world, and there are no easy answers to the problem of limited resources.

In many developing countries, medical services are funded and set up by governments, which unfortunately are often stretched thin by multiple demands for resources and are unable to meet the full need for medical services in the population. This situation has paved the way for competing private medical outlets to emerge. Private imaging centers compete with physicians regarding 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. Furthermore, the increasing penetration 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 developing world context, there is more likely to be a wide disparity in the types of imaging utilization between large cities and rural environments than in more developed areas. For example, in the USA, 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 the developing world context, 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 for there to be no advanced imaging (CT, MR, nuclear medicine) in regional medical centers serving up to a million people in under-resourced regions. 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 significant 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 the developed world, 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 MRI scan done in one region, the risk is likely to be similar to that in other regions. In the developing world, 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 the developing world.

One then faces the ethical dilemma of whether it is better to provide some medical imaging 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. We would simply point out that the reader may face a situation where limited resources will impact upon 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 one's 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 upward trend in the overall dose to the population from increased utilization of techniques such as CT imaging. These two factors highlight different ways in which ionizing radiation can pose a hazard. The first factor (radiation injury) 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.

Several recent 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 new 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 toxicities (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 injury, harm is caused to specific patients. More difficult to track are the 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 USA was 3.7 mSv/year, of which 14 % was due to medical imaging. By 2006, the average annual radiation dose to a person in the USA 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 0.3-s rotation time have opened the possibility for uses of CT in new and expanded applications such as cardiac angiography. Such high-tech imaging is often unfortunately not as readily available in the developing world, and as such, there will not likely be as rapid an increase in CT utilization as has been experienced in developed regions. While the overall increase in population dose from CT in developing regions is likely to trail that of the developed world, there is still a global concern for dose control from increasing utilization of CT.

The concern for patient dose from medical imaging is particularly important in pediatric patients. The use of imaging, especially in the emergency department, has increased in both adults and children. Overall, about 3.5 billion examinations using ionizing radiation have been performed per year globally. Approximately 10 % of all imaging examinations in the USA are performed in the pediatric age group [5]. The use of CT has increased over the past two decades in the emergency setting [6], and in one large population, nearly 43 % of children underwent evaluation using ionizing radiation in a 3-year period, and nearly 8 % of the study population had a CT over the same period [7]. Doses for some modalities, particularly CT, can be quite high when compared to exams such as chest radiography.

The pediatric population is a relatively more sensitive group than the adult population due to more vulnerable tissues 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 [8, 9]. Finally, there is a recognized elevated responsibility for the protection of children. Of note, recently, the first connection between CT examinations and increased risk for both leukemia and brain cancer was reported, and this was discovered in children [10]. 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 a 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 if the patient suffers from that condition.

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 to 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 afterwards 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 Ministry 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 ensuring the appropriate level of understanding regarding 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 USA 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 USA is 50 mSv/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 USA, 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 postnatal 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. This example indicates 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 [11]. 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 of 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 to staff members (such as cleaning staff) who may not be adequately informed of safety hazards.

In all of the considerations for protections of 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 typically the recommended beam filtration amounts in the USA 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 light field used for patient positioning be adequately aligned with the actual exposed image area. A medical physicist can do an alignment test to test 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 some to image contrast but also leads to photons that are spread across the detector that add 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 way in 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 0 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 overexposure 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 procedures. 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 [12–15]. In general, if image quality is inadequate, then radiation dose may be increased by raising exposure factors to compensate for poor contrast-to-noise ratio 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 online, 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 low-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 is widely recognized as one of the most valuable tools in medicine [16, 17]. 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 [18]. 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 [19–23]. Safety in CT also requires adherence to appropriate infection control, patient monitoring, and minimization of contrast-related events such as contrast reactions and extravasation [24, 25]. 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 [24]. 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 and 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 [26].
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. Such shields in CT scanning are controversial, but radiologists often use these in both adult and pediatric patients [27, 28].
7. Finally, and as important as any dose management strategy, consider 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 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 electrical 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. 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. A good general reference for MR safety is a paper sponsored by the American College of Radiology [29].

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 as follows: 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. 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. 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.

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 [30] and is also maintained online (http://www.mrisafety.com/). Having the patient remove all clothing in a dressing room and putting on a hospital gown without metal fasteners is another part of the safety effort. The clinic must be designed to have cupboards to secure the 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 specifically 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 so 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.

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 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.

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 should be documented diligently 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 using 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 receives 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 nonradioactive 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 should 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 a 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 clothing separately from that of other people for a few days.

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 [31].

Fetal imaging obviously 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 [32, 33].

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.

Communicable Disease Safety and Imaging

The radiology department is an area where hygiene, and consequently 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 as 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 physical 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. Oftentimes, 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 will be 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, 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 USA. In regions where tuberculosis is common, the use of portable HEPA filtration units and appropriate personal protective equipment should be employed. 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. Monitoring includes external review to assure sufficient adherence to institutional infectious control policies and reporting of metrics as part of departmental performance. Various articles listed below [34–37] 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 oftentimes 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 caring for the patient 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. Oftentimes, 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) examinations 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 cause increased 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 [38, 39].

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 a developing world context. Often, the devices encountered may be significantly less advanced than the more modern counterparts in the developed world. 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 situations 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 anytime something is seen that does not seem right. It is everyone's responsibilities to work cooperatively to ensure safety.

Conclusion

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 [40, 41]. 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.

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

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Information Technology in Global Health Radiology

8

Brian S. Garra

Introduction

Medical diagnosis in remote and under-resourced areas of the world has not kept pace with modern medicine as practiced in developed, industrialized countries. While medical diagnosis in under-resourced countries relies heavily on the physical examination, diagnosis in the developed countries focuses more on the combination of the patient history, medical imaging, and laboratory test results. Many tropical infectious diseases do not require imaging for accurate diagnosis, but imaging is nonetheless very useful, particularly in identifying complications of the primary disease processes. Imaging can, however, be critical to the diagnosis of a particular disease as is described elsewhere in this text, including malignancies, maternal-fetal conditions such as placenta previa, and in the setting of trauma or acute medical emergencies such as appendicitis.

Not only is lack of access to imaging a critical issue in developing countries, but in the small number of clinics and hospitals in which imaging can be performed, there is often a critical shortage of physicians, or other personnel trained to interpret the images. In the absence of reliable high performance electronic data transmission, the images must be physically carried to the site where interpretation will be performed. This creates an additional barrier to timely diagnosis and treatment.

The goal of this chapter is to explore strategies for accomplishing the basic tasks of effectively transmitting images from the point of acquisition (a low resource setting) to someone who can interpret them, and then providing a way for the report to get back to the treating healthcare worker. The current status of the information technology (IT) infrastructure will be reviewed along with some methods to most effectively harness. The available infrastructure a brief discussion of some strategies for future improvements to the imaging IT infrastructure will conclude the chapter.

Current Status of IT

Even though the developing world lags far behind the industrialized world in advanced information transfer, some electronic technologies, such as cellular phone technology and basic Internet connections, are widespread. In fact, many developing countries did not install wired telephone service when it was the principal communication technology available, and as a result they have effectively bypassed this infrastructure-intensive stage in development in favor of the more modern

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and, less expensive wireless technologies such as Wi-Fi (wireless Ethernet) and cellular phone systems. Wireless coverage, however, is extremely variable in its extent and quality. Data rates are commonly at or below 10 kb; this is equivalent to telephone data transmission speeds in the USA during the early 1980s. The cost is quite variable with some countries providing service at rates lower than in the USA, while others charge higher prices. Since incomes are far lower in under-resourced areas, only a wealthy few can afford cellular service or Internet even when it is available.

Using Existing Electronic Infrastructure

Electronic transmission of imagery is important in low resource regions for the following reasons:

1. Photographic film and chemistry is becoming increasingly expensive
2. Poor local expertise for image interpretation
3. Poor roads and costly fuel make physical transport of film or paper images exensive and unreliable
4. Remote monitoring of studies, maintenance, and training can be better accomplished using electronic image and data transfer.

So given the need to use electronic transmission for medical imaging, how can the infrastructure be used most effectively? Several basic principles apply, all revolving around the idea of using the limited resources of power and data communications as efficiently as possible. The basic principles are as follows:

1. Limit communication bandwidth use. This means the images must be compressed so that less data needs be transmitted. Although some have maintained that no image data loss is acceptable, in practice many if not most “diagnostic quality” images reviewed remotely are slightly degraded compared to the original with no clinically detrimental effects. Many high-quality “lossy” (compression causing data loss) compression schemes are available.
2. Avoid the need for constant use of the network connection. Applications such as “cloud”-hosted applications that require constant connection not only must transmit and receive a lot of data, but they may not even work if the network link is only intermittent or unreliable.
3. Plan for frequent periods of network unavailability and/or severely constrained data transmission rates. Even in the USA, “dropped” calls and slowdowns of data rates are the rule; in under-resourced areas, these problems are magnified greatly. Software that can still function with an intermittent connection and adjust to fluctuating data transfer rates is critical. To efficiently compensate for an intermittent connection, software that monitors the data transfer and begins where the transmission was interrupted, rather than starting over from the beginning, is necessary but hardly ideally suited. Also, software that adjusts data packet size, so that smaller packets are sent during times of network instability, can mean greatly increased transmission rates.
4. Remember power limitations. If the clinic is in an isolated region where solar power is being used, power may be very limited, and the power consumption of all needed devices should be checked while operating at maximum activity. Even if power lines supply the site where equipment is to be placed, interruptions in power may require some battery or generator backup capability. Accurate knowledge of power consumption will make it easier to determine the correct size of uninterruptible power supply (UPS) that is needed.
5. Avoid costly software and hardware. Higher initial hardware (computers, modems, Ethernet switches, wireless network adapters, etc.) cost limits the amount of equipment that can be purchased. Higher-priced equipment may also result in higher-cost repairs. Luckily, the cost of hardware solutions is rapidly declining and slightly used, or refurbished equipment is readily available at large discounts. Similarly, software costs must be held in check. Look for open-source software that has the required functionality and has received favorable reviews. Checking with various software vendors to inquire about software donation or discounts for charitable purposes is an excellent

strategy. Another strategy might be to look to other nonprofits who might be using similar software and propose lowering the cost for all by sharing software costs for multiuser licenses. Perhaps the best solution to adopting a very expensive software, or one that requires customization and maintenance, is to contact the vendor regarding the establishment of an ongoing partnership wherein they would gain positive publicity in return for ongoing software updates and support.

6. Weigh reliability against cost. High reliability components can be extremely costly, routinely double the price of alternative less durable components. Weigh the cost of having more reliable components against the cost of having a replacement on hand in case of a failure, account for the time and expertise required to make the swap. Since medical imaging is being offered in many cases as a new service, some lag time will probably be well tolerated by the people being served since they are accustomed to having no service at all. In most cases, replacing a low-cost component is a better option than buying a high-cost component with higher reliability, since failure rates are generally quite low for both, depending on the component. Situations where emergency imaging is frequently being performed or where no one is available to swap out components may be exceptions to this suggestion.

Seven Key Information Technology Steps to Deliver Medical Imaging to Remote and/or Low-Resource Environments

Step One: Select and Deploy an Imaging System

Extensive detail regarding the selection of a particular system or modality is outside the scope of this chapter and is covered elsewhere; however, a few key considerations in terms of information technology are relevant. Generally, there are several options for an imaging system, depending on many factors. However, if the key consideration for a particular imaging project is that the selected modality be low cost and consume few resources, three feasible solutions currently exist: a small ultrasound system, a webcam/cell phone camera for optical imaging, or a basic radiography (X-ray) system. The webcam or cellular phone camera is the lowest cost and draws the least power, but also provides less diagnostic information than a system that can look inside the body (however these options can be used to take photographs of hard copy imaging studies). Small ultrasound systems may be available for $8,000 or less (Fig. 8.1) and can draw relatively little power (75–100 W). A radiography system is the most expensive option in terms of cost (about $100,000 for both X-ray machine and a digital receptor system

Fig. 8.1 Three small ultrasound systems ranging in price from about $50,000 to $2,100

including the computed radiography plates and reader), and it draws considerable electrical power. There is also the issue of shielding from the emitted X-rays. If film and chemical processing are used instead of a digital receptor, the operating costs increase dramatically since film and film-developing chemicals are becoming more expensive and suppliers harder to find as fewer and fewer people use the outdated technology.

Other key requirements for any imaging device are that it being easy to use and maintain, and that it being able to transfer images electronically. The DICOM [1] (digital imaging and communications in medicine) standard 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 DICOM image format is similar to the Tagged Image File Format (TIFF [2]) used for nonmedical images in that information about the image and how it was created resides in "tags" located in the header. Each tag carries some specific form of patient, instrument, or image format information. For example, DICOM tag 0010, 0010 titled "PN" contains the patient name and can have a maximum length of 64 bytes [3]. The DICOM protocols and format are the standard for image transfer from medical devices, but unfortunately many inexpensive ultrasound imaging systems do not include support for DICOM. It can be added if the manufacturer is willing, since there are a number of freeware toolkits such as DCMTK [4] that can be used to help implement DICOM on a specific system.

Other transfer formats could be used including transfer of JPEG and/or AVI files, but the appropriate patient identification information would have to be transferred as a separate file, raising the issue of having unidentified or misidentified images should the identification file get corrupted or deleted. Also, such a custom transfer process could not be expected to work correctly for any devices other than the few it was created specifically for. Once implemented, a DICOM protocol should work with any other device also using DICOM.

A physical means of transporting the image data to the next step in the image transfer chain is also needed. Most systems support wired Ethernet and universal serial bus (USB). A rapidly expanding group of devices also support wireless Ethernet, often termed Wi-Fi. Wired data transfer from the imaging device is preferable because of its higher speed unless the device must be portable. In the case of a portable device, transfer via Wi-Fi or even a 3G or 4G cellular network may be acceptable. Exporting the data to a USB hard disk or other memory device, and then physically transporting the memory device to a display workstation or the next data transfer point, is an old-fashioned but reliable way to make transfers. This is an excellent backup method even if a wireless or wired network connection is normally used.

Step Two: Apply Data Compression

The next step in transporting an image or images is to apply data compression. The purpose of this step is to conserve bandwidth as the image is transmitted to the location where it will be interpreted. If that location is local and within range of Wi-Fi, then bandwidth may not be an issue, then either no compression or lossless compression may be employed. A number of lossless compression schemes exist, and they are able to achieve a modest compression level of approximately 2:1 (meaning that the compressed data is ½ of the uncompressed).

For transmission over longer distances, much greater compression is usually required as either maximum data rates may be very slow (as noted above) or high data rates could be achievable but would be very costly. Modern lossy compression schemes employing variants of MPEG-4 are extremely useful for compression of series of images such as in CT and MRI (not radiography) where one image is similar to the next. The compression efficiency is due to the fact that the compression algorithm can make use of the adjacent pixels in the same image and in adjacent images to help reconstruct what a given pixel in the

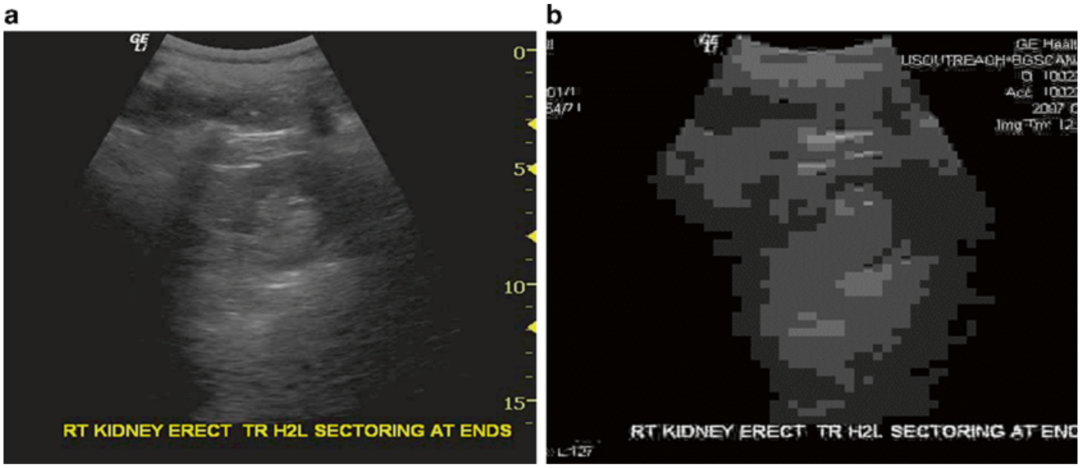

Fig. 8.2 Comparison of video compression to single image compression. A transverse image of the right kidney appears nearly identical to the original when compressed by XviD to a total file size of approximately 400 kB for 40 images (**a**). Images of the same series when compressed individually to the same total file size using JPEG compression yield images that are not even recognizable as ultrasound images (**b**)

image must be. Other image compression protocols such as JPEG can only use nearby pixels in the same image. Recent coder-decoders (CODECs) that are efficient in encoding series of images include MPEG-4, part 2, DivX, and XviD. These are much more effective protocols than JPEG2000 or JPEG; they can compress 40–80 MB video files down to only about 300–400 KB while producing images that are almost indistinguishable from the original [5] (Fig. 8.2). Newer CODECs such as H.264, MPEG-4 part 10 (AVC), and Dirac are more effective still, producing files about half the size of MPEG-4 part 2 [6]. The new High Efficiency Video Encoding Codec, HEVC (H.265), is expected to cut the data rate and file size by another 50 % compared with H.264 while producing little discernible reduction in quality [7]. In practical terms this level of compression could result in an entire series of CT or ultrasound images being compressed down to about 100–200 kB, half the size of a single image.

Step Three: Transmit Data

Several modes of electronic transmission are potentially available in low-resource regions. Cellular network transmission is widely available although speeds can be quite low. Cellular transmission capability can be built into the imaging device, but it is often more practical to send the data to a network gateway, an inexpensive laptop PC connected via cellular modem to the network. This prevents the imaging system from getting overloaded with transmission and retransmission tasks in the event of network instability and also allows upgrading the transmission software and hardware without changing the imaging device. It also allows for the addition of imaging devices that use the same gateway. Communication between the network gateway and the imaging devices can be by wired or wireless Ethernet. Both options are low cost and low maintenance. Wireless allows the imaging device to be moved around more conveniently while leaving the network gateway in one place.

Wired Internet service is available in many low-resource environments and is a faster alternative to cellular when the cost is reasonable. Data rates of between 125 Kbps and 1 Mbps may be expected. For really remote sites, satellite links can be used, but the cost for such a connection may be very high and is probably not sustainable in the long term. A satellite connection that can be turned on only when needed could be a solid backup system, but negotiating a plan suitable for intermittent use at a reasonable cost could be challenging. Some additional useful characteristics for a network gateway are:

1. Ability to back up studies to CD, DVD, or USB flash drive for "sneakernet" manual transfer to a reading site should the network connection be interrupted for an extended period.
2. Ability to connect to an external antenna and/or signal booster to increase signal for borderline signal reception areas.
3. Low power consumption. Less than 20 W is desirable and achievable for gateway, modem, and switch/router combined.
4. Adequate storage for queued studies awaiting transmission and as a backup location for studies. In addition to the system storage, a 500 GB - 1.5 TB USB-powered external drive is inexpensive, requires low power, and provides massive backup capability.

In addition to the Internet connection, suitable software will be needed to perform the data compression, transmission, and decompression. For regions where network instability is the rule, auto-restart of the modem software as well as selective retransmission of only those data packets that failed to be received is useful. Some modems advertise automatic restart as a feature, but most often one will have to experiment with various models to find one with appropriate software. Some modems have freeware that will perform auto-restart. Basic transmission of data can be accomplished by a number of file transmission programs. The Unix utility *rsync* can be used, for example, to ensure that data files not already present on the receiving system are transferred, but this utility (also available for Windows) will resend a complete file if data flow is interrupted during transfer. This is not ideal for a network subject to frequent interruptions such as many cellular networks. So a more sophisticated transfer that (1) retransmits portions of files not properly received, and (2) monitors network performance to adjust packet size and minimize packet loss during transmission, is desirable. Additional features that are useful if not critical are:

1. A logging utility that sends the logs periodically to the receiving site for evaluation
2. An easy-to-use graphical user interface with an equivalent command line interface that can be used remotely using minimal bandwidth—or an alternative method of issuing remote commands to the software (and receiving responses) using minimal bandwidth
3. Detailed error messages that inform the system administrator of likely causes of transmission failures
4. Automatic correction of common problems with data transmission
5. Email transmission of warning messages regarding transmission failures, number of images awaiting transmission if it exceeds a certain threshold, or other system problems

Step Four: Assure Access to Images by Qualified Interpreters

The physicians or other healthcare workers assigned to interpret the images may be local, regional, or remote to the site where images are being acquired. Local interpretation can be accomplished by connecting a reading workstation to the imaging source by an Ethernet connection or wireless Ethernet connection. A wired connection is faster and with modern equipment gigabit Ethernet (approximately 1 Gbps transmission rate, known as 1000baseT[1]) is feasible at low cost if the distance to the workstation is short (<100 m) using Category 5, 5e, or 6 Ethernet cable. For longer distances up to 500 m or more, 1000baseSX Ethernet using fiber-optic cabling is an option but is of higher cost and may not be readily available. Other versions of gigabit Ethernet using fiber-optic cables can communicate over distances of 70 km or more.

On the software side, the transmission protocol for the local (and remote) connection should be DICOM, since the DICOM standard provides

[1] There are actually two standards for gigabit Ethernet transmitted over copper wiring, 1000baseT which has a more complex signaling scheme and uses four wires in the cable for signal and 1000baseTX which uses a simpler signaling routine and only two wires to carry the signal. 1000baseT can use either Category 5, 5e, or 6 cable, but 1000baseTX must use Category 6 cable. 1000baseT is dominant, but many 1000baseT products are mislabeled 1000baseTX. One can buy a product advertised as 1000baseTX, and it will probably work with Category 5 or 5e cable.

Fig. 8.3 A simple two-screen workstation consisting of a laptop computer connected to a single 22 in. 1080p external monitor. The larger monitor is used for image display and the smaller for text

proper patient and study identification. All high performance image viewing software supports DICOM, making daily workflow much easier. This means that the imaging device should support DICOM. The degree of DICOM support is listed in a DICOM conformance statement, but at minimum the imaging device should be able to connect with a DICOM service class provider (SCP) and transmit images with a properly formatted DICOM header, correctly windowed and calibrated for image measurement on the reading viewer or workstation.

For a local reading station, having DICOM viewing software and a DICOM server to support reception and storage of the images is the optimal approach. Both the server software and the viewer can reside on the same computer. A large number of vendors supply DICOM workstation software at varying prices, and a number of freeware packages exist. Some of the freeware packages differ in that they are not cleared by the FDA, whereas others offer limited functionality and hardware support, often too limited to be of great use. Potential sources of DICOM workstation freeware for Windows include ClearCanvas [8], K-PACS [9], and Onis [10], and for the MacIntosh, OsiriX [11] is a common choice. In some cases, a viewer alone can be used, but storage of cases in this situation is either nonexistent or very limited. A number of vendors also offer DICOM toolkits to help with building new DICOM applications. It may be possible to partner with a PACS vendor and obtain donated software for specific projects.

The local reading workstation may simply be a laptop running Windows or it may be a larger system with multiple monitors. Adding a single high-definition (HD) monitor to an inexpensive laptop creates a simple and cost-effective two-screen workstation with one screen for the patient list (the laptop screen) and another for the images (Fig. 8.3). A minimal system consisting of a netbook plus a 21 in. (or larger) HD monitor will perform adequately provided the system is upgraded from Windows 7 Starter (which does not support two independent monitors) to Windows 7 Home Premium or higher and the system is upgraded to 2 GB of memory. A faster system with more memory would of course be more desirable since entire image sets are often held in memory while viewing (to improve responsiveness). For viewing large radiographs, a slightly larger monitor (23–24 in.) rotated to portrait mode may be needed. A monitor with an in-plane switching (IPS) LCD panel is preferable to a "TN" type panel to avoid color and intensity shifts with changes in head position and to provide better gray scale. To add additional monitors to a laptop-based system, inexpensive USB video adapters capable of supporting 1080p or higher resolution are inexpensive and readily available.

For images sent to a regional or national reader(s) for interpretation, electronic transfer has major advantages. Images would be uploaded to the Internet or some trusted wide area network (WAN) and transferred to a DICOM server either at a regional center with high-speed connectivity or to a server located at the site of interpretation. The reading physician would access the DICOM server using a DICOM client workstation for that server or another third-party DICOM viewer, and reports would be returned to the ordering provider by phone, email, or text message.

The advantage of using a server located in the country where the images are acquired is that the system is not dependent on a communication link to the outside world, but the disadvantages include greater difficulty maintaining and managing the server as well as vulnerability to power instability. If the local Internet/WAN is inoperative, then images must still be sent manually via courier or must be held until the network is again operational.

Another option is locating the DICOM server in another country with power and communication infrastructure stability. The readers could access the server via the Internet to interpret the studies. This would work for regional, national, and international readers but is dependent on reliable Internet communications to the outside world for in-country readers. Since readers in multiple time zones could be recruited, 24/7 coverage might be easier to implement and maintain compared with only in-country readers. Also, the pool of potentially qualified readers is much larger. For this type of implementation, hardware requirements may be decreased since qualified international readers in urban areas would likely already have a workstation that would be usable, especially if the PACS software is all web browser-based or "zero footprint," meaning that no client software resides locally at all—the browser is used and configured for all needed functions.

The disadvantages of locating the server in another country include the problem of local access to images if the international data link is down. This can be handled by having a backup system for transporting images to local or regional interpretation sites. Another disadvantage is management of readers scattered all over the world with varying languages and "styles" of interpretation. Just qualifying, training, and performing QA on such a diverse group is a daunting task because of its complexity. It might be possible though to limit the interpreting specialists to those speaking a few of the most commonly spoken languages and still recruit a large number of readers for studies.

Step Five: Provide for Reporting of Results

A reliable system for reporting results of imaging studies is needed for all situations except the local situation, where the treating physician actually performs or interprets the imaging all at one location. If the interpretation of the imaging study is local (meaning the same clinic or a nearby clinic), a verbal consultation, telephone call, or a handwritten note will suffice. This is not optimal for tracking results over time but it works and is inexpensive. For studies interpreted in the same region (e.g., the same district), face-to-face conversation is usually not feasible, but a telephone call and a written note carried to the requesting provider will work. This is inexpensive, but the report may not reach the requesting provider in a timely fashion. The alternative, making multiple telephone calls to referring providers, can be excessively time-consuming for the image reader.

Email and text (SMS) messaging are technologies that are available even in under-resourced areas because of the ready availability of cell phones and the low cost of many laptop and netbook computers. The problem with both may be lack of security, but even without a high level of security, this method may be a far better option than the slow and limited alternatives. Security can be increased by sending a very limited message by text or email that includes a link to a secure server that contains the complete report and possibly some example images. Email and text messaging are vulnerable to network outages, but regular telephone and hand-carried messages can always be used as backup in case of a cellular network failure.

A PACS-based reporting system can be implemented although this is often a feature of higher end (more expensive) PACS. The reporting system may include voice recognition, structured reports that can be easily translated, and recording of changes in reports including who the report was sent to. A PACS-based system may require more equipment (such as a limited PACS workstation) at the report-receiving end to obtain a complete report, but most also send basic reports as text messages, email, or voicemail. Many systems also record receipt of the report message electronically, and this feature could be made available in low-resource areas since it requires nothing more than an operational cell network to transmit the messages and confirmations. A search of the Internet for the terms PACS, reporting, and tracking will indicate vendors with capacity to provide these services.

Reporting by international readers will be limited to email, texting, and PACS-based systems. Phone calls are possible using inexpensive services such as Skype, and the various instant messaging (IM) services that also offer phone calling or inexpensive voice over Internet (VOIP) such as Vonage or Magic Jack. Telephoned reports will often not be practical however because of time zone differences between the reader and where the imaging study was created. On the other hand, having international readers can be a major advantage for covering night hours if nighttime imaging is part of the service plan provided. Readers that are four or five time zones away can cover the night hours during what for them will be regular day or early evening hours. PACS-based email systems and email alone may work best because of the variable complexity in setting up low-cost international texting.

A significant problem for international readers is proper translation of their report into a language that can be understood by the requesting provider. At this stage automated Internet-based translation for medical terminology is not mature enough to be of use for translating free-form (i.e., dictated or typed) imaging reports. Structured

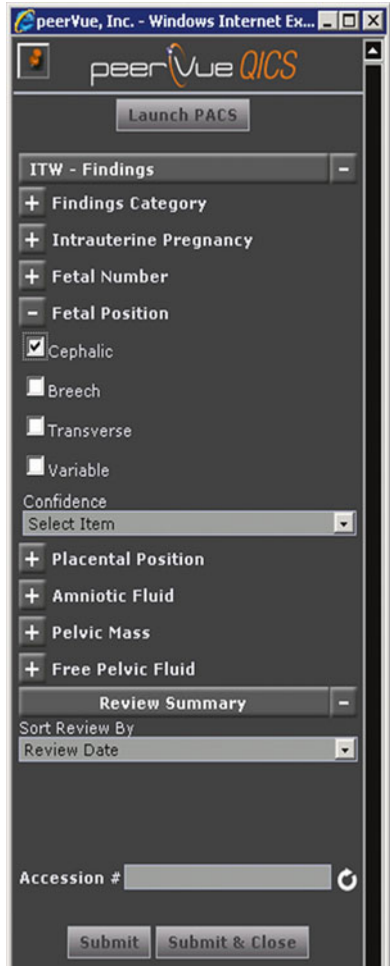

Fig. 8.4 Example of online structured reporting. In this implementation, the user clicks a pull-down menu from the PACS, and a findings window opens allowing the reader to click of various possible diagnostic findings. The example in the figure is for obstetrical ultrasound in which the reader has identified the fetus as being in head down (cephalic) position

reporting can help with this problem since the report can have a limited predefined vocabulary that makes automated software-based translation much easier. For example, a structured report for a right upper quadrant ultrasound that only has four diagnoses for the gallbladder could be created. The diagnosis options might be "normal," "benign gallstones," "cholecystitis," and "other." The reader picks one of the diagnoses by checking a box on the structured report menu displayed on the PACS workstation (Fig. 8.4). The diagnosis is automatically translated into the proper

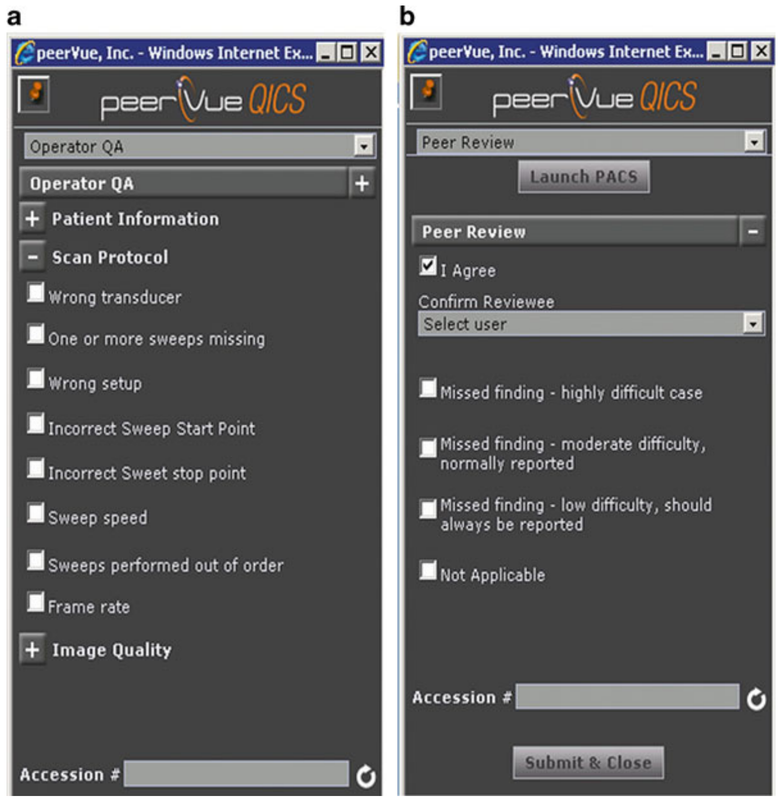

Fig. 8.5 Quality monitoring. Common technologist errors can be entered by the interpreting physician for each case (**a**), and interpreter peer review can be accomplished using the standard American College of Radiology (ACR) categories for missed findings (**b**). Cases may be automatically or manually selected for peer review. The reviewer may then agree with the findings or select another category if there is disagreement

language and sent (along with the diagnoses for the other organs in the right upper quadrant). The structured reporting menu can be pre-translated to display in the preferred language of the reader. Freeware-based translation programs such as Google Translate can be used to lower the cost of the translation process.

Step Six: Provide for a Quality Assurance (QA) Program

All countries want their citizens to have the highest quality health care possible in their environment. So it is important to develop a QA program that properly monitors performance of operators, readers, and equipment while not consuming large amounts of resources. Traditionally errors in technique or interpretation have been handled informally by personal communication and sporadic case reviews, but governments are moving toward requiring ever more stringent and systematic approaches. The extensive monitoring of performance required by regulators today is well handled by computerized systems. Hard-pressed clinical workers will certainly welcome any automation of the tedious and unrewarding task of peer review and quality monitoring. Many PACS systems have rudimentary QA modules built in, but add-in QA modules that provide greater functionality and reporting capability are becoming very popular. Some QA modules may be configured to allow outcome reporting by the treating physician or others who are following the patient. This can be very helpful for outreach projects where continued funding may depend on showing positive results (Fig. 8.5).

Step Seven: Provide for Network Maintenance and Redundancy

A feature of networks in developing countries or under-resourced areas is less reliable, since many are mostly wireless cellular networks subject to variable signal transmission quality. In addition, even the wired backbones of such networks may be vulnerable to outages lasting days or even weeks. Therefore having redundant methods of transporting images and reports is important. For example, one might have the primary network running over a wireless cellular data connection with a backup transmission system being a second cellular network, or even a shortwave radio link created from the point of image generation to a site that has wired Ethernet or to a primary interpretation site. The secondary backup system would be having a courier carry a USB flash drive to the interpretation site. It is important to recognize that 24/7 access is something that has never existed in many under-resourced environments, so system downtime will be more readily accepted by the patients and physicians than it would in a well-connected environment where downtime is rare.

No matter how reliable the network, problems with transmission will occur, so it is important to have the ability both to remotely monitor performance and to have a trained individual who can both troubleshoot and repair problems. Having a person conversant with the local languages is helpful in fixing problems on site, and it is ideal for larger networks consisting of several image acquisition locations. A person who can handle power problems (i.e., failure of a generator or solar array) in addition to pure network problems is ideal.

With respect to hardware components including computers and monitors, inexpensive small computer systems make the replacement of systems a better option than repair of these systems. Preconfigured spares can be placed in the region being served to enable rapid correction of hardware problems. The pretested and preconfigured spares may also be used to help diagnose network problems. To improve reliability and lifetime of electronics, dust control and cooling should be monitored. Simply covering systems with a clean cloth when not in use can be very helpful, and using cooling fans can improve cooling dramatically in high-temperature environments. Humidity control would be helpful, but it is not practical in most low-resource environments.

As mentioned previously, open-source software/freeware is a low-cost but reasonably reliable option for software. Support for such software is often informal via the Internet, but having high-cost software is no guarantee of improved reliability, since support for the software may not be available in remote under-resourced areas.

Data and System Security and Privacy

Ensuring the security of the imaging systems and network must be provided as part of any comprehensive plan or program to provide medical imaging technology. Specifically, privacy of patient data must be safeguarded and is expected from any provider permitted to operate within their borders. For a local imaging system at a single clinic, the traditional method of recording the patient information on the images and keeping all records secure by locking up both paper-based and digital records should suffice. The clinic may or may not keep a backup copy of the patient medical record if it is paper based, but for electronic data, including images and any reports, keeping a backup copy on a separate (secure) hard disk is good practice (a backup data drive can be very inexpensive given the low cost of high-capacity external USB disk drives).

In general, a system of backing up all electronic data collected during each day's activities at the end of the day or beginning of the next day is recommended; the backup software built into modern Windows computers should be sufficient for backup of both the system files and incremental backup of the data files. Time should be invested on the part of the designated system maintenance person(s) in learning how to use the software and developing a standard operating procedure for periodic backups and recovery of data or the operating system, should it be needed. A separate backup of the images and/or reports that can be accessed by medical personnel without special training may be useful as a secondary system. All backup hardware should be stored in a locked and safe area away from temperature extremes at a location or building different from the location of the main data archive.

Workstations and imaging equipment should be protected from theft by physical security measures such as locking cables, computer case locks, and in some cases, personnel. Access to the workstations and electronic databases should be controlled using "strong" passwords (i.e., more than eight letters with at least one capital letter, one number, and one special character such as & or ?) and Wi-Fi access to any computer systems should be disabled unless actively used for image or data transfer. Consideration should also be given to disabling unnecessary USB ports (but this may not be possible if the ports are used for backup or other peripheral hardware, such as printers).

For regional, national, and international imaging networks, the status of the actual network (cellular, broadband, or Internet) used to transfer images is uncertain, and some form of data encryption during transfers will probably be necessary. The most common approaches are to use a virtual private network (VPN) or transport layer security (TLS) which is also known as secure sockets layer (SSL) [12]. A VPN may securely connect an individual to a network or one network to another. A VPN creates a secure link by encapsulating the data using one type of protocol while transporting it using a different network protocol (called "tunneling") and adding data encryption. A number of different VPN implementations have been described [13] including Internet Protocol Security (IPSec), TLS, Datagram Transport Layer Security (DTLS used by Cisco AnyConnect VPN), Microsoft Point-to-Point Encryption (MPPE), Secure Shell (SSH), and others. A VPN can be very secure, but precautions must be taken to ensure security by protecting usernames and passwords by encryption if they are stored, and by implementing a secure method of user authentication. One potential problem with a VPN is a loss in performance that often occurs unless the VPN is very carefully optimized. Even an optimal VPN may decrease performance by increasing network overhead by 10–15 % and by increasing network latency [14].

TLS may be used to protect an entire network stack producing a VPN, but when TLS is implemented to protect a web server, the resulting system connections are designated HTTPS (hypertext transfer protocol secure). An HTTPS connection encrypts the entire underlying HTTP protocol including the request for a web page, query parameters, header, and cookies. Should the encryption key for an HTTPS link be compromised in any way, it may be revoked. Newer web browser versions of Internet Explorer, Chrome, Firefox, and Opera implement the Online Certificate Status Protocol (OCSP) to verify that the certificate has not been revoked. HTTPS may require client authentication allowing access to be limited to authorized users. While HTTPS is generally very secure, sophisticated software may be able to infer certain personal information based on the packet sizes being transmitted without knowing their contents [15]. This type of security compromise can be defeated by correct design of web applications being accessed by HTTPS. An HTTPS connection typically does not slow data transmission significantly, which may make it the preferred method for data-intensive traffic such as image transfer.

To further protect patient privacy, partial de-identification of the patient images, history, and reports can be performed prior to transmission. The most common example of this is use of a patient code in research studies such as "research patient 1" which is linked to the actual patient identification information on a master data sheet held by the research study coordinator. All other researchers have access to the data gathered from the patient, but cannot identify the patient information without access to the master data key. This differs from completely de-identified data where the link to an actual person has been lost or is otherwise not available. For patient care, some organizations implement partial de-identification by keeping the master data key at the site where images are created and giving the patient a card with their patient code. This way only the person creating the images or the patient will be able to identify their images or the corresponding reports. If the patient is sent to a hospital for treatment based on images taken, the hospital uses the patient code to find the appropriate reports sent as an email with links. Without the patient code, someone accessing the reports and images would at most be able to see them but would not know who the images came from. This technique strikes a reasonable balance between privacy protection and easy data access.

The Future

The future of imaging in low-resource environments is very bright. 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 are already so low that they are hardly a factor in project budgeting. New and still somewhat expensive technologies that could help in the expansion of medical imaging include solar power, satellite communications, "cloud"-based software and storage, and more capable cell phones for reports and reporting of patient follow-up.

Solar power is already widely available and is an easily adoptable power source for a field project, or in a remote country without reliable electrical infrastructure. For example, a field setup for ultrasound imaging was assembled by the imaging-based nonprofit "Imaging the World" which draws only 75 W while scanning and sending data; this amount of power can be delivered by portable solar panels that can be packed in a carry-on suitcase. High-output solar panels are still somewhat expensive, but the continuing advances in solar panel technology combined with the large number of competing manufacturers will likely cause prices to continue downward [16].

The practical and economic outlook for satellite communication is less certain; certainly, the trend in prices appears to be downward, which is likely due to lower costs for competing communication technologies and decreasing satellite launch costs due to low-cost competitors such as Space-X entering the launch vehicle market. Satellite communication is not critical for everyday use, but provides a solid backup option in case of failure of the primary communication system. New variants of Wi-Fi make the building of mesh Wi-Fi WANs, which make use of many small Wi-Fi routers, a possible option in the future. These trends plus continuing advancements in image compression technology will make it ever easier to transmit large image sets.

"Cloud"-based PACS systems, which run on typical web browsers and consume little in the way of local computing resources have advantages, and the implementation strategies are promising. The main advantage is, in the presence of a reliable Internet connection, nearly all "computing power" and storage space is offsite. This strategy may lead to reduced costs of remote image storage and allow individuals the ability to view and interpret images from virtually anywhere.

Finally, the capability of cell phones in under-resourced areas is rapidly increasing. As new low-cost "smartphones" proliferate, the ability of health professionals to receive patient information and to report on patient outcomes (including follow-up) will improve greatly; however, this is dependent on the availability of appropriate software to organize this information.

Conclusion

In conclusion, these and other improvements in information technology infrastructure will make it much easier for any imaging model intended for rural and under-resourced regions to be successful. Further research and objective evaluations of new field implementations 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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9 Technologists Role in Global Health Radiology

Jonathan R. Mazal and Christopher B. Steelman

Introduction

As international outreach organizations continue to work towards successfully increasing accessibility to medical imaging services in resource-limited settings around the world, there is a growing demand for appropriately trained imaging professionals. However, with a scarcity of qualified personnel locally available to operate medical imaging equipment, technologist volunteers from developed countries may be best positioned to offer medical imaging assessment and training in the developing world. This chapter will discuss the various roles which radiologic technologists are delegated as members of an international radiology outreach project team, as well as considerations that should be understood prior to conducting related tasks.

Didactic Education and Clinical Training

Regardless of an individual's prior experience in developing and implementing lesson plans pertaining to education in the radiologic sciences, the task of tailoring content to meet the needs of technologists within resource-limited settings is inherently a challenging assignment. The primary reason for this pertains to the differences that exist in the level of education available to technologists in the developed world and those in the developing world. For the majority of technologist volunteers, their own educational experience as a student within a radiologic science program is likely to vary drastically from that of the technologist personnel they are training.

Professional organizations representing technologists within the developed world have long strived for recognition via implementation of minimum educational standards, regulatory oversight, and development of national practice standards. These endeavors have resulted in increasing expectations of technologist capabilities, and in turn, development of comprehensive educational training programs available to student technologists entering the profession. For example, according to the American Registry of Radiologic Technologists (ARRT), the certifying body for radiologic technologists within the United States, an estimated 52 % of registered technologists within the United States hold a 2-year college degree, with an additional 25 % of technologists holding advanced educational degrees (e.g., bachelors, masters, doctorate) [1]. These data indicate that a majority of technologists within the United States share an educational foundation that includes anatomy, physiology, chemistry, physics, and mathematics, which serve as an important basis for their

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imaging-specific training. 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. According to a paper published by the International Society of Radiographers and Radiologic Technologist's (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 towards 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 [2].

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 are often more likely to be recruited to lead educational interventions. Through careful analysis of an assessment conducted on the host-imaging department's technologist personnel, information on their capabilities and learning needs must be taken into account. The volunteer must be prepared to implement educational strategies that range from the absolute basics of anatomic positioning and image generation to development of curricula needed for the establishment of a formalized radiologic science program.

If the latter is the case, it is recommended that the ISRRT Guidelines for the Education of Entry-Level Professional Practice in Medical Radiation Sciences [3] be reviewed early on. The ISRRT document was established to provide a framework for the development of professional standards of education in diagnostic radiography and radiation therapy by identifying the roles, fields of knowledge, and attributes that underlie competent professional performance. Furthermore, it was developed in response to requests for assistance from associations and schools in developing countries, and is intended to serve as a guide for international standards of education. Of equal importance was the decision of the ISRRT to provide insight into essential core requirements needed for successful educational program development such as the role of physical, financial, and human resources; essential organizational requirements; a suggested academic curriculum; insight into certification; maintenance of programmatic standards; and interfacing with legislation, regulatory frameworks, and key stakeholders.

Even those with prior experience as educators must understand that reliance on traditional methods of education, though effective within their respective medical imaging programs, can potentially limit their success volunteering in resource-limited settings. As already mentioned, the educational background of the individuals being trained, as well as their current learning environment, differs from what the technologist volunteer will be familiar with; this requires the volunteer to adapt from his or her default theory of teaching. It is well documented that every group engaged in learning will exhibit a diversity of abilities, experiences, personalities, and preferred learning styles [4]. For this reason, it follows that volunteer technologist educators should be prepared to try a range of educational strategies, ensuring that appropriate selection of materials, both visual and written, are on hand and ready for use.

Many of the educational content areas identified as needing remediation may be addressed efficiently through the use of lectures, group discussions, and support materials. Recognizing the high likelihood of language being a barrier to student-teacher communication, the need for clearly-defined terms, as well as information that is packaged into easily digested and logically sequenced topics, will help the volunteer effec-

Fig. 9.1 Leigh Giles-Brown, RAD-AID volunteer (*center*), provides group instruction on clinical sonography

tively and efficiently deliver the educational content. The volunteer technologist must also determine which support materials will be most appropriate to leave with the host-imaging department for use in continued, self-directed learning efforts. *The World Health Organization's (WHO) Manual of Diagnostic Imaging: Radiographic Technique and Projections* [5] is a resource often relied upon within the radiology outreach community. The manual serves as a practical reference and guide for radiographic exposures, projections, and positioning of patients, as needed for the majority of radiographic examinations more commonly performed. The WHO manual is specifically written for healthcare workers directly responsible for the production and interpretation of radiographic images, and thus contains content valuable not only to technologists but also to radiologists and general practitioners practicing within resource-limited settings. However, because even the best textbooks may fail to address all the needs of the host-imaging department, instructors should also consider providing supplementary materials such as reference lists or customized "course packs."

In regard to the clinical training of local technologist personnel, project-related time limits are often a factor. Thus, one method for providing learners with as comprehensive an education as feasible is the use of various clinical learning experiences via Problem-Based Learning (PBL). PBL is an approach where an authentic clinical scenario is presented to a group of learners (e.g., the local technologists). The learners engage in collaborative learning with the technologist volunteer by discussing the problem, identifying their existing knowledge base, determining the information they need to learn, and then formulating a solution (Fig. 9.1). PBL emphasizes the development of problem-solving skills within the context of professional practice, encouraging self-directed learning, and is focused on increasing the motivation needed for lifelong learning. Technologist volunteers may also find this educational method to be less language dependent than the traditional lecture format. Published literature has reported extensive experiences in locations as diverse as Sierra Leone and Nicaragua in which the presence of a translator is usually not necessary for hands-on training since rudimentary English, sign language, or a cursory knowledge

Fig. 9.2 Example of a RAD-AID certificate of completion that could be customized depending on instructional course audience and focus

of the native language (e.g., medical terms) are usually adequate for basic instruction [6].

Technologist volunteers should also be prepared to handle a situation in which there is a lack of technologist interest in the outreach initiative. It is often easy for volunteers to get caught up in the excitement of international outreach, and assume that their arrival within a host-imaging department will be met with enthusiasm and a warm welcome. However, local community members serving in technologist roles are often doing so not out of an interest in medical imaging but because they were assigned to these positions in an attempt to address personnel shortages within the host-imaging department. With this in mind, it is not difficult to understand how the sudden presence of a highly trained technologist counterpart, making recommendations on personal practice improvements, could come across as intrusive or threatening. However, in these same environments, academic standing often dictates the potential for an individual's career advancement, and thus a potential solution to garnering technologist engagement may be the provision of a certificate of completion awarded to those who participate in educational initiatives. An achievement recognition strategy which includes certificates of completion may assist the technologist volunteer to motivate and engage local technologist personnel, encouraging them to take responsibility for their own learning and enhancing overall project success (Fig. 9.2).

In contrast to the above scenario, technologist volunteers may also find themselves working with local technologist personnel who are excited at the prospect of receiving training and educational assistance. In such situations, it is important to recognize that a successful outreach initiative involves not only the teaching of complex theories but also the role modeling of skills and attitudes related to optimal patient care. Technologist volunteers may be looked upon as examples of how the ideal technologist should act and often will find their behaviors, attitudes, and actions looked upon as standards for the profession. For this reason, it is imperative that technologist volunteers have a high level of confidence in their particular imaging modality, demonstrating well-honed clinical reasoning, effective decision-making, accurate documentation, as well as compassion in patient care interactions. Errors made by volunteers related to poor professional practice could potentially lead to a miseducation of the local imaging personnel and the creation of poor habits that can be difficult to break later without a great deal of confusion and frustration on the part of both the trainees and future volunteer educators.

Imaging Department Assessment

Serving as the member of the radiology team responsible for acquiring medical images within the developed world, the technologist volunteer is able to provide a practical and well-informed perspective to the project site assessment process. For example, an experienced technologist can go beyond simply counting the number of radiography or ultrasound units present within a department and assess whether the number of imaging systems available is adequate given the number of exams being performed by the host department. Furthermore, while most individuals would be capable of powering on imaging equipment, or even assessing the ability of the unit to produce an image, a technologist is in a position to evaluate the level of function of the system in question.

In resource-poor communities, there are rarely service contracts or service engineers available to correct equipment malfunctions. The local technologists are often relied upon to fill the void in technical support and develop custom solutions and "work-arounds" to keep imaging systems operational. In such scenarios, a skilled technologist volunteer is capable of assessing whether the equipment adaptation has adequately restored functionality or whether a more advanced repair is required to optimize the images being produced. Additionally, prior determination of the specific equipment make and model available within the host department will aid in adequate customization of potential lesson plans to be implemented (Fig. 9.3). The technologist volunteer is often also responsible for assessing whether the number of technologist personnel available is suitable given

Fig. 9.3 Kristen Mitas and Kayiba Medlen represent RAD-AID during an on-site assessment of an imaging department in Haiti

factors such as the department's exam volume, the type of exams performed, as well as the typical patient condition. Having advanced knowledge of these details is key to developing educational initiatives that are student centered and customized for what the trainee needs to know rather than what the educator assumes they need to know.

A second benefit of pre-assessing the specific content areas in need of educational intervention pertains to the optimal selection of technologist volunteers, best suited to develop and implement such interventions. With no shortage in technologist volunteers interested in radiology outreach opportunities, decisions regarding volunteer selection should never be made with the assumption that all technologists can address tasks equally. For example, an imaging department may need assistance in enhancing the quality of their images that are processed with an analog (film-based) system. Sending a volunteer technologist who was not trained prior to the widespread introduction of digital imaging systems would be of little use in such a situation in which a strong understanding of film chemistry and development procedures is required.

When conducting an assessment of the host department's technologist personnel, there are two initial decisions that need to be made. Namely, how the volunteer will determine which radiology content areas should be evaluated and the format the assessment will follow. When determining the content areas to be evaluated, it is best to use a standardized model that defines what a competent technologist would need to know in order to provide optimal imaging services. One recommended source is the American Society of Radiologic Technologist's (ASRT) Curricula documents [7]. The aim of the curricula documents is to outline a common body of knowledge that is essential for entry-level technologists in various modalities of interest. Specific instructional methods have been intentionally omitted to allow for programmatic prerogative as well as creativity in instructional delivery. The authors of the document recognize that traditional technologies are still part of the fabric of many communities and subsequently are inclusive of various radiologic science topics such as clinical practice, image acquisition and display, image analysis, imaging equipment, human structure and function, patient care, ethics, and many others that are foundational to technologists practicing in all healthcare settings.

A combination of methods can be utilized as potential formats for evaluating the level of imaging knowledge and clinical skill set of local technologists. For instance, for projects in which detailed outcome measures are desired, a pretest/post-test assessment model may be utilized. However, despite the obvious benefits of taking a rigorous scientific approach to the personnel assessment, it is important to keep in mind that the use of examinations may come across as threatening to members of the host-imaging department. Such an approach could be potentially damaging to a collaborative partnership in the early stages of development. An alternative method for conducting an assessment of personnel is dependent on the technologist volunteer's attention to detail and recording of personal observations regarding areas of improvement that are not readily apparent to members of the host-imaging department. For example, volunteers could recognize and note points of improvement regarding suboptimal patient positioning or a limited knowledge of anatomical landmarks. A third, and more direct, method of assessing for educational need is to simply ask the local staff or department head for recommendations of radiology content areas where they would like to see improvement, and in which potential lesson plans can be developed. It is well documented that individuals are more likely to commit to an activity to the extent that they have participated in planning of the activity [3]; therefore, an effective way to create dialogue about needed improvements is by first finding a common starting point and successfully completing agreed-upon project goals.

The availability of medical supplies for clinical examinations is also 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.), technologist volunteers will often find unique systems implemented to alleviate supply shortages. For example, it is not uncommon for imaging departments within resource-limited settings 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. This said, it should be noted that although providing supplies to a host department may be necessary to complete project tasks initially, this is not a sustainable practice. Attempts to connect the host department with a reliable source of supplies will be required early into project development.

Valuable information regarding protocols and procedures can also be attained via a departmental assessment. For example, are biohazard waste materials being disposed of in unmarked all-purpose trash receptacles, potentially exposing department personnel to harmful pathogens? Are there issues related to missing exam images, or progressive degradation of the images due to inadequate storage methods or suboptimal processing procedures? The number of potential areas for improvement can often be overwhelming, which is why a systematic approach to conducting a thorough departmental assessment is required. One recommendation is to follow several patients through the imaging department process. This would begin with the patient's arrival within the imaging department, and continue with patient registration, completion of the imaging exam, patient discharge, provision of images for physician interpretation and dictation, and finally storage of the exam images and associated report of findings.

Finally, overall departmental infrastructure and condition should also be assessed and documented in order to better prepare future radiology outreach teams that will be visiting the clinical project 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 that they care for.

Protocol and Procedure Development

There is little argument that focused education and training efforts can result in substantial host-imaging department service improvements. However, these initiatives alone will not address all the possible issues affecting service delivery. Besides preparation of local technologist personnel, a comprehensive radiology outreach initiative will also work to prepare the host-imaging department as a whole through addressing potential safety issues as well as issues related to workflow that could potentially impact overall departmental sustainability. The process for identifying these concerns is through review of, recommended changes to, and occasionally introduction of imaging 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. When a patient arrives for an exam, it is the departmental protocols that direct the technologist personnel to screen the patient for potential pregnancy or isolation precautions, and it is the department procedures that direct the technologist personnel on how to act when such situations demand special attention.

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: referring physicians, department heads, and nursing staff. Furthermore, the adherence to imaging protocols and procedures for technologists practicing in the developed world often comes as second nature due to the long history of regulatory oversight of professional practice. However, in developing countries in which technologists are still working towards professional recognition, departmental protocols and procedures tend to develop on an as-needed basis. They are identified and implemented by department leaders as the situations present themselves as opposed to a response to governmental decree. It is for this reason that it is incumbent upon experienced technologist volunteers to also serve in an advisory capacity, identifying and recommending solutions to suboptimal or nonexistent department protocols and procedures that impact service delivery.

Perhaps the most pertinent example deals with protocols and procedures related to radiation safety practices. Exposure to medical radiation continues to be a topic of public concern in developed countries, despite rules requiring radiation safety and dose monitoring. This said, is not hard to imagine the potential dangers associated with medical imaging within developing countries in which such concerns may be far from being a priority. For example, despite the progressive growth in the number of imaging exams being performed annually within the developing country of Nepal, radiation exposure monitoring among radiation workers is yet to be regulated by the Nepali government [8]. The challenge in informing the technologist staff of the need for strict radiation safety practices is inherent in the fact that ionizing radiation cannot be recognized through human senses, and thus easily dismissed or forgotten about. Fortunately, through the introduction and implementation of a few key protocols and procedures that instruct local technologist personnel to decrease time of exposure, increase distance from exposure, and increase shielding from exposure, as well as the practice of keeping all exposures as low as reasonably achievable (ALARA), these initial steps can yield immediate and meaningful impact on the host-imaging department's services provided.

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.

Relationship Building

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 opportunity. 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 mindset that the local technologist personnel are equal partners in the outreach efforts. Developing a team approach to enhancing the host-imaging department's services will not only benefit the members of the local community but also create a mutually beneficial learning experience for all involved in the outreach initiative.

Beginning with an open and honest assessment of needs, followed by a round table discussion of potential areas for improvement and aid, project objectives that are sustainable in nature should always be the end goal. After agreed-upon interventions have been successfully implemented, encouragement of self-directed imaging department enhancements and routine self-evaluations should be fostered through open and frequent communication. This said, the evaluation process, as with all parts of an outreach initiative, should be a mutual undertaking. During this process, the strengths and weaknesses of the interventions applied to the host department's routine practice should be constructively assessed and evaluated for potential benefits or hindrances. Likewise, volunteers must set an example of being open to feedback regarding their respective performance as well. By doing so, opportunities for growth and lessons applicable to future site visits can be gained. More importantly, continuous efforts at relationship building may lead to project expansion, eventually serving as an example of the level of impact that technologist-specific outreach assignments can have on bridging the global imaging gap.

Conclusion

Upon completion of any international radiology outreach project, it is important for the volunteer technologist to dedicate time to reflect on their recent outreach experience and appropriately record and transmit a detailed report to other interested parties. This can range from publication in a peer reviewed journal to a lecture at a national conference, or even to an informal Internet-based blog. Considering the scarcity in which such information is currently available, and the sheer size of the global access to imaging issue, any source of related information is considered beneficial, especially when it is provided from the unique perspective of a medical imaging team member such as the radiologic technologist. It is the responsibility of those fortunate enough to experience clinical practice of imaging environments in resource limited settings to share the knowledge they have acquired. This information is extremely valuable, not only to those tasked with subsequent visits to that environment, but also to those facilities with similar clinical challenges.

Sponsors or beneficiaries of a recent outreach initiative will be interested to know how their financial support or personal participation has been utilized. Information regarding the challenges faced as well as pressing needs of the host facility should be highlighted if there is any intent to attract further funding and continuation of the outreach project. Always consider the inclusion of host technologists as coauthors on a publication as this will help provide a balanced perspective for the final project report, provide the coauthor with professional exposure within their own country, and hopefully strengthen dedication to teach and collaborate with other technologists locally.

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10 Cultural Competency in International Health Program Collaboration

Christie Caldwell

Introduction

Culture can vary widely across populations while permeating all aspects of daily life, including diet, clothing, and language. But other realms of our societies are considered culturally neutral space, such as science and, in particular, medical science; after all, medical science has its own unique language and culture, felt to be immune to the cultural verities which so drastically differ across populations. But this assertion is often in error, and instead, medical science too harbors vast differences due to culture.

An excellent illustration of how powerfully culture can impact medicine can be 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" which is a narrative chronicling the struggles of a Hmong refugee family from Sainyabuli Province, Laos, and their interactions with the health care system in Merced, California [1]. 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. As the tragic story unfolds, due to cultural misunderstanding and poor communication, Lia's condition worsens, and she eventually slips into a fatal coma at 4 years old.

The dichotomy between the Hmong cultural belief that epilepsy is a rare spiritual gift and the American medical culture's assertion that it is a neurological disorder highlights the need for the medical community to bridge multiple culturally embedded understandings in order to heal. While many medical professionals practice some aspect of cultural bridging on a daily basis, this chapter will address the centrality of cultural awareness and skills to successful international medical partnerships.

The first step towards cross-cultural competence is to develop a level of *cultural self-awareness*: recognizing how one's own approach to medicine and healing is a product of one's acculturated values and beliefs. This awareness lays the foundation for the cultivation of the other behaviors essential to cross-cultural communication and collaboration: (1) The ability to *invite the unexpected*, taking on a learning posture in order to create space for views and behaviors which might exist completely outside of our normal frame of reference. (2) The ability to *frame-shift*, adapting behavior to be more effective in a different environment. These three characteristics are all crucial to successfully navigate the inherent complexities of global medical partnerships and will be discussed in further detail throughout the chapter [2].

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Cultural Self-awareness

Effective international medical partnership requires the ability to identify the cultural differences that are most likely to impact the success of that collaboration. When medical practitioners or trainers do not notice or adequately address differences within the cultures with which they are collaborating, what results is often wasted time, effort, and money. *Cultural self-awareness* is the first step towards navigating crucial cross-cultural differences and 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 style as the product of particular cultural influences will naturally enable self-examination of actions and assumptions. The first step in cultural self-awareness is to obtain a framework for understanding the source of some key cultural differences, and anticipate how these cultural differences may impact a cross-cultural outreach effort. The discipline of intercultural studies has identified through extensive research a framework made up of dozens of dimensions of cultural difference. In applying this research to international medical partnerships, this chapter will address the following four dimensions of independence/interdependence, egalitarian/status, direct/indirect, and task/relationship. These dimensions serve as helpful generalizations which can be used to assess a particular situation, but one must always consider the other factors that are influencing the situation beyond national culture (see Fig. 10.1).

Independent/Interdependent

The first dimension in this framework is the concept of cultural dependence. This cultural dimension speaks to how individuals define themselves. For example, in independent cultures, the emphasis is on the individual and people tend to define themselves as independent actors, are comfortable standing out from the group, value diverse thought, and make decisions based on what is best for the individual. The ultimate value is placed on individual freedom over group conformity. In contrast, in interdependent cultures, individuals identify themselves more as part of a larger group: a family, a clan, a religious sect, or a team. The individual's wants or desires are less important and should be sacrificed for the greater good of the group. The emphasis is often maintaining harmony and conforming to fit the broader needs of the group.

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 independent 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 interdependent cultures, where individuals and information about their health are seen as belonging to the family. 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 interdependent 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 interdependent cultures making decisions about a patient's health that would only be made by an individual in a more independent society.

Egalitarian/Status

Status is the cultural dimension which speaks to the differences that exist across cultures in terms of power distance[1] or hierarchy. 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

[1] Extent to which the less powerful members of organizations and institutions (like the family) accept and expect that power is distributed unequally.

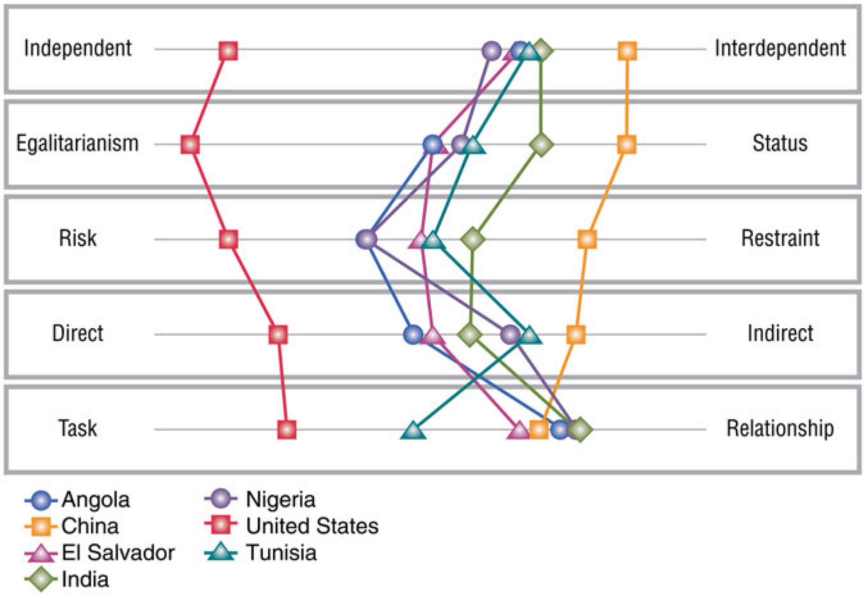

Fig. 10.1 GlobeSmart® country profiles. The GlobeSmart® webtool provides a visual representation of some of the key cultural differences that appear in a cross-border collaborative partnership. Some of the gaps along the five cultural dimensions are quite significant and have the potential to impact the success of medical partnerships. Adapted from: What is Global Leadership?: 10 Key Behaviors that Define Great Global Leaders by Ernest Gundling, Terry Hogan and Karen Cvitkovich (Jun 16, 2011)

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.

Egalitarian societies are often very uncomfortable with any power distance 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.

In a medical collaboration context, 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 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 me blindly, 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 a critical thinking approach.

Hierarchical or vertical 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 do not tend to question or to formulate their own approach to solving an issue. To many of the radiologist volunteer trainers coming from the extremely egalitarian culture of the United States, the behavior of the Haitian technologist trainees was very surprising. Volunteers elaborated on this "high dependency on the top-level person."

> In the US, most technicians, after taking the required pictures, will often take additional pictures in order to be helpful to the radiologist. But here in Haiti, they just do exactly what they are told and do not think to include another picture because they see that the patient is 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. When we were trying to train the technicians on the anatomy factors that impact a good scan, like, for example, what happens if the patient does not take a deep breath, they were not interested 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 the doctor's responsibility.

Direct/Indirect

This cultural dimension addresses how information is communicated. An indirect communication style is often found in hierarchical cultures, where one has to take care how information is conveyed based on the status of one's counterpart. An indirect communication style places emphasis on how a message is delivered, often more than the actual content of the message itself. The use of silence, nonverbal cues, tone of voice, eye contact, "flowery" speech, and stories is often used to get a point across in a way that will not offend the listener. Direct communicators are often task-oriented and like to get to the point 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.

Visiting medical teams from more direct cultures sometimes encounter these communication differences in the consulting room. One medical volunteer describes a diagnostic consultation:

> When I asked a general question, the patient would tiptoe around the issue. Instead of saying, 'I have a headache', he would start telling a long story. In my mind, what was a simple 'yes' or 'no' answer would take ten minutes to get through. He would actually never say that he had a headache. I was supposed to infer his problem from his long 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 indirect cultures are often frustrated that seemingly obvious messages are not understood by their more direct counterparts. They are sometimes surprised and offended by the manner in which their more direct partners convey information. In traditionally indirect 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 physically impossible for them to use the word "no" directly. The cultural conditioning against this is just too strong. In order to ensure understanding and clear communication, awareness of these communication differences is critical for cross-cultural medical collaborators.

Task/Relationship

The task/relationship dimension concerns priorities around what needs to happen in order for a task to be completed. In relationship-oriented cultures, a personal relationship is often requisite before engaging in collaboration. In more task-oriented cultures, relationships are often built through working together on a shared task. Many task-oriented cultures rely on processes or systems that are equally accessible to all and which do not require dependence on others. In relationship-oriented cultures, getting things done is almost entirely contingent on knowing the right person. Investing the time up front to establish a personal connection and a sense of trust is therefore essential in these cultures and little will be accomplished until this happens. 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 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 know. They do not have a way to measure competency so they rely on personal trust instead.

Short-term medical teams from task-oriented cultures often arrive with a set of very ambitious targets that they hope to accomplish during their 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, recognizing outcomes were not met. The receiving partners (particularly in more relationship-oriented 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 in cross-cultural collaboration, and in particular, can often be identified as the most commonly encountered area of cultural conflict.

Cultural Self-Awareness among a medical partnership team enables members from different cultures 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 and leads 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.

Invite the Unexpected

The second critical behavior, *Invite 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. In many ways, this posture is a natural by-product of *Cultural Self-Awareness*. After reflecting on one's own cultural norms and expectations, then it is natural to be curious about other approaches and realities. Successful cross-cultural collaboration requires that medical staff relearn, in a sense, how to approach everyday interactions.

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 experience 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.

> 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 the technology and 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 interrogated 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 contemplate 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.

Common examples of the unexpected in an international medical collaboration context include:

- Different needs and expectations within patient populations.
- Different understandings of illness and the body based on cultural philosophies (examples include traditional Chinese medicine and Ayurveda, which approach the illness, diagnosis, and treatment primarily from a philosophical foundation of energy flow).
- Religious approaches to healing and diagnosis (consider the previous example from the Hmong community where the 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 (examples are most prominent in cases of mental illness. One can readily distinguish the cultural influence of psychology and psychoanalysis on the understanding and related ability to articulate mental or psychological conditions).
- 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 flat cultures, the patient often takes ultimate responsibility for determining the applicability or appropriateness of this advice, sometimes taking it wholly and sometimes seeking a second opinion or augmenting the advice with their own research and diagnosis from various other disciplines (naturopathy, alternative medical practice, internet medical forums, etc.). In more hierarchical societies, the doctor is in more of an expert position and can be in a role to dictate behavior. Her opinion is often unquestioned and ultimate responsibility for the outcome is totally in her hands. In these cases, the patient sometimes abdicates responsibility for their own role in recovery.

In the Democratic Republic of Congo, for example, one generally only goes to the doctor if one believes death is imminent. Most Congolese do not expect to return from this visit. Because a doctor's visit is so closely associated with death, there is a huge stigma and fear attached to subjecting oneself to medical analysis. In many communities, natural healing remedies such as plant salves are used and small symptoms are quickly dismissed as insignificant. The economic realities also heavily impact the community's perception of medical care. In many impoverished areas of the world, the decision to visit a doctor is often a decision not to spend that money on food or perhaps to take time away from earning wages to support the family. In weighing their respective hierarchy of needs, those suffering from a headache or some physical discomfort will choose not to "waste" that money on a doctor's visit.

In medical collaboration efforts, learning to position oneself to learn about critical, unexpected aspects of the culture is essential. 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. Those involved in cross-cultural collaboration can position themselves to invite the unexpected by

- Asking many questions and listening carefully to hear new messages, while consciously holding prior experiences in check.
- Reading nonverbal reactions and not filling in pauses or silence.
- Proactively looking for hidden issues and power dynamics.

- Acknowledging that you do not know and asking for help.
- Asking open-ended questions and providing time for a response.
- Opening to indirect responses or feedback that comes through stories or other forms.
- Entering the collaboration with an attitude of humility which assumes that there are many unexpected elements at work which you do not understand.

Frame-Shifting

For members of medical collaboration teams to be successful in a cross-cultural partnership, awareness of cultural differences is just the first stage. They must also learn how to constructively address the differences. *Frame-shifting* is the ability to change one's perspective and behavioral approach in order to be effective in different cultural situations. After gaining an awareness of the style gaps that exist between oneself and one's global partners, the next step is learning how to style-switch in order to achieve better results.

One medical volunteer working in Haiti recognized the more interdependent orientation of the Haitian patients she was seeing and realized that she had to change her 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.

Given the central importance of communication in any medical collaboration, shifting how one gives and obtains information is often the first priority. Those from more direct cultures may learn to deliver their messages more softly or in a more "round-about" manner. Those from more indirect backgrounds may need to formulate their messages in a more clear and precise manner, not assuming that their inferences will be understood. This frame-shifting skill can also be employed to emphasize the importance of relationships when working with more relationship-oriented cultures.

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 no rush for anything or sense of urgency. The concept of time 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, maybe even wait for a year. Just saying something once is not enough to get action.

Partnering with a new country or within 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.

Conclusion

The hard science of medicine is understood through a kaleidoscope of different value systems and beliefs. It is also delivered through cultural vehicles such as communication, training, partnership, and knowledge-sharing. Expertise in the hard science then must be accompanied by the soft skills that enable cultural fluency in order for an international medical partnership to be successful.

If the goal of international medical collaboration is to provide access to and establish best 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. A fundamental shift is essential in this process. Gaining *cultural self-awareness* and positioning oneself to *invite the unexpected* create the mental and attitudinal foundation necessary to start to practice behavioral agility—or *frame-shifting*—across borders. Medical teams with this high level of cross-cultural competence will be ideally positioned to skillfully navigate the requirements of successful international medical collaboration.

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11 Educational Strategies and Volunteering in Global Health Radiology

Matthew P. Lungren, Bianca T. Nguyen, Marc D. Kohli, and Ali M. Tahvildari

Globalizing medical education is an imperative, not an option [1].

Introduction

In 2010, an independent global commission supported by the Bill & Melinda Gates Foundation and led by the Harvard School of Public Health published a landmark report in *The Lancet*, ultimately concluding that the current medical education infrastructure as a whole should be held accountable for persistent and appalling worldwide healthcare disparities; the published report describes the "fragmented, outdated, static curricula that [produce] ill-equipped graduates" as unable to adapt to a new century in which staggering numbers of people, pathogens, technologies, and information move freely across the globe like never before. The proposed overhaul of medical education would include, at its core, new system-wide curricula, which draw on a global, multidisciplinary, systems-based approach equipped to respond to current and emerging global healthcare challenges (Fig. 11.1).

US organizations and institutions send roughly 6,000 international short-term missions annually with the goal of providing healthcare-related services or education in resource-poor countries, at an estimated cost of $250 million [2]. Though only a small fraction of these efforts are focused on imaging alone, from a broader perspective, the conceptualization of "global health imaging" connotes the role of radiology in guiding public policy, in improving health care in global health programs, and in highlighting epidemiological challenges [3]. A multifactorial conceptualization of global health imaging insists that, for the incorporation of radiology and imaging services in resource-poor countries, there must be an in-depth understanding of a population's culture, disease patterns, political environment, and healthcare system.

How can radiology as a specialty respond to this new global vision for medical education, or, for that matter, fit into a seemingly endless number of ongoing global health efforts? Certainly, there is much work to be done to improve access to vital medical imaging for populations in need. According to recent reports from the World Health Organization (WHO), one-half to two-thirds of

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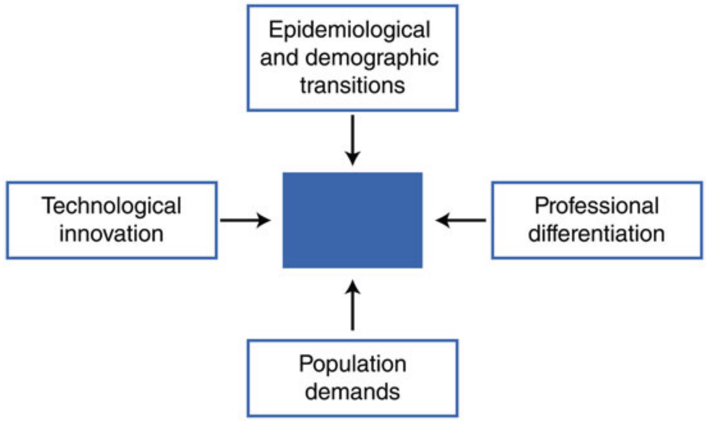

Fig. 11.1 Emerging challenges to health systems

the world's population lacks access to medical imaging, afflicting an estimated 3.5–4.7 billion individuals throughout the world [4, 5]. This stands in stark contrast to the critical role of imaging in the practice of modern medicine in the developed world; for example, imaging is critical in the management of pulmonary disease, AIDS, maternal-infant health, tuberculosis (TB), cancer screening/management, and trauma, further highlighting the healthcare access disparities in countries that lack imaging services [6–9]. In parallel to the increasingly disparate accessibility of radiology services, there are large gaps in opportunities in the developing world for high-quality medical imaging education, and as a result, a lack of qualified and experienced practitioners. This, in turn, contributes to problems of quality and radiation safety, even when access to medical imaging is technically possible, further exacerbating imaging disparities and resulting in a self-defeating cycle.

In response to the growing need for imaging services in medical outreach efforts, the field of radiology has become more active in recent years, as evidenced by new American College of Radiology (ACR) programs such as the Barry Goldberg/Maurice Reeder International Travel Grant Program and the Foundation International Outreach Committee, imaging-based nonprofit organizations such as RAD-AID, and individual radiologist efforts which are frequently highlighted in ACR publications [10–12]. These efforts share a common goal to increase access to medical imaging to underserved populations in the developing world. Yet despite a growing cohort of global health imaging initiatives, there are no known curriculum guidelines or training programs that provide radiology trainees structured opportunities to develop skills and experiences in global health imaging applications. Indeed, while global health electives have been a significant component of residency training in numerous medical specialties (and have even been shown to demonstrate a positive impact on resident recruitment), evidence shows that radiology residency programs have lagged behind in involving their trainees in international experiences [26]. Some causes for the deficiency of adequate global health training in radiology include the significant challenges encountered in prior international imaging outreach efforts, including limited access to equipment, lack of sustainability, shortages of qualified personnel, and inadequate preparation for infrastructure disparities [7, 11, 13–17].

In contrast to most other medical specialties, the modern radiology enterprise consists of a variety of skilled stakeholders with diverse expertise, including radiologists, radiologic technologists, radiology nurses, medical physicists, engineers, administrators, and information technology (IT) specialists. Local healthcare providers in low-income regions require training and educational materials developed through input from each of these complementary professions; this necessitates collaborative educational outreach models that blend specialized perspectives to create balanced strategies for project development [18]. In terms of global health imaging outreach, a dedicated global health imaging curriculum or pathway for imaging-related practitioners is a logical step; for example, a US-, Canadian-, or European-trained radiologist, technologist, engineer, or other imaging professional functioning as an individual volunteer may lack the proper skill set, experience, or international connections to effectively develop, deploy, and participate in a radiology development project in the developing world. Lungren et al. reported that although a majority of radiologist physicians in training plan to pursue international medical aid work in the future, the majority feel that they would be ill-prepared to pursue this career goal given their current training. Furthermore, there are virtually no institutional opportunities in place to allow participation in structured global health training as part of their specialty training [17]. In fact, an overwhelming majority of trainees in the same study believed that an organized global health imaging curriculum would improve understanding of basic disease processes and cost-conscious care, prepare residents for lifelong involvement in global health, and increase interpretative skills in basic radiology modalities [17].

Thus, global health education in radiology can provide long-lasting benefits to both parties: the volunteer and the host community or country at large. This being said, the sustainability of such educational efforts is paramount. After all, the primary driver in developing global health imaging education is to improve imaging access in the long term. Unless local knowledge and expertise are developed, the inadequate supply of sufficiently trained radiology personnel in the host community will persist as a barrier to sustainability. Planners should strive to include a holistic education plan as part of every radiology outreach effort. The objectives of training should be targeted at the specific needs of the local facility and its personnel, including but not limited to, technical aspects of image acquisition, image interpretation, device maintenance and repair, workflow, as well as resource management, radiation safety, and utilization criteria. Radiology business management and entrepreneurship training may also be needed. In academic centers, training in research design and development should be included [11, 19]. Other important instructional topics for global health volunteers include local disease epidemiology, indigenous and endemic diseases and their imaging appearances, and perhaps most importantly, cultural competency. Cultural competency training in particular is vital for volunteers traveling abroad, as it helps build the trust and credibility required for successful long-term collaboration.

In this chapter, we will discuss (1) global health imaging program development, (2) principles in successful models, (3) the role of research, (4) challenges and controversies, and (5) future directions for global health imaging education and volunteer programs.

Designing and Planning On-Site Education or Volunteer Programs

There are many potential avenues to engage in global health work, be it as an individual or a group, as a trainee or a practicing radiologist, technologist, medical physicist, or radiology nurse, through de novo partnership or preexisting ones (i.e., NGOs or university affiliations), direct (on-site) or indirect (i.e., Internet-based image interpretation or equipment donation) involvement, short-term or long-term engagements, etc. While these variables each have their pros and cons, one advantage of group or organization-directed efforts (i.e., through a university or NGO partnership) over individual-driven efforts is that the former lends itself more easily to sustainable and responsible imaging implementation due to the number of people involved. Furthermore, early exposure to global health work during the formative years of training may serve to inspire future volunteer efforts when these health care workers have more experience to share.

What follows is a brief overview of considerations in designing a structured global health imaging experience, keeping in mind the principles of responsible, sustainable program development as well as the more specific education objectives set forth by individual certification and specialty governing bodies. The concept of sustainability here refers to the ability to develop and maintain knowledge, equipment, skills, and other resources as part of an enduring radiology infrastructure that addresses the healthcare needs of a community by integrating with existing healthcare infrastructure; in this construct, sustainable radiology development can occur at any level, from a single clinic to an entire nation [19].

Choosing a Site

There are many important considerations when deciding on a location or site to establish a global health imaging elective experience. Chiefly among them is deciding on a country, hospital, clinic (with or without a radiology training program), or community with whom to partner. Factors to consider include language, stability and safety of the area, and existing infrastructure. Creating a de novo international partnership can be a daunting and difficult feat without the right connections. Fortunately, in today's world, with the ease of international travel, telecommunications, and increasing globalization, it is far more common than not that preexisting partnerships (or at least attempts at partnerships) exist. There is no need to reinvent the wheel, but instead it may be possible to steer the wheel in a new direction and build off of what has come before. It is often the case that training programs affiliated with large academic institutions have unprecedented access to well-established partnerships with a wide variety of institutions all over the world. These relationships may be managed by a dedicated global health committee or department, and in partnership with clinical and nonclinical global health institutional colleagues, much of the difficult relationship building and contact development is already in place. Oftentimes the most useful guidance comes from physicians and other healthcare volunteers who are already directing established global health education and outreach programs, most commonly in other disciplines such as surgery and internal medicine. For example, the Emory University Department of Radiology is currently home to one of the few established international elective imaging experiences in the USA for radiology resident physicians, located at Addis Ababa University (AAU) in Addis Ababa, Ethiopia; in choosing a site for the rotation, they built off of preexisting international connections established by other specialties in their academic center [20].

However, the presence of a preexisting relationship to a medical community in the developing world may be the exception, rather than the rule, for many individuals, organizations, or training programs interested in incorporating medical imaging outreach. Alternative strategies in site selection for establishing or participating in a developing world imaging education program may include partnering with an international clinical or nonclinical nonprofit organization, researching contacts or opportunities via a national specialty governing body or society, researching and reopening communications with prior international short-term image equipment donation or other efforts, or establishing new ties to a specific medical community via personal contacts or initial in-country visits. Oftentimes much of the most useful guidance comes from physicians and other healthcare volunteers who are already directing established global health education and outreach programs, most commonly in other disciplines such as surgery and medicine.

Once a group of sites are chosen and all partners identified, it is important to balance the priorities among the specific geographic locations, the objectives of the program, safety, and funding. As an example, the cost differences for travel alone between the USA and candidate locations in Haiti versus locations in Tanzania are substantial. Also, some funders or institutions will not provide resources for efforts in certain locations due to liability or safety considerations.

Performing a Site Assessment

No matter how well established the relationship is between home institutions or organizations and the host site, a comprehensive imaging-related site assessment is critical to the development of a responsible and targeted imaging outreach education and training program. The WHO asserted that there is a "prevailing but mistaken belief that anything is better than nothing… [and that] unsolicited and unnecessary health care… is wasteful." Site and country-specific assessments must be completed before the design and promotion of new initiatives. An example is the RAD-AID Radiology-Readiness™ assessment tool, which provides an analytic framework for the structured assessment of local disease epidemiology, facility physical and technology infrastructure, clinical referral networks, access to medications and clinical consumables, availability and training of local healthcare personnel, availability of complementary laboratory testing, existing radiology infrastructure, and institutional financial health, among other areas. To date, the Radiology-Readiness™ tool has been used in multiple locations around the world as part of collaborations between RAD-AID and other partnered organizations such as Project HOPE, Imaging the World, and the WHO [19]. The assessment process is designed to aid program design and identify important barriers in a given location before planning a sustainable clinical radiology program.

However the site assessment is conducted, the information gained in this process is important both as a starting point for collaborative discussions and data to be used in the development of future project metrics and research initiatives. The assessment data must be made available to the host institution leadership and any other partners so that a targeted project can be designed.

For example, based on data gathered from a targeted site assessment, RAD-AID engaged public health and medical institutions in Northern India to develop a strategy to improve access to medical imaging for the massive, impoverished slum population. The data indicated an overwhelming need for women's health, in particular breast and cervical cancer evaluation as well as osteoporosis screening. In addition to these targeted epidemiological health needs, transportation and connection to clinical systems for follow-up were major obstacles to overall health care and were identified as reasons prior outreach efforts had failed. This work led to the implementation of a mobile women's health outreach program. The mobile unit offers screening for breast cancer, cervical cancer, and osteoporosis as well as targeted health education. This partnership will aid data collection on women's health, including barriers to engaging the healthcare system, obstacles to referrals, as well as patterns and rates of disease. In addition, the volunteer radiologists, technologists, nurses, and medical physics professionals will have the opportunity to practice medical imaging in a resource-poor setting and collaborate on research and imaging education projects with the partnered Indian medical center. Because there are multiple stakeholders, all with a well-defined targeted focus, this work will hopefully inform government partners in creating policies that will better incorporate radiologic services into public health programs [21].

An on-site assessment should also obtain detailed knowledge of the rules governing the scope of practice of foreign trainees, and ideally includes planning meetings with the host country's ministry of health or equivalent governing agency. Otherwise, problems can arise to undermine the project. For example, a global health imaging program staffed mainly by US physicians and other imaging practitioners put in place unilaterally might possibly highlight the administrative failings of the host country's medical delivery system, place non-partnered rival local medical practitioners and institutions in an uncomfortable position, violate local laws governing the privileges of foreign practitioners and trainees, or deliver services deemed inappropriate by the host country officials. Any of these scenarios could engender significant conflict despite the underlying good intentions. Therefore, it is important to fully engage both the partner and the host government representatives as part of an initial assessment to build trust, and obtain an understanding of the public health policies, local politics, and potential ramifications of the proposed program.

Program Curriculum Development

Though individual programs, stakeholders, locations, and objectives will differ, curriculum development can become critically hampered by a lack of standardized guidelines. In an essentially

Table 11.1 ACGME core competencies in the context of global health imaging

ACGME competency	Global health imaging application
Medical knowledge	Imaging appearance of endemic disease, tropical diseases
Patient care	Compassionate and culturally appropriate care in a resource-limited setting
Professionalism	Responsiveness to new, diverse patient populations and healthcare system
Interpersonal communication skills	Collaborating with local imaging and clinical colleagues
Practice-based learning and improvement	Education and clinical program development, quality metrics
Systems-based practice	Operating in resource-limited settings, adapting medical imaging in a cost awareness and risk-benefit analysis to optimize patient care

new field of study such as global health imaging, this concern becomes more important because there are no preexisting models, as there are in other clinical and nonclinical disciplines, to adopt. However, there are numerous existing competencies that may be used as a basis for the development of a targeted but acceptably inclusive curriculum. For example, core competency topics can be constructed within an established framework set forth by a national governing body, such as the American College of Graduate Medical Education (ACGME), the Association for Radiologic and Imaging Nursing (ARIN), and the American Society of Radiologic Technologists (ASRT) (Table 11.1). Collaborating with partnered institutions or colleagues in medical education can also help expedite the process of developing a comprehensive curriculum.

Because it is important to begin the process of curriculum design with a model in mind, a first strategy could be to develop or adopt specific competencies unique to the particular program or discipline. Ideally, global health imaging education should span the length of a given training program, not just the period of international travel to the host country. At the minimum, an educational curriculum should span a sufficient period of time before and after the international rotation, to gain the necessary skills in advance of the on-site experience and to later reflect on the experience with newer trainees to the curriculum. There are a variety of options with regard to methods of curriculum content delivery. An educational curriculum may involve regular (e.g., monthly) group discussions on required readings or brainstorming sessions. For example, discussions may focus on analysis of global health literature, work-shopping strategies for implementing imaging in a resource-poor setting, or didactic lectures on the clinical and imaging presentation of tropical diseases in the developing world. Resources for imaging presentation are currently scarce, but include this text as well as the comprehensive Reeder and Palmer volumes entitled *The Imaging of Tropical Diseases* [22, 23]. Many of the articles listed in this chapter's bibliography may also serve as "journal club" topics for discussion. At institutions with established global health departments, public health schools, or resident global health electives in other medical specialties, multidisciplinary meetings and lectures are a particularly useful tool as they serve to develop a "global health community" with interdisciplinary cooperation and collaboration. These types of group sessions would allow trainees to explore global health systems at large and would serve as an excellent adjunct to imaging-specific didactics.

No matter the discipline or background of the trainees, dedicated coursework on the topic of cultural competency should be at the core of every global health education curriculum, and a requirement of all participants in a global health imaging outreach and education program (Table 11.2). Cultural competency training in particular is vital for volunteers traveling abroad, as it helps build the trust and credibility required for successful long-term collaboration. One in-depth cultural training resource presented at the 2010 RAD-AID conference is Aperian Global's GlobeSmart® Web tool [19]. Another resource which includes didactic case-based material is the Web-based Ethics of International Engagement and Service-Learning Project Web-Based Guidebook (EIESL)—an easily accessible resource that provides students, faculty, staff, and

Table 11.2 Cultural competency topics for global health curricula

Global health imaging cultural competency curriculum content
Overview of global health and global burden of disease; health indicators and an understanding of their use and limitations
Site-specific epidemiologic information; location, size, government framework, economic and social development, policy and trade agreements, immigration issues
Healthcare system; major healthcare issues, method of healthcare delivery, regional traditional beliefs regarding health and illness, cultural and social and behavioral determinants on health
Environmental health; water acquisition and safety, disaster response (natural and man-made)
Safety and legal considerations; each program in conjunction with its risk management or legal department needs to develop policies and procedures and make administrative support available to trainees abroad

international organization members with materials designed to provoke ethical reflection on international engagement and service learning projects, and is particularly useful as part of a larger global health curriculum. The EIESL materials are designed to "challenge how we engage as global citizens committed to social and ecological justice."

Within a radiology department, a global health imaging curriculum could be tailored to either the training program as a whole or simply to interested parties including not only residents but also faculty and other medical imaging professionals. Institutional support would be essential in order to provide faculty-protected teaching time, and a high level of trainee interest would be needed in order to incorporate global health topics into an existing residency lecture series framework, as the content may have limited applicability to those not interested in global health. As an alternative, an evening elective seminar series on global health imaging is perhaps a more feasible option and would require a commitment by faculty and trainees alike to dedicate time outside of routine training obligations to participate. This would allow for more freedom from daytime residency program restrictions, and course content would be directed by a core group interested in the subject matter. It should be noted that this strategy may cause conflicts with regard to call responsibilities and, potentially, work hour violations. Attendance may be sporadic due to personal or family obligations.

Another option in training programs with available elective time, or during "mini-fellowship" time, an entire elective "rotation" (lasting from one to several weeks) could be set aside as an option for those interested in concentrated global health imaging instruction; however, this strategy may cause difficulties in that the elective time may be limited and better served as the travel component of the global health program. Much of the content could be provided as part of the on-site field experience in which the faculty would have an opportunity to provide focused instruction to trainees from both the host and visiting partner institutions. Lastly, in programs with limited extracurricular time, informal self-study via journal articles, Web-based resources, and other global health text assignments may also serve as an alternative to formal didactics.

A global health imaging curriculum must also take into account the structure of the international, on-site experience. The on-site experience should be tailored to the host location and will depend on the available resources and imaging modalities. If visiting an imaging training program (or radiology residency program) in the host country, close coordination with host faculty will be necessary, as they will be responsible for supervising the visiting resident per ACGME guidelines if/when the resident is not traveling with a faculty member from the home institution. An example on-site curriculum may include spending 1 week with each available imaging modality (plain film, ultrasound, fluoroscopy, etc.). Due to potential legal restrictions by hospital or governmental/Ministry of Health regulations, the visiting trainee or faculty may be confined to a more observatory role during film interpretation, image acquisition, or during procedures, though this is entirely dependent on the location and specific context.

The visiting resident should be encouraged to save a certain number of cases with a digital camera, including clinical data and outcomes. Unlike in the USA, patients will often be directly available during imaging interpretation, and such interactions can provide invaluable insight into a country's culture and health care. If traveling with another clinical service from your institution, clinical rounds with other specialties (e.g., in the emergency department, inpatient wards, or medical ICU) may prove fruitful for all parties involved, as shown by the Emory-AAU experience [26]. Given that PACS is often nonexistent in many developing countries, patients are often responsible for their own films, which are often interpreted by non-radiologist clinicians at the bedside. Thus, there may be ample opportunity for visiting trainees and radiologists to be involved in direct patient care and bedside teaching.

Just as trainees serve as teachers for other peers in US training programs, an important component of the on-site experience is education. It is recommended that visiting teams inquire what topics are of interest to the host institution. For example, the host radiologists may want to learn about advanced imaging techniques that are not yet available in their country in addition to more directly pertinent topics, such as maternal-fetal imaging with ultrasound. Inquiry into teaching methods and equipment should also be made (i.e., Is there a projector? Is computer software such as Microsoft PowerPoint available? If so, what version?). The traveling team would then be able to prepare relevant case material in advance; examples of educational material would include case-based conferences covering abdominal imaging, head CT, medical radiation safety, maternal-fetal imaging, technologist instruction on optimal image acquisition positioning, etc. As a component of the curriculum, trainees should be encouraged to participate in systems-based practice or practice-based improvement projects. Project design can be planned before travel and coordinated with an interested party at the host location, realizing that international research projects may be a more complex process than those carried out domestically. The role of research will be covered in more detail later in the chapter.

The ideal educational curriculum should continue after the international visit, wherein the returning trainee or team should share their experiences, as a part of the global health imaging lecture series, in the context of a multidisciplinary global health meeting, or to the radiology department at large. This should include saved cases and any potential research projects undertaken. Support for global health programs at the highest levels of administration (e.g., the program director, department chair, and deans of graduate medical education) is critical for the sustainability of such programs. Regular demonstrations of global health program results and successes (by way of grand rounds talks, lecture sessions, poster presentations, or journal publications) can go a long way to help garner support from administrators.

As previously stated, sustainability should be a constant objective of an ideal curriculum; this refers not only to the sustainability of the global health imaging program but also to the partnership with the host location. Strategies for sustainable partnership development include teleconferencing if adequate equipment and Internet connections are available, interdepartmental research and quality improvement projects, and educational rotations for international partners to visit the home institution; this last strategy may require shared funding responsibility from both parties. Methods for imaging professionals to obtain such funding include grants from radiology societies such as the Radiological Society of North America (RSNA) or from governmental or NGO funds, such as the Medical Education Partnership Initiative (MEPI), which is a program of the US President's Emergency Plan for AIDS Relief (PEPFAR).

Choosing a Team

There is rarely a shortage of enthusiasm for international aid experiences among trainees in medicine, nursing, and other disciplines. But enthusiasm cannot substitute for a lack of knowledge and skills specific to global health work. When choosing a team, there should be careful consideration of the program goals and objectives, and in particular, how imaging needs will be effectively addressed during in-country experiences.

Ideally, there should be a "critical mass" of culturally and, as applicable, linguistically competent team members. Global health programs in other specialties, for example, tend to identify at least one faculty member who has the skill set to lead a team of trainees for short-term experiences, and rely on additional support from the host partners only when needed.

For the trainees, ensuring accountability, supervision/mentorship by a qualified individual, and a reasonable expectation of safety are important to guarantee the program's credibility and ability to fulfill the mission. Furthermore, the presence of an experienced radiologist on the traveling team may lend more interest for the host site, as the host healthcare professionals may perceive supervising a trainee as a burden, and there may be more educational value with the presence of a practicing radiologist. Emphasis must be made to select the proper mentors and to develop institutional relationships with international colleagues. This type of partnership may be developed specifically for this program or based on a previously established program or relationship. Collaboration on objectives, responsibilities, and an approach to ongoing evaluation should be undertaken to ensure accountability and minimize conflict. Another strategy includes making additional arrangements with a host faculty member who demonstrates some ownership of the program. For example, providing the host country faculty with an "adjunct" appointment in the home institution would be an excellent way to develop an existing relationship and add credibility and prestige to colleagues abroad. Other benefits of this arrangement include recognition by the institution, which may aid in gaining formal credit for the trainees who participate in the curriculum [24].

Selecting the trainees who will participate in the program ideally should consist of several steps which aim at assessing intellectual and emotional abilities to meet the demands of the elective, motivation, commitment to a career in public health, and commitment to future medical service overseas. When possible the process should be overseen by a departmental committee that includes faculty mentors and trainees who have completed the on-site component of the curriculum. Some well-established global health outreach programs have extensive application processes in place which include administering a series of closed-ended evaluative statements which cover ability, motivation, interpersonal skills, level of language training (if a student wishes to go to a non-English-speaking country), commitment to a career in public health and to future overseas medical service. In these programs the interviewers are especially alert to unacceptable motivations for participation in the elective such as an opportunity to simply explore or travel.

In the case of medical radiology residents, the selected trainees should undertake the international, on-site rotation during the third or fourth year of residency, in order to allow for adequate time and experience to develop a radiology-based fund of knowledge and skills. The fourth-year "mini-fellowship" time is likely the most suitable time for such elective rotations. Coordination with residency program leadership to guarantee a sufficient period of time for travel without on-call responsibility will be necessary.

Most global health programs select students that are proficient in the principal language of the target community. In most cases, trainees expressing a preference for non-English-speaking countries have generally had a fair level of fluency in the national language. This has often been gained through residence or study in French- or Spanish-speaking areas, for example, or previous overseas service with an organization such as the Peace Corps. Some students possess second language fluency as a result of being either immigrants or the children of immigrants [24].

Preparing for On-Site Experiences

Thanks to the presence of many established global health experiences, there are numerous references and resources available in preparing on-site trainees (Table 11.3). No matter how intensive the formal preparation, in general, four broad areas should be addressed prior to travel: (1) emergency health care and vaccines, (2) travel and lodging logistics, (3) safety, and (4) characteristics of the

Table 11.3 Popular resources for global volunteerism preparation

Resources for global volunteerism preparation
Brennan RJ, Nandy R. Complex humanitarian emergencies: a major global health challenge. Emerg Med (Fremantle). 2001;13(2):147–156
Dara Sl, Farmer JC. Preparedness lessons from modern disasters and wars. Crit Care Clin. 2009;25(1):47–65, vii. International Medical Volunteers Association Web site (http://www.imva.org)
O'Neil E Jr. A Practical Guide to Global Health Service. Chicago, IL: American Medical Association Press; 2006
Roberts L, Hofmann CA. Assessing the impact of humanitarian assistance in the health sector. Emerg Themes Epidemiol. 2004;1(1):3. http://www.ete-online.com/contentpdf/1742·7622+3.pdf
Roberts M. A piece of my mind. Duffle bag medicine. JAMA. 2006;295(13):1491–1492
Suchdev P. Ahrens K, Click E. et al. A model for sustainable short-term international medical trips. Ambul Pediatr. 2007;7 (4):317–320
Wolfberg AJ. Volunteering overseas-lessons from surgical brigades. N Eng/J Med. 2006;354(5):443–445
Partners In Health's *Program Management Guide:* http://www.pih.org/pmg/
International SOS alerts: www.internationalsos.com
The Community Toolbox: http://ctb.ku.edu/en/default.aspx
TEDTalk by Chimamanda Adichie—*The danger of a single story* http://www.ted.com/talks/lang/eng/chimamanda_adichie_the_danger_of_a_single_story.html
Unite for Sight's Cultural Competency Online Course: http://www.uniteforsight.org/cultural-competency/
US State department http://travel.state.gov/travel/cis_pa_tw/cis_pa_tw_1168.html
American Medical Student Association (AMSA) http://www.amsa.org/AMSA/Libraries/committee_docs/abroad_checklist.sflb.ashx
World health organization (WHO) Web resources for clinical and technical radiology http://new.paho.org/hq/index.php?option=com_content&task=view&id=3363&Itemid=599
World health organization (WHO) Web resources for international travel and health http://www.who.int/ith/en/

host country culture surrounding basic social norms (i.e., gifts, greetings, etc.). When possible trainees should visit an international travel office for preparatory counseling and vaccines, often provided via a major academic medical institution or state government. In addition, some offices may have resources which can provide contact information of other volunteers who have recently traveled to a particular country or community. Overall, trainees who have previous overseas travel or volunteering experience often require the least preparation, and fortunately this proportion of experienced volunteers is increasing due to the many programs available at the high school and college levels.

Safety considerations are paramount, and regional hazards include endemic disease, regional violence, or conflicts, terrorism, and kidnapping. The US State Department Web site is an excellent resource for travel warnings and a general estimation of certain risk factors. Of all the potential dangers in international travel, one of the most overlooked safety considerations worth mentioning is local transportation—worldwide, an estimated 1.2 million people are killed each year in road traffic crashes and as many as 50 million more are injured. In many low- and middle-income countries, traffic laws are inadequately enforced, and the traffic mix is often more complex than that in high-income countries and involves two-, three-, and four-wheeled vehicles, animals, bicycles, and pedestrians, all sharing the same road space. Further, the roads may be poorly constructed and maintained, road signs and lighting inadequate, and driving habits poor. In some countries, it may be unsafe to be a pedestrian at night. It is important to ask safety advice from the host healthcare professionals.

It is important to establish an emergency plan well in advance of travel, and to maintain constant awareness of where each team member is at all times. Emergency airlift evacuation insurance can be considered, and may be covered by some academic institutions. Cellular phones are often more established than electricity, running water, or even paved roads in many parts of the developing world. Given the low cost and relative ubiquity of cellular coverage, it is critical to have immediate use of a cellular phone, either prepaid or an international plan for routine and/or emergency use. One strategy may be to bring a tri-band or quad-band cellular phone from home (not a dual-band phone which is the more common type in the USA) and rent or purchase a local subscriber identity module (SIM) card to use with the phone. Alternatively, where cell phone service is unreliable, a satellite phone can be rented or purchased. Another option is the use of a satellite global positing system (GPS) messenger, which has the advantage of a low-cost emergency system as it is connected to an emergency evacuation service arranged in advance of the travel.

Principles of Successful Global Health Imaging Models

As outlined earlier, there are multiple avenues for pursuing global health work (individual versus group, de novo partnership versus preexisting affiliation, direct on-site versus indirect through the Web, etc.). In this section, we provide examples of different types of global health imaging models that have found success [25].

An example of individual efforts in global health imaging is Dr. Helmut Diefenthal and the East Africa Medical Assistance Foundation. Diefenthal, a retired University of Minnesota radiologist, who relocated to Tanzania for more than 20 years, established the radiology department at the Kilimanjaro Christian Medical Center. For many years, radiology residents interested in global health experience, but without infrastructure at their home institutions, have had the opportunity to work at this site [25].

Given the vast infrastructure across the developing world that exists within the framework of government and nongovernment organizations of all sizes, partnering with local community representatives or well-established sustainable programs in the target community is a key strategy that is often neglected in global health program development in general, and specifically in prior imaging-related outreach efforts. For example, as an imaging-centered outreach organization in partnership with another global health program, the missions often complement each other well, particularly as the addition of imaging to nearly any specialty or healthcare outreach effort, when done responsibly, will greatly impact the effectiveness of the program and add a critical element to public health programs. A current example of this model can be found in iRadX, a nonprofit organization sponsored by Partners in Health, which provides imaging interpretation for humanitarian medical organizations such as Interplast. Volunteer radiologists in this organization range across a multitude of US academic centers [26].

Some groups choose to partner with and train host practitioners as future community leaders for project development—in this setting the community leaders become primary stakeholders in the aims of the program and, ultimately, in working toward sustainable success. As the project matures, the local leaders become capable of more meaningful collaboration with their academic partners and the US communities they represent, and are able to set the vision for the project and define the governance of the organizational mission. An excellent example of this approach is the extremely successful Jefferson University Research and Education Institute (JUREI) "Teaching the Teachers" approach in which training of developing world medical practitioners is accomplished via both in-country training and 3 months of US training in medical ultrasound as well as dedicated instruction in effective teaching techniques. After returning to their home nations, students often establish JUREI-affiliated ultrasound education centers; there are now more than 72 JUREI-affiliated centers in 55 countries on five continents, each using the JUREI model to provide ultrasound training locally [11, 19].

A similar example of a mixed direct and indirect approach can be seen in Imaging the World, an organization connected to the Department of Radiology at the University of Vermont, which provides on-site training of sonographers who perform ultrasound scans according to set protocols and send images electronically (via cellular phones connected to the Internet) to expert radiologists for interpretation. This project has found success in Uganda. Another successful model of a university-based resident global health radiology elective can be found in the aforementioned Emory University-AAU partnership. This partnership was initiated using preexisting connections between other specialties at their home institution and AAU. They have demonstrated an emphasis on sustainability, with aid in the development of a neuroradiology fellowship curriculum at AAU, involving time spent by Ethiopian radiology faculty at Emory [20].

In general, programs that incorporate partnerships directly with existing systems or organizations in developing countries have the best chance of making a positive, sustainable impact on community health. At the most basic level, working with community leaders allows short-term medical teams to learn local customs and culture, understand the local "healer" and "healing arts," and avoid making erroneous assumptions about local needs. Cultural sensitivity and understanding increases the effectiveness of care and may facilitate long-term relationships that help build local healthcare infrastructure.

In addition to diversifying local partnerships, employing more than one radiologic modality into a targeted needs-based global health outreach strategy may also result in sustainable efficiencies. Research presented at the 2011 RAD-AID conference shows a strong perception among radiologists and allied professionals that radiography and ultrasound are essential synergistic modalities in developing nations [11, 19] and agrees with the assessment from the WHO Department of Essential Health Technologies. Ultrasound, radiography, and mammography are clinically complementary, and models that integrate complementary modalities may be more cost effective and provide superior care. When needed, clinical support can be received from the developed world via teleconferencing, teleradiology, online education modules, and periodic on-site consultation [11, 19].

The Role of Research

An international health outreach curriculum provides an essentially unlimited number of opportunities for research initiatives and practice quality improvement projects. Indeed, an argument should be made that a well-designed program

Table 11.4 Roles of medical imaging outreach in global health research priorities

Global health research priorities	Roles of medical imaging research applications
Maternal and infant morbidity and mortality	Ultrasound in women's health outreach initiatives
Infectious diseases including HIV/AIDS	Imaging in screening, diagnosis, and evaluation of therapy effectiveness
Healthcare delivery systems in resource-poor settings	Novel healthcare delivery models centered on diagnostic imaging
Effects of sociocultural context on health care and burden of disease	Cultural attitudes and perceptions of technology and medical imaging
Chronic illness (diabetes and cancer)	Screening and diagnosis
Trauma/disaster relief	Imaging for complications of trauma, guiding therapy/intervention

WHO 2003, Ahn, Grimwood, Schwarzwald, Herman 2003, Dickenson-Hazard 2004, Giger and davidhizar 2004

must have a research component in order to at least gauge effectiveness of the efforts, and submit findings to a peer-reviewed forum such as an academic journal or a conference, so that the community at large can benefit from the efforts and build upon the advances in knowledge.

The topic of global health research is immensely broad, and in the context of education, much of this topic is outside the scope of this discussion. In general, complex global health issues set as priorities by large organizations and governing bodies in multidisciplinary forums such as the WHO and the United Nations include malnutrition, infectious disease, maternal-fetal health, and chronic illnesses such as diabetes and cancer (Table 11.4). The value of imaging in addressing many of these priorities has been demonstrated in established public health programs seeking to tackle these issues. In addition, the research priorities are designed to focus on the burden of disease in the developing world. It should be emphasized that all research be designed in an effort to create cost-effective, sustainable programs.

Even in the best of circumstances, research is extremely time-consuming to bring to completion, and internationally based research adds a great deal of additional complexities, not the least of which is a limited timeline in most instances. Practicality and relevance are paramount in designing research projects in the developing world for trainees, as are clearly defined outcome measures. It is important to resist designing research projects prior to communication with the host country, as often this can lead to failure as the outcome may not be aligned with the host country priorities. Ultimately, the project may be dominated by the visiting research team, and the impact of the eventual outcome may not be important toward shared goals. Also, avoiding research projects which take away already scarce resources from patient care is important, as the host clinicians and leaders may go out of their way to complete a research project at the potential expense of their patients.

In general, service-based research projects may be more practical, particularly those with uncomplicated defined outcome measures such as clinical improvement projects (i.e., needs assessment, PACS solutions) or education or training projects. For example, a targeted needs assessment, such as the RAD-AID Radiology-Readiness Survey tool, has been used in multiple countries and endorsed by organizations like the WHO and the ACR as an evidenced-based framework for collecting and analyzing data vital to deploying medical imaging in a variety of environments. These efforts often gain traction with local leaders and establish the foundation for a working relationship. Though the outcome measures data can be used for planning larger long-term projects, these initial smaller projects are often better suited for limited time and budgets, and the extensive preparatory planning required of research is often not applicable (i.e., IRB, etc.).

There are numerous challenges of international research collaboration, and the complexity may lead to disincentives. The primary challenge is distance, and a solid strategy for overcoming this includes regular phone, email, or Web-chat discussions to ensure regular contact—through these forms of communication alone, even simple survey, descriptive, and small intervention studies can be conducted with little or no costs. Funding, as will be discussed in further detail, presents a significant barrier as well. However, clever strategies have been described. One of the most prevalent in global health research is "piggybacking" small pilot projects on top of existing funded international studies; this is particularly applicable in the arena of medical imaging as many ongoing larger clinical projects would likely benefit from the incorporation of medical imaging, and an opportunity to share resources may be present. Pilot data from these collaborations can then be used as a foundation for funding applications for standalone medical imaging research projects [27–29]. Finally, obtaining human subjects approval in international research is a complex process in most countries where there are vast inequalities in power and status; each partner should be responsible for gaining approval with their own institutional review board, and ethical issues can be mitigated by ensuring all stakeholders understand roles and responsibilities [30–32].

Funding Considerations

The primary and most significant barrier to establishing any global health education program is reliable financial support. In the beginning stages, a catch-22 scenario often arises: funding follows results and proof of lasting effectiveness, which can only come from significant funding to design and implement a quality sustainable program. Some programs are able to get started with significant institutional funding, often those housed in larger academic centers with established global health initiatives. Alternative strategies include partnering with an existing NGO to leverage existing infrastructure; this can provide credibility as well as sustainability in planning, which in turn helps expand funding options. Raising money via grant and foundation applications can be very challenging without an experienced fund-raising leader or contact, and programs in the concept design phase are most vulnerable to rejection. However, this can be mitigated with the use of site assessment data and developing a well-researched, targeted proposal. The initial site assessment can often be funded with a small seed grant or through local fund-raising such as through silent auctions, alumni mailing lists, or private/corporate donations.

In the case of physician radiology residents, the funding for their graduate medical education is composed of direct graduate medical education disbursements and indirect medical education disbursements to compensate medical schools for the higher costs of patient care in educational institutions; reimbursements can only be used to support residents participating in approved clinical service activities and are subject to audit by Centers for Medicare and Medicaid Services. These funds could not be used to fund resident salary during an international global health elective rotation and would need to be covered as an addition to any off-site global health elective experience cost.

The reality is that funding streams change constantly and are extremely vulnerable changes in support based on the international spotlight, new outbreaks and challenges in public health, and unrelated economic difficulties. In the arena of global health, the most successful programs are supported and sustained by a diversified funding strategy, largely a combination of educational institution and private funding. Ideal starting points for any trainee or program director seeking funding for global health imaging outreach include national societies, such as the Barry Goldberg/Maurice Reeder International Travel Grant Program and the Foundation International Outreach Committee. Interested radiologist technologists may consider the RAD-AID/American Society of Radiology Technologists (ASRT) cosponsored travel grants for technologists which have funded technologist participation in global health imaging outreach programs in India, China, and Haiti; this program is the first of its kind an example of a national society-led multidisciplinary outreach effort.

Controversies and Socially Responsible Global Outreach

This discussion has focused primarily on developing long-term sustainable global health imaging programs, but it is important to acknowledge that the overwhelming majority of radiology-related global outreach work has historically been by individuals who have gone abroad alone or in small groups, sometimes with the intent to donate imaging equipment to a resource-poor community; the pervasiveness of this type of experience is multifactorial, predominantly tied to the low initial threshold for entry in terms of ease of funding and arranging individual contacts and lack of alternative formalized global health imaging programs. Yet, despite more than two decades of sporadic individual radiologist short-term visits and equipment donation, it is impossible to understand the impact or effectiveness of these efforts; few if any of these experiences had defined goals and objectives, measurable outcomes, or led to deliverables such as data-driven assessments for presentations at national meetings or publication. Furthermore, the data that is available regarding medical equipment donation in general suggests that the overwhelming majority sits idle, either broken or unused [11].

A growing consensus in the global health community in recent years has called into question the ethical and long-term impact of short-term global health work, also pejoratively referred to as "hit and run" or "medical tourism" projects. No matter what the intent, any new global health program must be introspective regarding the goals of the effort, and how those goals may be interrelated to both positive/intended outcomes as well as negative/adverse consequences. Institutional resistance to incorporating a global health curriculum may be related to perceptions of trainees using developing world opportunities as simply a "free pass" to travel to exotic locations with minimal supervision. Measured criticism has been leveled that some existing international health electives may lead to vulnerable populations serving only as a means to fulfill the needs of the visiting trainee rather than facilitating the empowerment of the host community [33].

These criticisms reinforce the need to develop accountable programs with measured outcomes, collaborative objectives, and sustainable goals; only by doing this can the field of global health imaging begin to realize the significant potential to offer future health professionals the opportunity to learn about and address the health advocate role, foster global citizenship, and develop a sense of social responsibility to tackle worldwide disparities and inequities in health and social development.

Conclusions and Future Directions

Over the past 20 years, the need for imaging expertise and resources has increased in many parts of the developing world, particularly as many public health programs and, in general, much of modern health care rely on medical imaging. Although short-term efforts may make some headway in addressing radiology-related inequities, a strategy for sustained responsible imaging outreach program development is ultimately necessary for long-term success. As a component of a discipline-wide effort, a formalized multidisciplinary curriculum which helps to train medical imaging professionals to become the future leaders for sustainable longitudinal program development will be needed. Accreditation and society oversight organizations, such as the ACGME, ISRT, ASRT, ARIN, ABR, or others, could serve as ideal starting points to establish criteria and identify components necessary for acceptable international electives in order to guide training programs in building global health imaging programs. The success of this strategy can be seen in the examples of other training programs, specifically surgery, family medicine, internal medicine, and emergency medicine as well as many medical and nursing schools, which have all made advancements in terms of established elective experiences for their trainees and have gained recognition of these efforts by the specialty board or governing body [34–39]. As discussed, radiology as a whole has significantly lagged behind in both the opportunities for a structured international imaging experience and in gaining significant support by the various imaging societies and the ACGME [11, 17–20]. It is clear from other successful efforts that consensus among the leaders of medical imaging will be needed to truly formalize a sustainable system designed to overcome significant barriers and offer training that will achieve educational and service goals.

In conclusion, globalization is progressing more rapidly now than in any other time in history. Medical imaging professionals have an unprecedented opportunity now to lead a paradigm shift—one that will bring medical imaging to the front lines of global health outreach and education, and in doing so answer the challenge to reinvent the "fragmented, outdated, static curricula that [produce] ill-equipped graduates" to become globally literate leaders.

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12 Legal Nonprofit Planning

Brendan M. Wilson

Part I: US Operations

Individuals and organizations seeking to develop an international radiology project must first decide what type of entity they will need to establish in order to conduct their activities at home and abroad. In many cases, the individuals and organizations working on the project will be motivated by charitable impulses and will want to establish a tax-exempt organization that has a social or charitable purpose. This section describes two of the most common types of US tax-exempt organizations that are used for international radiology projects—public charities and social welfare organizations—and explains how they are formed and what laws govern their operations.

Choice of Entity

Section 501(c)(3) Public Charity

Most often individuals and organizations seeking to develop an international radiology project elect to establish a nonprofit organization that qualifies as a public charity described in section 501(c)(3) of the Internal Revenue Code. Section 501(c)(3) provides for the exemption from federal income tax of an organization organized and operated exclusively for charitable purposes, which include the advancement of education and the promotion of health. An organization that satisfies the requirements of section 501(c)(3) enjoys exemption from federal income tax, and may also be exempt from state and local income taxes, real and personal property taxes, and sales and use taxes. Most importantly, perhaps, a 501(c)(3) organization is also eligible to receive tax-deductible contributions from donors.

Along with these advantages come a variety of hurdles an organization must clear to gain, and retain, tax-exempt status as a public charity. In particular, a 501(c)(3) organization must be operated exclusively for exempt purposes and not for the benefit of any private shareholders. This means, for example, it may have its tax-exempt status revoked if it has a substantial purpose of benefiting a private party or operating a commercial business. The organization may pay its leaders reasonable compensation, but it can put its tax-exempt status in jeopardy if any of its income or assets inure to the benefit of shareholders, officers, directors, or others with control over the organization. Other restrictions also apply. For instance, a section 501(c)(3) organization is limited in the amount of lobbying it can conduct, and it cannot directly or indirectly participate in, or intervene in, any political campaign on behalf of (or in opposition to) any candidate for elective public office. A section 501(c)(3) organization is also subject to various reporting obligations, including an extensive annual public filing on

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IRS Form 990 and various state filings depending on where it operates or solicits contributions.

To qualify as a 501(c)(3) organization, a public charity must file an initial exemption application on IRS Form 1023. Completing the Form 1023 can be time consuming and relatively costly—the initial IRS filing fee is currently $850 for most organizations. A new organization can begin its operations before the IRS has approved its exemption application, but it should not represent to donors that their contributions are tax deductible until the IRS has granted the organization a determination letter recognizing it as a 501(c)(3) organization. Unfortunately, the IRS often takes many months to process exemption applications and it is not uncommon for organizations to wait for 6 months or more before receiving the necessary IRS approval. As a result, many new nonprofit organizations use fiscal sponsors (described below) to help them raise funds until they receive their IRS determination letter.

Once the organization receives its IRS determination letter, it may begin soliciting tax-deductible contributions from donors. If the organization succeeds in raising funds, it may use those funds to support its activities overseas or it may regrant those funds to foreign organizations that will use the funds in furtherance of the organization's charitable purposes. It is important to note, however, that the organization may treat donations as tax-deductible gifts only if the organization exercises dominion and control over the donated funds. It cannot act as mere pass-through entity transferring earmarked funds from donors to designated foreign organizations. Instead, it must retain the authority to withhold funds from its foreign partners and use the funds for other charitable purposes if those foreign partners are unable or unwilling to use the funds in furtherance of the organization's charitable purposes. Additional restrictions on the organization's ability to transfer funds international are described in Part II below.

Section 501(c)(4) Social Welfare Organization

Instead of creating a charitable organization, individuals and organizations seeking to conduct an international radiology project may want to consider creating a tax-exempt social welfare organization described in section 501(c)(4) of the Internal Revenue Code. To qualify for exemption from federal income tax, a 501(c)(4) organization must not be organized or operated for profit and must be operated exclusively for the promotion of social welfare. An organization is considered to be operated exclusively for the promotion of social welfare if it is primarily engaged in promoting in some way the common good and general welfare of the people of the community. A nonprofit organization that conducts programs that promote health or education, or that provides medical services to underserved or low-income communities, will likely qualify as a social welfare organization within the meaning of section 501(c)(4).

Unlike a charitable organization, a section 501(c)(4) organization is permitted to engage in unlimited amounts of lobbying at the federal, state, and local level. In addition, a section 501(c)(4) organization is permitted to engage in partisan political campaign activity provided that such campaign activity is not its "primary" activity. Whether an activity is primary depends on all of the relevant facts and circumstances, but generally an activity will be a treated as a secondary activity if expenditures for it are 35 % or less of the organization's total annual expenditures. In some cases, organizations take the position that an activity will constitute a secondary activity if expenditures for it are as high as 49 % but less than 50 % of the organization's total expenditures. The IRS is reviewing this issue, however, so it is advisable to consult with an attorney before using a social welfare organization to engage in any substantial amount of partisan political campaign activity.

To qualify as tax-exempt organization, a section 501(c)(4) organization may file an application for exemption on IRS Form 1024. A section 501(c)(4) organization is not technically required to file the Form 1024 with the IRS in order to operate as a tax-exempt social welfare organization, but many organizations choose to file the application in order to have written confirmation from the IRS of the organization's tax-exempt status. Recently, the IRS has issued guidance indicating that any organization that wants an IRS determination letter recognizing it as a tax-exempt social welfare organization retroactive to the date of the organization's formation must submit the application for exemption within 27 months of the date of its formation. Any social welfare organization that applies for exemption after this 27-month window has lapsed will generally receive an IRS determination letter recognizing its tax-exempt status back to the postmark date of the application. The IRS will no longer be issuing retroactive recognition of exemption for organizations that have not filed within 27 months of formation. This does not mean that a 501(c)(4) organization that filed after the 27-month window has lapsed was not tax exempt during the first 27 months of its existing; it merely has failed to obtain IRS assurance that it qualified as a tax-exempt organization during the first months of its existence.

Although the social welfare organization has many advantages, there are at least two major drawbacks to operating as a tax-exempt 501(c)(4) organization. First, a social welfare organization is not eligible to receive tax-deductible contributions, which can severely limit its ability to raise money from donors. As a result, a 501(c)(4) organization should be established to conduct an international radiology project only if it is confident that it will not need tax-deductible gifts from individual donors in order to sustain its operations. Second, a social welfare organization may have less favorable tax treatment than a 501(c)(3) organization under the laws of various US states. In some cases, state laws do not grant a social welfare organization exemption from sales taxes, personal property taxes, or real property taxes to the same extent as a 501(c)(3) organization. Accordingly, if the organization intends to conduct significant activities or purchases medical equipment or other valuable items in the United States, it should check its state and local tax rules before seeking to qualify as a section 501(c)(4) organization.

Forming and Launching the Entity

Regardless of whether a radiology project is structured as a public charity or social welfare organization, the initial steps involved in creating the organization and qualifying for tax-exempt status are nearly identical:

Step 1—Incorporation. First, the organization will need to prepare and file articles of incorporation with the secretary of state in the organization's home state or the state where the organization would like to form. If the organization intends to qualify as a tax-exempt public charity, its articles of incorporation should provide that the entity is organized and will be operated exclusively for charitable purposes within the meaning of section 501(c)(3) of the Internal Revenue Code, and will not engage in activities that do not further exempt purposes. The articles of incorporation should also provide that in the event of its dissolution, the organization's assets will be distributed for an exempt purpose.

Step 2—Initial Board Meeting. After the organization is incorporated, the Board of Directors must hold an organization meeting to adopt bylaws, appoint officers, and authorize the organization's officers and agents to open bank accounts and complete other organizational tasks. The meeting can be held in person or by phone, or the directors may be able to simply sign a written consent approving the required actions if permitted under the bylaws and applicable state law.

Step 3—Tax Identification Number. Before it can apply for tax-exempt status, the organization must obtain a federal employer identification number by filing with the IRS a Form SS-4, which can be submitted by mail, by fax, or through an online process. To obtain an employer identification number, the organization must provide the IRS with the name and social security number (or taxpayer identification number) of at least one of its officers.

Step 4—Apply for Federal Income Tax Exemption. If the organization wishes to qualify as a public charity, it will have 27 months from the date of its incorporation to file with the IRS an application for exemption from federal income tax (Form 1023). If the organization files an exemption application within that 27-month period, and the IRS approves its exemption application, the organization will be granted tax-exempt status retroactive to the date of its incorporation. As described in Part I, Section A(ii) above, the organization does not have to file an exemption application with the IRS if it intends to qualify as a social welfare organization, although there are many reasons why it may want to do so.

Step 5—Complete State Registrations. Either simultaneously with, or immediately after, it applies for federal exemption, the organization also should complete the following state filings:

1. *Registration to Operate in Other States*. If the organization will maintain an office or employees outside of its state of incorporation, it will need to register to do business in those other states. The registration process in most states is relatively simple and usually requires the filing of an application with the secretary of state in the relevant jurisdiction.
2. *Charitable Solicitation Registration*. If the organization intends to solicit donations from the public, it will likely be subject to state laws that govern charitable solicitations. As a consumer protection measure, a vast majority of states require public charities to register with the state before soliciting charitable contributions from the general public. A more limited number of states also require social welfare organizations to complete such filing activities.
3. *Payroll Processing*. If the organization intends to hire employees to work in the United States, the organization will need to register with the state in which its employees will provide services to ensure that it is processing employment-related taxes properly. In many cases, nonprofit organizations simply hire a payroll processing company to handle all payroll-related issues, including federal and state income tax withholding.
4. *State Tax Exemptions*. Although tax laws vary from state to state, most states exempt from state income tax any organization that has received an IRS determination letter recognizing it as either a 501(c)(3) or 501(c)(4) organization. In many states a section 501(c)(3) organization may also qualify for exemption from state real and personal property tax, and sales and use tax.

In addition to completing the federal and state filings described above, the nonprofit organization may have to complete other state-specific filings or registrations, including business license registrations. States differ dramatically on what forms are required to be filed, so it is important to consult with state officials or knowledgeable attorneys who can ensure that the organization has complied with applicable registration requirements and remains up to date with its ongoing reporting obligations.

Operations in the United States

Once the organization has been established, it may immediately begin its operations. In many cases, however, the organization may need to focus initially on raising the funds it needs to carry out those activities. This section describes briefly some of the strategies that a nonprofit organization can employ to raise funds to support its mission, particularly if it is organized as a section 501(c)(3) organization that is eligible to receive tax-deductible contributions from donors.

Fiscal Sponsors

As described above, a public charity should not represent to donors that it is eligible to receive tax-deductible contributions until it has received its IRS determination letter recognizing it as a 501(c)(3) organization. Before the organization receives its IRS determination letter, the organization may need to begin raising funds and receiving donations. In many cases, a section 501(c)(3) organization seeking donations during its start-up phase will rely on a "fiscal sponsor" to accept and administer donations on its behalf. In general, a fiscal sponsor is a nonprofit organization that has received an IRS determination letter recognizing it as a public charity and has agreed to accept and administer charitable contributions on behalf of the new section 501(c)(3) organization until it receives its own IRS determination letter. The fiscal sponsor will receive donations, issue charitable contribution receipts to donors, and then distribute the funds to the nonprofit organization in accordance with the terms of any fiscal sponsorship agreement between the sponsor and the organization. Most fiscal sponsors charge nonprofit organizations a small administrative fee to provide these services.

Charitable Deductions

Once the organization has received its IRS determination letter recognizing it as a 501(c)(3) organization, it will no longer need a fiscal sponsor to accept and administer charitable contributions on its behalf and can begin receiving tax-deductible gifts directly. Once a section 501(c)(3) organization begins receiving tax-deductible gifts from donors, it must provide its donors with a contemporaneous written acknowledgement of any donation of $250 or more, including contributions of cash or property. The acknowledgement must indicate the amount of any cash and a description of any property contributed, and must state whether the organization provided any goods or services in exchange for the gift and, if so, a description and a good faith estimate of the value of those goods or services.

In some cases, a donor must obtain an appraisal prepared in accordance with specific standards and within a specific period of time qualified appraiser for any contribution of property to a section 501(c)(3) organization in any taxable year in which the fair market value of the property exceeds $5,000. If the fair market value of such property is $500,000 or less, the donor must attach an appraisal summary (IRS Form 8283) to his or her federal tax return. If the fair market value of such property exceeds $500,000, the donor must attach the appraisal to the tax return.

Donors may want to earmark their gifts to the 501(c)(3) organization for the benefit of a particular individual working on or served by the project. In numerous rulings, the IRS has concluded that donations are not deductible as charitable contributions where a section 501(c)(3) organization does not exercise full control over the donated funds. One indicia of the lack of sufficient control is if the nonprofit organization commits to pay any amounts donated to a particular person. In those cases, the contributions are treated as gifts to the individual, not the section 501(c)(3) organization, and the donor is deemed ineligible to claim a charitable contribution deduction for the gift.

As noted above, a section 501(c)(4) organization is not eligible to receive tax-deductible contributions. If operating as a section 501(c)(4) organization, it is important to notify donors that their contributions are not tax deductible in the manner required by IRS Notice 88-120, 1988-2 C.B. 454, which provides guidance on when such disclosures must be made and how they should be made. It is also important to note gifts to a section 501(c)(4) organization may be subject to federal gift tax. Accordingly, a 501(c)(4) organization should consult with a tax advisor before engaging in a fundraising campaign.

Corporate Sponsorships

In addition to receiving gifts from donors, a section 501(c)(3) organization may receive donations of cash or other property from for-profit businesses, vendors, or other corporate sponsors. After receiving a donation, the organization may feel compelled to recognize and promote the work of the sponsor on its website or in other venues. Under section 513(i) of the Internal Revenue Code, an organization that receives "qualified sponsorship payments" from a sponsor is not required to pay tax on the amount of the sponsorship payment as long as there is no arrangement or expectation that the sponsor will receive any "substantial return benefit," other than the use or acknowledgement of the sponsors name, logo, or product line by the organization. However, if the organization makes qualitative or comparative descriptions of the sponsor's products, services, or facilities while displaying the sponsor's name or logo the organization may be providing the sponsor with a substantial return benefit and subjecting itself to tax on some or all of the sponsor's donation.

Part II: Moving Individuals and Assets Overseas

Once the nonprofit organization is formed and ready to begin its international radiology projects, it will need to determine how to effectively move personnel and assets into the foreign countries in which it operates. These international transfers can be complicated and expensive, especially if the organization is operating in countries that are in high-conflict areas or known to harbor terrorists. Accordingly, a nonprofit organization operating in such countries must be certain to take adequate measures to ensure that its officers, employees, contractors, and volunteers comply with existing laws and avoid activities that expose the organization to significant liability.

Moving Individuals Overseas

Preparing employees or volunteers to work overseas can be a demanding task, but spending the time and resources to properly prepare individuals for their overseas experience usually pays significant dividends in the long run. Overseas projects can easily get derailed if a visa is not approved in advance or if an individual has not obtained the proper work permit to carry out his or her assigned task. To prevent such delays, it is important for a nonprofit organization conducting an international radiology project to make sure everything is in order before sending anyone to work abroad.

It is often helpful for an organization that regularly sends individuals to work overseas to develop a handbook that describes the organization's policies and procedures for preparing and sending its people overseas. A handbook can help explain to employees and volunteers what tasks the organization will complete on their behalf and what tasks they must complete on their own. A handbook can also describe the organization's policies and expectations for employees and volunteers working overseas, and what to do in case of an emergency. The major topics that are often covered in organizational handbooks are described in greater detail below.

Worker Classification

Before sending workers overseas, an organization must determine whether to classify those workers as employees, contractors, or as unpaid volunteers. Correctly classifying workers is important because it can affect how the organization reports and pays taxes in the United States, whether the organization and the individuals will be covered by the organization's insurance policies, and what liability risks the organization and the individuals will assume during the work assignment.

In general, the distinction between an employee and an independent contractor turns on the level of control that the employer exercises over the worker. A person is generally treated as an employee if the employer controls the services performed by that person. In contrast, a person is generally treated as an independent contractor if the employer has the right to control or direct only the result of the work and not what will be done or how it will be done.

To determine whether a worker is an employee or independent contractor, the IRS uses a multifactor test that looks at (a) whether the employer exercises behavioral control over the worker (e.g., does the employer direct when, where, and how the work is performed), (b) the financial arrangement between the employer and the worker (e.g., who pays for the equipment, does the worker provide services to other clients, does the worker have unreimbursed expenses), and (c) the nature of the relationship between the worker and employer (e.g., the terms of the written contract, the nature of the compensation and benefits provided to the worker, how important is the work performed to the organization, anticipated length of the relationship). In general, the determination of whether a worker is an employee or independent contractor does not turn on a single factor but must be made by looking at the facts and circumstances in each case.

In most situations, a nonprofit organization will prefer to treat its workers as independent contractors rather than as employees. An organization that has employees is required to withhold tax on the wages paid to its employees, pay the employer portion of the Federal Insurance Contribution Act (FICA) taxes on those wages, and comply with a wide variety of federal and state employment laws. As a result, an organization that has employees typically has to retain a payroll processing company to complete its payroll and tax filing obligations, and may also have to obtain applicable workers' compensation and employment-related insurance policies to protect against employment-related claims. An organization that has only independent contractors generally does not have to incur those costs.

Worker classification issues also come into play when a nonprofit organization engaged in an international radiology project sends individuals to work overseas without offering to provide them with any compensation or benefits. Under the federal Fair Labor Standards Act, an individual who provides services to a nonprofit organization without any expectation of compensation, and without any coercion or intimidation, generally is recognized as a volunteer. In some cases, however, an individual who does not receive traditional forms of compensation may be treated as an employee if the organization provides that person with other types of remuneration, such as long-term housing or noncash compensation. An organization that wrongly classifies an employee as a volunteer can be liable for failing to pay wages and withholding taxes on such wages, and may be required to provide the employee with workers' compensation insurance if its insurance policy does not otherwise cover volunteers.

A nonprofit organization that makes use of volunteers must understand whether its insurance policies cover its volunteers, and whether those policies protect the organization for injuries resulting from the acts of volunteers. In the United States, the Volunteer Protection Act of 1997 generally eliminates the liability of an individual volunteer for damage caused by his or her simple or ordinary negligence, but it does not protect a nonprofit organization from liability for the acts of its volunteers. As a result, a nonprofit organization conducting an international radiology project must carefully consider how it manages its volunteers and the risks inherent in sending volunteers overseas.

Tax Issues

As described above, an organization sending individuals abroad will need to determine whether to classify such individuals as employees, contractors, or volunteers. If the individuals are classified as employees or contractors, the organization sending them abroad will need to comply with the tax rules that apply when a US employer pays a US person to perform services overseas. If the individuals are classified as volunteers, the organization likely will have fewer tax issues to resolve.

If a US organization pays a US employee (including a US citizen or a US resident), the organization must withhold on his or her wages and issue the employee a Form W-2. If the organization pays a US contractor (including an individual or a company) more than $600 in the calendar year, the organization must provide the contractor a Form 1099 and, if it does not obtain proper documentation of the contractor's social security number or tax identification number, withhold certain taxes on payments to the contractor (this is called "backup withholding"). In contrast, an organization that pays nonresident aliens for work performed entirely outside the United States generally is not required to withhold on those payments. These tax rules are complicated and it is advisable for any organization paying individuals or contractors for work done overseas to consult with qualified tax advisors to ensure that it has collected the proper documentation and withheld the appropriate amounts on payments made to those working abroad. Failure to properly report and withhold payments can expose the organization to significant liability for taxes and penalties.

Liability Waivers

In many cases, an organization that sends individuals to work overseas will ask them to sign forms waiving their right to sue in the event that they are injured or killed while working overseas. The individual's execution of the waiver may not completely immunize the organization from liability, but it can provide the organization with a means of defending itself if an unfortunate incident occurs. Liability waivers can address a host of issues and may include provisions requiring the individuals traveling overseas to acknowledge and assume the risks inherent in the work they will be performing, waive their right to sue and release the organization from liability, indemnify the organization against claims arising from their acts or omissions, and take responsibility for obtaining medical or travel insurance.

Visas

In general, a nonprofit organization should encourage any individuals that it intends to send overseas to start the visa application process as early as possible. Many countries process visa requests very slowly and may require individuals seeking visas to complete significant amounts of paperwork, especially if the individuals intend to work for an entity located in the foreign country. The US Department of State has helpful online resources describing the specific visas requirements of various countries, and most embassies also provide information about the visa requirements for working in or traveling to their respective countries.

Insurance

An organization conducting an international radiology project must ensure that it has adequate insurance in place to protect itself and its employees, contractors, and volunteers from a variety of harms. In most cases, an organization will need to obtain a directors' and officers' insurance policy to protect those serving in leadership roles, and a general liability insurance policy to protect the organization against third-party claims. In addition, an organization with employees may need to obtain workers' compensation insurance or other employment-practices liability insurance policies to protect the organization and its workers in the event of an accident or injury. If the organization's workers will be in a high-risk area, the organization may also want to consider obtaining a kidnapping, ransom, and extortion insurance policy to protect the organization if an unusual tragedy or violent event occurs.

An organization working overseas should consult with an insurance agent to ensure that it has the right type and amount of insurance in place to protect against risks. An organization should ask its agent to verify that its workers' compensation policy applies to employees and volunteers who sustain injuries while working abroad. In some cases, the insurance carrier will require the organization to purchase a special rider before the policy will cover such injuries. The organization should also discuss with its agent what sort of protections its insurance policies provide if claims are filed against the organization or its agents in the foreign country where it is operating.

In addition to these basic types of insurance, an organization with projects overseas may want to obtain travel insurance that provides coverage for trip cancelation, travel delays, lost luggage, medical emergencies, and medical evacuation. In some cases, an organization may require its volunteers or contractors to maintain this type of travel insurance themselves. The organization may also want to consider purchasing additional insurance from a provider in the countries where it will operate if it is unable to obtain adequate coverage from a US insurance carrier.

Emergency Plans

In addition to having the proper insurance in place, a nonprofit organization conducting an international radiology project must ensure that it has provided its workers with a way to handle emergency situations while living or working a foreign country. For example, an individual who experiences a medical, surgical, or security situation may require immediate evacuation or extraordinary care that is not available in the foreign country. In such cases, the organization should ensure that it has a plan in place to help the individual evacuate the country, which may include the retention of a third-party evacuation service. To help prevent emergency situations from arising, organizations may also want to monitor the US Department of State webpage that lists travel warnings for citizens traveling or working abroad and other sources that can provide up-to-date information on safety conditions in the foreign country. If a situation becomes dangerous, the organization can also hire security personnel for their workers or other types of in-country assistance.

Working in Countries Subject to Embargoes or Sanctions

The US government maintains sanctions and economic embargoes against a variety of countries, including Cuba, Iran, Sudan, Syria, and certain designated terrorist persons or groups. If an organization wishes to send individuals to a work in a country subject to an embargo or sanction, it may have to obtain special licenses or other permits from the Treasury Department or other governmental agencies before it can transport medical equipment, laptop computers, and other materials into that country or participate in certain commercial transactions with foreign nationals or companies located in those countries. Obtaining the required permits can be a time-consuming process, and the organization should commence the application process for the permits as soon as possible.

International Transfer of Assets

The US government began focusing more attention on the foreign activities of US charitable organizations after the events of September 11, 2001. As a result, any section 501(c)(3) or 501(c)(4) organization operating in a foreign country or sending funds, individuals, equipment, or supplies to a foreign country must ensure that it is in compliance with applicable anti-terrorist and anti-corruption laws that govern these transactions. Violating such laws can be extremely costly to the organization from both a financial and reputational standpoint. Provided below B a brief summary of some of the most important laws and rules that apply to international activities of US nonprofit organizations.

Foreign Corrupt Practices Act

The Foreign Corrupt Practices Act ("FCPA") regulates two kinds of conduct. First, the "anti-bribery provisions" prohibit the bribery of foreign officials. Second, the "accounting provisions" require companies and organizations to maintain accurate books and records and to institute adequate internal accounting controls. The accounting provisions only apply to companies whose securities are registered with the Securities and Exchange Commission ("SEC"). Accordingly, the accounting provisions do not apply to US nonprofit organizations and will not be covered here.

The anti-bribery provisions prohibit US "domestic concerns" (which includes US persons and corporations), and any officer, director, employee, or agent of such domestic concern, from corruptly giving, offering, authorizing, or promising anything of value to any foreign official, foreign political party, or candidate for foreign political office through an instrumentality of interstate commerce. This prohibition applies to payments made for purposes of (1) influencing an act or decision of the official, (2) inducing such official to do or omit to do an act in violation of a lawful duty, (3) securing an improper advantage, or (4) inducing such official to use his influence with a foreign government or instrumentality, "in order to assist such domestic concern in obtaining or retaining business for or with, or directing business to, any person[.]" The prohibition includes payments to third parties while knowing that all or a portion of such thing of value will be offered, given, or promised, directly or indirectly, to any foreign official, foreign political party, or candidate for foreign political office for the same purposes.

An organization conducting an international radiology project that needs to regularly interact with foreign government officials may consider adopting an anti-bribery policy. Anti-bribery policies vary widely in their scope and level of detail (which is tailored to suit the risk profile of the organization), but generally include the following:

- The organization's approach to reducing and controlling the risks of bribery
- Its rules about making and accepting gifts, hospitality, or donations
- Guidance on how to conduct its business (e.g., negotiating contracts)
- Rules on avoiding or stopping conflicts of interest
- Procedures for monitoring and enforcing the policy
- Consequences for violating the policy

Anti-Terrorism Laws

In the wake of September 11, 2001, the US government adopted the "Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism Act of 2001," also known as the USA PATRIOT Act, which enhances penalties and liability for supporting terrorism. Prior to the USA PATRIOT Act, US law provided that whoever within the United States provides material support or resources or conceals or disguises the nature, location, source, or ownership of material support or resources, knowing or intending that they are to be used in preparation for or in carrying out a terrorist act, shall be fined, imprisoned for up to 10 years, or both. Similarly, US law also provided that whoever, within the United States or subject to the jurisdiction of the United Stated, knowingly provides or attempts or conspires to provide material support or resources to a foreign terrorist organization shall be fined, imprisoned up to 10 years, or both. The USA PATRIOT Act amended US law increase the maximum prison sentence to 15 years or, if the death of any person results, from a terrorist act for any term of years or for life. In addition, the USA PATRIOT ACT expanded liability to include attempt and conspiracy, and amended the definition of "material support or resources" to include expert advice or assistance.

In addition to criminal penalties, US anti-terrorism laws provide that US nationals who are injured in their person, property, or business by reason of an act of international terrorism may pursue civil penalties against the responsible parties. Such persons may recover threefold the damages they sustained and the cost of suit, including attorneys' fees. The Seventh Circuit has held that such civil liability can extend to a nonprofit organization that gives funds to a terrorist organization. *See* Boim v. Quranic Literary Institute, 127 F. Supp.2d 1002 (N.D. Ill. 2001), *aff'd* 291 F.3d 1000 (7th Cir. 2002) (holding that a civil action for treble damages could be brought under 18 U.S.C. § 2333 against a US charity that purportedly aided and abetted terrorist activities by providing financial support to Hamas, a terrorist organization). In light of these potential penalties, any nonprofit organization sponsoring an international radiology project should educate its staff about US anti-terrorism laws to ensure that they understand their responsibilities under the law.

Executive Order 13224

On September 24, 2001, President Bush issued Executive Order 13224. This Executive Order blocks the property of persons identified as terrorists in the Annex to the Order or in lists maintained by the State Department and Treasury Department (all of which are updated as needed). The Executive Order also prohibits US persons or persons within the United States from dealing with or entering into transactions with respect to property blocked pursuant to the Order, including but not limited to the making or receiving of any contribution of funds, goods, or services to or for the benefit of those persons listed in the Annex to the Order or determined to be subject to the Order. Any nonprofit organization operating internationally should take adequate steps to ensure that no person or entity on the list of Specially Designated Nationals (SDN) or Blocked Individuals maintained by the Office of Foreign Asset Control receives funds from the organization or other types of material support. Often it is helpful for a nonprofit organization to incorporate into any agreement it enters into with a foreign grantee or contractor a provision addressing these anti-terrorist rules and providing the organization with the ability to ensure that they are observed.

Treasury's Voluntary Guidelines

On November 8, 2002, the Treasury Department released the "U.S. Department of the Treasury Anti-Terrorist Financing Guidelines: Voluntary Best Practices for U.S.-Based Charities" (the "Guidelines"). Compliance with the Guidelines is meant to reduce the likelihood that charitable funds will be diverted to terrorist organizations and to reduce the likelihood of a blocking order against a US-based charity or donor. It should be emphasized that compliance with the Guidelines is voluntary. Moreover, compliance does not prevent a charity's assets from being blocked and does not preclude the Department of the Treasury or the Department of Justice from imposing any other criminal or civil sanctions.

The Guidelines are divided into four sections: (1) Governance, (2) Disclosure and Transparency in Governance and Finance, (3) Financial Practice and Accountability, and (4) Anti-terrorist Financing Procedures. The first three sections of the Guidelines contain provisions that are substantially similar to requirements currently imposed by federal tax laws. The Anti-terrorist Financing Procedures, however, go beyond the scope of current legal requirements and contain a list of steps that the Treasury Department advises US charities to take before distributing funds to a foreign organization. Any organization engaged in ongoing work in foreign countries would be advised to read these voluntary Guidelines to understand best practices in this area. Although a nonprofit organization may find it difficult or impossible to comply with all of the requirements of the Guidelines, they serve as a strong indicator of the types of procedures a nonprofit organization should have in place to protect itself from inadvertently engaging in activities that support terrorism.

Other Restrictions

In addition to the anti-terrorist and anti-corruption laws described above, a nonprofit organization engaged in an international radiology project should also be aware of other restrictions that apply to its overseas activities. First, a US nonprofit organization must ensure that its foreign activities advance its charitable purposes, rather than the private interests of any foreign individuals or organization. In addition, the organization must not engage in any excessive lobbying activities or any impermissible political campaign activities—even if those campaign activities occur overseas.

In addition, any US person who has a financial interest in or signature authority or other authority over any financial account in a foreign country, if the aggregate value of these accounts exceeds $10,000 at any time during the calendar year, must file with the Department of the Treasury a Report of Foreign Bank and Financial Accounts on Form TD F 90-22.1 ("FBAR"). A "US person" includes a citizen or resident of the United States, a domestic partnership, a domestic corporation, and a domestic estate or trust. As a result, a US nonprofit organization that controls a foreign account, and its officers or other employees who have signature authority over the account, may need to file an FBAR. In general, an officer or employee of a nonprofit will have signature authority over an account if such person can control the disposition of money or other property in it by delivery of a document containing his or her signature (or his or her signature and that of one or more other persons) to the bank or other person with whom the account is maintained. Failure to file the FBAR can result in both criminal and civil penalties.

Host Country Restrictions

In addition to complying with US laws governing the international transfer of workers, funds, and assets, the nonprofit organization must also comply with local laws that govern who may enter the country, who may work in the country, and what supplies or equipment may be transported or shipped into the country. The foreign country where the nonprofit organization operates may also charge fees or impose taxes of various types on equipment and supplies moving into and out of the country. Accordingly, a nonprofit organization should consult with local counsel in any country in which it intends to operate to make sure that it is able to comply with the requirements of local law.

Part III: Operating in a Foreign Jurisdiction

An ongoing challenge for a nonprofit organization conducting an international radiology project is to determine how to operate effectively under the laws of the foreign countries in which it operates. The laws governing corporate activities, intellectual property, labor and employment, banking, and insurance vary dramatically from country to country. As a result, it is often impossible for an international nonprofit organization to adopt a single strategy that will work flawlessly in every country. Instead, a nonprofit organization conducting an international project in multiple countries generally must be flexible and willing to adapt to local standards if it wants to successfully operate in the countries where it will serve.

Establishing a Foreign Presence

Branch Office

If a nonprofit organization operates overseas it will likely need to register as a foreign entity in the countries where it operates. In general, the process of registering an already-existing US organization as a foreign entity in the host country is usually administratively easier, more efficient, and less costly than establishing a new entity in the host country. It usually requires the foreign nonprofit organization to file registration paperwork with the appropriate government authority and pay a registration fee. Every jurisdiction has unique rules, however, so it is important for a nonprofit organization to consult with a local attorney to determine what rules apply to branch offices in the host country.

A nonprofit organization that establishes a branch office in a foreign country may be limited in what activities it can undertake within the country. For example, some countries prohibit branch offices from fundraising in the country, seeking loans from national banks, or purchasing real property. In addition, many countries require foreign branch offices of a nonprofit organization to be funded entirely by sources outside the country, and prohibit such offices from engaging in a range of business activities within the country. These limitations vary from country to country, but they are often so significant that they make it impossible for a nonprofit organization to successfully operate through a branch office.

Forming a Foreign Affiliate

If a nonprofit organization cannot operate successfully through a branch office, it may need to form a separate entity under the laws of the host country in order to be able to conduct activities there. Before forming a new entity, a nonprofit organization would be well advised to consult with local attorneys in the host country to determine what legal structures are available. Many foreign countries have laws that regulate entities differently than the United States, so an organization that qualifies as a charitable or social welfare organization in the United States may not qualify as a tax-exempt organization in every foreign country. In some cases, the nonprofit organization may find that it is easiest to establish a for-profit affiliate in the host country rather than trying to go through the process of registering as a charity, which is often an arduous and costly process.

If the nonprofit organization elects to establish a new entity in the host country, it must determine how it can control the new entity from afar. Some countries will allow a foreign nonprofit organization to have some type of membership or controlling interest in the local organization. In other cases, the nonprofit organization may be limited in its ability to directly control the local organization due to local laws or regulations. For example, many countries require the local organization to be controlled by citizens or residents of the local country, rather than by any foreign individual or organization. In such situations, the nonprofit organization may need to ask local citizens or residents of the country to serve as owners or directors of the new entity. However, it may be possible for the nonprofit organization or its representatives to retain some veto powers over key decisions of the local organization, or to control the local organization's activities through a licensing or affiliation agreement.

Professional Employer Organization

In some cases, a nonprofit organization may find that it is impractical to maintain a branch office or establish a new entity in the countries in which it works. As an alternative, the nonprofit organization may elect to use a professional employer organization (PEO) that can serve as the de facto employer of the nonprofit organization's in-country employees. Through a written agreement, the nonprofit organization can retain the PEO to hire its in-country employees and assume responsibility for payroll services, tax withholding, insurance, and related human resources compliance issues. These PEO arrangements are often very useful when a nonprofit organization has to transfer an employee to a country for a short or fixed period of time, but they are not always an ideal solution for long-term employment arrangements.

Partnering with an Existing Organization

Instead of hiring a PEO, a nonprofit organization can try to find partners or organizations that will help it to carry out its activities in the foreign countries in which it works. In some cases, the nonprofit organization may be able to enter into a partnership or affiliation agreement with a partner organization that is already established in the country and capable of carrying out a project on behalf of or in collaboration with the nonprofit organization. Although these affiliation arrangements can help a nonprofit organization to leverage the partner organization's existing infrastructure to achieve its objectives, they can also lead to problems if the relationship between the two organizations is not well managed or the partner organization lacks the skills or resources to adequately deliver on its commitments. In most cases, it is advisable for a nonprofit organization entering into such a partnership to put in place as many controls as possible to ensure that it retains some ability to incentivize the partner organization to fulfill its obligations and complete its tasks on time and within the established budget.

Protecting Intellectual Property

A nonprofit organization that has valuable intellectual property will want to protect it from being misused or appropriated by a third party when operating in a foreign country. The organization's intellectual property may include trademarks, patents, service marks, domain names, naming rights, and copyright materials. While the nonprofit organization may be able to effectively protect its intellectual in the United States by filing appropriate applications with the US Patent and Trademark Office, US Copyright Office, or other similar government agencies, or by actively enforcing its rights through legal channels, the protections afforded by US laws generally do not extend to foreign countries. The laws governing intellectual property differ from country to country, and there is no way for a US nonprofit organization to easily protect its intellectual property on a global basis. As a result, a nonprofit organization that has a valuable patent or trademark, or other intangible property, must protect its intellectual property in accordance with the laws of each of the countries in which it operates.

Conclusion

This chapter provides only a brief overview of some of the most important legal issues that an individual or nonprofit organization must address when conducting an international radiology project. In addition to the legal challenges involved in creating a nonprofit organization, transferring personnel and assets overseas, and establishing a presence in the host country, an individual or nonprofit organization operating a radiology project must also be aware of and comply with domestic and foreign health laws, including patient privacy and anti-kickback rules. Given the many legal challenges that a nonprofit organization may face when operating overseas, it is often helpful for the organization to retain both domestic and foreign counsel to help overcome legal obstacles that will inevitably arise. With careful planning and a willingness to be flexible, an individual or organization conducting an international radiology project can usually comply with its legal obligations under domestic and foreign law while still fulfilling its mission of providing medical services to individuals and communities in foreign countries.

Part II

Global Health Radiology Clinical Applications

13 Diagnostic Imaging for Global Health: Implementation and Optimization of Radiology in the Developing World

Pablo Jiménez, Kayiba P. Medlen, and Ileana Fleitas-Estévez

Introduction

According to the World Health Organization (WHO), diagnostic imaging is a means to take pictures of the structure and processes in the body and make them visible or "accessible" to the human eye [1]. The services of diagnostic imaging encompass a wide spectrum of clinical applications, which includes the diagnosis and monitoring of common diseases (respiratory diseases, injuries, digestive conditions, pregnancy, or breast pathologies) as well as more complex diseases (cancer, HIV, neurological disorders, or cardiovascular diseases (CVDs)). Modalities such as ultrasound and X-ray examinations alone can solve most of diagnostic problems and or common diseases/conditions in developing countries. These medical imaging modalities can be utilized to diagnose, prevent, and treat both common and serious illnesses in low-income countries, making these technologies key elements to address urgent public health concerns.

Medical imaging has been fast developing in the last few decades. For example, interventional radiology has modified the management of many diseases that previously required complex surgeries. New high-dose X-ray technology (particularly computed tomography scanning) has led to rapid growth in the annual number of procedures performed in many countries and, by extension, a marked increase in collective radiation doses. Clinical applications of hybrid imaging modalities (PET/CT, SPECT/CT) and magnetic resonance imaging (MRI) are also increasing worldwide for neurological, cardiovascular, and oncological diseases [2]. Demand for radiology services has increased worldwide due to the global increase in illness, new clinical applications, and broader societal trends, including the increase in world population and specifically aging population, lifestyle changes, and increase in worldwide healthcare programs and reforms.

The WHO estimates that more than half of the world's population lack access to radiology services [3]. Even where diagnostic imaging is available, both the quality and safety of the procedures may be questionable or even dangerous to the patient, the healthcare worker, and the

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public. The technology is also often unreliable, and a large number of the most complex equipment imported from industrialized regions does not work when they reach low-income countries [3]. Additionally, there is a significant shortage of radiologists, medical physicists, radiological technologists, and biomedical engineers for radiology services in low-income countries.

Diseases and Conditions of Public Health Concern Where Radiology Has an Impact

Maternal Mortality

The five major causes of maternal mortality listed by the WHO are as follows: hemorrhage, sepsis, unsafe abortion, eclampsia, and obstructed labor. In addition, the most common causes of neonatal mortality include infections, birth asphyxia, birth injuries, preterm births, and birth defects. With the exception of infections, eclampsia, preterm births, and obstetric hemorrhage are the most common causes of maternal mortality occurring postpartum and accounting for 25–33 % of all maternal deaths. Postpartum hemorrhage accounts for 25–30 % of deaths in India, 43 % of those in Indonesia, and 59 % of deaths in Burkina Faso [4]. Additional causes include obstructed labor, complications of anesthesia or caesarean section, and ectopic pregnancy [5]. These causes account for 11 % of all deaths during pregnancy or childbirth.

In 2010, 287,000 women died during and following pregnancy and childbirth. Almost all of these deaths occurred in low-resource settings. The maternal mortality ratio in developing countries is 240 per 100,000 births compared to 16 per 100,000 in developed countries [6].

The maternal mortality rate in the Region of the America is an estimated 71 deaths per 100,000 live births in the Southern Cone, compared to an estimated 364 deaths per 100,000 live births in the Latin Caribbean, including Haiti. An estimated 30–60 maternal deaths per 100,000 live births occur in Costa Rica, while in Guatemala, an estimated 290 (140–1,600) women die per 100,000 live births [7].

The current estimates of perinatal deaths occurring in the period from 5 months before birth to 1 month postpartum stand at roughly 6.3 million. The developing world accounts for almost 98 % of this number. In low-income countries, births often occur at home with unskilled or minimally trained attendants instead of hospitals where prophylaxis can be administered decreasing the risk of death [4]. These mortality causes are conditions for which timely ultrasound imaging could increase survival rates [5].

Ultrasound technology could most likely address some of the most important factors in maternal and infant mortality. These include diagnostic imaging of intrauterine growth restriction, multiple gestations, obstructed labor, congenital anomalies, as well as a number of tropical diseases and pathological conditions commonly found in low-resource countries [8]. Although ultrasound imaging is one of the most efficient diagnostic tools for perinatal care, it is seldom available in the developing countries mainly due to maintenance needs, limited availability of trained personnel, and difficult environmental conditions for protecting the technology [9].

Infant Mortality

Acute lower respiratory infection, and particularly pneumonia, is the leading cause of childhood mortality accounting for 1.1 million deaths per year worldwide. Pneumonia accounts for 18 % of all deaths of children under 5 years old worldwide. The disease is most prevalent in South Asia and sub-Saharan Africa [10].

Although vaccination is an approach to reduce mortality, factors such as access to vaccines due to the cost, as well as the increasing incidence of antimicrobial resistance contribute to pneumonia mortality. Various pathogens may cause pneumonia, but two bacteria are the leading causes: *Haemophilus influenzae* type b (Hib) and *Streptococcus pneumoniae* (pneumococcus) [11]. The appropriate case management, focusing on early detection and treatment of the disease, has been challenging to implement especially in low-income countries that often face poor access to basic health care. Almost all child pneumonia deaths occur in low-income countries, especially in sub-Saharan Africa, Latin America, and South Asia.

The usual treatment strategy begins with a clinical examination of the patient followed by a chest X-ray. Therefore, radiography would appear to be the best available method for diagnosing pneumonia only if (1) radiologists (and other health professionals such as pediatricians) know how to interpret the images shown in the radiographs, and (2) these images meet a high standard of quality.

Tuberculosis and HIV

Tuberculosis (TB) is an infectious disease caused by the bacillus *Mycobacterium tuberculosis* affecting the lungs, although other sites could be affected as well. In 2012, there were an estimated 8.6 million incident cases of TB, and 95 % of TB deaths occur in low- and middle-income countries. In 2012, an estimated 530,000 children became ill with TB, and 74,000 HIV-negative children died of TB. In addition, TB is a leading killer of people living with HIV causing one quarter of all deaths [12].

Current TB diagnostics include TB skin testing (TST), sputum smear and culture, and radiology [13]. Direct microscopic detection of acid-fast bacteria in sputum generally detects a limited percentage of true TB cases and is particularly problematic in individuals who are coinfected with HIV [14]. The role of chest radiography in the diagnosis of TB relies on the available resources and on TB prevalence in the population. The use of chest radiography is highly recommended for TB-suspected cases with three negative sputum smear microscopy. Chest radiography is a highly sensitive technique for diagnosing pulmonary TB in immune-competent individuals, but it is unspecific. In addition, chest radiography plays a significant role in shortening delays in diagnosis and should be performed early in the course of investigation of TB suspects among seriously ill cases infected with HIV. Several limitations on the wider use of chest radiography need to be addressed, such as resource constraints to equip district hospitals with X-ray equipment and difficulty of interpreting results [15]. CT and MRI have been used for the demonstration of intrathoracic lymphadenopathy and pleural effusions [16].

In many populations, chest X-ray screening for asymptomatic TB-infected patients is currently used as a first-line screening test or secondary after symptoms screening. Low-cost chest X-rays have been developed and are discussed elsewhere in this chapter, but overall, their accessibility is still limited. Research into the root causes of the limited accessibility of affordable X-ray equipment may help future projects become more successful.

Cardiovascular Diseases

The WHO estimated that 17.3 million people died from CVDs in 2008, while over 80 % of these CVD deaths take place in low- and middle-income countries. By 2030, almost 23.6 million people are projected to die from CVDs [17].

The major cardiovascular conditions include atherosclerosis, which is a condition where there is an accumulation of lipid in various arteries of the body. Heart failure occurs with the enlargement or remodeling of the heart, resulting in a decreased pumping ability often linked to atherosclerosis. Stroke is another major consequence of atherosclerosis occurring with scarring caused by an interruption in blood supply. Atrial fibrillation is an irregular and chaotic heart rhythm. Sudden cardiac death, obesity, and aging are also conditions of CVD [18].

The high burden of CVDs in developing countries is attributable to the increasing prevalence of atherosclerosis due to progressive urbanization and westernization of lifestyle (diet high in saturated fats and sugar, sedentary lifestyle) among other factors. Cigarette use is increasing significantly in most African countries, and thus has implications for the incidence of lung cancer in this region.

Cardiac ultrasound has diagnostic applications that are particularly suited to the developing world because of its noninvasive and portable nature. Echography is a useful tool in establishing cardiac diagnosis and evaluating the performance of the heart in various disease conditions. Those conditions include the diagnosis of pericardial effusion, lowered left ventricular ejection fraction, and abnormal stroke volume status in patients with shock [19]. As a result, ultrasound has grown to become the most widely used cardiac imaging technique and a powerful tool.

In this context, radiological applications have an important role. The diagnosis of CVD is aided by diagnostic imaging, while some of the treatments for these pathologies are based on interventional radiology procedures. It is now possible to treat different CVDs using catheterization-based techniques, which permit patients to be treated as outpatients with a shorter convalescence and lower costs in most circumstances compared with surgical intervention.

Injury and Trauma

Injury is the eight most common cause of premature death worldwide and the third most common cause of years lived with disability. More than 90 % of global deaths from injuries occur in low-income countries [20].

Bone trauma resulting from fractures due to road traffic accidents can be considered a major burden of disease. Untreated fractures can lead to severe functional problems, further adding to this burden. Each year, road vehicle crashes kill 1.2 million people and injure or disable tens of millions of people, with most traffic-related deaths taking place in low- and middle-income countries among young men 15–44 years old [21]. In Latin America, road traffic injuries are the leading cause of death in children aged 5–14 and the second leading cause in the group aged 15–44 and in 2010. It caused an estimated 149,992 deaths in the Region [22]. Road traffic deaths are likely to increase by more than 80 % in developing countries and to decrease by nearly 30 % in industrialized countries up to 2030 [23].

Low-income countries are also particularly vulnerable to intentional or non-intentional injuries including natural disasters and war. The weak infrastructure, inadequate public health capacity, insufficient healthcare structures, and insufficient human, technical, and material resources contribute to this vulnerability. It is estimated that two-thirds of the world has no access to orthopedic care since the world's 80 % trained orthopedic surgeons are mostly found in high-income countries. Musculoskeletal injuries represent approximately 70 % due to bullets, blasts, and landmines. Landmines are still present in many sub-Saharan African countries [24].

Much of the mortality due to injuries and trauma could be avoided by timely stabilization and medical care, and prompt utilization of emergency services, including basic diagnostic tests. Easy-to-use and portable ultrasound devices for diagnosis of internal, especially intra-abdominal bleeding would also be useful in this setting. Emergency radiology, including plain X-ray imaging techniques to diagnose bone trauma in a healthcare facility, is necessary for immediately addressing urgent health issues and to prevent long-term disability.

Breast Cancer

Breast cancer is the second most common cancer in the world and the most frequent cancer among women with an estimated 1.67 million new cancer cases diagnosed in 2012 (25 % of all cancers). Incidence rates vary nearly fourfold across the world regions, with rates ranging from 27 per 100,000 in Middle Africa and Eastern Asia to 96 in Western Europe [25]. Total mortality from breast cancer is already higher in the low- and middle-income countries. Contrary to the declining mortality in most high-income countries, it is estimated that it will increase by over 100 % in developing countries by 2020 [26]. By 2030, the global burden is expected to grow to 21.4 million new cancer cases and 13.2 million cancer deaths [27].

Lack of comprehensive cancer control programs represents the major obstacle for reducing cancer mortality in developing countries.

Early diagnosis of breast cancer improves the outcome of treatment. However, many patients in low-income settings do not have access to early detection methods such as clinical exploration, ultrasound, and mammography. The availability of mammography, the method of choice in industrialized countries, is 1 per 47,000 people compared to 1 per 5.7 million people in low-income countries [3]. Mammography is a well-established imaging method to diagnose breast cancer in most of Europe and North America, but is not universally accessible. In addition, ultrasound is also an essential component of the diagnosis and staging of breast cancer in most circumstances. Aside from the equipment, the specialized training needed to diagnose breast cancer is a challenge for low- and middle-income countries.

Osteoporosis and Osteoarthritis

Osteoporosis is characterized by reduced bone mass and disruption of bone architecture, resulting in increased bone fragility and increased fracture risk. The most common osteoporotic fractures comprise vertebral compression fractures, fractures at the hip, and proximal humerus fractures. The vast majority of osteoporotic fractures occur in women after the age of 50 years since they are about twice more likely to experience any fracture than men [28].

Single-energy X-ray absorptiometry (SXA) and dual-energy X-ray absorptiometry (DXA or DEXA) are methods for measuring the mineral content of the entire skeleton including specific sites. DXA measures spine, hip, and total body density. DXA is generally the method of choice because it has low radiation exposure, is fast, and renders precision measurements at the spine, hip, radius, or other peripheral site. DXA at the hip is the best predictor of hip fracture [29].

In low- and middle-income countries, the facilities for bone mineral density (BMD) measurement using DXA are scarce. For instance, in Morocco, Egypt, Tunisia, and South Africa, the device is available for research purposes, and screening occurs in major centers [30]. Osteoarthritis is the most common form of arthritis and a leading cause of disability and pain. Bone trauma resulting from fractures (e.g., from road traffic accidents, natural disasters, war trauma, and osteoporosis) can lead to posttraumatic osteoarthritis.

Current Imaging Challenges in Developing Countries

The Pan American Health Organization (PAHO) and WHO are promoting Universal Health Coverage to ensure that all people have access to quality health services that they need, without suffering financial hardship. Universal Health Coverage builds on the renewal of Primary Health Care, and the commitments adopted in the Rio Declaration on the Social Determinants of Health. At the practical level, it aims to ensure access to good quality services based on need, not on the ability to pay; it seeks to reduce the financial hardships caused by reliance on ineffectual health systems and healthcare markets, and having to pay fees at the point of service. The Integrated Health Service Delivery Networks (IHSDNs) is a way PAHO/WHO proposes to address the approach of primary healthcare-based health systems at the health services level. Radiology services when established as part of the IHSDNs should include essential attributes such as model of care, governance and strategy, organization and management, and financial allocation and incentives [31].

However, health systems in many developing countries are characterized by highly fragmented health services. Experience to date demonstrates that excessive fragmentation leads to difficulties in access to services, delivery of services of poor technical quality, irrational and inefficient use of available resources, unnecessary increases in production costs, and low user satisfaction with services received.

Fragmentation is also evident in the lack of coordination across the different levels and sites of care, duplication of services and infrastructure, unutilized productive capacity, and the provision of health services at the least appropriate location, particularly hospitals. Regarding the experience of system users, fragmentation is apparent in the lack of access to services, loss of continuity of care, and failure of services to meet users' needs.

The available services and the need of the population are often disproportionate in low-income countries, further inhibiting diseases management and public health priorities. The appropriate services ought to be identified or recommended to decision makers and healthcare professionals for prevention, diagnosis, treatment, and rehabilitation purposes.

Most patients in low-income countries currently lack access to any form of imaging. While 96 % of emergency departments in the United States have CT scanners, most of rural populations in low-income countries lack access to basic ultrasound and X-ray [32]. Many of the developing countries are forced to allocate scarce resources to basic lifesaving issues such as the supply of safe, clean water and nutrition.

Poor governance and lack of strategy also impact financial allocation and incentives. Almost two-thirds of all low-income countries do not have a national health technology policy in the national health programs to guide the planning, assessment, acquisition, and management of medical equipment [32]. As a result, inappropriate medical devices that do not meet priority needs of the population, are unsuited for the existing infrastructure, and are too costly to maintain, are acquired. This system drains funds needed for essential services. Better policy in countries will lead to an increase in the quality, effectiveness, and coverage of health care with regard to medical devices.

Imaging Technology and Infrastructure

Diagnostic radiology is a major growth industry in the healthcare sector worldwide.

Radiology equipment is associated with high costs from the acquisition to operation of the equipment. Almost two-thirds of all low-income countries do not have a national health technology policy to guide the planning, assessment, acquisition, and management of medical devices, including diagnostic imaging. The recommendations are to implement policies that may lead to investment of appropriate medical devices to meet the needs of the population, and are compatible with the existing infrastructure and level of health worker skills. Such policies will also impact the procurement positively with proper installation, preventive maintenance, rational usage, and quality assurance (QA) [32].

The developing countries face different challenges in adopting health technologies, since most of the medical devices are designed for use in the industrialized countries. The WHO has worked for many years in the design and distribution of the World Health Imaging System for Radiography (WHIS-RAD). The WHIS-RAD was developed specifically for underserved areas of the world because of the inadequacy of equipment not designed for these environments. This equipment is reliable and safe to use, even where there is no fully trained radiographer/technologist. It is simple to operate and maintain, and it provides very high-quality images. The WHIS-RAD has been successfully tested, installed, and clinically proven in developing countries [33].

Maintenance of diagnostic equipment plays a very significant role in the longevity, effectiveness of diagnostic machines, as well as safety and image quality. Unfortunately, most of the equipment is poorly maintained by either engineers or technicians. Further, many facilities in resource-poor settings do not have appropriate room design and architectural specifications designed to minimize radiation scattering, maintain reliable electricity supply, or prevent voltage fluctuations. For the WHIS-RAD, room sizes recommended (the minimum is at least 16 sq. m, 172 sq. ft) will usually not need any additional wall thickness, unless there are more than 50 examinations every day (about 250 examinations every week). The system's design operates where power is unreliable and unavailable for periods of time.

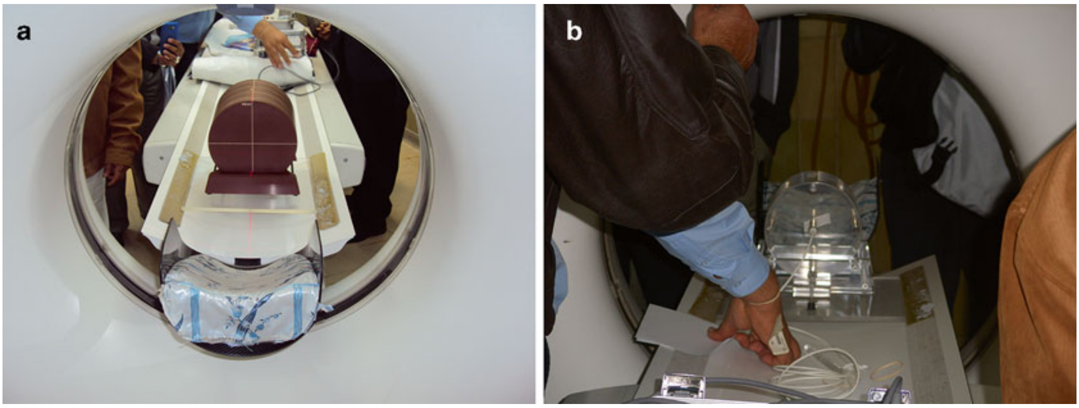

Fig. 13.1 (**a**, **b**) PAHO educational activities in Latin America. Computed tomography (CT) courses in Peru

Human Resources

Most low-income countries face challenges in radiology services because of the lack of skilled human resources. As a consequence, general practitioners often have to make the radiological interpretation of images. Nurses or technical personnel without adequate education and training carry out the diagnostic examinations, and inappropriately trained physicists or engineers assume quality, safety, and maintenance responsibilities. There are few mechanisms for the certification or recognition of these professionals. In some countries, these human resources are so low that it is not possible to include formal educational programs at the national level; in those countries that do host national educational programs, these programs are often of low quality. The opportunity of continuing education for professionals is also very limited in developing countries. As a result, many diagnostic technologists and radiologists choose to migrate due to a lack of opportunities for postgraduate training, underfunding of health service facilities, lack of established posts and career opportunities, lack of continuing education, health service management shortcomings, civil unrest, and lack of personal security.

To be effective, education, training, and continuous professional development need support at the local, national, regional, and global levels. The relevant international organizations and professional bodies can contribute substantially through the development of appropriate training material and through the organization of educational activities targeted at particular audiences, taking account of their specialties (Fig. 13.1a, b).

Radiation Protection and Safety

It is imperative to protect both patients and health workers from the dangerous risks of excess radiation exposure. Although radiation doses to patients in radiographic examinations are generally considered to be small in comparison with the immense benefits derived from these examinations, it is appropriate to reduce the dose to the lowest amount that is necessary to produce the image quality required for a diagnosis [34]. Poor-quality images result in unnecessary radiation exposure to patients through repeated radiographic examinations, loss of diagnostic information, and increased costs of health care [35].

The lack of appropriate infrastructure, well-maintained equipment, trained staff, governmental regulations, among other factors, threatens the safety of patients, workers, and the environment. About 40 % of low-income countries lack an expert responsible for implementing and enforcing regulations that ensure the safety of the device for the medical professional and the patient [32].

Quality Assurance and Accreditation

Quality assurance (QA) is a management tool, which aims to ensure that every exam or treatment in a radiology department is necessary and appropriate to the medical problem, and performed with the utmost level of quality and safety for the patient. These procedures should be performed according to previously accepted clinical protocols, by adequate trained personnel, with properly selected and functioning equipment, to the satisfaction of patients and referring physicians, in safe conditions and at minimum cost. Thus, a QA program should include periodic reviews of referral patterns, clinical protocols, continuing education opportunities for staff, facility inspections, equipment testing, and administrative procedures related to the purchase of supplies and billing. The ultimate goal of QA is to improve patient care.

Implementation of quality assurance programs is essential for obtaining accurate diagnoses. A PAHO assessment of imaging services conducted in public and private hospitals of five Latin American countries showed that very few services had implemented periodic quality control programs. As a result, more than 30 % of the clinical images from gastrointestinal tract exams and more than 50 % of lumbar spinal studies were not of diagnostic quality [36].

Accreditation programs represent a method for establishing and monitoring a set of quality standards. Regardless of the limitations that developing countries face, they can benefit from accreditation programs if they are to be tailored to the country's specific needs, in order to meet the demands of the population. With this in mind, PAHO developed a model of accreditation programs for imaging services in Latin American and the Caribbean countries, based on the experiences of the ACR program [37].

Cultural Attitudes About Radiology and Technology

In some countries, the low demand for medical technology often derives from deep-rooted culture and social norms. At the beginning of the symptoms, persons tend to solve their problems with traditional medical services, or via regional religious or folk-healing practitioners. Often when expected results are not produced with local folk medicine, the patient then seeks modern medicine. Although the introduction of new technologies and techniques in some countries is necessary, awareness of the traditions and beliefs may be crucial to the success of any project. Some cultural beliefs can affect medical imaging's acceptability and accessibility. For example, in Bangladesh, women are considered expendable and one with cancer is viewed as "bringing a curse to the family," and often leading to separation or divorce. They are therefore less likely to seek care or screening [38].

Improving Access to Basic Radiology in Low-Resource Settings

Access to appropriate healthcare services is very limited in rural areas, where approximately one-half of the global population lives and heavily depends on the numbers and types of qualified workers available. Only 38 % of the total nursing workforce and by less than a quarter of the total physician workforce practice in rural areas. For 57 countries, the critical shortage of trained health workers means an estimated one billion people without access to essential healthcare services. In Bangladesh for instance, 30 % of nurses are situated in four metropolitan districts where only 15 % of the population lives. In South Africa, 46 % of the population lives in rural areas, but only 12 % of doctors and 19 % of nurses are working there [39].

Basic Ultrasounds and Radiology

Diagnostic imaging (X-rays and ultrasound) has potential benefits to public health programs in low-resource settings by integrating simple strategies in health care in rural settings. In addition, ultrasound evaluates abdominal or pelvic pain, diagnose masses, musculoskeletal conditions, and assist in interventional procedures. Richter reported the diagnosis of schistosomiasis-induced periportal fibrosis and bladder abnormalities as well as manifestations of tuberculosis and HIV infection through ultrasound [8]. Ultrasound is safe, portable, inexpensive, and requires a simple power supply with minimal maintenance. Portable ultrasound is likely the most feasible in terms of transportation and maintenance, and an approximately 3.5 MHz convex transabdominal transducer that will be the most widely used and have the broadest public health impact.

There is also a pressing clinical and public health need for diagnostic radiography services globally. Studies in many countries have shown that the majority of patients need medical care after injury or because they have a cough or other chest complaints [33]. They then will benefit from radiography to image the lungs or abdomen, including intravenous or oral contrast to show details of the urinary tract or the gall bladder.

Telemedicine

Telemedicine or “healing at a distance” signifies the use of Information and Communication Technologies (ICT) to improve patient outcomes by increasing access to care and medical information. Teleradiology is a branch of telemedicine in which telecommunication systems are used to transmit digital radiological images, such as digital radiographs, CT, MRI, ultrasound, and nuclear medicine studies.

The demand for diagnostic and image interpretation services in radiology is growing rapidly in low-income countries due to the lack of adequate staff for providing interpretative coverage and the lack of specialty expertise. Teleradiology is very important as a means to provide access to expert assistance or specialist opinion in remote areas where physician access is otherwise unavailable or limited. The program benefits both patients and the healthcare system by reducing the distance traveled for specialist care and the related expenses, time, and stress.

Telemedicine networks in developing countries could also offer secondary benefits such as opportunities for learning and professional development by enabling the provision and distribution of general information and the remote training of healthcare professionals [40]. However, developing countries face challenges implementing teleradiology programs, and there are not many examples of successful programs. Some of the problems have been related to inadequate and unstable communication infrastructure, and the lack of financial resources for initial investment and maintenance of the networks [41].

Traveling Volunteer Teams and Mobile X-Ray Clinics

Many volunteers from high-income countries serve periodically in radiology services in low-income settings. In most cases, their work has an impact on the coverage and quality of services, as well as on the professional development of the local working force. For example, US health workers travel to Uganda as part of the Imaging the World initiative. During their stay, they offer basic training to utilize ultrasound in order to prevent maternal and fetal morbidity and mortality. The training portion of the protocol included a group of volunteers who spent 2 days training nurse midwives in a rural health clinic to use external anatomical landmarks to obtain hundreds of obstetric images [42].

Mercy Ships is a global charity that has operated hospital ships in developing nations since 1978, by mobilizing people and resources worldwide to serve poor people. Short-term crew can volunteer from 2 weeks to 2 years depending on the position, and typically fill service roles or very specialized medical or technical positions. In addition to providing thousands of free surgeries, Mercy Ships also builds local capacity by providing training programs and healthcare development projects, including the distribution of appropriate medical equipment and resources, along with biomedical training in equipment maintenance and operation, and construction/renovation of services to increase access to local health care [43].

Geographical factors, such as long distance to health service providers and blocked roads due to floods or snow, may suggest the option of mobile units. In order to improve access to imaging services, some equipment are installed in buses, trucks, or vans, which move them through towns, suburbs, and rural areas. For example, screening for detection of breast cancer relies very often on mobile mammography units and ultrasounds. RAD-AID International, in collaboration with Postgraduate Institution of Medical Education and Research in Chandigarh, India, developed a mobile health program with the aim to integrate community health education with imaging-based screening and diagnostic programs for women's health and broad public health programs [44].

Conclusion

In spite of increasing technological advancement and the use of diagnostic imaging globally, low-income countries face an increase in incidence and mortality of many of the diseases discussed in this chapter. Radiology, including ultrasound, can provide public health programs with tools to screen and diagnoses many illnesses, and should be scaled up in these regions. The incorporation of such technology in developing countries requires a careful study of feasibility that ensures sustainability. Additionally, it is essential for personnel working in diagnostic imaging to be trained to operate and maintain equipment appropriately. Relevant authorities should be committed to incorporate and maintain the technology as well as to provide the necessary infrastructure to support its use. A more widespread use of medical imaging and improvement in treatment approach will lead to the reduction of mortality and many conditions of public health concern, and ultimately improve the quality of life of the people in developing countries.

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14 Public Health and International Epidemiology for Radiology

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 14.1). 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.

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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 14.1). 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" [2]. This notion was further expanded in 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 [3]. 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" [4]. Effective networks and sophisticated 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 [5] and the surveillance of H1N1 influenza pandemic [6] are two such examples.

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Table 14.1 Public health definitions, mission and scope, functions, and relationship with radiology

Aspects	Detail	Reference
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 • What we, as a society, do collectively to assure the conditions in which people can be healthy	[58]
	Public health involves the application of many different disciplines including epidemiology, biostatistics, anthropology, medicine, sociology, and public policy, to name a few	[59]
	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	[60]
	The approach to medicine that is concerned with the health of the community as a whole	[62]
	Science and art of preventing disease, prolonging life, and promoting health through organized community efforts	[63]
	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	[65]
Mission and scope	Fulfilling society's interest in assuring conditions in which people can be healthy	[58]
	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 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	[61]

	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	[64]
	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	[62]
Core functions	• The assessment and monitoring of the health of communities and populations at risk to identify health problems and priorities	[62]
	• 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	
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	[61]
	Public health involves the application of many different disciplines including epidemiology, biostatistics, anthropology, medicine, sociology, and public policy, to name a few	[59]

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.

Mammography for Breast Cancer Screening

Breast cancer was diagnosed in almost 1.4 million women in 2008, and approximately 460,000 deaths were recorded [7, 8]. Although developed countries found higher incidence than less developed ones, 5-year relative survival estimates were much more (12 % in Africa to 90 % in the United States, Australia, and Canada) [8]. One potential explanation of this inequity is the different performances of healthcare systems in terms of preventive measures.

Early detection by mammography screening was shown to reduce risk of breast cancer death [9]; mortality in the screened group was 35 % lower than in the unscreened group [10]. Improvements in survival in more developed parts of the world have been attributed to the introduction of population-based screening using mammography [8], the systematic use of adjuvant therapies [8], and multidisciplinary medical care [11]. Based on the data from population-based mammography screening in Australia, Protani et al. was able to identify modifiable lifestyle factors associated with breast cancer, which is very useful for further development of public health interventions [12].

Nonetheless, like other tests, mammography screening does have some negative side effects such as false-positive results, which can lead to anxiety and discomfort [13]. Zahl and Maehien analyzed 14-year Norwegian data and reported that mammography screening resulted in "overdiagnosis" and "overtreatment" [14].

Chest X-Ray for Tuberculosis Screening

Tuberculosis (TB) is the leading cause of death worldwide, only second to HIV/acquired immune-deficiency syndrome (AIDS) [15]. 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 [16]. 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 [17]. Not only does HIV increase the risk of rapid TB progression, but it can also reactivate latent *Mycobacterium tuberculosis* infection [18, 19].

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) [5]. 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 [20], and the patients with cavity and positive sputum therefore require longer therapy [21]. However, limitations on the wider use of CXR, such as nonavailability at health facilities in the prevalent areas and the difficulty of interpreting results, have been of great concern [22]. While better diagnostics for TB is not available as of yet [23], 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 [24, 25] and was suggested as a cost-effective strategy in low- and middle-income countries with high prevalence [15]. 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 [26].

Nonetheless, specificity of the CXR has been questioned, especially among patients with the AIDS, who may present with various respiratory illnesses. In the past, experts missed approximately one-quarter of tuberculosis cases in a series of films [27]. However, the reliability of radiographic interpretation has greatly improved [20], 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 [22], and better positive predictive value [28].

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 [29, 30]. 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 [29].

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 [7]. The significant higher incidence and mortality in developed countries than in the developing ones have suggested the importance of dietary and environmental exposures [31, 32].

Endoscopic screening with flexible sigmoidoscopy or colonoscopy has been widely regarded as the standard for detection of colorectal tumors [33]. 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 [34]. 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 [35]. With insufficient evidence to assess the benefits and harms, CT colonography has not been recommended in the USA [33]. 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 2,600 asymptomatic adults and reported 90 % sensitivity for detecting a 10-mm lesion [36]. 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 [37]. CT colonography can also be used for evaluation of the colon after an incomplete conventional colonography [38]. 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 [7]. Case fatality rate is as high as 90 % [39].

In 1987, the Japanese government introduced lung cancer screening using CXR and sputum cytology [40]. The matched case-control studies suggested that mass CXR screening for lung cancers contributed to a significant mortality reduction of about 40 % [41]; however, potential bias from self-selection of the studies limited the generalizability of the findings. In 1997, a population-based cohort of almost 6,000 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 [42]. 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 [43]. 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 [44].

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 7,191 participants (27.3 %) had a positive screening result, compared to 2,387 (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 [45–51] and patients [52–54] 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 % early 1980s to 48 % in 2006 according to the U.S. National Council on Radiation Protection and Measurements [55]. 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 [56]. 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” [57]. 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 developing countries, the World Health Organization (WHO) has proposed a basic operational framework and some useful guidelines on radiology policy, quality, and safety [4].

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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Disaster Response

15

Ryan Sydnor, Stephen Ferrara, David Townes, and John H. Clouse

Introduction

The threat of natural disasters constitutes one of the few constants along the timeline of human existence. Capable of causing immediate, unthinkable devastation with little or no warning, "acts of God" such as earthquakes, tornados, hurricanes, floods, tsunamis, and wildfires far exceed the protective range of modern technology. While theories concerning the recent rise in frequency of natural disasters are somewhat controversial and beyond the scope of this text, there is no question that they remain one of mankind's greatest challenges. This fact becomes acutely apparent when natural disasters strike the developing world, where lack of preparedness and resources needed for recovery renders them utterly catastrophic. In 1970, cyclones in Bangladesh claimed 300,000 lives, roughly equivalent to the entire population of Pittsburgh, PA. The tsunamis produced by an earthquake 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 [1].

Ironically, the cost of such disasters both in terms of human life and economically is expected to rise as developing countries 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. From the perspective of healthcare costs, the potential impact of a major disaster rises dramatically with increasing concentrations of patients and advanced technology. Examples of the staggering economic costs of natural disasters in more developed regions were seen with Hurricane Katrina in 2005 ($144 billion) and with the earthquake and subsequent tsunami off the coast of Tohoku, Japan, in 2011 ($210 billion) [2].

In the face of such tremendous humanitarian and economic hardship, the necessity of

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Fig. 15.1 Field use of a portable ultrasound unit to evaluate a young woman with pelvic pain

well-organized medical relief efforts is clear. What this chapter aims to describe is the vital, expanding, and largely unrecognized role of radiology in disaster relief efforts. Diagnostic imaging and minimally invasive, image-guided procedures have become essential to modern emergency medical care, and these services should not be considered luxuries in the setting of disaster response, regardless of the affected region's economic status. The goal, after all, is to provide the best care possible. Because radiology now pervades nearly all aspects of health care, from surgery to obstetrics to the diagnosis and treatment of infectious diseases, it is increasingly challenging for the various clinical specialties to provide optimal care in its absence.

Certain elements of radiologic technology, such as portable ultrasound (US) and robust, mobile digital radiography (DR) units (Figs. 15.1 and 15.2), 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 inappropriate." Again, it is very clear in the humanitarian disaster relief community that 'more is not always better'. We should be very careful about the message we send as if the impression is 'the more technology the better' rather than 'appropriate technology' the chapter will be immediately outdated. Furthermore, any of these technologies that are in place prior to a major natural disaster are likely to be damaged, resulting in disruption of patient care across numerous components of the healthcare institution. The process of repairing or replacing such services is expensive, time-consuming, and logistically complex, and this can impede the implementation of important medical services in the midst of disaster relief efforts.

To fully understand the role of radiology in the setting of natural disasters, it is necessary to examine the setting of such disasters, 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.

Defining the Mission

Aid efforts can generally be categorized as either humanitarian assistance or disaster relief. 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

Fig. 15.2 (**a**) Digital portable radiography unit (**b**) Digital radiology unit used by the Japanese Red Cross in Haiti after the 2010 earthquake. (Photo credit: David Townes)

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 objective of the response is to both provide immediate life-saving medical care for those with acute, disaster-related injuries and illnesses as well as improve the health of a population through primary care services and public health initiatives. (Box 15.1).

While the acute trauma patients are the most obvious victims and garner the majority of the media attention, there are generally two additional populations of patients to consider in planning disaster relief missions. One includes patients whose ailments are not related to the disaster but who are displaced from the medical system due to loss of infrastructure. This group includes patients with chronic illnesses such as diabetes and heart disease as well as patients who develop acute, non-disaster-related illnesses such as acute appendicitis, pneumonia, or motor vehicle trauma. The third population is often overlooked and underestimated but carries important value to the success of the mission. This group is at the heart of what is known as "medical diplomacy."

Box 15.1 Patient Populations During Disaster Relief

- Those acutely injured or ill as a result of the inciting event
- Those with acute illnesses unrelated to the event (e.g., pneumonia, appendicitis, etc.)
- Those with chronic illnesses who have lost access to care due to loss of infrastructure
- "Special interest" patients

Local officials request personal medical assistance for themselves or on behalf of their family members for acute or chronic conditions that may not otherwise be triaged as urgently. While this goes against the classical teachings of medical delivery during crisis, it is crucial to embrace the fact that in many communities foreign medical team access to the general population resides in the hands of a small group of leaders. Establishing and maintaining a good rapport with this leadership may help facilitate the delivery of care to the populace [3].

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 [4], "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 developing 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 United States, response to international disasters is coordinated by the Office of Foreign Disaster Assistance (OFDA) at the United States Agency for International Development (USAID). Disaster relief efforts in the developing world have had highly varying degrees of success over the years. In comparison to affluent 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.

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 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 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.

Box 15.2 Overview of the Cluster System

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*

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 (Box 15.2).

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

Before discussing the role of radiology in the disaster relief paradigm, it is worth reiterating that 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. Radiology is not considered a luxury within the realm of "first-world" medicine; it is considered a necessity. This fact is obvious in settings such as trauma and critical care, where basing decisions regarding surgery and other potentially lifesaving treatments on physical exam and laboratory findings alone would be considered negligent. The role of radiology is less immediately apparent but still vital in primary care, where services such as mammography and imaging evaluation of masses or infections have long been the standard of care.

The inability to offer anything close to the standard of care has long frustrated medical aid workers across the entire spectrum of care. A common scenario is the privately sponsored medical mission trip, in which a collection of healthcare workers and non-clinical volunteers go abroad with donated medications and supplies. They often set up makeshift clinics in local churches or schools and provide very basic care to the best of their abilities. While these operations can benefit local populations with services such as obstetrics and perinatal care, vaccinations, and public health education, they tend to be limited by their lack of diagnostic capabilities and inability to provide treatments such as extended intravenous antibiotics and minimally invasive procedures. In many cases, substantial language and cultural barriers minimize the effectiveness of clinical history taking, leaving little on which to base management beyond physical exam findings. Given these formidable challenges and frustrations, it is no surprise that aid workers around the globe are desperate for even the most basic forms of diagnostic imaging.

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, relatively inexpensive, and can provide useful diagnostic information with less user training/experience than most other imaging modalities. With US, 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, 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. In the less emergent setting, ultrasound can play a major role in areas such as obstetrics and perinatal care, gynecologic care, evaluation of acquired and congenital heart disease (echocardiography), diagnosis of vascular anomalies, renal and hepatic imaging, evaluation of thyroid lesions, and aneurysm screening. Chronic or primary care applications of DR could include screening for breast cancer (mammography) and tuberculosis, evaluation of chronic lung disease, and characterization of certain tumors (e.g., primary bone neoplasms). There are also X-ray and ultrasound applications for bone densitometry, an important adjunct to women's health services in areas where osteoporosis is endemic.

Returning to the concept of providing the best care possible, physicians in developed countries rarely find US and DR adequate for diagnosis and management of complex pathology. Computed tomography (CT) is logistically more difficult to establish in low-resource settings due to its cost, lack of portability, need for consistent maintenance/repair and robust power supply, inherent radiation safety risks, and requirement of fairly 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. There will, however, be certain cases in which CT evaluation of a mass or other non-acute abnormality is justified. Aside from supporting the ideal of first-world health care, services such as these can have a great impact in the realm of healthcare diplomacy, as discussed previously.

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 right 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.

Other cultural factors may be difficult to predict or overcome, even with cultural training prior to deploying. For example, radiology teams deployed to areas where there is a sharp divide between economic or social classes can find themselves in a cultural quandary. In societies with openly discriminatory policies and customs, Westerners may have difficulty abiding to social norms. Foreign aid workers tend to believe in the ideal of providing equal care to all patients, regardless of social or economic status. In practice, this may test the "medical diplomacy" concept and lead to strained relationships with local hospital staff and leadership. 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). In many cases, patients use hospitals and clinics as their last resort, and their beliefs may prevent them from trusting the advice and treatments offered by foreigners. 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. It is important, therefore, for healthcare workers to develop a strong cultural knowledge base prior to going abroad and to adapt their practices appropriately.

Finally, it is worth considering difficulties faced on the opposite side of the cultural divide. Providing advanced, Western-style medicine for a limited period of time can undermine the local medical establishment, rendering the existing system "substandard" in the eyes of the public. This is by no means a reason to refrain from providing high-quality medical care, but such dynamics should be examined as long-term plans are devised for communities receiving aid.

Case Studies

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 1,000 hospital beds (including 100 ICU beds), 12 operating rooms, full lab and blood bank capability, *Mercy* also has a highly functional radiology department (Box 15.3). 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 [5].

> **Box 15.3 Imaging Capabilities of USNS Mercy and Comfort**
>
> (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

The "Standard" Model

The *USNS Mercy* deployed with 3 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. 15.3).

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,

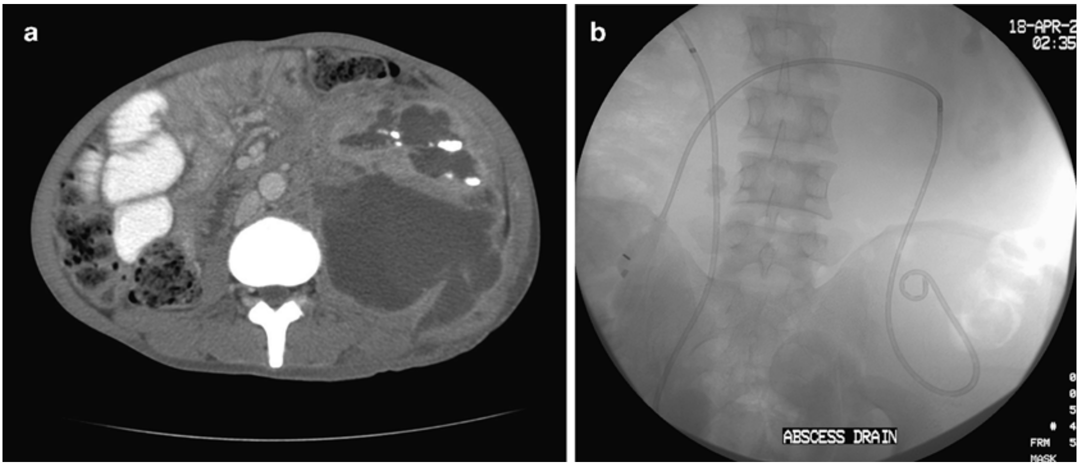

Fig. 15.3 (**a**) Contrast-enhanced CT of the abdomen in a patient with sepsis demonstrates a large left retroperitoneal abscess. (**b**) Spot fluoroscopic image following placement of two percutaneous drainage catheters

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 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. 15.4).

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* (Fig. 15.5). With the addition of a massive civilian volunteer contingent, the *Comfort's* capacity could be expanded to 1,000 beds, including 880 ward beds, 80 intensive care unit beds, and 20 postanesthesia 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

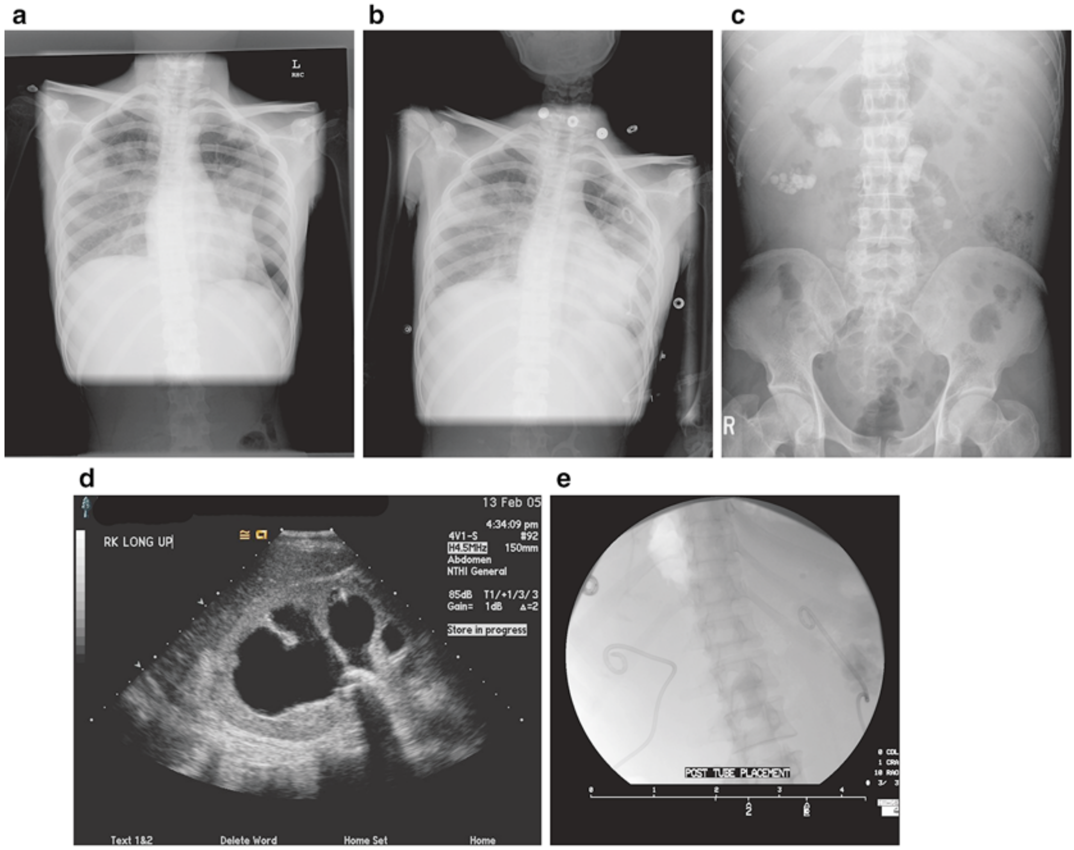

Fig. 15.4 (**a**) Frontal portable chest radiograph in a patient with "tsunami lung" reveals left pneumothorax with air space consolidation and cavity formation [6]. (**b**) Frontal portable chest radiograph following left pigtail tube thoracostomy placement. (**c**) KUB reveals multiple bilateral uroliths. (**d**) Ultrasound demonstrates right-sided hydronephrosis secondary to large pelvic urolith. (**e**) Spot fluoroscopic image following placement of bilateral nephrostomy tubes

Fig. 15.5 The US Navy hospital ship, *USNS Mercy*

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 [7].

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. Portable US was particularly useful in the identification of internal hemorrhage, fluid collections, and obstetrical pathology. Digital radiography sufficed for diagnosis of most orthopedic injuries, and CT was available for more complex injuries including spinal fractures, intracranial injuries, and solid organ damage. Interventional radiology was employed in a variety of contexts as described above, both for emergent management of traumatic injuries and for other, less emergent but lifesaving treatments. 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.

Box 15.4 Essential Components for Successful Radiology Implementation in 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
- Crucial infrastructure components intact
- Well-trained individuals

Looking Ahead

From the perspective of professionals in the field of radiology, what preparations can be made to maximize the benefit of radiology services in the setting of a natural disaster? We have already touched on many of the essential elements of disaster relief and humanitarian aid programs (Box 15.4). Portable technologies such as DR and US should be transported directly to the hospital(s) in need in order to replace or augment existing imaging technology. Mobile healthcare units equipped with imaging units may also be employed in certain areas. In addition, more advanced services such as CT and fluoroscopy should be made available immediately off-site when possible, as was done with the *USNS Mercy* in Indonesia and the *USNS Comfort* in Haiti. When this is not possible, efforts should be made to provide transportation to radiology-equipped tertiary care sites remote from the disaster.

While temporarily replacing or augmenting imaging technology, aid workers should strive to repair existing equipment and/or install functioning donated equipment for use after acute relief efforts have ended. This will require involvement of physicists, engineers, and specialists capable of training the local staff to use the new technology effectively and safely.

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 developing 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 natural 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 in the field of radiology must strive to implement vital technology and training programs in vulnerable regions, and they must insist on having a place at the table in the planning of disaster relief programs. The radiology community has little excuse for allowing their area of expertise to remain a weak spot within the disaster relief paradigm.

Disclaimer The views expressed in this article are those of the author and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government. The author has identified no conflicts of interest.

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16 Infectious Disease Imaging

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Introduction

The topic of infectious disease imaging in the developing world 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 developing world settings and includes clinical cases in multiple modalities, exhaustive reviews on pathophysiology and medical management, all of which are based on meticulous epidemiology and pathophysiology discussions. In contrast, what follows in this chapter is an introductory review of imaging for common endemic infectious disease processes organized by modality with the purpose of providing context in the larger framework of this textbook.

Background

Infectious diseases continues to remain a major cause of morbidity and mortality in the world [1]. 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 through 2017 [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 CT, MRI, and PET expected to continue to grow through 2017 [2]. 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

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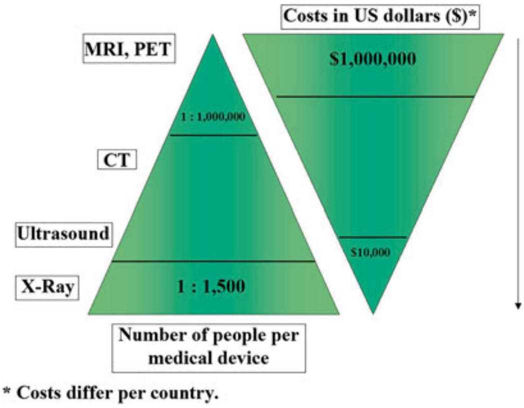

Fig. 16.1 Graphical representation illustrating the availability of the imaging modality (number of people per device) versus the cost of purchasing the imaging scanner (in US dollars)

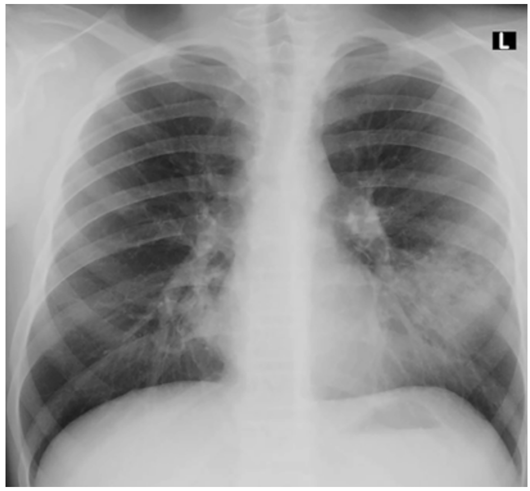

Fig. 16.2 Frontal chest radiograph demonstrating left lower lobe airspace opacities in a patient with community acquired pneumonia

the higher economic strata in the developing world. 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) [3–6]. The availability and relative cost of the various imaging modalities are shown in Fig. 16.1.

Thoracic Radiography

Plain film radiography is the most widely used imaging modality. One of the most common applications for radiographic imaging is in the diagnosis and monitoring of thoracic infectious disease, particularly pneumonia. Worldwide, pneumonia is a leading cause of death and hospitalization, particularly among children and the elderly [7]. In many instances the specific appearance or distribution of abnormalities on the chest radiograph due to infection can aid in identification of the involved pathogen, informing treatment and identifying complications and/or treatment response. Lobar consolidation, cavitation, and effusions often suggest a bacterial etiology (Fig. 16.2), but also can be seen in polymicrobial (i.e., multiple pathogens at once) infections in addition to fungal and mycobacterial etiologies; in the case of consolidation, pyogenic bacteria are commonly diagnosed [8]. Diffuse bilateral involvement may also be a presentation of bacterial pneumonia, but more often suggest an atypical infection, such as *Mycoplasma, Pneumocystis jiroveci, Legionella*, or a primary viral illness [8]. A chest radiographic appearance more severe than suggested by the clinical examination has been described in both viral and mycoplasma pneumonias [8]. Although specific pathogen diagnosis is often not possible by radiography given the overlapping imaging features of these diseases, radiography is important for (1) localizing the site of infection at diagnosis, (2) monitoring progression versus regression, (3) estimating severity, and (4) diagnosing complications such as pneumothorax and atelectasis (lung collapse). Therefore radiography is a vital tool for managing lung infections even when the specific pathogen is not identified, particularly since many antibiotic therapies can cover a wide range of the possible pathogens.

Pneumatoceles (cavities filled with air) may be seen in pneumonia caused by *Staphylococcus aureus, Klebsiella pneumoniae, Haemophilus influenzae*, and *Streptococcus pneumoniae* [8]. Streaky peri-hilar shadowing can be an early stage of *Pneumocystis jirovecii* pneumonia (PCP), most often seen in HIV-infected patients [9]. In more advanced stages, PCP presents with

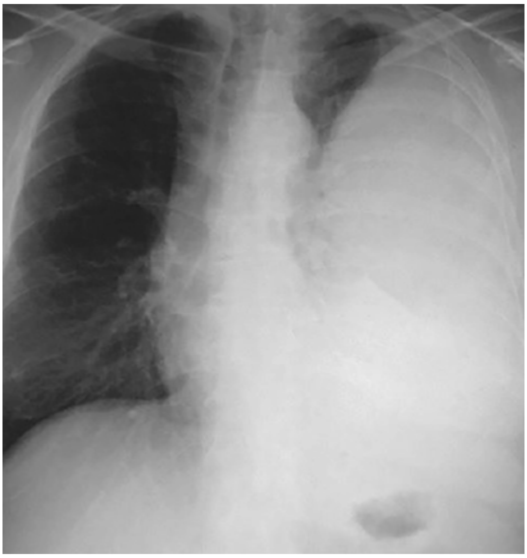

Fig. 16.3 Frontal chest radiograph demonstrating a large, lens-shaped opacity in a patient with an empyema as complication of community acquired pneumonia

Fig. 16.4 Frontal chest radiograph reveals a localized, walled cavity, with an air-fluid level in the left mid-lung compatible with an abscess

a butterfly-shaped appearance or diffuse ground-glass opacities [10]. Other less common patterns have been reported, including lobar infiltrates, pulmonary nodules, pneumatoceles, and other cystic changes [10]. These diverse features of PCP are important to recognize in imaging because this is a common infection in HIV-infected patients and the treatment is different and longer term than the therapies for other lung infections.

An 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 [11]. The chest radiograph will classically demonstrate a large, lentiform (lens-shaped) pleural opacification [12] (Fig. 16.3). Pulmonary abscess, in contrast to an empyema, describes 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) [13]. Similarly, *Echinococcus granulosus,* a cyst-forming tapeworm especially prevalent in parts of Asia, north and east Africa, Australia, and South America, can also present as a cavitary lung lesion, often containing smaller collections referred to as "daughter cysts" [12, 14]; Echinococcus infection also is seen to affect other areas of the body, most commonly the liver, as is discussed later in this chapter.

Another endemic parasitic infection commonly diagnosed on chest radiographs, Paragonimiasis, also leads to the formation of aggregate pulmonary cystic lesions. 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) [15]. 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 [16]. 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 [15]. Hemoptysis can often occur irregularly and continue for years. The chest radiographic appearance has been shown to vary with the stage of infection, however most commonly demonstrates focal mass-like consolidation containing aggregated thin-walled cysts (Fig. 16.5). The radiographic

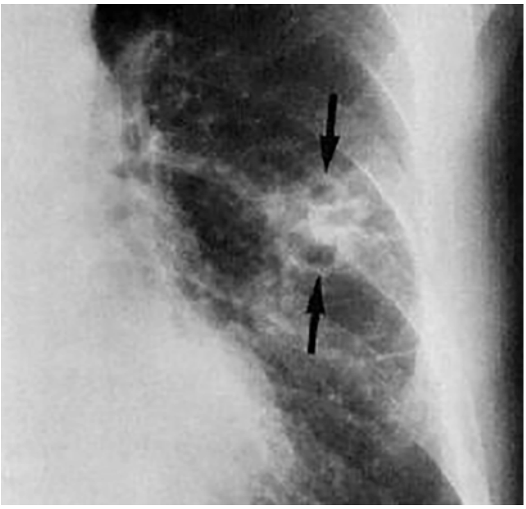

Fig. 16.5 Focal view of a left mid-lobe lesion demonstrating multiple small aggregated cysts in a patient with Paragonimus (*arrows*)

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 [17]. The lifecycle 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.

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, one third of the world's population is thought to have been infected with *M. tuberculosis* (latent infection), with new infections occurring in about 1 % of the population each year [18]. According to the 2013 WHO report on tuberculosis (TB), there were an estimated 8.6 million new cases of active TB and 1.3 million deaths, mostly occurring in developing countries [18]. There are increasing rates of TB in Africa and Eastern Europe, and it is currently the leading cause of death in HIV-infected patients. Diagnosis of active TB relies on imaging, as well as microscopic examination and microbiological culture of body fluids, 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. Therefore the imaging diagnosis 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 [19]. 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). 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 (or secondary), and miliary. Primary TB occurs most commonly in children but is being seen with increasing frequency in adults and presents with lymph node enlargement, often unilateral hilar nodes, seen in 90–95 % of cases [20]. Other imaging findings in primary pulmonary TB range from a simple pleural effusion to poorly defined opacification in the peripheral lung fields [21]. 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 [20]. Cavities, the radiologic hallmark of reactivation TB, are evident radiographically in 20–45 % of patients (Fig. 16.6) [19]. Finally, in cases of miliary TB, the chest radiograph may demonstrate characteristic innumerable 1- to 3-mm diameter nodules randomly distributed throughout both lungs; thickening of interlobular septa is also frequently present [15, 20] (Fig. 16.7).

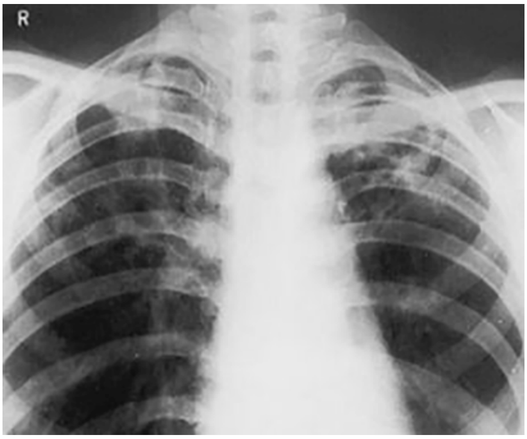

Fig. 16.6 Frontal chest radiograph demonstrating bilateral upper lobe asymmetrical cavitation. Note that the presence of pulmonary cavitation is evidence of necrosis, which is part of the natural history of disease

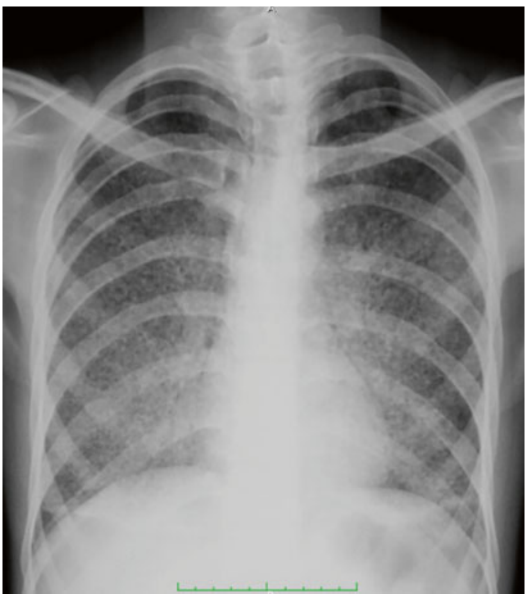

Fig. 16.7 Frontal chest radiograph demonstrating diffuse bilateral reticulonodular opacities in a patient with miliary pattern of TB infection

Melioidosis, a deadly gram-negative bacterial infection found primarily in Southeast Asia, can also cause a TB-like pattern of disease [15]. 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 [22, 23] 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 [15].

Fig. 16.8 Lateral cervical radiograph demonstrates a markedly thickened epiglottis (*arrow*) in a patient with epiglottitis

Plain film radiography is most frequently utilized to examine the chest/lungs, but is also often used to examine the airway and soft tissues of the neck. Epiglottitis, a potentially life-threatening condition of inflammation, edema, and obstruction of the epiglottis and surrounding structures that classically occur in children aged 3–7 years, has a characteristic appearance on lateral radiographs of the neck known as the “thumb sign”—an enlarged epiglottis that protrudes from the anterior wall of the hypopharynx (Fig. 16.8) [11], thereby causing obstruction of the airway (either partially or entirely). Like epiglottitis, retropharyngeal abscess is also a potentially life-threatening condition due to the risk of compromising the airway [8], and carries significant morbidity and mortality if not managed properly [24]. Because of the deep location within the neck, this condition is difficult, if not impossible, to evaluate on clinical examination [25], which is why imaging techniques are critical. A lateral soft-tissue radiograph of the neck (during inspiration and with the neck in normal extension) may show widening of the prevertebral tissue [8].

Abdominal Radiography

Just as radiography is invaluable in the evaluation and diagnosis of thoracic infectious diseases, it can also be an excellent tool, for intraabdominal infections. In general, abdominal radiographs are particularly useful for demonstrating bowel obstruction or ileus, pneumatosis (air in the bowel wall), free intraperitoneal air, abscesses, etc. [26]. At times, severe gastrointestinal infections, caused by bacterial, viral, or parasitic disease can lead to dilation, ischemia, and perforation of the gastrointestinal tract; these complications are often readily demonstrated on abdominal radiography. Abdominal radiographs may also demonstrate the sequela of severe cholecystitis by demonstrating air within the lumen or wall (though ultimately for hepatobiliary examination ultrasound remains the initial study of choice) [14]. Finally, calcified processes in the abdomen, in particular the genitourinary and hepatobiliary system, can also be evaluated by plain film radiography.

In general, a large number of endemic infectious and parasitic diseases can lead to findings on abdominal radiography and may be useful in settings where more advanced imaging such as CT or ultrasound are not available. One of the most common and insidious endemic infectious diseases throughout Southeastern Asia, Coastal South America, and Africa is Schistosomiasis; which has a characteristic imaging appearance on abdominal radiography. In endemic areas, children are usually exposed early in life and in fact in some areas childhood infection is almost universal. For instance, in Niger (West Africa) over 80 % of children are infected and in rural Zambia the rate is nearly 70 % [15]. The abdominal radiographic findings involve the genitourinary (GU) system where calcification within the bladder and ureters are seen (Fig. 16.9); in severe infections the calcified eggs can be visualized in the soft tissues. In general, the kidneys are uncommonly calcified, and even in advanced disease, will be calcified out of proportion to the ureters and bladder [27].

Fig. 16.9 AP radiograph of the pelvis demonstrating thick circumferential calcification of the bladder and distal ureters, which are dilated in a patient with longstanding Schistosomiasis infection. A large calcified bladder stone is also present

TB, which can be found in nearly every part of the body, can also be identified on abdominal radiographs. As in other endemic infections, the GU tract is commonly involved. Differentiation from other causes of calcification, 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) [28].

Radiographs, in combination with administration of oral contrast agents (such as barium sulfate) can be used to evaluate the entire gastrointestinal tract. Drawbacks of these imag-

Fig. 16.10 AP radiograph of the pelvis demonstrating multiple dense calcifications replacing much of the right kidney as a result of late stage renal tuberculosis infection. This appearance is also referred to colloquially as "putty kidney"

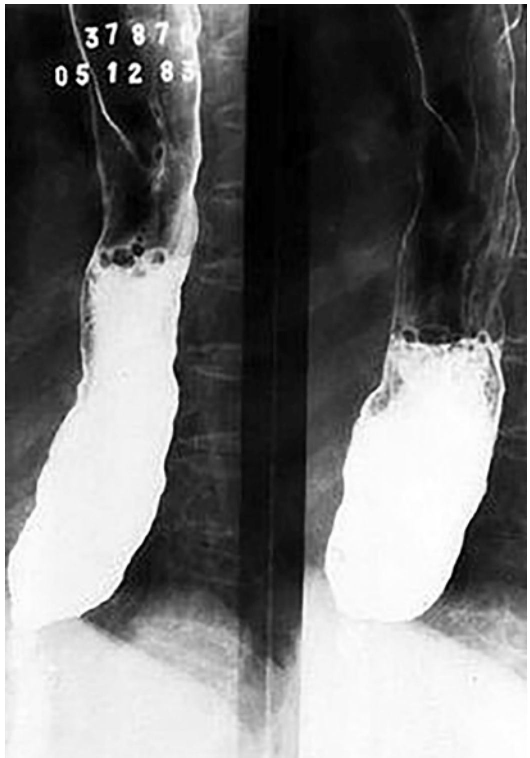

Fig. 16.11 Lateral two view barium esophogram demonstrating marked esophageal dilation with characteristic "beaked" appearance near the gastroesophageal junction in a patient with Chagas' disease

ing examinations are that both availability and relatively high cost associated with contrast agents may be limiting in many parts of the world. Further, although CT would be the modality of choice in regions of the developed world, the limited availability of CT and the limited number of trained radiology professionals creates barriers to diagnosing infectious diseases with these techniques. As a result, radiographic and fluoroscopic examinations may still be useful in settings where resources for advanced imaging, such as CT, are limited.

Enterography, including barium esophagram, can identify complications of infections such as Chagas' disease (American trypanosomiasis) which can present with severe esophageal dysfunction [29]; Trypomastogotes, the differentiated offspring of the parasite, tend to invade the esophagus and give rise to a megaoesophagus and/or achalasia (Fig. 16.11), which can be visualized with a lateral radiograph during a barium contrast esophagram [29]. Interestingly, 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 barium contrast enterography [29].

Intestinal parasitic infections with roundworms are exceedingly common in many parts of the world. In fact, it is thought that a considerable percentage of the world's population (perhaps as high as 23 %) harbor various species of roundworms [15, 30]. Infection due to Ascaris (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 [15, 18, 28]. 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. 16.12). In heavily infested patients, large collections of ascarids can frequently be identified on abdominal

Fig. 16.12 Barium examination of the stomach clearly demonstrates the outlines of individual ascarids (worms) as elongated radiolucent filling defects within the barium column

Fig. 16.13 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

radiography without oral contrast [15, 27, 30]. 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. 16.13). 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 non-infectious 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 are diagnostic.

Extremity Radiography

Radiographs are invaluable in the workup of skeletal abnormalities. Even in the setting of advanced imaging such as CT and MRI, radiographs of the affected bone are a useful first step that may reveal other diagnoses, such as metastases, fractures, or other metabolic and systemic bone diseases. In the setting of osteomyelitis, radiography usually does not demonstrate significant abnormalities until roughly 50 % of the bone mineral content has been lost due to the infection [31]. The most common pathogens in osteomyelitis depend on the patient's age; however, *Staphylococcus aureus* is the most common cause of acute and chronic pyogenic hematogenous osteomyelitis in both adults and children. Atypical endemic infections can also involve the musculoskeletal system and, in certain cases, have characteristic imaging appearances which aid in making the correct diagnosis.

One of the most notorious, and stigmatized, infections in the developing world 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 while radiology is not often necessary for an initial diagnosis, imaging does play a vital role in assessing the activity and extent of

Fig. 16.14 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, leaves little normal anatomy or function

the disease, and in helping to plan surgery and rehabilitation [15, 32]. 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 [15, 32]. Leprosy presents in many different ways, both clinically and pathologically, but generally is divided into two different types: tuberculoid leprosy and lepromatous leprosy. 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 [15, 32] (Fig. 16.14). The disease is often 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.

Musculoskeletal involvement of *Taenia solium* (cysticercosis) infection can be readily diagnosed with radiography because the appearance is pathognomonic. 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

Fig. 16.15 Plain film AP radiography of the bilateral femurs. Cysticercosis infection manifesting as calcifications in the soft tissues and muscles of the lower extremities. The calcified cysticerci are aligned with their long axes in the plane of the muscle bundles of the legs

[15, 33]. Calcified lesions have been demonstrated in up to 97 % of patients examined 5 or more years after infection and can be easily demonstrated by soft-tissue radiography of the extremities [15] (Fig. 16.15).

Another common and longstanding musculoskeletal endemic infection is Guinea Worm (*Dracunculias medinensis*); the infection by this nematode and the primitive treatment have been described as far back as 1550 BC, referenced first in the Ebers papyrus, and still retains significant cultural and mythical significance. For example, it is believed that the caduceus, the symbol of the medical profession, is derived from the guinea worm, since the worm was for centuries removed from subcutaneous tissues by winding it around a small stick, twisted slightly more each day until the entire worm was removed. In the mid-twentieth century it was estimated that over 48 million people in Africa, India, Arabia, the Middle East, and parts of Asia were infected [15, 34]. After 2000, it is thought that most areas of infection are in tropical Africa due to the success of the massively scaled multinational and multiorganization initiative (including WHO, UNICEF, CDC, and

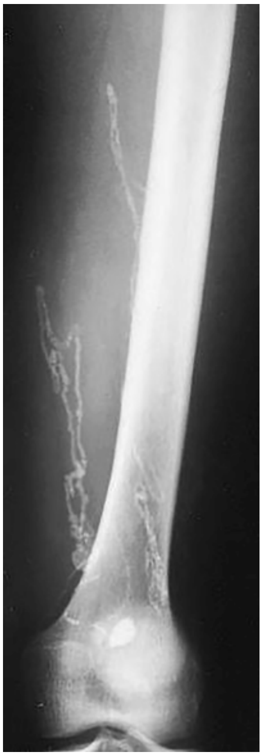

Fig. 16.16 AP radiograph of the right femur demonstrating several calcified worms in the overlying soft tissues. This is the classic type of calcification seen in guinea worms in the extremities

the Carter Center's Global 2000 Program) to eradicate the infection [34]. The *live* guinea worm will not be identified radiologically as it lies near the skin surface and is radiopaque. After its death, however, the guinea worm often calcifies, particularly when entrapped within the subcutaneous tissues or muscle, and can be readily identified on radiographs of the extremities (the typical locations in the lower extremities) as a long serpiginous calcification [15] (Fig. 16.16).

Cardiac Ultrasound

Like radiography, ultrasound imaging is less expensive with higher availability in comparison to CT and MRI. Additionally, ultrasound does not use ionizing radiation. It is especially useful in diagnosing the complications of various cardiac, hepatobiliary, renal, and gonadal infections. Ultrasound is also extensively used to evaluate the neonatal brain and often useful in the diagnosis of ventriculitis [29, 35].

Ultrasound imaging of the heart (or "echocardiography") is an essential tool to assess the heart and blood vessels and can provide both anatomic as well as functional information such as cardiac function and blood flow. [36]. We devote a separate chapter to cardiac imaging in this text, but cover some infectious disease issues in this section. For example, Endocarditis is an infection of the endocardium, which lines the inner surface of the heart and has varying etiologies, and heart valves [37]. When available, transoesophageal echocardiography (TEE) is the study of choice because of higher sensitivity compared with the transthoracic route (TTE) [38]. Echocardiography is also very useful in assessing rheumatic heart disease—a disease still prevalent in the developing world. It is triggered by certain strains of group A β-haemolytic streptococci, typically after a bout of pharyngitis and affect children, adolescents, and young people during their most productive years [39, 40]. Echocardiography typically shows mitral or aortic valve regurgitation [39]. Unlike endocarditis, the cause of myocarditis is not identified in most cases [41]. While viruses are the most common causes in the developed world, a broader range of pathogens are involved in developing countries; these include parasitic infections, such as *Trypanosoma cruzi* (Chagas' disease) in South America, and disseminated infections in immunocompromised patients, such as *Toxoplasma, Aspergillus,* and *Cryptococcus* spp. [41]. Although unable to delineate the etiology, echocardiography is able to demonstrate cardiac function and can be used to track the progression of disease [41]. Similarly, echocardiography is useful to assess pericardial effusions (Fig. 16.17) and pericarditis [29] which can be viral, bacterial, or due to TB.

Abdominal Ultrasound

Ultrasound imaging is an excellent modality for assessing abdominal organs, especially the liver and hepatobiliary system. One of the most common hepatobiliary infections in the world is Echinococcosis or hydatid disease (most commonly *E. granulosus*), which is a small tapeworm whose lifecycle involves dogs as definitive hosts and sheeps, pigs, goats, horses as intermediate hosts; humans become inadvertant 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 [42]. The infection is endemic worldwide, with the highest prevalence in sheep-raising communities. Becasue of the wide prevalance, 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 [15]. Ultrasound is highly helpful in the diagnosis/classification of hydatid liver disease and a grading scale has been developed by the WHO [43] (Fig. 16.18). 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. However, ultrasonography is not always able to differentiate hydatid cysts from tumors or liver abscesses

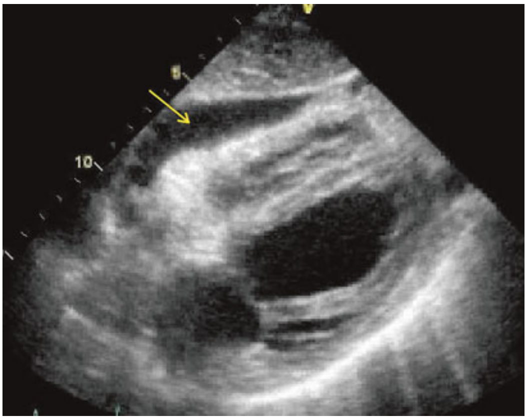

Fig. 16.17 Transthoracic echocardiogram image demonstrates hypoechoic pericardial fluid in a patient with a pericardial effusion due to TB (*arrow*)

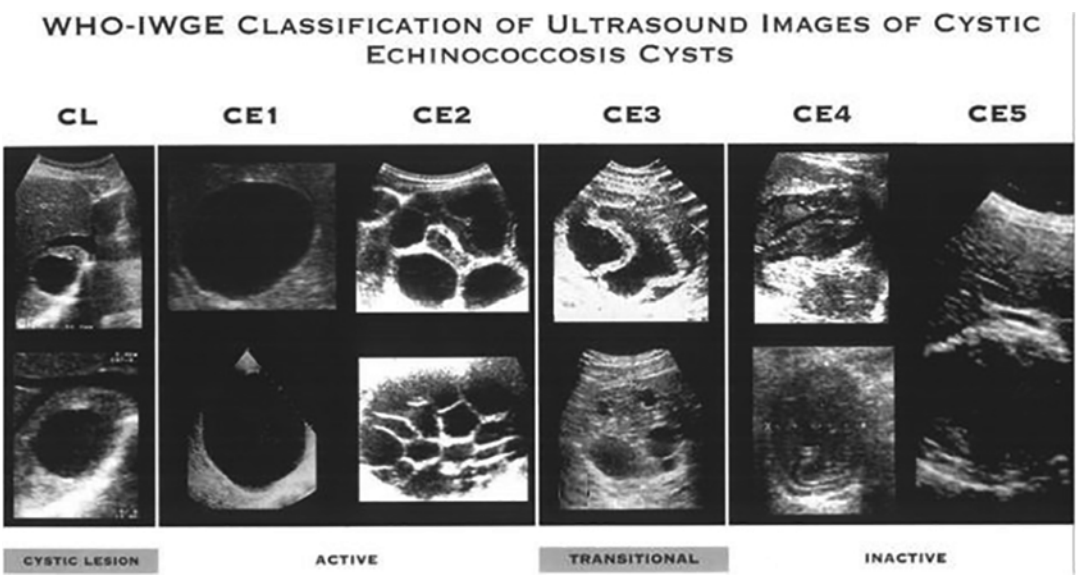

Fig. 16.18 WHO cystic echinococcosis (CE) grading scale by ultrasound. The classification is intended to follow the natural history of CE and starts with undifferentiated simple cysts, as presumably hydatid cysts evolve from these structures. The first clinical group starts with cyst types CE 1 and 2 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

and additional imaging, such as CT or MRI, may be required.

Another prevalent liver infection is caused by *Clonorchiasis sinensis*; an estimated 19 million people are infected mainly in Asia, specifically including southern China, Taiwan, Hong Kong, Korea, and Japan. Infection in humans is mainly via ingestion of usually raw or undercooked freshwater fish. The eggs hatch, migrate and colonize the biliary ducts of the liver. The infection is often asymptomatic for many years, but complications include the development of bile stones, cholangitis (including recurrent pyogenic cholangitis), pancreatitis, and cholangiocarcinoma. The principle imaging finding of clonorchiasis is diffuse dilatation of the peripheral intrahepatic bile ducts while larger intrahepatic and extrahepatic bile ducts are not dilated or minimally dilated [44, 45]; this pattern is observed because the adult worms reside in the peripheral small bile ducts. However it is important to note that in most cases the often-subtle changes of the intrahepatic bile ducts go unrecognized on imaging, and high index of suspicion, along with stool testing, is needed to confirm the diagnosis [15, 44].

Infections and associated complications in other abdominal organs can be diagnosed with ultrasound imaging including the pancreas, kidneys, spleen, as well as the reproductive tract [26]. Related infections of the female genitourinary tract that can be diagnosed with pelvic or transvaginal ultrasound include pyosalpinx, tubo-ovarian abscess, endometritis, and cervicitis [46]. Abscesses and pyosalpinx are depicted as fluid-filled cavities and in endometritis they may be microabscesses with infiltration and destruction of glandular epithelium in the endometrium [46]. Ultrasound scanning is often utilized to assess scrotal infections as well; epididymitis and orchitis, common causes of acute scrotal pain in adolescents and adults, have various infectious etiologies, including TB in many parts of the world. Indirect signs of inflammation, such as reactive hydrocele or pyocele with scrotal wall thickening, will often be present in most cases. Lastly, ultrasound imaging is also useful to guide surgical interventions, such as aspiration or drain placement as mentioned elsewhere in this book [26].

Fetal Ultrasound

The use of ultrasound during pregnancy is important for monitoring the health of the mother and developing fetus. Infection is a potent cause of mortality and morbidity among pregnant mothers and their babies. We do not address the details of fetal ultrasound for infections here because we have a separate chapter devoted to fetal imaging in this text. Moreover, many infections are diagnosed by clinical exam and blood/sputum/urine tests. However, ultrasound is important for identifying the development of fetal organs after 20 weeks gestation and can identify changes in fluid and cardiac status when an infectious exposure has occurred. Some infections during pregnancy produce imaging features on ultrasound, such as in the fetal central nervous system (CNS) and cardiovascular system. If an infection is clinically suspected in a pregnant mother or detected in blood/urine/sputum tests, or if there is an elevated risk of stillbirth, ultrasound is helpful for detecting anomalies, monitoring the health of the fetus, and determining the need for early delivery. The worldwide effort to reduce maternal–fetal death is based on growing knowledge that many of these deaths of the mother and/or baby can be prevented by detecting risk factors via ultrasound and improved testing during pregnancy.

Computed Tomography

CT imaging 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. CT imaging is relatively rapid making it invaluable, especially in emergent or life-threatening situations [47]. 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 is out of reach for a majority of the world's population.

Central Nervous System CT

Infections in the brain and spinal cord can have a protean appearance on CT imaging, ranging from space-occupying lesions to subtle leptomeningeal thickening and enhancement. Diagnosis is often supplemented with laboratory examination of the cerebral spinal fluid. For example, meningitis (of any cause) is diagnosed clinically and by evaluating the cerebro-spinal fluid. However, CT imaging is often performed as supportive evidence to evaluate the extent of disease (i.e., abscess, mass effect), to exclude other causes, and to monitor treatment. For example, cerebral abscesses on contrast enhanced head CT examinations (Fig. 16.19) classically appear as a ring-enhancing lesions surrounded by edema [48]. Similarly, subdural empyema, is seen as a crescentic or elliptical area of hypodensity below the cranial vault adjacent to the falx cerebri; a fine line of enhancement is seen between the subdural collection and the cerebral cortex [49].

Other diseases, including parasitic and atypical infection, also can involve the CNS. In fact one of the most common CNS infections worldwide is cysticercosis [50]. Patients often present initially with seizures in up to 70 % of cases. Similar to the calcifications seen in skeletal muscle, head CT findings include multiple calcified lesions throughout the brain paranchyma measuring between 2 and 10 mm, with or without mass 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 [15, 50].

Another of the most geographically widespread parasitic infections in the world is Toxoplasmosis (*Toxoplasma gondii*), a protozoan that infects humans and commonly involves the CNS. 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, unpasteurized dairy products, organ transplantation, and congenital transplacental infection. The oocysts hatch and the sporozoites quickly become widely distributed within the host blood stream

Fig. 16.19 Axial contrast enhanced head CT demonstrates a large rim enhancing mass in the left frontal lobe (*arrowheads*) surrounded by vasogenic edema (*arrows*). This was confirmed to represent an intracerebral abscess; however, the differential is broad for this appearance

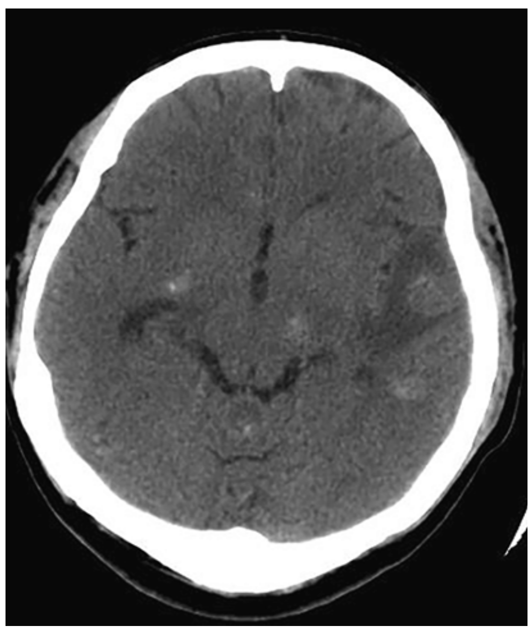

Fig. 16.20 Axial noncontrast head CT demonstrates multiple parenchymal calcified lesions, some with mild surrounding edema characteristic of the nodular calcified stage of cysticercosis

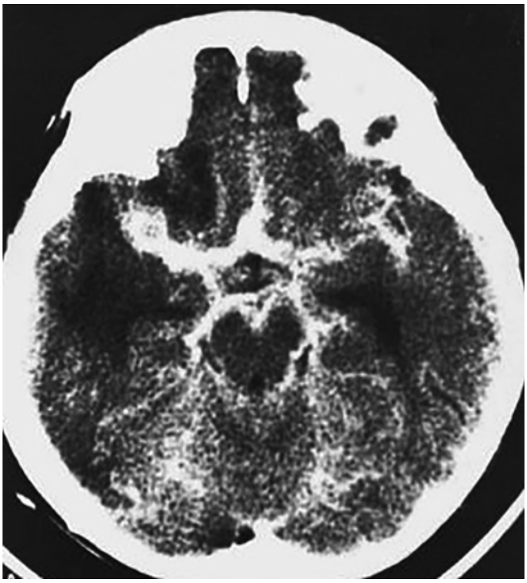

Fig. 16.21 Axial contrast enhanced head CT demonstrates basilar meningeal enhancement and hydrocephalus (as evidenced in this image by dilated temporal horns of the bilateral ventricles) with periventricular edema in TB meningitis

and intestines. The preferred extraintestinal sites for *T. gondii* include skeletal and heart muscle, brain, and other tissues of the CNS.

CT is also an excellent modality to diagnose CNS TB which accounts for approximately 1 % of all TB disease and has high mortality [51]. Imaging appearances are variable, but classically include the "triad" of meningeal enhancement predominantly in the basal regions of brain, hydrocephalus, and ring enhancing lesions (Fig. 16.21) [15, 51]. TB can also infect the spine, leading to central disease in the form of myelitis, spinal meningitis, and arachnoiditis, but more commonly the infection leads to spondylitis (Pott's disease); TB is the most common cause of spondylodiscitis in the developing world [15].

Thoracoabdominal CT

CT is often the workhorse imaging modality for evaluating patients in most hospitals for infectious complications in the chest, and as a first line evaluation for infection in the abdomen and pelvis. CT is less operator dependent than, and in general more accurate than both ultrasound X-ray and ultrosonography. In particular, CT allows visualization of mediastinal and retroperitoneal structures and intraluminal fluid collections, which may not be visualized with other imaging techniques. In addition, contrast enhancement may be used to define the intrathoracic or intraabdominal anatomy, identify/define the disease process, and plan therapy.

Abdominal CT is used extensively in medical management for abdominal pathology, and is the modality of choice for many common infections such as appendicitis, diverticulitis, pyelonephritis, pancreatitis, and others. CT is also an excellent modality to evaluate manifestations of TB in the abdomen. TB can affect any organ or tissue in the abdomen, and can be mistaken for other inflammatory or neoplastic conditions [54]. 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 [54]. Other sites that are affected include the genitourinary tract, peritoneal cavity, and gastrointestinal tract. In the setting of HIV, the liver, spleen, biliary tract, pancreas, and adrenals are also commonly involved [54].

The lung is often infected secondarily in the setting of a wide variety of parasitic organisms and the imaging appearance on chest radiography is often nonspecific, and in some cases better evaluated with CT. For example, Echinococcosis is reported to be the most common parasitic lung infection world-wide, and the lung is the second most common organ affected after the liver [15]. The majority of cases present with lung cysts, most commonly solitary, and initial growth of the cyst is asymptomatic and are often recognized on imaging for another purpose (Fig. 16.22) [15, 52]. CT is invaluable in diagnosing this at early stages when they are largely clinically occult, particularly in the liver (Fig. 16.23).

Other parasites affecting the lungs may be diagnosed by CT, mainly due to the common acute pulmonary hypersensitivity manifestations that often occur, which cause a "ground-glass"

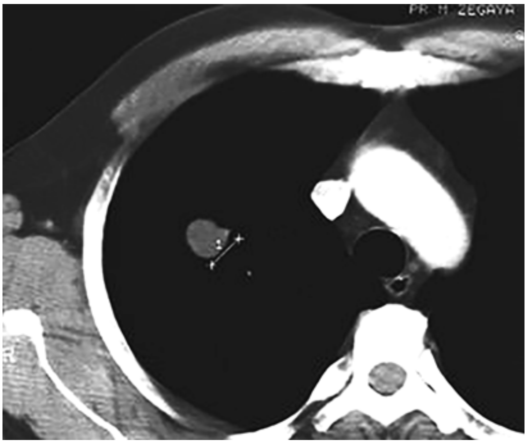

Fig. 16.22 Axial CT scan with contrast of the chest demonstrates a small uncomplicated cyst not recognized on chest radiographs. This was confirmed to be early pulmonary hydatid disease

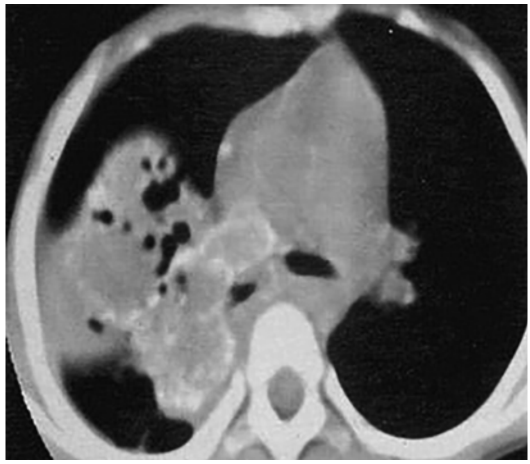

Fig. 16.24 Axial CT scan of the chest demonstrates calcification in the right lung parenchyma and mediastinal lymph nodes as part of a complex infection due to TB

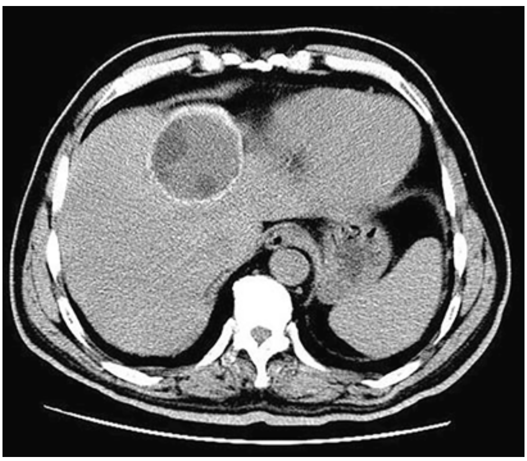

Fig. 16.23 Axial CT image of the liver without intravenous contrast demonstrates a large cystic lesion in the liver with curvilinear peripheral calcifications in a patient with hydatid liver disease

parenchymal appearance on chest CT that is difficult to visualize on chest radiographs. This phenomenon is felt to be a reaction caused by the migration of the parasite through the lungs, and is most commonly seen in parasitic infections such as ascariasis, toxocara, and trichinosis.

CT is also an excellent modality for evaluation of the airways. For example, it has been used as a pre-planning modality for identifying and localizing adult parasitic worms which have migrated into the airway in anticipation for endobronchial removal [52].

Chest CT is also often used to identify or better delineate community acquired lung infections due to more common bacteria such as *Staphylococcus*, and can aid in monitoring therapy for complications of infection. In addition, CT is also the imaging modality of choice for diagnosing early TB, even in the setting of a normal chest radiograph. As in other chest infections, both in later stages of the 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 (Fig. 16.24) [53].

Clonorchiasis infection is also well evaluated with abdominal CT, particularly as the principle early imaging finding is diffuse dilatation of the peripheral intrahepatic bile ducts while larger intrahepatic and extrahepatic bile ducts are not dilated or minimally dilated (Fig. 16.25) [44, 45]; this pattern is observed because the adult worms reside in the peripheral small bile ducts. However it is important to note that in most cases the often-subtle changes of the intrahepatic bile ducts go unrecognized on other imaging modalities, and high index of suspicion, along with stool testing, is needed to confirm the diagnosis [15, 44].

Fig. 16.25 Axial CT image of the liver demonstrates diffuse uniform dilatation of small and medium-sized intrahepatic ducts in the liver periphery due to Clonorchiasis

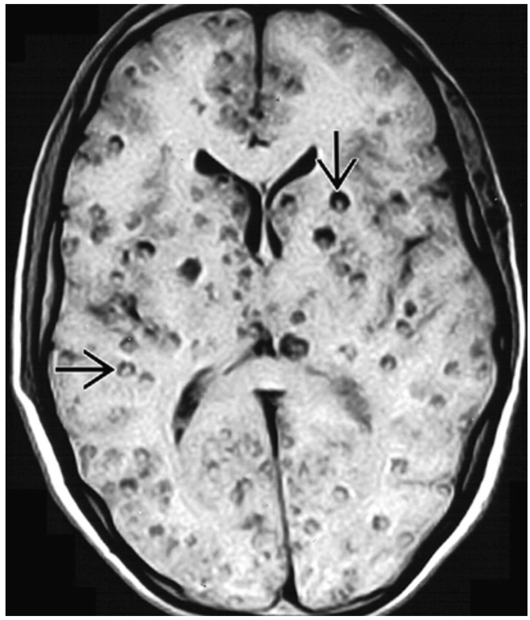

Fig. 16.26 Noncontrast T1-weighted axial brain MR demonstrates multiple cysts throughout the brain parenchyma (*arrows*) in a patient with neurocysticercosis

Magnetic Resonance Imaging

MRI is the most important imaging modality for evaluating the CNS as well as defining pathologic processes in the musculoskeletal system. MRI, while less available in the developing world, more expensive and longer in duration (patient-exam times), has great sensitivity [48]. 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. Since 1977, when the first human in vivo images acquired by MRI were published [55], this system has rapidly developed into one of the most widespread medical imaging techniques [56]. One of the main downsides to the use of MRI is the cost: capital equipment, maintenance. 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 acquire in low-resource countries. However, though not as widely available in the developing world 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) [57].

MRI is most extensively used for head and spine imaging. It is particularly useful in evaluating the brain parenchyma and spinal cord, and unlike CT has unparalleled ability to display anatomical detail and differentiate early pathology. For example in neurocysticercosis, MRI is able to demonstrate greater detail during the initial stages of infection which are often not seen on CT imaging. MRI can reveal even small cysts (Fig. 16.26). Later, when the larva begins to degenerate, the cysts may be seen well as thicker walled eccentric cystic lesions on both CT and MRI. In addition, the accompanying edema is often well demonstrated on T2-weighted or 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 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,

Fig. 16.27 Saggital T1-weighted MR image demonstrates a large cyst due to cysticercosis in the trigone of the right lateral ventricle

Fig. 16.28 Saggital T2-weighted MRI of the lumbar spine demonstrates an isointense elongated mass at the level of L3–L4 compressing the canal in a patient with an epidural TB abscess

potentially leading to acute hydrocephalus and sudden death (Fig. 16.27).

MRI is also an ideal imaging modality to evaluate the spine, where many infectious processes such as TB can cause leptomeningitis, epidural abscess, and spondylodiscitis (Fig. 16.28). In the case of early spinal TB, radiographs and even CT imaging can be normal. However on MRI, changes in signal intensity demonstrating bone marrow edema or small epidural/paraspinal fluid collections are often seen. It is important to be able to diagnose TB because it can be successfully treated, especially if detected early.

Musculoskeletal MRI

Most cases of osteomyelitis may be diagnosed using MRI [58]. The usefulness of MRI in musculoskeletal infections is the detection of marrow disease before radiography and CT can detect bony changes surrounding the marrow. Detection can be enhanced by using intravenous contrast agents (including gadolinium, iron oxide, and iron platinum), but the challenge lies in identifying changes during the early stages of the infection [59]. MRI may facilitate differentiation of acute from chronic osteomyelitis, determine extent of infection, and help to detect foci of active infection in the presence of chronic inflammation or posttraumatic lesions [60]. Due to image distortion, MRI is less useful in locations with surgical hardware such as joint prostheses [61, 62].

MRI is helpful in defining the extent and nature of abnormal tissue and, therefore it is the imaging modality of choice when diagnosis of a soft-tissue infection is required [63, 64]. Cellulitis is usually diagnosed clinically, but MRI can be used to identify the extent of the disease and determine possible complications including the involvement of the fascia [63, 65] e.g., necrotizing fasciitis. When used for diagnosis of soft-tissue abscess, specific gadolinium-DTPA-enhanced MRI findings have been reported to have a sensitivity of 89 % and specificity of 80 % [66]. Investigators are currently working on the development of a MRI contrast agent capable of visualizing inflammation and monitor treatment efficacy. Recently developed inflammation-specific contrast agents such as the ultra-small paramagnetic iron oxides (USPIO) [67] have been able to identify infection in murine models of *S. aureus* soft-tissue infection [68] and *Toxoplasma gondii* brain lesions [69]. Superparamagnetic iron oxide (SPIO) nanoparticles conjugated with *M. tuberculosis* surface antibody have been investigated as a probe specific for the extrapulmonary forms of TB [70]. Perfluorocarbon nanoemulsions visualized by ^{19}F-MRI have been used to observe the migration of inflammatory cells [71] and murine *S. aureus* infection models [72]. There is also interest in using MRI to provide detailed information about bacterial localization in tissues with promising results [73].

Applications of PET and SPECT

Molecular imaging such as PET and SPECT have the potential to provide highly sophisticated information about the disease processes and are currently being utilized as sensitive ways to detect changes before more late stage anatomic changes as measured by CT or MRI are detected. Both PET and SPECT imaging are generally complemented by anatomic imaging modalities such as CT and MRI for purposes of coregistration. These imaging modalities are currently better developed for cancer, and neurology [74, 75], but significant strides are being made in the field of infectious diseases. Some common examples of SPECT imaging that are currently utilized for infectious diseases imaging include injection of autologous ^{111}Indium-labelled white blood cells (WBC) or of various radio-labelled compounds that accumulate at the site of infection [76]. These forms of imaging have been effective in diagnosing infections such as osteomyelitis, cellulitis, diabetic foot infections, and fever of unknown origin (FUO) [77]. Another promising technique to investigate infections without source includes [^{18}F] 2-fluoro-deoxy-d-glucose (FDG)-PET which appears to be more sensitive [78]. While 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. Therefore, there is increasing interest in developing more specific PET or SPECT imaging biomarkers for infections. However, all of these new tools are currently in development and not available clinically. Examples include the use of ^{68}Gallium-siderophores for the specific diagnosis of *Aspergillis fumigatus* infections [79]. There has also been significant interest in developing bacteria-specific probes. One example is [^{124}I] FIAU, a substrate for bacterial thymidine kinase [80], which has been utilized to image bacterial infections using PET [81]. Moreover, development of bacteria-specific tracers is also underway, which could be particularly beneficial in neutropenic patients, where nonspecific markers of inflammation and accumulation of WBC may not work well.

Finally, PET-imaging has also been applied to evaluate the host-microenvironment or for studying pharmacokinetics of anti-infectives. Examples include the use of [^{64}Cu]-ATSM to assess hypoxia [82] as well as the use of an F-18 analog of isoniazid (an anti-TB drug) to evaluate multi-compartment drug pharmacokinetics [83]. Although not likely to be available to much of the world in the near future, these tools will prove essential to study disease pathogenesis as well as inform early clinical studies about appropriate drug dosing. The challenges for nuclear medicine in the developing world are not only the capital cost of equipment and the need for trained personnel but also the development of networks for synthesizing, handling, and delivering the radioactive radiotracers.

Conclusion

Global infectious diseases, significantly contribute toward treatable causes of morbidity and mortality. Imaging is essential in the diagnosis and management of many of these diseases, as well as in monitoring, reporting outbreaks and identifying public health threats. Major studies are being made in developing imaging capabilities in the developing world as well as in developing pathogen specific imaging biomarker.

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17 Interventional Procedures for Global Health Radiology

Mark L. Lessne, Bryant G. Oliverson, and Paul Suhocki

Introduction

While the impact of diagnostic imaging has revolutionized modern medicine, its availability in developing 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 highly morbid open surgeries. However, while the challenges of modernizing diagnostic imaging capabilities in poorly developed nations are great, there is little doubt that the hurdles that must be overcome to safely and practically implement technologically demanding interventional radiological procedures are even greater.

This chapter will discuss the financial and intellectual challenges involved in establishing effective interventional radiology (IR) service in developing countries, as well as outline practical approaches to current IR techniques that may make them more accessible to technologically devoid counties. It is expected that with emerging interest in and ability to provide minimally invasive therapies to a wider global population, many of the challenges addressed below will be overcome, while others will be newly discovered. However, with the generosity and dedication of interventionalists and colleagues all over the world, even the seemingly most insurmountable obstacles can be overcome. The ultimate goal is to provide the best care to even our most vulnerable patients.

The Cost-Effective Approach

The equipment used by interventional radiologists for diagnosing and treating patients is capital-intensive. While the subspecialty is highly technical, innovative, and integral to modern medical management, a healthy perspective must be used to determine exactly what role interventional radiological procedures can play in limited-resource countries. For help in achieving that perspective, one has only to review the mission of the World Health Organization (WHO), the United Nations agency that provides guidance on health policy and resource allocation for improving the quality of human life worldwide. The WHO acts as broker and arbiter, helping shape the rules of engagement between government, development agencies, and civil society in promoting equitable and sustainable health for all.

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In bringing radiology services to countries where resources are limited, the WHO has stated that the majority and most marginalized should be prioritized. In the WHO estimates, 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 the 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.

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 adapted to withstand hot and dusty climates and may not run on the insufficient electricity supplies of low-income settings. Generators break down, equipment does not get serviced, and there are no service engineers in the country. An engineer may have to be flown in, put up in a hotel, and replacement parts ordered that may take months to arrive. Sometimes, even if the representative is present, there may not be a full service and maintenance contract between manufacturers, suppliers, or maintenance companies with the users; this disconnect leads to long periods of inactivity and frustration.

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 expense may prove to be a powerful obstacle to the ongoing functioning of an interventional radiology lab. One of the more obvious—and common—ways to mitigate this hurdle is to recycle and reuse interventional tools [2, 3]. 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 and fracture; again, 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 when the patient tests positive [4]. One pediatric cardiology catheterization lab in India has described >32,000 catheterization procedures with no cases of procedural-related sepsis or endocarditis; though the center did report occasional catheter breakage, fragments were successfully snared [3].

Interventional Radiology Training and Education

Meeting the financial requirements of image-guided interventions is arguably less of a challenge than satisfying the intellectual requirements. Unlike diagnostic radiology, in which telemedicine allows for "outsourcing" practitioners competent in the imaging interpretation, minimally invasive procedures demand that a skilled provider be physically present. Though medical volunteerism and international health rotations may provide interventionalists from other parts of the world, their numbers are insufficient to match global demand; effective training of local providers should be the ultimate goal in establishing an IR practice.

In a perspective essay on overseas medical experience, Henderson [6] delineates the 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? [6]

These scenarios present real challenges and are often unique to the procedural radiologist in developing countries; the overseas interventionalist is likely not only unaccustomed to such problems but also may be unaware of their existence and untrained to handle them. 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 first world trained trainees—residents and fellows—occupying a trainer role in the developing world [8]. 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 [8]. The argument that "desperate times call for desperate measures"—that is, offering some physicians with some level of training is better than not having training for physicians at all—may be true due to the lack of resources in developing world healthcare systems. The constrained resources further limit the ability of the physician to manage iatrogenic or avoidable complications, and thus necessitate optimal medical care being delivered on first attempt [9]. However, with appropriate supervision, critical appraisal of resident or fellow skills, managed expectations, and well-delineated guidelines, domestic trainees can help initiate and support a developing interventional service overseas.

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 interventional radiology, there is little substitute for experience; however, the opportunities for an interventionalist to practice his or her skills are far less readily available than for our diagnostic colleagues, who can review vast teaching files to test their abilities. Simulators may play an expanding role in procedural training both domestically and in resource-restricted areas as computer technology is becoming more accessible worldwide. Simulators may be model-based, computer-based, or a hybrid; while model-based simulators may be inexpensive, there is usually little objective feedback that can be provided from the model [10]. The hybrid-type simulator can combine physical models with a computerized interface to allow for a more robust, tailored, and interactive experience [11]. Recently, the concept of telesimulation was introduced by Canadian physicians in order to teach laparoscopy to African surgeons [11]. This distance learning technique relies on the computerized linking of medical simulators at the trainers' and the trainees' sites and relies on computer videoconferencing 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 [11, 12].

Once the decision has been made to train providers from developing countries, one must choose the types of procedures that warrant exportation 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 physician extender specifically trained for the procedure, operations normally performed by someone with higher qualifications and training, or operations that require subspecialty training beyond the scope of the general surgeon [13]. A similar organization hierarchy may be applied for interventional procedures, ranging from paracentesis to transjugular intrahepatic portosystemic shunt or complex embolization procedures. 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 from abroad [5, 13].

A final consideration critical to the implementation of an interventional radiology training program in developing nations 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 [14]. 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, interventional radiology programs that have recently emerged outside of the Western world have already begun embracing this concept, allowing the interventionalist to assume care for the entirety of periprocedural care and follow-up [15].

Beyond redesigning training programs, there have been many innovations to 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 interventional radiology service in the developing world. It is crucial to reevaluate the necessity of the technologies and techniques that have become standard in developed nations. For instance, whereas percutaneous nephrostomy for obstructive uropathy is typically performed with 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 outcome, eliminating the need for additional equipment at additional expense [16]. 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 [17–19]. 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 [20]. Other diseases for which the proceduralist traditionally offers image-guided therapy may be replaced completely with medical management, as in tPA for cerebrovascular accident [21].

Innovative Strategies for Interventional Radiology Outreach

As noted above, a relative lack of resources and expertise can make translating the practice of interventional radiology in the developed world to the underdeveloped world very difficult. The purpose of this section is to look at ways interventional radiology has been applied in a resource-constrained environment and understand how that can be translated to the developing world.

Fluoroscopically Guided Interventional Radiology

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 [23]. In an extraordinary initiative by Drs. Nestor Kisilevzky and Henrique Elkis, uterine artery embolization was offered to women in underserved, impoverished areas of Brazil using a portable C-arm, and necessary supplies were loaded on a truck and delivered on rotation to four public hospitals [22]. They used a small truck to transport a mobile C-arm and angiographic supplies rotating among four hospitals every week for a total of 6 weeks. All equipment and supplies were moved into either an operative suite or obstetric suite in the hospitals in order to 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.

On a much larger scale are two 1,000-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 interventional radiology suite, 80 intensive care units, and 20 postanesthesia care units. They are fully equipped with CT, ultrasound, and MRI. Working on a ship can present unique challenges to an interventional radiologist [7]. 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 massive 2004 Asian tsunami, the USA deployed the USNS Mercy. On board Mercy were a dedicated angiography suite, CT scanner, C-arm capabilities, and ultrasound. 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 in 2005. Nearly two thirds of the interventional procedures were done with US and/or fluoroscopy [7]. This example of interventional radiology in disaster relief illustrates how the most basic and most widely available imaging modalities can be easily applied to the most primitive of environments.

Combat necessitates the need to provide high levels of acute care in unique and varied situations. In wartime US medical bases, interventional radiology 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 [7]. Even the most advanced endovascular treatments such as endovascular aortic repair are now performed in combat—these examples serve as a blueprint for efforts in applying these procedures in developing countries [25].

Access to the latest technology and appropriate expertise will always be a relative challenge in the practice of interventional radiology in the developing world. Examples of interventional radiology 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 [26]. Finally, as imaging modalities become more ubiquitous, expertise in the application of these modalities will also grow.

Ultrasound-Guided Interventional Radiology

One consideration that offers very high value and low resource requirement is to concentrate image-guided procedures around an ultrasound-heavy technique. The utility of diagnostic ultrasound in modern medicine extends far beyond maternal/fetal health care. Ultrasound exams account for 25 % of all diagnostic imaging studies performed in developed countries. There is growing evidence for its effective use in the developing world, having been used in the diagnosis and management of many tropical and parasitic diseases, including echinococcosis, schistosomiasis, amebiasis, filariasis, ascariasis, river blindness, loaiasis, lung-fluke infections, larva migrans visceralis, gnathostomiasis, anisakiasis, oesophagostomiasis, tuberculosis, and HIV infection [27].

One of the most immediately beneficial procedures to implement in a remote, impoverished region with limited resources would be the image-guided drainage of infected fluid collections, as first described in1977 [28], as well as percutaneous procedures. As specified by the Society of Cardiovascular and Interventional Radiology (now Society of Interventional Radiology) Standards of Practice Committee, percutaneous aspiration and drainage of fluid collection is indicated when there is suspicion of infection, if there is a need for fluid characterization, or if there are related symptoms [29]. 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 add to the cost and resources required.

Ultrasound is also being used in increasingly more complex procedures that include biopsies, vascular access, urologic surgery, orthopedic surgery, and regional anesthesia [30–34]. It is also increasingly being used endoluminally by cardiologists, gastroenterologists, interventional radiologists, pulmonologists, and vascular surgeons for guiding procedures [35]. The WHO has already recognized the utility of ultrasound in guiding interventions in developing countries, having distributed guidelines for its use in guiding the transcutaneous treatment of echinococcal cysts, an endemic disease with high morbidity.

Adler et al. reported their experience in training healthcare providers in the use of ultrasound in a refugee camp in Tanzania [36]. They conducted a 4-day ultrasound training course for healthcare providers on a donated SonoSite Titan ultrasound unit. Four physicians and six nonphysicians were supervised while conducting at least 20 patient 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 [24]. 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 a fully equipped angiography suite and interventional computed tomography rooms lying far beyond the reach of developing countries, a shift in focus onto the use of ultrasound technology may best meet the public's needs. As noted above, ultrasound offers a relatively inexpensive, efficacious, and portable modality to facilitate interventional procedures [37–39]. For these reasons, a WHO study group has advised that ultrasound be disseminated to developing nations as part of a radiology system initiative [40].

Fortunately, there exists an inexpensive ultrasound unit that is well suited for use in remote areas: the compact or handheld unit. These highly portable units, which can be carried in a backpack, were introduced to the market 13 years ago. Although the purchase price for a new unit is $20,000.00–$30,000.00, refurbished first-generation units cost less than $5,000.00. They are simple to operate, robust, and have rechargeable batteries. The sturdy SonoSite 180 Plus is the most widely distributed compact unit [41]. In the Philippines and Honduras, this has 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 it easy to transport them to service sites when necessary. Batteries have a life span of 1–2 years, with a $200.00 replacement cost. Where grid power is unreliable, alternative recharging sources are a wall main (120.220 Hz), a cigarette lighter plug, solar energy, and a gas generator. Solar recharging time is 4–6 h at 45° latitude.

Ultimately, despite the versatility of ultrasound guidance for invasive procedures, there remain many valuable interventions that require direct visualization under fluoroscopy. These include some procedures that are lifesaving and eliminate the need for surgery: embolotherapy for hemorrhage, esophageal and enteric dilation and stenting, transjugular intrahepatic portosystemic shunts, and arterial thrombosis and dissections. 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 those patients within reach. Of course, outside of major cities, few areas in the developing world 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 the developing world 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 interventional radiology practice in the developing world. 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 impoverished nations can be trained to offer comparable life-saving, minimally invasive procedures that currently benefit so many patients in well-developed 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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18 Cardiovascular Imaging in Global Health Radiology

Katherine C. Michelis and Brian G. Choi

Introduction

Until recently, the global healthcare community has directed most of its efforts in the developing world toward the prevention and treatment of infectious diseases. Chronic and noncommunicable diseases (NCDs) have received more attention in industrialized nations despite the fact that NCDs are a greater contributor to mortality in nonindustrialized countries. Eighty percent of deaths due to cardiovascular disease (CVD), the number one cause of death worldwide, take place in developing countries (Fig. 18.1). The percentage of Mortality from noninfectious diseases, especially cardiac disease, is escalating in these countries, and it is estimated that the African continent will be affected most, with a 27 % relative increase in deaths over the next 10 years [1]. By 2030, CVD is projected to be the most common cause of mortality in nonindustrialized nations [2].

These statistics are very alarming because patients with CVD in low- and middle-income countries (LMICs) tend to have poorer outcomes and die younger than their counterparts in the United States (US) and other high-income countries. The burden of disability caused by CVD is extensive (Fig. 18.2), and not surprisingly, emerging evidence indicates that CVD contributes to poverty in LMICs as a result of its negative effects on household and countrywide economics [3]. According to the World Health Organization (WHO), heart disease, stroke, and diabetes together reduce gross domestic product (GDP) by an estimated 1–5 % in rapidly growing LMICs [3].

Despite the grave impact of CVD on the health and overall well-being of individuals in the developing world, efforts to reduce them are grossly underfunded [4], with many donor countries operating under a policy ban on funding NCD programs. 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 estimates that approximately 95 % of imaging technology is imported into developing countries, and over 50 % of this equipment is not utilized due to inadequate servicing or a paucity of trained personnel [5].

Comprehensive training programs in cardiac imaging for technicians and cardiologists are nonexistent in most LMICs. Consequently, images may be captured 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

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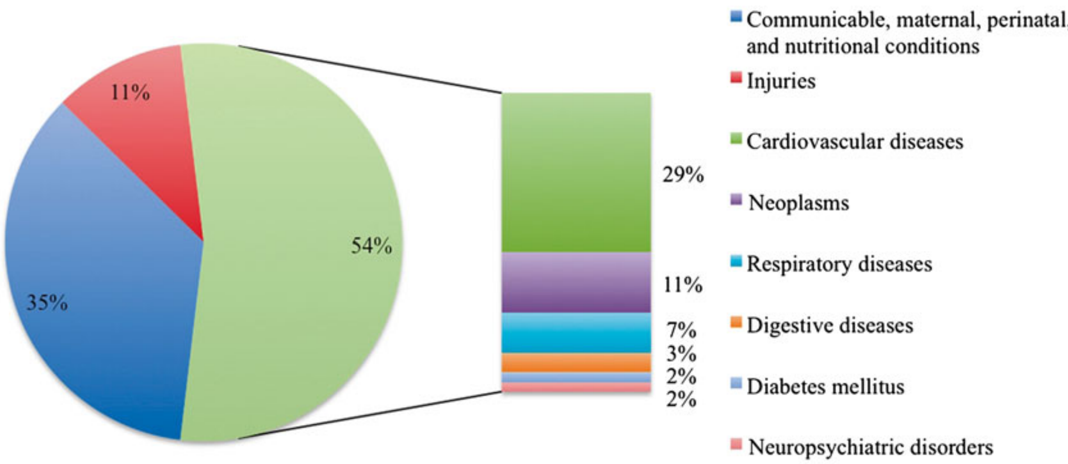

Fig. 18.1 Deaths by cause in individuals aged 0–59 years in LMICs in 2004. Cardiovascular diseases (CVDs) are the leading cause of death of all noncommunicable diseases (NCDs) [4]

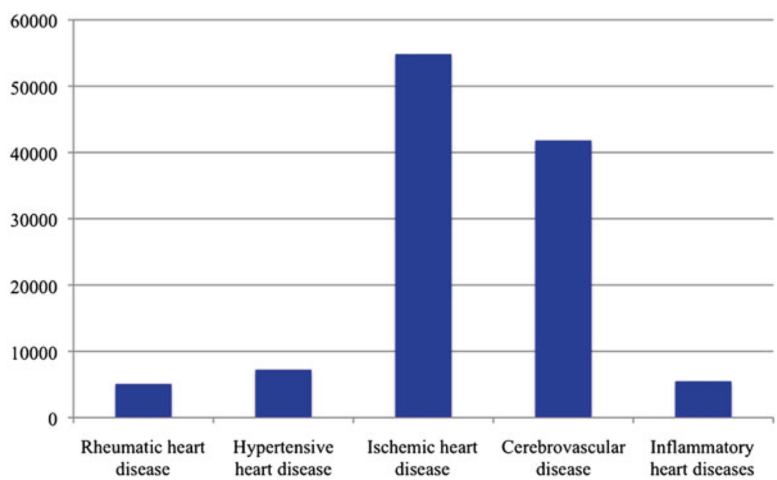

Fig. 18.2 Burden of CVD in disability-adjusted life years (thousands) by type in LMICs in 2004. Inflammatory heart diseases include myocarditis, endocarditis, pericarditis, and cardiomyopathies. As shown here, CVD is a significant contributor to disability and economic drag [4]

cardiac images are now transferred over wireless networks and stored digitally, but many developing nations do not have high bandwidth networks in place. These realities are troublesome because diagnostic imaging plays a very important role in early detection and treatment of CVD. Without accessible or reliable cardiac imaging programs, intervention is delayed.

In order to meaningfully expand the global availability of cardiac imaging, it is necessary to understand the etiologies of CVD in developing regions (Fig. 18.3). 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 reportedly affects 15.6–19.6 million people worldwide and causes up to 492,000 deaths each year, 95 % of which occur in developing countries [6]. Additionally, many children and young adults in developing nations suffer from untreated or unrecognized congenital heart defects. In developing countries

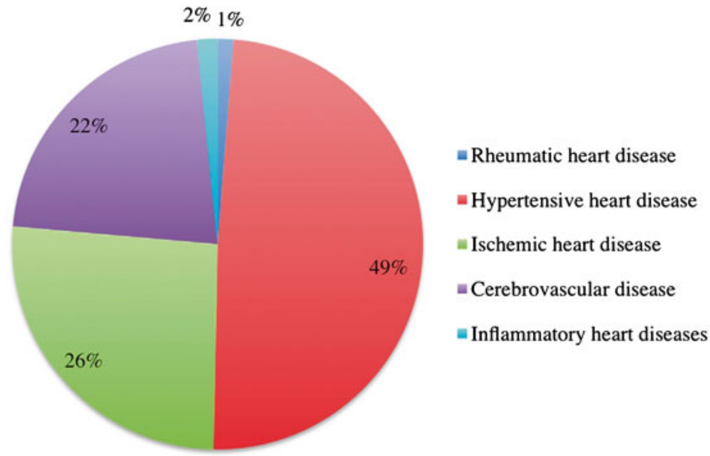

Fig. 18.3 Percentage of deaths from CVDs in LMICs in 2004 by disease type. Inflammatory heart diseases include myocarditis, endocarditis, pericarditis, and cardiomyopathies [4]

with a high burden of human immunodeficiency virus and acquired immunodeficiency disease syndrome (HIV/AIDS), CVDs due to the infection itself or antiretroviral treatment are widespread. As in industrialized nations, ischemic heart disease is a growing problem, and cardiac risk factors are on the rise. India's population in particular is overwhelmed by these health hazards, with 69.8 million cases of diabetes mellitus and 214 million cases of hypertension projected by 2025 [7]. Adequate control of CVD risk factors (physical inactivity, tobacco use, obesity, diabetes, hypertension, hypercholesterolemia) has been projected to prevent 80 % of premature heart disease, stroke, and diabetes, underscoring the need for earlier identification of patients whose cardiovascular future is still modifiable [2].

This chapter will provide a review of advanced techniques in cardiac imaging and then highlight approaches that have been successfully implemented in developing countries. Appropriate referral for cardiac imaging and 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 frequent introduction of new or improved technologies into clinical practice. This section will survey the tools employed in advanced healthcare systems.

Echocardiography is the most common diagnostic imaging procedure performed in cardiac patients [8]. Echo can be used to obtain two-dimensional (2D) or three-dimensional (3D) images, which can be augmented by color and spectral Doppler recordings or injection of intravenous (IV) contrast. 2D echo reliably measures cardiac chamber volumes and ejection fraction [9–11], but 3D echo may have an incremental advantage in the assessment of congenital heart disease (CHD) and the right ventricle [12].

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 [13]. Doppler can also be used to evaluate myocardial contractile performance, either by quantifying regional strain (tissue Doppler imaging) or by tracking individual myocardial speckles of grayscale images [14].

Another application in cardiac echocardiography is the use of contrast-enhanced ultrasound (CEUS). This modality utilizes the property that, in ultrasound, contrast is produced via the different ways in which sound waves are reflected from interfaces between substances or tissues. Gas-filled microbubbles can be administered intravenously to the systemic circulation that can be visualized with ultrasound as they travel through

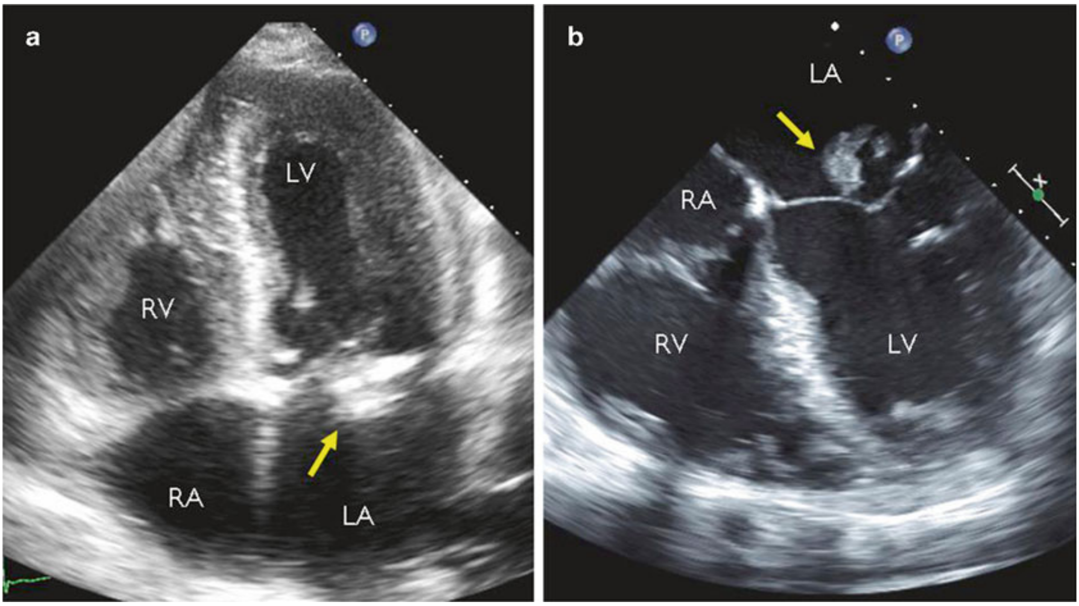

Fig. 18.4 Representative images acquired by transthoracic echocardiography (TTE, **a**) and transesophageal echocardiography (TEE, **b**) in the same patient with mitral valve endocarditis (*arrowhead* points to bacterial vegetation adherent to the anterior leaflet). The proximity of the mitral valve 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

the heart or other structures due to their high degree of echogenicity (the ability of an object to reflect the ultrasound waves). In this way, CEUS can be used to image blood perfusion in organs, measure blood flow rate in the heart and other organs, and has other applications as well. In the case of contrast-enhanced echocardiography, IV microbubbles are injected to opacify the left ventricle (LV) so that areas of abnormal myocardial contraction can be identified [13]. In most cases, transthoracic echo (TTE) sufficiently characterizes cardiac function and anatomy. However, because the esophagus is adjacent to the left atria and thoracic aorta, transesophageal echo (TEE) is a better tool to visualize these posterior cardiac structures, prosthetic cardiac valves, and structures less than 3 mm in size [15, 16]. Additionally, TEE is especially valuable in the diagnosis of infective endocarditis (Fig. 18.4), aortic dissection, and in guiding interventional procedures [17, 18].

Echocardiography can also be used for stress testing. Images acquired before and after either exercise- or pharmacologic-based stress may point to obstructive CAD by the presence of wall motion abnormalities that indicate inadequate perfusion, but cardiac angiography is the gold standard for viewing coronary anatomy. Stenotic lesions, intracoronary thromboses, atherosclerotic disease, areas of poor perfusion, and collateral vasculature are easily evaluated by this method [19]. Left ventriculography is included in most studies and employs contrast opacification of the LV to reveal wall motion abnormalities, which may be consistent with myocardial infarction. Capturing angiographic data 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 at a 180° angle to each other around the patient. Although complications are rare, the invasive nature of cardiac catheterization entails inherent risks, which can include myocardial infarction, stroke, infection, blood loss, and pain.

Nuclear imaging is very important in the care of patients with CAD. Its main indications include assessing the likelihood of CAD in intermediate-risk patients (high-risk patients are better suited for cardiac catheterization) and estimating the presence or amount of ischemia in patients with known disease. More than 95 % of all nuclear cardiology procedures are gated single-photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI) [20]. 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 [20], and perfusion defects may signify obstructive CAD (Fig. 18.5). Commercial software packages can assist in image interpretation, but results should always be checked by a trained individual [21]. Positron emission tomography 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 in blood or myocardium can be noninvasively determined over time.

Cardiac computed tomography (CT) has applications in many cardiac pathologies, including CAD, anomalous coronary arteries and other CHDs, valvular calcification or stenosis, pulmonary artery embolism, pericardial disease, and cardiac masses [22, 23]. Images can be obtained with multidetector 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), whereas MDCT produces better images (Fig. 18.6) with cardiac CT angiography (CCTA) of diagnostic quality for the determination of obstructive CAD [24]. CACS not only correlates with the number of conventional CAD risk factors but is also an independent risk factor for future coronary events [25–27].

Cardiac magnetic resonance (CMR) 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 [28]. CMR is the emerging modality of choice for determining ejection fraction, myocardial viability (Fig. 18.7), and evaluation of CHD [29, 30]. CMR with adenosine stress perfusion captures the transit of IV contrast, which is typically gadolinium-based, through the myocardium of the LV in order to evaluate ischemic heart disease, and CMR with dobutamine stress perfusion assesses for wall motion abnormalities that may signify obstructive CAD.

Approaches to Cardiac Imaging in the Developing World

As previously discussed, there are various challenges to the implementation of cardiac imaging technology in developing countries. This section will review effective approaches in LMICs.

Echo is by far the most widely used cardiac imaging tool in developing countries. This modality is well suited for low-resource settings for the same reasons that physicians in the developed world have so readily adopted its use in the clinic or at the hospital bedside. It is small, portable, 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 make up a large percentage of 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 it in a remote tropical setting in 1990 [31]. They used ultrasound to evaluate 67 patients at a hospital in central Sudan. Cardiac abnormalities identified included valvular disease, pericardial effusion, dilated cardiomyopathy, CHD, mitral valve prolapse, and cardiac masses.

More specifically, echo is very valuable in diagnosing RHD in developing countries. A group of Kenyan physicians who employed echo to identify functional consequences of RHD reported that even in schools without electricity, it was feasible to carry out echo exams using a portable generator [32].

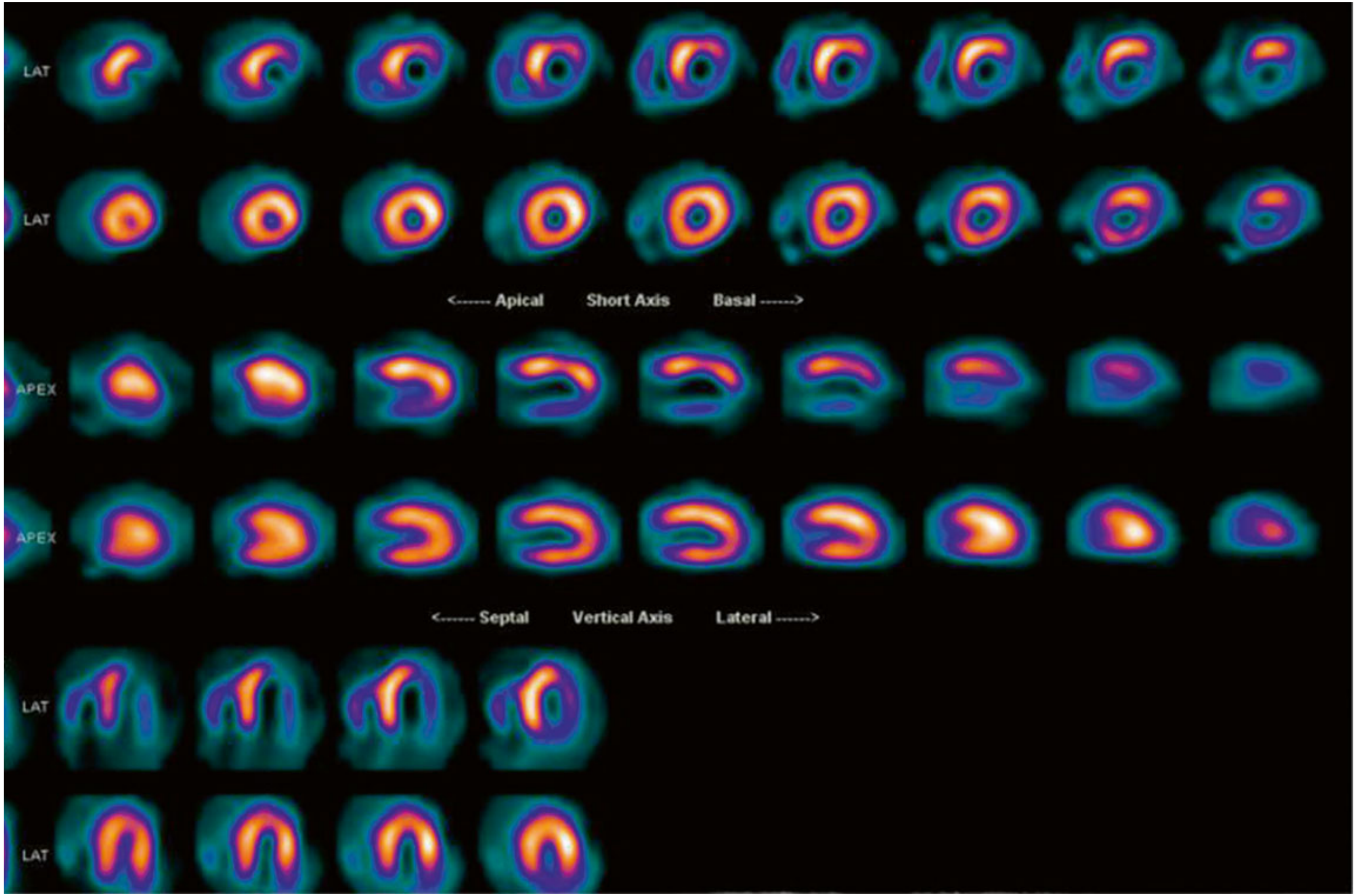

Fig. 18.5 Representative single-photon emission computed tomography myocardial perfusion imaging (SPECT MPI) demonstrating normal perfusion at rest (*lower images* in each series) and a perfusion defect after stress (*upper images* in each series). After exercise, a new perfusion defect was observed 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

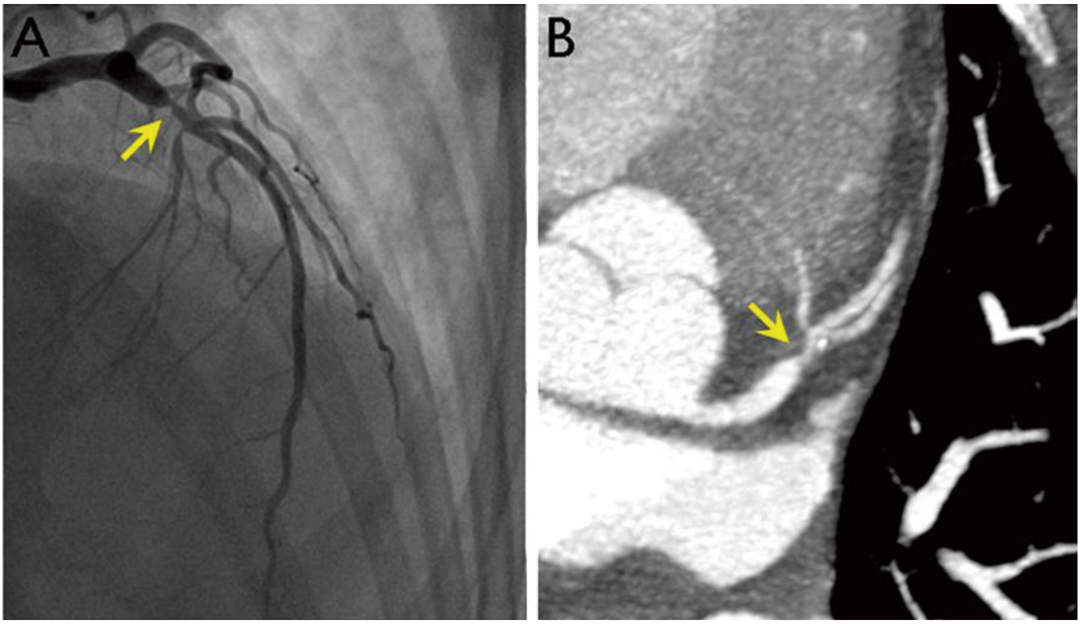

Fig. 18.6 Images of a proximal left anterior descending (LAD) coronary artery stenosis (*arrowhead*) obtained by cardiac catheterization (**a**) and coronary CT angiography (**b**). CT allows noninvasive imaging of the coronary arteries with some loss of resolution but without the complications associated with invasive procedures. Images courtesy of Robert Zeman, MD, George Washington University

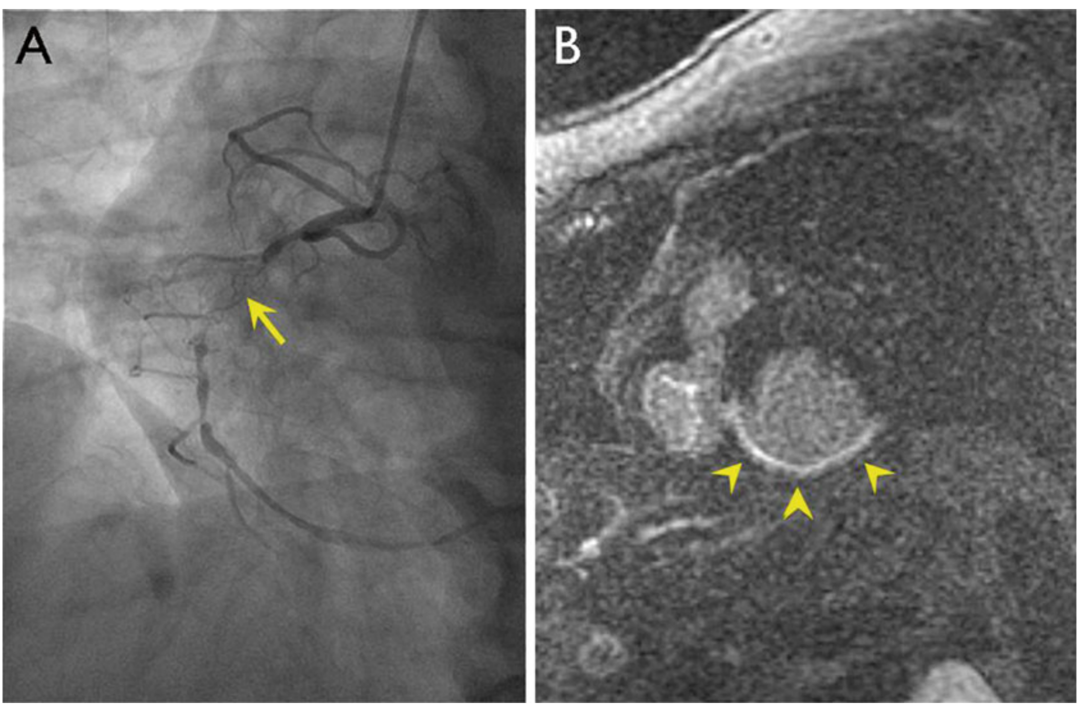

Fig. 18.7 Representative myocardial viability study by MRI. Cardiac catheterization (**a**) demonstrates a total occlusion (*arrowhead*) of the right coronary artery (RCA). Assessment of viability was done by MRI. In the short axis view of the left ventricle by MRI, late gadolinium enhancement is seen in areas of nonviable 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

Marijon et al. took advantage of more recently available high-quality portable ultrasound equipment to screen for RHD in a large population of school-aged children in two developing nations, Cambodia and Mozambique [33]. They employed an echo machine with a Philips Sonos 4500 4–7 MHz transducer and recorded images on super-VHS videotape. The results of this study showed that systematic screening with echo, as compared with clinical screening, identifies approximately ten times the number of cases of RHD. This again highlights the usefulness and practicality of echo in the developing world. 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 [34, 35].

Echo screening for RHD is also fast, inexpensive, and accurate even when performed by a nonexpert [36]. A trial of more than 362 children aged 5–14 years in Fiji showed that patients could be evaluated by echo in less than 4 min on average by an individual with no prior echo experience and at a cost of less than 40 US dollars per case of RHD detected. Given all of the advantages of RHD detection by echo, the World Heart Federation has recently published standardized criteria for the echocardiographic diagnosis of RHD [37]. The goal is to provide quicker and more reliable identification of RHD in patients worldwide so that treatment with penicillin is started before irreversible damage is done.

Portable echo is helpful in the evaluation of many other diseases endemic to developing countries. It was used to assess cardiac function and hemodynamic status in 30 children admitted to a Kenyan hospital with severe malaria [38]. Moreover, hand-carried cardiac ultrasound (HCU) devices proved to be a feasible method for diagnosis of various cardiac conditions in a cardiology clinic in rural Mexico [39]. The HCUs were about the size of a laptop computer, 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 electrocardiographs. Images produced by the HCU clarified the clinical picture in 93 % of cases and confirmed a cardiac diagnosis in 63 % of cases.

Innovation in echo technology continues to expand its utility in the developing world. A pocket-sized ultrasound (PCU) device is a new tool that is approximately the size of a smartphone and has comparable accuracy to traditional echo modalities [40–42].

Our collaborative group at George Washington University in Washington, DC, used a PCU in a remote Honduran village where echo was previously unavailable to make point-of-care diagnoses that were remotely verified by experts in the United States who reviewed the images on a smartphone-based application [43]. PCU assessments on 89 Honduran patients referred by local general providers were performed by a cardiology fellow. The most common indications for examination included arrhythmia, cardiomyopathy, and syncope. The PCU device used was small as its name suggests, measuring 1.4×7.3×2.8 cm and weighing 390 g, with an 8.9 cm diagonal display. It was equipped with color flow Doppler. Captured images were transmitted directly from the field via a dialup 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. 18.8). This approach was validated against the standard workstation evaluation and enabled patients to receive sophisticated care in areas with minimal capabilities and expertise.

In addition to its clinical applications, echo has great potential as a research instrument in developing countries. Despite having little funding, researchers from low-resource countries have employed it as a means for clinical discovery. For example, in Nigeria alone, several trials have employed echo in the investigation of various CVDs, including hypertensive heart disease, heart failure, dilated cardiomyopathy, and valvular heart disease [44–48].

Speaking more generally, the availability of all imaging modalities, including echo, is con-

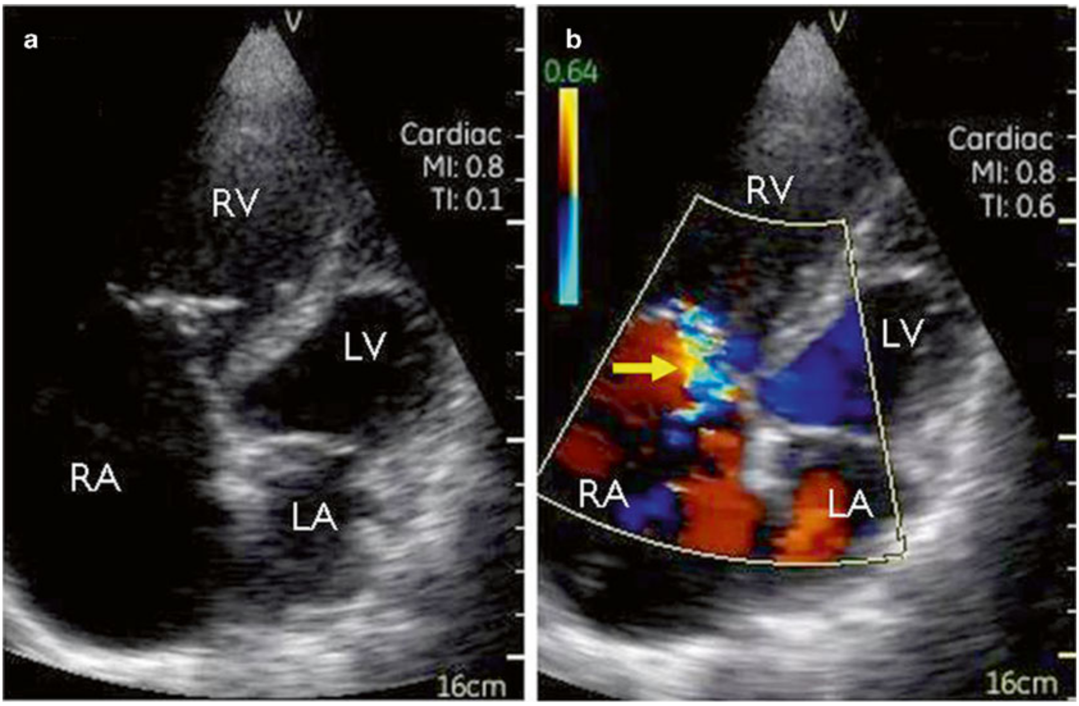

Fig. 18.8 A representative case in which expert remote interpretation corrected point-of-care diagnosis [45]. During a medical mission in a developing country, a cardiology fellow sent for remote evaluation these echocardiographic images taken with a handheld ultrasound device from a 43-year-old man 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 acknowledged that the small jet size was more consistent with high-velocity mild regurgitation. *RA* right atrium, *RV* right ventricle, *LA* left atrium, *LV* left ventricle

centrated in capital cities [49, 50]. The cardiac imaging equipment in these facilities is similar to what is available in the United States and wealthy European countries. For example, hospitals in urban areas of India have rapidly adopted advanced diagnostic techniques such as CMR, CTCA, or coronary angiography [51]. However, they are often provided on a fee-for-service basis at a cost that is unaffordable for the majority of the population. The average cost to patients of SPECT MPI with a Technetium-99-m tracer is approximately $180. While this is markedly more affordable than in industrialized nations, it is still more than one-third of the average monthly middle-class income of about $500 in India [51].

Regarding nuclear imaging, rates of use reflect a country's GDP and are highest in developing countries that border "high user" nations, such as the United States or countries in the European Union [52]. This information suggests some degree of diffusion of expertise and resources from neighboring developed countries and has implications for future initiatives in expanding the availability of advanced cardiac imaging tools in LMICs. Additionally, in some countries, novel methods are used to decrease the cost of a nuclear cardiology procedure to even lower than what it would typically cost in the developing world. These include greater use of generic drugs and radiopharmaceuticals as well as cheaper labor costs [52].

Developing countries acquire some equipment through international donation of used equipment. Many LMICs also rely on training programs provided at minimal cost by developed nations. The International Atomic and Energy Agency (IAEA) has created a module about radiation protection (RP) that is tailored to the needs of interventional cardiologists in developing countries [53]. RP is an important subject in patient and operator safety but is overlooked in many developing countries because of the lack of educational resources. In some LMICs, cardiac imaging education is part of the curriculum for cardiology training, but there is often no formal accreditation process to denote expertise in a specific imaging modality as there is in the United States or Europe [49].

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 developing nations. 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; digital chapters on ultrasound of the carotid arteries, deep venous thromboses, and the vascular systems; and links to commercial websites. Imaging the World is an organization that seeks to increase availability of echo and other types of ultrasound in developing countries, and plans relief trips to these regions. RAD-AID International assists developing nations in expanding their health imaging services, including echo and other cardiac imaging devices. The organization spreads awareness of cardiac imaging technology in low-resource settings through its annual conference and website featuring a bibliography of relevant medical research. RAD-AID also facilitates volunteering opportunities and global distribution of cardiac imaging resources.

The Need for Optimized Referral and Treatment

Establishing cardiac imaging services in the developing world is only the first step. Patients must be referred for testing in a timely and thoughtful manner. Since many cardiac imaging tests are expensive and can have potential complications including radiation exposure, patients should be selected carefully. As suggested by Lele et al., appropriate patients should be identified by accessible, noninvasive testing, which can be followed up with more expensive and invasive cardiac testing [51]. Performing a complicated study is sometimes not necessary if a simpler test can be ordered and can 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 [39]. Therefore, this technology not only is practical for resource-poor areas but also optimizes referral of patients for testing that is less available in developing countries.

In addition to identifying patients who need more sophisticated diagnostic testing, simplified cardiac imaging modalities can be used to identify patients for medical treatment or surgery. This classification is especially important for the care of patients with CHD. Although CHDs are typically diagnosed by 1 week of age in up to 50 % of patients and by 1 month in 60 % of patients in the developed world [54], presentation of patients in nonindustrialized countries is often delayed. At the time of diagnosis, patients may already be suffering from the consequences of untreated disease such as severe polycythemia, heart failure, fixed pulmonary hypertension, infective endocarditis, and stroke [55]. Of note, some of these sequelae preclude the patient from being eligible for surgery. Therefore, early detection by echo is critical so that patients can undergo surgery before their only option is palliative therapy.

The results of the Heart of 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 [56]. Of the 1,593 individuals with newly diagnosed CVD, the most common conditions were hypertension (56.3 %) and heart failure (HF, 53.0 %), and more than a third of patients with HF most likely had an advanced stage of disease, as indicated by clinically significant dyspnea.

The greatest challenge may be after imaging has established a diagnosis. While the optimal intervention for newly diagnosed heart disease may be easily identifiable—for example, surgical repair of a congenital defect—the availability of such intervention may be highly limited, even in the LMIC urban tertiary care center. In Africa, thousands of children with known CHDs die each year in anticipation of treatment [57]. After the diagnosis has been confirmed by echo, patients requiring surgical correction are placed on a wait-list, with times to surgery that typically span months to years [58]. Only a fraction of patients are selected by international charities to undergo surgery abroad, while the majority of patients have surgery locally, with the process sometimes expedited by individual ability to pay or support from visiting nongovernmental organization (NGO) missions. West Africa has no pediatric cardiac surgery centers, and only four of the 16 countries in this subregion have facilities for open heart surgery in general. Additionally, many families cannot afford the cost of treatment, so these 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 less than 15 years old with CHD requiring surgery could afford the operation within 1 year of echocardiographic diagnosis [57].

Surgical interventions for other cardiovascular pathologies, such as CAD and valvular disease, are also delayed with unfavorable results in many areas of the developing world. A clinical trial in Brazil found that the mean wait time for surgical treatment of CAD was 23 months, and the mortality rate was 5.6 deaths per 100 patients per year [59]. 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. Even medical management of CVD diagnosed by imaging can be problematic. Essential medications, such as beta-blockers for congestive HF, are often inaccessible and too expensive for patients [60, 61]. One model for enhanced distribution of cardiovascular medicines in LMICs emphasizes the importance of increased availability of generic substitutions with both public and private efforts to limit cost [62]. There is much room for improvement in the comprehensive model of care that includes accessible cardiac imaging services.

Future Directions for Cardiovascular Imaging in Developing Countries

Although many gains have been made in the advancement of global cardiac imaging services, there is still a major discrepancy between what is available in industrialized regions and the rest of the world. As discussed in the White Paper Report of the 2011 RAD-AID Conference, a multidisciplinary approach is ideal, with strategies that target financial sustainability, improved technology, educational programs, clinical models unique to the needs of the developing world, and public policy [63].

Funding for cardiac imaging modalities is crucial, since these important diagnostic services can be costly. Unfortunately, many stakeholders in the economies of developing countries, such as large international donors, are not aware of the urgency in addressing CVD. Less than 3 % of development assistance was aimed at chronic diseases from 2001 through 2007 [64]. Moreover, leaders of developing economies have limited resources and many competing interests; as a result, directing funds toward the improvement of cardiovascular health through diagnostic imaging is usually considered a low priority [65]. In smaller cities and rural areas, economic factors play a substantial role in deciding which cardiac imaging facilities are available [51].

Moving forward, it is critical that local governments, international aid agencies, individual donors, and community-based organizations recognize the vital role that cardiac imaging plays in managing CVD, which has the highest mortality worldwide, and allocate finances accordingly. Efforts to donate equipment, isotopes, and other pharmaceuticals should be continued. Another idea is to create programs that establish a sliding scale for cost based on need and ability to pay [52].

There have already been great examples of enterprise in the field of global cardiac imaging. Portable echo is just one invention that has saved numerous lives in the developing world; the need for continued innovation and creativity is tremendous. Telemedicine is an area of great promise, as proven by the accuracy of remote interpretation of echocardiographic images transmitted via a secure mobile-to-mobile system [43].

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 detection of lesions that occluded more than 50 % of the coronary artery [66]. Real-time echo at long distance has also been piloted with a remote-controlled robotic arm connected to a mobile ultrasound unit [67]. 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 [68]. In addition to expanding upon these or similar ideas, further innovation must take place to generate cardiac-specific cameras and equipment that is both affordable and adaptable to limited resource settings [52]. Easily maintained machines with on-site service would be preferable.

Many cardiologists and healthcare workers from developed nations generously donate their time and skills to countries with limited resources. This charitable work is greatly appreciated by those in need; however, local diffusion of skills is probably most valuable. Some developing countries include cardiac imaging modules in training programs for cardiologists, but they are often too basic and need to be augmented.

While cardiologists with imaging experience may informally disseminate knowledge during relief visits, structured educational programs are most effective. Distance-assisted learning programs or web-based educational tools may be especially helpful in isolated areas [52]. 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 experienced physicians with superior knowledge of image acquisition and interpretation [52].

Clinical models implemented in developing countries should be designed according to the needs of the patients in a specific region. As discussed in the previous section, referral for cardiac imaging should be well planned to maximize available resources. Additionally, all efforts to streamline care after cardiac imaging diagnosis should be made.

Public policy initiatives to address cardiac imaging are very important but poorly developed or nonexistent in most resource-poor countries. Most developing countries do not have health insurance systems in place, so patients must pay completely out of pocket for cardiac imaging. As a result, there is a great need for some sort of public program to reduce the expense of costly but necessary cardiac imaging tests regardless of the individual patient's ability to pay. Moreover, public policy programs to develop the infrastructure necessary for employing 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 growing epidemic of CVD in the developing world 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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19 Pediatric Imaging in Global Health Radiology

Sinisa Haberle and Charles Maxfield

Introduction

The health of children in the developing world should be of great concern to all of us. Each year, 10.6 million die before age 5, and undernutrition is an underlying cause of over half of these cases [1]. During the period of 2000–2003, half of these deaths were attributable to three major causes: pneumonia (19 %), diarrhea (18 %), and malaria (8 %). Another 25 % succumb during the immediate postnatal period, due to neonatal pneumonia/sepsis, birth asphyxia, or complications of preterm delivery [2]. Approximately 1.9 billion children live in the developing world. One third of these have inadequate access to shelter. One fifth have no access to safe water and one seventh have no access to health services [2]. Many of these problems can be solved with improved immunizations, appropriate nutrition, and clean water. We will concentrate our discussion in this chapter on those disease entities in which diagnostic imaging may have a public health impact.

Overall, children have unique disease processes and manifestations of disease when compared to adults. Additionally, familiarity with the variations and changes in the maturing child and adolescent is necessary to care for this patient population; for these reasons, pediatric radiology emerged as the first radiology subspecialty in the early 1900s [3]. The practice of pediatric radiology was initially limited largely to conventional radiography and fluoroscopy until the 1980s, with most cross-sectional imaging and interventional procedures being performed by adult radiologists. Since that time, the subspecialty has matured and further subspecialized, and now includes the application of all imaging modalities, including ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine, as well as interventional procedures.

Pediatric imaging is practiced much differently in the developing world, where it faces major challenges, not the least of which are that CT and MRI are often unavailable or strictly limited to major metropolitan areas. Ultrasound and conventional radiography are the workhorses of diagnostic imaging, but even their availability can often be limited in low-resource settings.

Challenges for Pediatric Radiology in the Developing World

Pediatric radiology requires specialized knowledge of pediatric anatomy and pathology, dedicated imaging equipment, and an awareness of the risks of ionizing radiation and its effects on children. A major challenge that needs to be

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overcome, before diagnostic imaging can realize its full impact on public health, is the shortage of radiologists, especially those with expertise in pediatric radiology. 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 [2]. Furthermore, those radiologists in developing countries who go elsewhere for additional training tend not to return. Therefore due to the dire shortage of radiologists, unqualified general practitioners perform and interpret most of the pediatric radiographs and US scans.

WHO recommends that every hospital should have basic imaging equipment and that simple radiographic and US equipment should be available to all children. Those working in pediatric intensive care units in the developing world face lack of subspecialist support but also lack of diagnostic facilities (imaging and laboratory) and lack of appropriate medications and supportive equipment [4]. Donation of old and used equipment is less than ideal as equipment arrives without a repair manual, maintenance records, or staff training [2]. Thus the upkeep of old equipment may make it prohibitive for hospitals to accept old equipment.

Since 1995, WHO has recommended the WHIS-RAD (World Health Imaging System for Radiography) unit, successor of the WHO-BRS (World health Organization—Basic Radiological Services), which has the highest possible safety profile and is therefore more suitable for children. A WHIS-RAD unit estimated cost as of 2009 costs approximately $36,000; digital units can cost up to $72,000.

Appropriate Use of Advanced Imaging: ALARA (As Low as Reasonably Achievable)

A special consideration in the treatment of children is the consideration of the radiation risk associated with radiographic image acquisition. Children are more radiosensitive than adults, and their longer life span allows a longer time frame to acquire a radiation-induced malignancy. Physicians in the developing world who are utilizing X-rays, fluoroscopy, or CT should understand the risks of radiation in order to use the technology safely and appropriately.

The discovery of computed tomography (CT) has had a dramatic effect on the field of medicine and has revolutionized diagnostic radiology. Since it was initially discovered in the 1970s, the developed world has seen a great increase in the use of CT [5, 6]. CT overutilization is not currently a concern in the developing world, but it is important that all physicians practicing radiology understand the risks and respect safe practice principles.

Ionizing radiation, such as that emitted by X-ray and CT, has by definition enough energy to remove electrons from their orbitals. In human bodies, hydroxyl radicals are formed from the interaction of water particles and ionizing radiation. These radicals can lead to double-strand breaks or base damage; ionizing radiation can also directly damage DNA [5]. The human body constantly repairs damage that is caused by ambient radiation and other mechanisms, but double-strand breaks are harder to repair. When these double-strand breaks are not repaired by natural defenses, point mutations, chromosomal translocations, and gene fusions may develop [5]. These processes can all lead to the induction of cancer that can have a lead time on the order of decades [7].

CT is a very useful diagnostic modality. It has improved outcomes, but must be used in the appropriate clinical situation to avoid putting the patient at unnecessary risk. Pediatric healthcare professionals should be judicious when ordering CT scans, and the radiologist and the technician should inspect all CT requests that come in, in order to avoid unnecessary CTs. When a CT is indicated, the responsible radiologist should protocol the exam in order to use the lowest radiation dose necessary to answer the clinical question. Any physician performing CT scanning should be aware of the ALARA principles and put them in practice.

In the developed world, the Alliance for Safety in Pediatric Imaging has formed the Image Gently campaign that has set out to provide imaging guidelines for physicians. The Alliance was established in July of 2007 and the 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 child size kV and mAs settings, only one pass through the scanner (one phase), and scanning of only the indicated area. They also advocate scanning only when necessary.

These changes are a product of SPR's ALARA conferences, multiple journal articles about the risk of radiation, practice guidelines from the ACR and CT accreditation programs, and manufacturer's protocols for pediatric patients. The lessons that we have learned over the last decade should be transferred to the developing world when introducing and scaling up radiology services. We should strive to minimize unnecessary exams, adjust the settings, replace exams by ultrasound or MRI if available, and educate future physicians about the harms of radiation.

Imaging Appearance of Common Pediatric Clinical Disease

Tuberculosis

Tuberculosis (TB), due to *Mycobacterium tuberculosis*, is among the most important causes of morbidity and mortality worldwide, but particularly affects the developing world. Overcrowding, poverty, lack of sanitation, 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 [8]. Children are particularly susceptible to TB. Children are more likely to develop disease after infection than adults and are also more prone to develop extrapulmonary disease and severe disseminated disease [8].

Infection with TB is indicated by a positive tuberculin skin test (TST). Tuberculosis disease is indicated by clinical symptoms and positive findings on chest radiograph. The risk of developing disease after infection has been estimated at 5–10 % in adults, 15 % in adolescents, 24 % in children 1–5 years of age, and as high as 43 % in infants less than 1 year of age [8, 9].

The diagnosis of TB is dependent on many factors, including clinical history and presentation, history of infectious contact, sputum smears, and the TST. Lack of resources in developing countries makes the diagnosis of TB difficult. 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 [10, 11]. Less than 20 % of children with proven TB will have a positive sputum or gastric aspirate as compared with 75 % in adults [12, 13]. Moreover, the TST can be negative in a large proportion of children as a result of a weaker immune system due to human immunodeficiency virus (HIV) or severe malnutrition [14, 15]. Diagnostic imaging, if available, can 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 may be 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. 19.1). 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 [14]. Cavitation is rare in primary TB. These findings can be subtle on the chest radiograph. Thoracic CT, if available, enhances visualization of small parenchymal lesions as well as mediastinal and hilar lymphadenopathy. CT, however, is scarcely available in the developing world and cannot be relied upon for diagnosis.

Miliary disease, a complication of primary infection, is defined as manifestation of disease that leads to discrete tiny nodules diffusely throughout two or more organs (Fig. 19.2). This form of TB is more common in very young patients and immunosuppressed [8, 14]. When there is

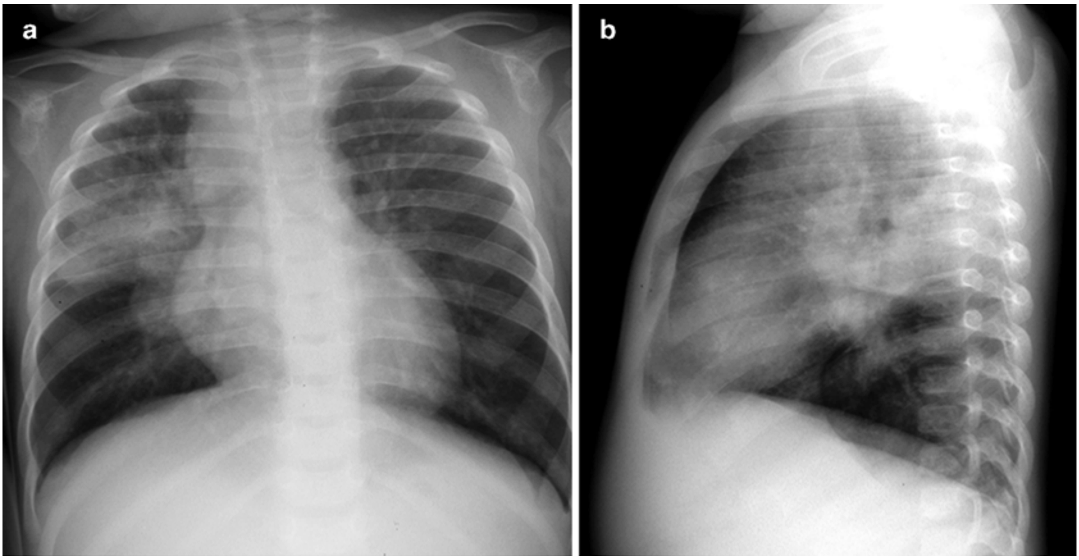

Fig. 19.1 Tuberculosis in a young boy. (**a**, **b**) Frontal and lateral radiographs of the chest demonstrate a right upper lobe opacity and associated right hilar lymphadenopathy

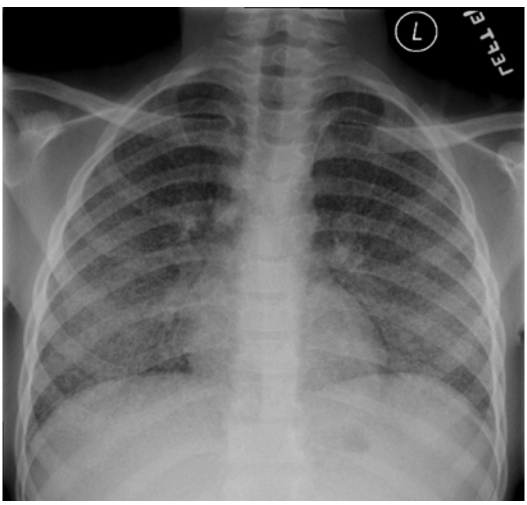

Fig. 19.2 Miliary tuberculosis in a 9-year-old male. Diffuse discrete tiny nodules are seen throughout the bilateral lung consistent with complication of primary infection. Miliary TB is a common manifestation in young and immunosuppressed patients

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 [16]. Ussery [17] found that 22 % of patients younger than 15 had only extrapulmonary disease. Morbidity and mortality associated with TB is greatest when there is CNS involvement, especially with tuberculous meningitis, which can lead to blindness, deafness, intracranial calcifications, diabetes insipidus, and mental retardation. Of the patients presenting with meningitis, 80 % of these patients are younger than age 4 [17].

The abdomen is the most common site of extrapulmonary 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, 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 [16]. Enlarged lymph nodes may be seen in the mesentery and omentum, characteristically with hypoattenuating centers and hyperattenuating, enhancing rims. Renal involvement may be manifest on CT, and occasionally on radiographs, as renal calcifications. Caliectasis and hydronephrosis may also be seen [16]. TB can also involve the adrenal glands.

Fig. 19.3 Tuberculous arthritis. Most commonly affects the hips and the knees. Reactive hyperemia leads to juxta-articular osteoporosis, erosions and, in this 9-year-old boy, severe joint space narrowing

When bilateral, this can lead to adrenal insufficiency. Classic imaging findings include small adrenal glands with calcifications [18].

Musculoskeletal involvement is most often seen in the spine (50 %). Tuberculous spondylitis most commonly affects the lower thoracic and upper lumbar spine [19]. 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 the joint (Fig. 19.3) [16].

HIV/AIDS

HIV/AIDS has devastated children of the developing world in many ways. Thirteen million African children have been orphaned due to their parents having died from AIDS. Many more are infected directly, most often acquiring the virus through vertical (mother-to-child) transmission.

One third of infants born to HIV-infected mothers acquire the virus through a combination of intrauterine, intrapartum, and postpartum exposures [20]. Many more acquire the virus through breastfeeding, which in most instances is the only form of nutrition that these children will receive. The 30–35 % rate of vertical transmission in the developing world compares to a rate of only 4–6 % in the developed world, where highly active antiretroviral therapy (HAART) and formula feeding are readily available [21]. There are approximately 1,500 new pediatric cases of HIV per day in sub-Saharan Africa [22].

Once infected, children with HIV in the developing world are particularly prone to complicating infections due to poor nutrition, lack of access to clean water and health care, as well high prevalence of gastrointestinal and respiratory pathogens in the community [22]. Opportunistic infections seen in HIV-infected children most often involve the upper and lower respiratory tract infections, the intestine, and the brain.

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 [22]. The most common respiratory infection is of bacterial etiology. Fifty percent are focal and consolidative, while 50 % are diffuse, nodular or form cavities. Findings of bronchopneumonia in HIV patients have significant overlap with those of TB.

AIDS patients are predisposed to opportunistic infections such as PCP (*Pneumocystis* pneumonia), although its prevalence may be decreased where HAART and prophylactic trimethoprim-sulfamethoxazole (TMP-SMX) are available [11]. 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. 19.4) [23]. Other opportunistic fungal infections may demonstrate focal alveolar opacities or multiple pulmonary nodules.

HIV-infected pediatric patients may also suffer from dilated cardiomyopathy that may be

Fig. 19.4 PCP in an HIV-positive young adult. Diffuse granular and reticular opacities in a perihilar distribution. The incidence of PCP has significantly decreased with TMP-SMX prophylaxis

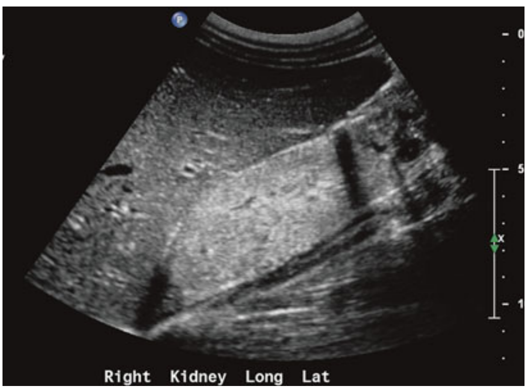

Fig. 19.5 An HIV-positive male with diffusely echogenic right kidney consistent with HIV nephropathy. There is loss of corticomedullary junction, and there is a clear increase in echogenicity of the kidney in relation to the normal liver

due to immune-mediated mechanisms, opportunistic infections directly invading myocardial cells, or primary infection of myocardial cells by HIV itself [21]. The CXR may reveal cardiomegaly, and in severe cases, 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. 19.5) [24].

CNS involvement is common in HIV/AIDS. In Chakraborty's study, 18 % of HIV/AIDS-infected children died from pyogenic meningitis [22]. CT findings of HIV infection include generalized (or frontally predominant) cerebral atrophy and basal ganglia calcifications [25].

Diarrhea

Diarrhea is a significant public health risk in the developing world. Although often thought of as simply a nuisance in the developed world, diarrhea leading to dehydration is one of the leading causes of death of children in the developing world; lack of clean water is the major cause, although other endemic disease such as HIV are also significant contributors. Common pathogens causing diarrhea in children include rotavirus and *Escherichia coli* [26], and in the HIV population, other pathogens must be considered, including cytomegalovirus, *Mycobacterium avium-intracellulare* (MAI), *Giardia*, and cryptosporidiosis [26, 27].

Imaging does not play a major role in the diagnosis and management of the child with diarrhea; in particular, radiographs of the abdomen are rarely helpful as many of the imaging findings are not specific to any particular disease entity. For example, there may be focal dilatation of small bowel loops, air fluid levels, or bowel wall thickening, primarily due to malabsorptive fluid loss [28].

If needed, the small bowel can be more thoroughly evaluated with an upper GI study with small bowel follow through, which is a study that 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 for diarrhea is Whipple disease, caused by *Tropheryma whipplei* which preferentially affects the duodenum and proximal jejunum with thickened mucosal folds [29].

Overall, contrast studies are not felt to discriminate reliably and rarely alter management and are rarely indicated for the diarrhea workup [29–32]. If CT is available, it may show wall thickening of the colon or small bowel, and perhaps associated mesenteric lymph nodes [29].

Malaria

Imaging plays little role in the diagnosis of malaria, as the diagnosis is based on peripheral blood smears and clinical history. Imaging, however, may show findings concordant with the diagnosis of malaria. For example, ultrasound of the abdomen may reveal hepatosplenomegaly [31]. In fact, in presentation of 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, and emergent ultrasound in the setting of acute abdominal pain and malaria infection can help identify this complication [33].

Parasitic Infections

Echinococcus, the pathogen leading to hydatid disease, is still a frequent cause of liver and lung disease in many countries in the developing world. Hydatid disease is endemic in China, Africa, the Mediterranean, Balkan Countries, the Middle East, and South America, but is now being seen more commonly in the developed world due to globalization and migration [34].

The most common routes of infection are through ingestion of contaminated water or uncooked food, or from direct hand-to-mouth fecal transmission, as can often occur in settings of low socioeconomic status and poor sanitary conditions [35]. 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 rely on a competent immune response, which can be lacking if the patient has an underlying disease like HIV. Furthermore, the sensitivity of tests is inversely proportional to the degree of sequestration of the echinococcal antigens inside of cysts, causing the diagnosis to be elusive [36].

The liver is involved in 50–89 % of cases of hydatid disease, more than the lung (10–30 %) and other organs (10–20 %) [37]. Most often, liver involvement takes the form of a solitary cyst although multiple liver cysts may also be seen [38]. Classic radiographic findings include hepatomegaly and scattered radiolucencies which are outlined with calcified rings which is seen in up to 30 % of cases on plain radiographs [39]. Densely calcified cysts are usually thought to represent inactive disease [40]. 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 an anechoic fluid content with posterior acoustic enhancement. A cyst can also have mobile, dependent, echogenic hydatid, which is composed of brood capsules and free scolices [41]. 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. 19.6) [34].

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 [34, 39]. Both US and CT can demonstrate a cyst wall defect with passage of cyst contents outside of this defect, and 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 and demonstrate poorly defined margins with a solid appearance, mixed solid and

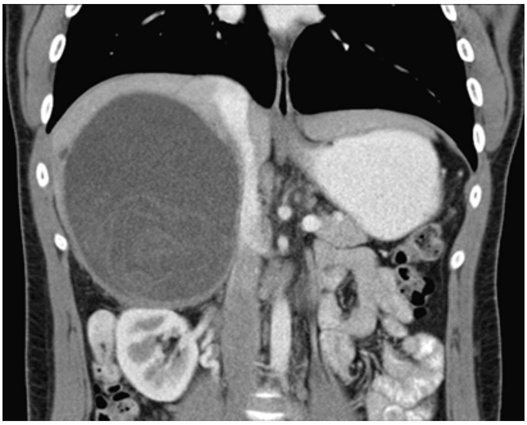

Fig. 19.6 *Echinococcus* (hydatid) disease. An 18-year-old male from Egypt with right upper quadrant pain. There is a large complex cystic mass within the right lobe of the liver. Numerous septations are also seen. Furthermore, the wall of the hydatid cyst is well defined without definitive surrounding edema

Fig. 19.7 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

fluid appearance with internal echoes, and air fluid levels. CT is more sensitive, and findings include a poorly defined mass and a high attenuation rim suggesting an abscess surrounding the underlying cyst; gas and air fluid levels can also be seen [34].

Echinococcus infection may reach the lungs via hematogenous spread, which are the second most common sites of documented involvement second only to liver cysts. On plain radiographs, uncomplicated cysts appear as well-described masses and vary from 1 to 20 cm [42]. 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 [43]. 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 the developing world 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 by a fecal-oral route from a tapeworm carrier as is common in a household or in other 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 the developing world. MRI is the most sensitive modality to detect neurocysticercosis but is rarely available in the developing world. Therefore a combination of CT (if available) and serological testing should be used in developing the diagnosis [36].

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, there is demonstration of round or ovoid cysts which are solitary in 20–50 % of cases (Fig. 19.7). 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. 19.8). In the granular stage, mild edema is the predominant finding, while in the nodular stage, a small, calcified nodule may be seen [44]. It is important to note that lesions may be at different stages in the same patient.

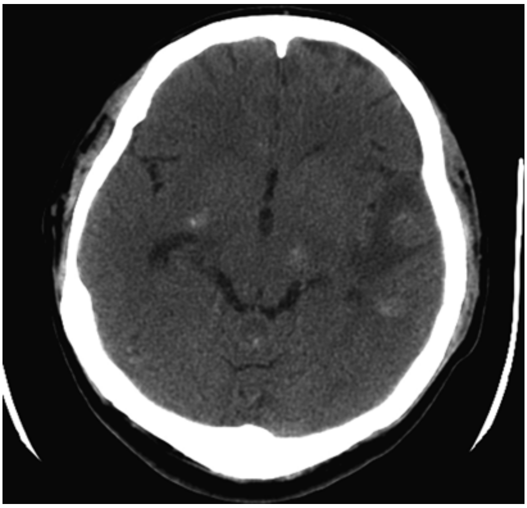

Fig. 19.8 Neurocysticercosis. An 18-year-old female with numerous areas of hyperdensity within the cerebral hemispheres. Furthermore, these hyperdense lesions are surrounded by areas of hypodensity likely consistent with surrounding edema

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 [45, 46]. The inflammatory changes within the colon are particularly seen within the cecum and the ascending colon (Fig. 19.9) [46]. Hepatic infections occur as a result of colonic trophozoites ascending via the portal vein and invading 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 [45]. CT findings demonstrate a unilocular or multilocular hypodense lesion made up of complex fluid (10–20 HU). Furthermore, a hyperdense capsule and an area of peripheral low attenuation, due to marked edema, surround the abscess (Fig. 19.10) [45].

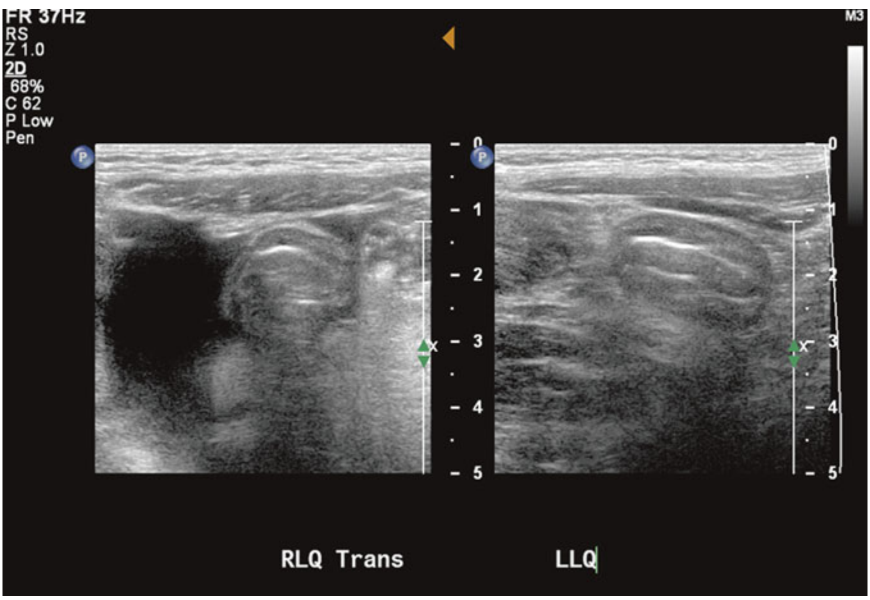

Fig. 19.9 Amebic pan colitis. A 10-year-old male from Peru with diarrhea. US shows diffuse mural thickening of the colon within the right and left lower quadrant consistent with pancolitis. There is an appearance of echogenic submucosa due to edema

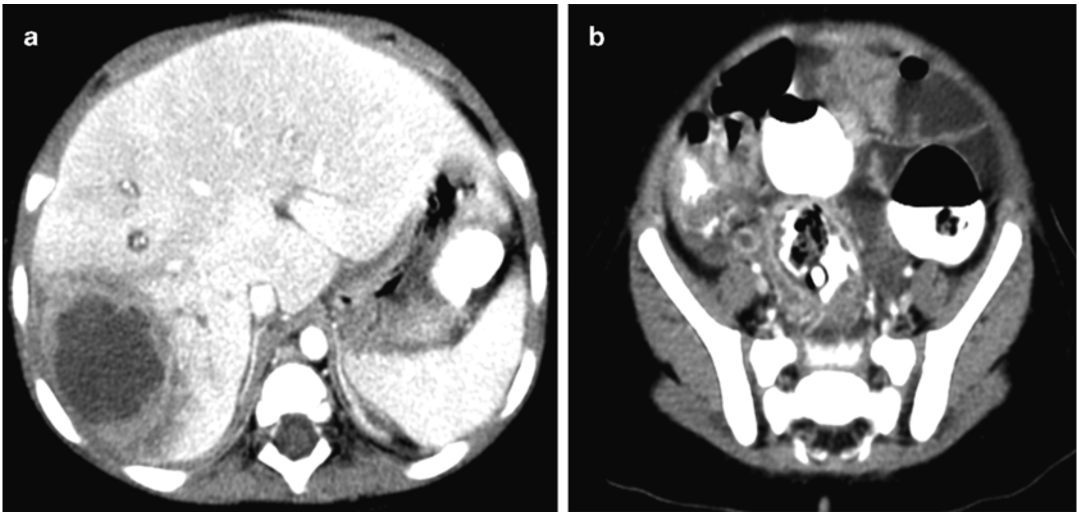

Fig. 19.10 (**a**) Amebic abscess. A 4-year-old male from Central America. There is a large amebic abscess within the right hepatic lobe with a shaggy internal wall and peripheral zone of edema. The abscess was treated with antimicrobials and a pigtail drainage catheter. (**b**) Amebic colitis. Patient also demonstrated diffuse right colonic thickening and inflammation on the same CT

Neonatal Pneumonia, Meconium Aspiration, and Surfactant Deficiency

Infant mortality rates in the developing world are significantly higher than in the developed world. Prenatal care is often lacking, as is the capability to address acute perinatal problems. Because of the availability of conventional radiography, diagnostic imaging has the greatest potential to impact pulmonary disease in the developing world population. 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 the developed world, exogenous surfactant is administered to premature infants at risk. This therapy can decrease the need for oxygen and ventilator support, risk of intracranial hemorrhage and bronchopulmonary dysplasia, and morbidity. Exogenous surfactant, however, is expensive and not widely available in the developing world. The classic appearance of SDD is that of diffuse ground glass opacification with air bronchograms and low lung volumes (Fig. 19.11). When surfactant therapy is administered, there is a near complete, central, or asymmetric clearance of findings of SDD [47].

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 can be acquired via an intrauterine route, during birth, or soon after delivery. Many women in the developed world are tested and receive treatment for b-hemolytic streptococcal pneumonia. Premature infants are at greater risk for developing GBS pneumonia after being exposed to the bacteria during delivery. The radiographic findings of group B streptococcus pneumonia can mimic SDD [47].

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

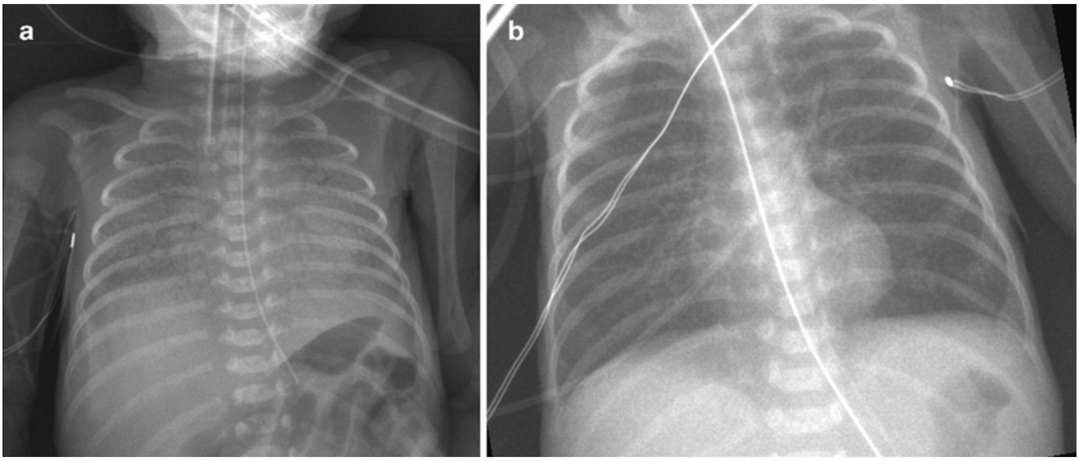

Fig. 19.11 (**a**) Surfactant deficiency disease in a premature infant. Diffuse ground glass opacities are seen with low lung volumes bilaterally. (**b**) Same patient after receiving surfactant therapy leading to complete resolution of the previously seen diffuse opacities

Fig. 19.12 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

increased. Pneumothorax complicates meconium aspiration in approximately 20 % of babies (Fig. 19.12). The radiographic picture can be difficult to distinguish but the clinical history if often strongly suggestive. The delivering physician will suspect meconium aspiration based on meconium-stained amniotic fluid. If suction devices are available, meconium will be suctioned below the vocal cords [47].

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 not commonly seen in the developing world, like *M. tuberculosis*, HIV/AIDS, and parasites, to which children are particularly susceptible.

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20 Prenatal Maternal-Fetal Imaging for Global Health Radiology

Toma Omonuwa, Maria Small, and Sujata Ghate

Introduction

The gap in healthcare outcomes between high-income countries (HIC) and low-income countries (LIC) is especially disparate in the field of maternal-fetal medicine. While global maternal mortality rates have declined since 1980, they still remain unacceptably high in the developing world. Of the nearly 287,000 reported maternal deaths in 2010, 99 % were preventable and occurred in LICs [1, 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 [3].

High maternal-fetal death rates not only impact the affected individual, but also affect the local community and nation. The World Health Organization (WHO) posits that maternal-fetal health tragedies contribute significantly to "poverty and [inhibit] affected individuals' full participation in socio-economic development" [4]. Most of these tragedies are preventable; thus, this knowledge creates an incentive for further action on this issue.

This chapter will review the epidemiological characteristics of disease in perinatal medicine as well as the impact of imaging, particularly ultrasound, on these disease processes. The unique legal and regulatory settings of different countries regarding maternal-fetal imaging will be examined along with accompanying sociopolitical and ethical issues.

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) in an attempt to improve socioeconomic conditions in the developing world. 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 time period. Although some reduction in maternal mortality has been achieved, 12 years later, Goal 5 remains elusive with persistently high MMR in LICs; the rate is

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nearly 15 times higher in LICs than HICs, with Sub-Saharan Africa and Southeastern Asia accounting for 85 % of the global burden [1, 2, 5] (Fig. 20.1).

Similarly, perinatal and neonatal mortality rates remain unacceptably high in LICs with a majority 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, experts believe this reduction is not sufficient to reach the target for MDG 4 by 2015 [6, 7].

The leading causes of maternal mortality are hemorrhage, infection, eclampsia, and obstructed labor; for perinatal mortality, the leading causes are infection, birth injuries, preterm births, and birth defects [3, 8]. These deaths are largely preventable and a number of publications have discussed potential strategies for intervention: increasing access to emergency obstetric services, increasing availability of skilled health care providers, increasing access to antibiotic treatment, employing safe abortion practices, and promoting disease prevention through hygiene-focused health education [9–11].

Although the utility of ultrasound imaging in LICs has not been extensively studied, experience from the developed world 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 developing countries.

Role of Imaging

Ultrasound is currently the most widely employed imaging modality for evaluating fetal well-being during pregnancy [12–14]. While access to sonography may be limited in developing countries, the recent introduction of compact, portable and affordable units may allow more widespread use of this technology [15]. The most widely available compact units are manufactured by two companies: GE Healthcare (Milwaukee, WI) and Sonosite, Inc. (Bothell, WA); other global manufacturers are not far behind, producing their own low-cost machines. These small units are sturdy, portable, and offer unique features such as a rechargeable or solar battery, which are well-suited for areas with unreliable electricity. Most of the currently-offered compact machines lack the more advanced features of full-sized units such as color Doppler technology or high resolution transducers. There is little scientific data on whether these features are necessary for detection of life-threatening obstetric complications in low resource settings; furthermore, there are few studies that compare the accuracy of full-sized ultrasound units with compact machines in obstetric imaging [15]. However, there is some early evidence that compact machines may provide enough information to determine appropriate triage for patients with obstetric emergencies [16].

The impact of imaging on maternal-fetal outcomes in developing countries remains an ongoing area of research, and currently very few controlled trials on this subject are available for review. However, 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.

Causes of Maternal Mortality

Maternal Hemorrhage

Ectopic Pregnancy

An ectopic pregnancy, or eccysis, 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

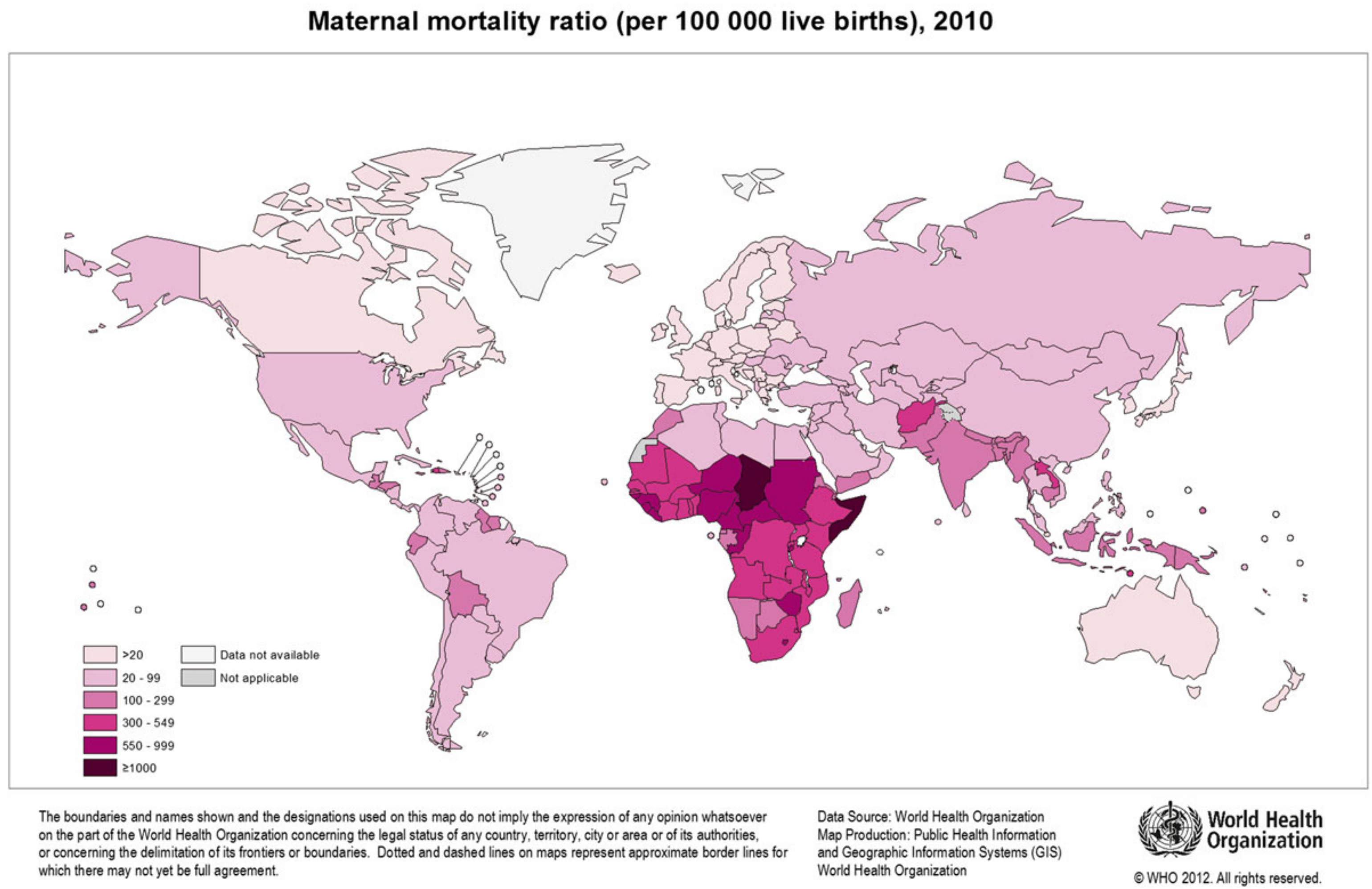

Fig. 20.1 Maternal mortality ratio worldwide in 2010. Courtesy: World Health Organization (reprinted with permission)

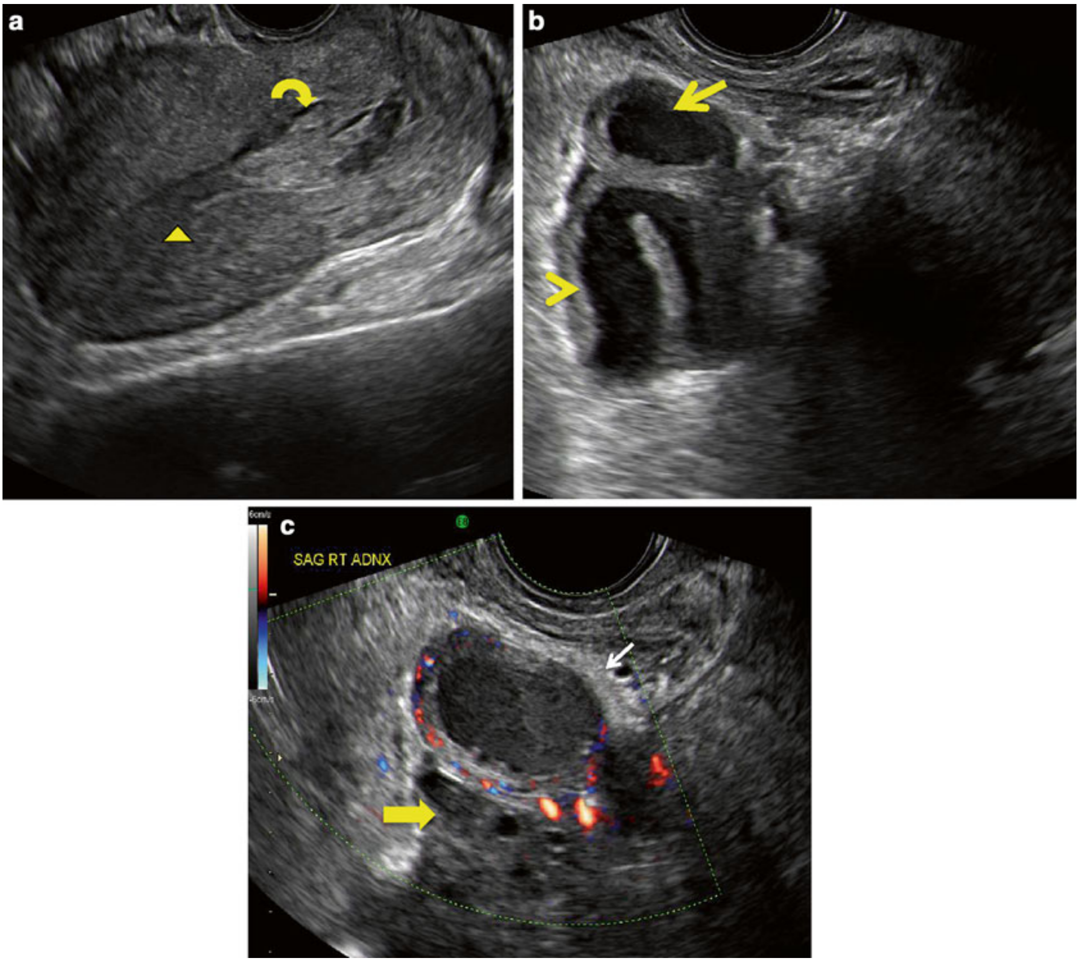

Fig. 20.2 (**a**) Sagittal midline view of the uterus on endovaginal ultrasound performed at 10 weeks gestation by clinical dates. There is a thin endometrial stripe (*arrowhead*) in uterus without gestational sac. Note blood products in the lower uterine segment and cervix (*curved arrow*). (**b**) 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*). (Courtesy S. Ghate, Author)

of irregular vaginal bleeding (tender palpable adnexal mass, and abdominal or pelvic pain) may not 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. 20.2), 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. 20.3). 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

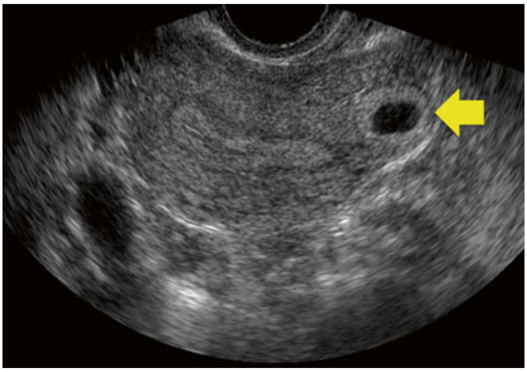

Fig. 20.3 Endovaginal ultrasound of another patient with positive beta-HCG. Transverse view of the superior uterus shows an eccentric implantation of the gestational sac in the uterine fundus with minimal myometrium surrounding it (*wide arrow*). The ovaries were normal (not shown). Findings are consistent with cornual ectopic pregnancy. (Courtesy S. Ghate, Author)

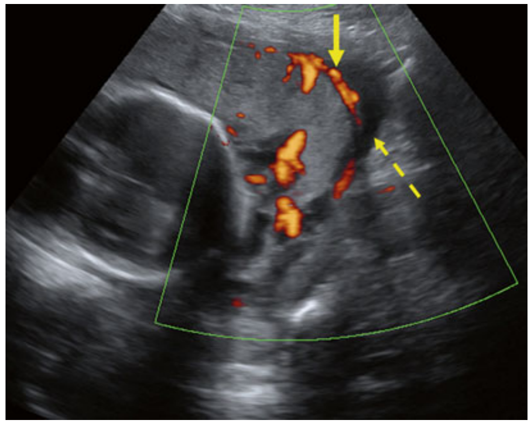

Fig. 20.4 32-year-old patient with history of prior Caesarian section, presented with hematuria. Color Doppler imaging demonstrates placenta (*solid arrow*) abutting the maternal bladder (*dashed arrow*) without intervening myometrium, suggesting invasion of the placenta to the level of the bladder wall. These findings are highly suggestive of placenta percreta. (Courtesy S. Ghate, Author)

complications has declined in recent years. Much of this decrease has been attributed to early detection by ultrasound imaging [17, 18]. Similarly in LIC, 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 [19, 20].

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 endometrium. 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 in order 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 US is also reliable, detecting 50–80 % of placenta accrete [21]. 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. 20.4). For women who are at high risk for an implantation abnormality, US may be an effective, low cost alternative to MRI, particularly in developing countries where access to MRI may be limited [21].

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 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. 20.5). During vaginal delivery, these vessels

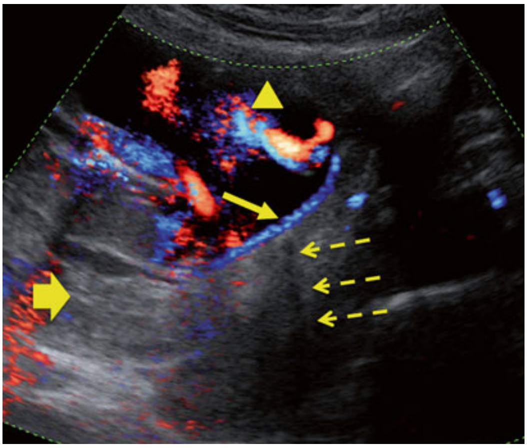

Fig. 20.5 25-year-old patient presented with painless vaginal bleeding. Color Doppler imaging of a gravid uterus at 20 weeks gestation demonstrates a posterior placenta (*wide arrow*) with velamentous insertion of the cord anteriorly (*arrowhead*). In addition, cord vessels (*solid arrow*) are seen crossing the internal cervical os, (*dashed arrow*) consistent with vasa previa. (Courtesy S. Ghate, Author)

can tear and result in fetal blood loss. Vasa previa carries a fetal mortality risk of 33–100 % [22]. Early prenatal identification can avoid this outcome [22].

Careful ultrasound imaging with or without Color Doppler can detect these abnormalities prenatally and guide the obstetrician to appropriate cesarean delivery planning.

Gestational Trophoblastic Disease

Gestational trophoblastic disease (GTD) describes a group of rare pregnancy-related trophoblastic neoplasms. Histologically, these tumors are classified as benign hydatiform moles, invasive mole, choriocarcinoma or placental site trophoblastic tumor (PSTT). Patients may present with hyperemesis, bleeding, enlarged uterus, and elevated serum beta-HCG levels. Ultrasound findings of an abnormal mass with multiple cystic spaces (Fig. 20.6) may help differentiate GTD from a multiple gestation pregnancy which may have similar signs and symptoms, but where clinical management will differ greatly.

Early identification of GTD by US and subsequent early surgical intervention may reduce the risk of maternal morbidity from severe hemorrhage, preeclampsia, thyrotoxicosis or ovarian hyperstimulation syndrome [23].

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 [24, 25]. 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. Imaging 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 [25–27].

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. 20.7).

Maternal Sepsis

Maternal sepsis, an uncommon but important complication of pregnancy, is responsible for 10–12 % of maternal deaths in LICs [8, 26]. Clinical signs and symptoms of fever, chills, abdominal pain, or vaginal discharge in postpartum or post-cesarean section patients, may indicate infection resulting from endometritis, chorioamniotis, POC or abscess [27]. Early diagnosis, broad-spectrum antibiotic therapy and treatment of the underlying cause of sepsis may prevent serious complications such as maternal

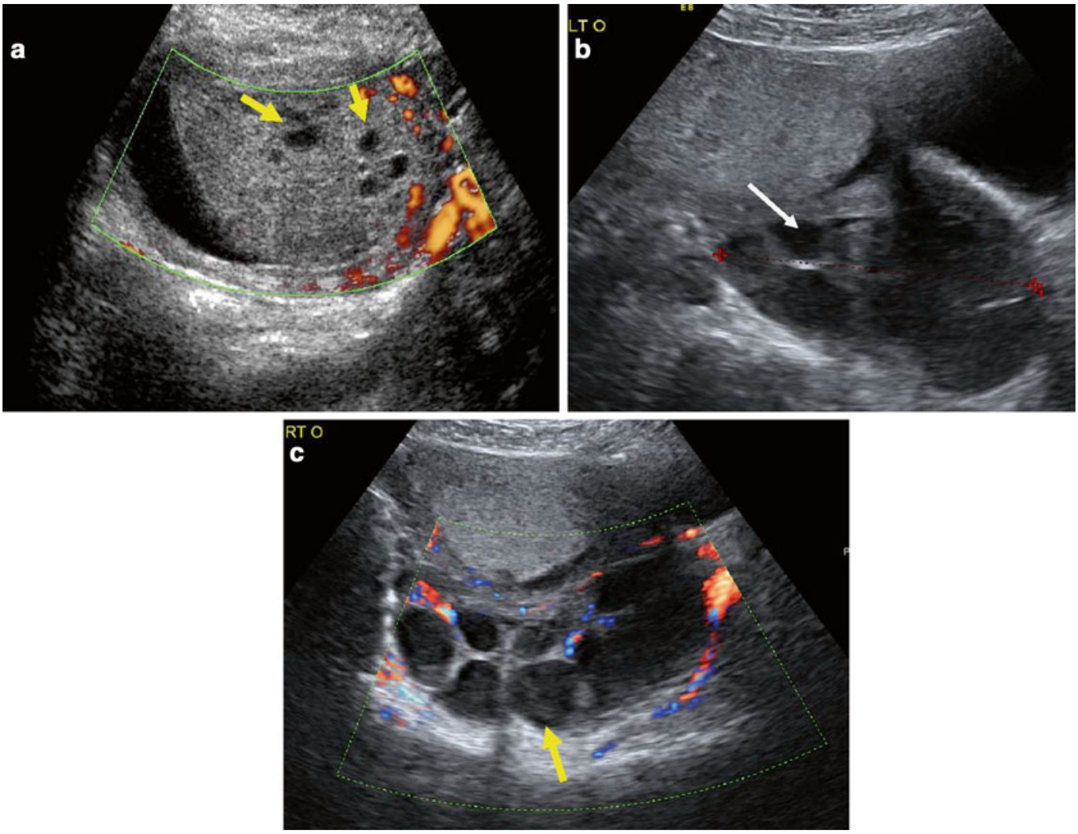

Fig. 20.6 (**a**) 32-year-old patient with a positive beta-HCG presented with symptoms of hyperemesis. This is a thickened placenta with multiple cystic spaces (*arrows*). No fetal tissue or oligohydramnios are present. (**b**, **c**) Images of the ovaries in the same patient shows multiple large cysts (*arrows*) consistent with theca luteal cysts. This constellation of findings is suspicious for a complete molar pregnancy. (Figure courtesy S. Ghate, Author)

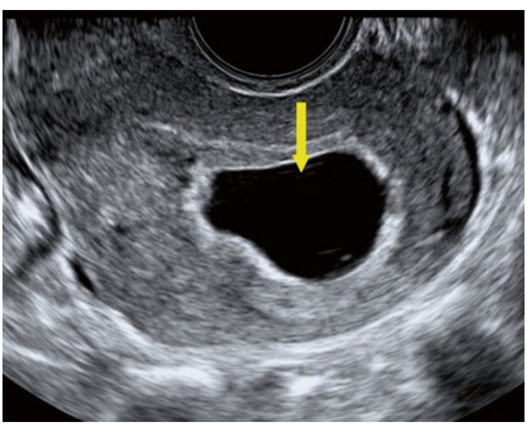

Fig. 20.7 Sagittal view of the uterus from endovaginal ultrasound performed for vaginal bleeding at 6 weeks and 5 days of gestation. *Arrow* denotes abnormally large, irregular gestational sac measuring 2.1 cm. No embryo or yolk sac is identified within the gestational sac. The findings are consistent with an anembryonic, nonviable pregnancy. (Figure courtesy S. Ghate, Author)

death, secondary infertility, or long-term morbidity from chronic pelvic pain [28]. A diagnosis of sepsis is generally made based on clinical presentation of the patient. While US 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 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 [29]. A precise estimation by sonography is necessary in order to avoid unnecessary preterm or post-date deliveries, which are important causes of perinatal mortality [30]. 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 and therefore, potentially facilitating timing and mode of delivery.

FGR is a complex diagnosis 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 decreased cellular growth. Asymmetric FGR is far more common and implicated in 90 % of cases [31]. While FGR may be suspected clinically, sonography may be more accurate in predicting causes of and confirming presence of a compromised fetus [32]. 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.

Abnormal Lie and Malpresentation

Malpresentation can cause birth injury, 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 obstetrician to determine appropriate delivery planning.

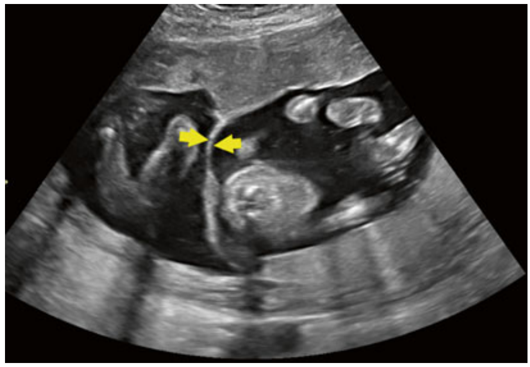

Fig. 20.8 Transverse view of twin pregnancy demonstrates a *triangular peak* of villi extending into the intertwin membrane consistent with "lamba" or "twin peak" sign in a dichorionic diamniotic pregnancy. (Figure courtesy M. Small, Author)

Causes Affecting Both Maternal and Fetal Health

Multiple Gestation Pregnancies

Twin pregnancies carry a higher maternal risk of preterm delivery, post partum hemorrhage, preeclampsia, and eclampsia [33]. Perinatal mortality is also approximately five times higher in twin pregnancies when compared with singletons [34]. 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 identification of potential risk factors during pregnancy. Monochorionic twin pregnancies have roughly 2.5-fold increase in perinatal morbidity and mortality compared with dichorionic twins [35].

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 presence of a "lambda" or "twin peak" sign [36, 37] (Fig. 20.8). Monochorionic twins share placental vessels, which may lead to shunting of blood from one twin to the other. This is often referred to as twin–twin transfusion syndrome (TTS), a complication seen in up to a 30 % of monochorionic gestations and best identified by US. TTS is a leading cause of fetal mortality. Early detection with careful follow-up and potential early delivery could lead to improved outcome [38].

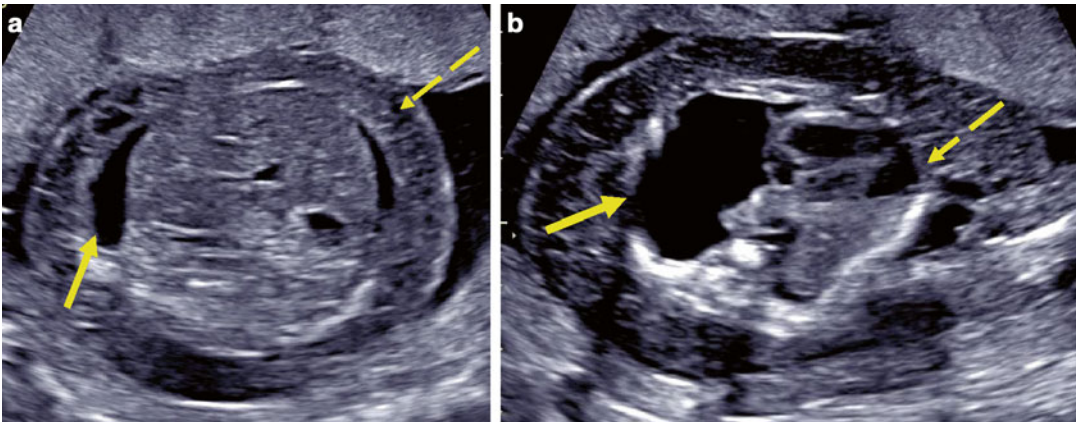

Fig. 20.9 (**a**) Axial view of the fetal abdomen demonstrates fetal ascites (*solid arrow*) and skin thickening (*dashed arrow*). (**b**) Axial imaging of the fetal thorax in the same patient demonstrates a large pleural effusion (*thick arrow*) with associated mass effect on the fetal heart (*dashed arrow*). (Figure courtesy S. Ghate, author)

Hydrops Fetalis

The classic definition of hydrops fetalis is the abnormal presence of fluid in two or more compartments [39]. The most common ultrasound findings include polyhydramnios, fetal pleural effusions, ascites, pericardial effusions, hepatosplenomegaly and skin edema (Fig. 20.9). 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 and follow-up with aggressive medical treatment, as well as close monitoring of the pregnancy and possible early delivery, can 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 [39–41]. 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.

Safety and Efficacy of Obstetric Ultrasound

In general, 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 bioeffects, and were mostly published before 1995 when the intensity of the ultrasound equipment was lower than in modern machines [42]. Nevertheless, the AIUM and other major international organizations consider ultrasound relatively safe during pregnancy.

In an effort to better regulate safety of obstetric ultrasound, the AIUM along with other international societies suggest the following general guidelines for clinical use [43, 44].

- Keep US 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 result in a significant increase in 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 Concerns

Implementation of diagnostic obstetric ultrasound in LICs may face a number of 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 [45]. Prenatal imaging is partially implicated in this phenomenon [46].

Historically Chinese culture encouraged parents to continue having children until a satisfactory number of sons were born. Obviously, this carried some economic costs, 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 [45, 47]. 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 [48, 49].

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 [50, 51]. 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 [52]. 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 [53].

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 necessary 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 health care infrastructure, it may be difficult to identify subpar or illegal practices [54–57].

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 [58]. 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 LIC's.

In the developing world, patient perception of obstetric US may be influenced by education level, local culture, or religion. In a study which took place in Botswana, the act of "looking inside the womb" was perceived by some patients as invasive and inappropriate. 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 health care providers in this same study, the introduction of imaging sometimes replaced history-taking, critical thinking, careful physical exams; all of these skills are essential for health care 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 [59].

Sociopolitical Challenges

In formulating the MDG, increasing the number of skilled birth attendants at delivery was identified by the WHO as a strategy for improving maternal-fetal health outcomes. By itself, this strategy has had mixed results. 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 [60]. 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 skill levels of these "skilled practitioners" [61, 62]. In contrast, one study in rural Bangladesh demonstrated that the MMR significantly decreased in villages where trained midwives participated in home-deliveries [63].

Countries which have implemented 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, have achieved greater success in the reduction of maternal mortality. Both Malaysia and Sri Lanka reduced their MMR substantially over four decades by improving female education, increasing attendance of midwives at delivery, as well as providing access to health care resources in emergent situations [60, 64–70].

The benefits of diagnostic ultrasound in HIC's are well-known; however, its role in the reduction of maternal mortality in low-resource areas is still not supported by an evidence-based analysis. In the paradigm above, perhaps the US may have an important role in obstetric emergencies as an adjunct to skilled prenatal and antenatal care. Additional research is necessary to better define its role in the future.

Conclusion

The state of maternal-fetal health in developing countries remains a challenge. 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 fashion as to stay within regulatory guidelines and should not contribute to technology-based malpractice. Ultimately, effective prenatal imaging requires basic health care and national infrastructure including electrical power, sustainable equipment maintenance, low cost, trained personnel, available skilled birth attendants and referral centers, in order to improve health outcomes in a sustainable manner.

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Trauma Imaging in Global Health Radiology

21

Rodney D. Welling and Matthew P. Lungren

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 towards increased socioeconomic development and urbanization, the worldwide costs of trauma are expected to significantly increase. In 2012, trauma ranks ninth as the leading cause of worldwide morbidity, and results in five million deaths annually, accounting for 15 % of years of life lost (an estimate of the 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].

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Much of the global burden of traumatic 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 LMIC. 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 developing countries [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 LMIC exceed US$65 billion per year; this amount is 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 work-related injuries and physical violence worldwide [7], while other studies state 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, $4 for HIV/AIDS and other sexually

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transmitted diseases, and $0.11 for accidental injuries/trauma (per affected person per event per year) [8].

The disproportionate rise in traumatic injuries and deaths in LMIC is further complicated given the endemic disparity in post-traumatic outcomes between LMIC 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 adult 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 the developing world are X-ray and ultrasound [11]; in fact, these two modalities are alone able to 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 developing countries [15]. In certain trauma populations in the developing world, 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 CT. 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], the 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].

Traumatic Spinal Cord Injury

Like TBI, traumatic spinal cord injury (TSCI) is an increasing health care challenge in the developing world. While difficult to gather exact statistics, the average age of patients with TSCI in the developing world has been reported to be below 30 years old [22], 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 [23]. While falls are reported to be the most common primary cause of traumatic spinal cord injury in developing countries, with incidence ranging from 23 [24] to 37 % [25], many developing countries now report traffic accidents as the most common cause of TSCI [26].

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 developed countries, very few long-term outcome studies exist in developing countries. 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], a much more affluent developing country. 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 the developing world. Many authors have advocated for a more comprehensive spinal injury response system in developing countries, including environment modification, vocational rehabilitation, and caregiver education [28].

Abdominal Injury

In addition to TBI and TSCI, post-traumatic 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 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 the developing world, 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 a developing world setting 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].

As described elsewhere in the text, 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. Ultimately any strategy seeking to incorporate clinical ultrasound in LMIC for trauma evaluation will require an effective clinical education component for effective implementation beyond simply equipment procurement related efforts.

Extremity Injury

In addition to TBI, TSCI, and traumatic abdominal injury, traumatic injury of the extremities is a significant worldwide cause of morbidity. Socioeconomic change within developing countries, 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 [44, 45]. Resources are often in short supply to address such injuries. This has led, as one author described, to the dilemma in developing countries 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 [46, 47].

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 developing world and proves to be a multifactorial problem.

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 the developed world. One study reported that in the presence of an organized trauma team, resuscitation time was reduced by 54 % [48]. 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 [49]. 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 [50]. It has been reported that the establishment of organized trauma teams can be accomplished at very little cost [51].

While organized trauma teams have significantly impacted morbidity and mortality related to trauma in the developed world, such organization is often lacking in the care of trauma patients in LMIC. Preliminary studies evaluating the utility of organizing trauma teams in developing countries have been conducted [52, 53]. 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 % [54]. These and other studies from both developed and developing 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 [55].

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 developing world, 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 the developing world and can be downloaded (no charge) at the following link:http://whqlibdoc.who.int/publications/2004/9241546409.pdf

Conclusion

The worldwide incidence of morbidity and mortality related to trauma is increasing as developing countries continue to undergo an epidemiological transition related to socioeconomic development and urbanization, with trauma expected to become an ever-increasing cause of worldwide disease burden in coming years. It is important to understand the socioeconomic and demographic data as related to trauma in the developing world and to evaluate how the implementation of medical imaging and organized trauma responders can minimize post-traumatic morbidity and mortality in low-income countries.

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Women's Imaging in Global Health Radiology

22

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Introduction

This chapter focuses on preventative health care after a woman's childbearing years, particularly breast and bone health; prenatal and maternal fetal imaging are discussed in a separate chapter.

Rates of breast cancer and osteoporosis are increasing in low- and middle-income countries (LMICs) and have become a major cause of morbidity and mortality for women of all socioeconomic classes and ethnicities [1–3]. Women are a major source of support in multigenerational households that require both elder and child care. At the same time, in countries such as India and China where a single income is often deemed insufficient to provide for a family's modern needs, women are also increasingly accepted as part of the workforce. As a result of working outside the home, there is often a concomitant increase in average education level and decrease in fertility rate [4, 5]. Additionally, dietary changes and sedentary lifestyle have increased obesity rates. Many environmental factors, including those mentioned above (i.e., Westernization of lifestyle), have been implicated in the significant increase in breast cancer and osteoporosis rates that affect many LMICs [6–8].

Preventative care barriers are rampant for women aged 40 and older in LMICs who face increasing responsibilities both at home and in the workplace. Lack of health care education and access to primary care facilities, misconceptions about disease screening, fear and stigma of disease, and financial instability all contribute to poor care for this population worldwide. Studies in high-income countries (HICs) have demonstrated that women of lower socioeconomic status and education levels, increasing age, and lack of insurance are offered screening services less often and additionally are less likely to seek these services for themselves [9, 10]. It is important to consider these factors as part of a larger discussion on breast cancer and osteoporosis. Better access to and appropriate use of radiologic screening for these diseases may significantly improve quality of life and lengthen the lifespan of women worldwide.

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Epidemiology

Breast Cancer

Global health statistics published in 2011 shows that 1.38 million women will be diagnosed with breast cancer worldwide in 2012, accounting for 23 % of new cancer cases and 14 % of cancer deaths (458,400) [11]. Although early reports indicate that breast cancer rates are decreasing in HICs such as the USA, Germany, Sweden, and Australia, there are many LMICs that have seen significant increases in breast cancer incidence, particularly in Asia. Some reports state that in China, for example, there was a 20–30 % increase in cancer rates over the past decade [7, 12–15].

The incidence of breast cancer in LMICs has also recently surpassed that of cervical cancer, which was previously the most common cancer affecting women worldwide. Despite the fact that breast cancer is less common in LMICs compared to HICs, women living in LMICs bear a disproportionate burden of the disease's mortality with up to half of diagnosed cases and over 60 % of the worldwide deaths each year [11]. This statistic, in reality, remains a gross estimate due to the lack of data collection. Breast cancer statistics in India are from registries that only track approximately 3 % of the population. 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 [7].

It has also been suggested that women may be diagnosed younger with more aggressive tumors in LMICs such as India, where it is estimated that the average age at presentation is up to a decade younger than western female counterparts [16]. It is unclear if the younger age is secondary to an average younger population overall or if there are genetic differences among these women. The majority of women in LMICs, up to 75 %, still present with locally advanced breast cancer (LABC) or metastatic disease (stages III and IV), while up to 70 % of cancers in North America are stages 0 or I [17].

The rise of breast cancer incidence in LMICs is not well understood but is likely multifactorial. It has been suggested that "westernization" of lifestyle has had a substantial impact including increased life expectancy, dietary changes, and sedentary lifestyle. Increased control over reproduction has allowed women to delay childbearing with overall decrease in parity and time spent breastfeeding, likely contributing to decreasing maternal mortality but increasing the risk of breast cancer [18]. While these changes may contribute to an increased incidence of postmenopausal breast cancer, they cannot fully explain the premenopausal cancer rates that are also sharply rising. It may be that efforts to improve early detection and increased awareness of the medical community have led to an increased number of correctly identified cases. It has been noted that early-onset, aggressive estrogen-receptor negative cancers may account for many of premenopausal cancers, particularly for women with African heritage, and more research on genetic and biologic influences is needed [7].

Osteoporosis

Osteoporosis is generally defined as a decrease in bone mass with microscopic bone tissue deterioration. This greatly increases the risk of debilitating fractures of the hip, forearm, and vertebral bodies. The World Health Organization (WHO) defined osteoporosis based on measurement of bone mineral density (BMD) as compared to the average bone density of young healthy women (T-score). Osteoporosis is defined as a BMD more than 2.5 standard deviations (SD) below the mean BMD for young women (T-score <2.5). Osteopenia is defined as a BMD between 1.0 and 2.5 standard deviations below the mean [19]. Dual X-ray absorptiometry (DXA) is a widely accepted technique to evaluate BMD. Pharmaceutical research targeted at osteoporosis treatment requires a diagnosis of low BMD, and often uses DXA T-scores to provide thresholds for intervention.

A recent meta-analysis of the literature was performed 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 [20]. Hip fracture rates are often used as a surrogate for osteoporosis rates due to the associated high morbidity and health care costs and the high probability that patients with hip fractures will require medical attention. The majority of countries at highest risk are HICs, and include Denmark, Sweden, Austria, Norway, and Switzerland [20].

The WHO estimates that the remaining 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 increases are likely to occur outside the USA and Europe, particularly in Asia and Latin America [21].

The International Osteoporosis Foundation (IOF) has also published statistics indicating that the increase in osteoporotic fractures over the next 40 years will mainly come from Asia and Latin America. The IOF also warns of the escalating costs of osteoporotic fractures, placing a large financial burden on health care systems and possibly becoming an economic threat. Asian countries will be some of the worst affected due to recent socioeconomic development and a rapidly aging population. 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. It is estimated that one in three Indian women and one in eight Indian men suffer from osteoporosis, making India one of the most affected countries in the world [22].

It is generally accepted that differences in 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 BMD, low calcium intake, reduced sunlight exposure, early menopause, smoking, alcohol consumption, and decreased physical activity [20].

Screening Recommendations

Breast Cancer

Many countries not have published breast cancer screening guidelines. HICs such as the USA are still actively debating breast cancer screening guidelines including patient age for first and last screening exam, how often to screen, and which screening modalities to use (particularly for women deemed to be high risk of cancer or who have dense breasts). This uncertainty regarding best practices has made it difficult for LMIC governments and NGOs to develop breast cancer screening and treatment programs.

The Breast Health Global Initiative (BHGI) was founded in 2002 in an attempt to standardize 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, health care systems, research agendas, and communication strategies [23]. 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.

The BHGI guidelines and recommendations provide key definitions of resource levels with appropriate detection methods, program evaluation goals, and metrics to monitor a breast care program. These guidelines are subdivided based on the level of resources available: basic, limited, enhanced, and maximal, and the first three are discussed in more detail below as they apply to LMICs. Further details can be found through the BHGI library in the 2008 article entitled Consensus on Early Detection (http://portal.bhgi.org/Docs/default.aspx).

Basic resources: According to the BHGI, all breast health programs should be built upon a culturally sensitive public education and awareness platform, preferably supported and endorsed by the local and national government. Public health awareness programs can be an effective means to downstage breast cancer and improve mortality rates. Teaching women the importance of seeking clinical evaluation immediately after detecting a lump or other symptoms associated with breast cancer can facilitate early treatment and effectively downstage disease. This may be particularly effective if the possibility of breast-conservation therapy and improved survival are emphasized [24].

Attempts to improve early detection and decrease mortality through breast self-exam (BSE) have shown a high false-positive biopsy rate without a decrease in mortality [25–28]. The American Cancer Society website states that “women in their 20s should be told about the benefits and limitations of BSE. Women should be aware of how their breasts normally look and feel and report any new breast changes to a health professional… [29].” In a study of over 266,000 women in Shanghai, China, the teaching and practice of BSE did not reduce breast cancer mortality [30]. A study in Russia included over 122,000 women and found no significant difference between BSE intervention and control groups, but was criticized for inconsistencies in methods and reporting [26, 31].

Education of local female health care practitioners on the clinical breast exam (CBE) to recognize both early and late physical exam findings and symptoms of breast cancer and to refer women for further workup and treatment is also important. A program in Malaysia implemented widespread training of health care workers for early breast cancer detection and also made efforts to improve public awareness. In 4 years, the number of late stage breast cancer diagnoses decreased from 60 to 35 % [32]. A randomized trial at the Tata Memorial Hospital in Mumbai, India, has published promising interim results for compliance and downstaging in a study population of over 150,000 women [33]. In the Philippines, however, a randomized trial to introduce CBE was discontinued after the first round of screening due to unacceptably low compliance to follow-up exams which illustrates the importance of community education and emphasis on follow-up exams [34]. Identifying women with palpable lumps or other breast symptoms through CBE may be the only economically feasible breast care program in the poorest of countries [16, 23, 35, 36]. These women can then be referred to the nearest tertiary facility for further diagnostic testing. The burden of travel to a tertiary care center may need to be offset for many women in rural settings, as the cost of travel and lodging, as well as time away from family and jobs, may be difficult, if not impossible, to overcome. Adequate regional facilities for treatment and pathologic diagnosis are required if a breast health program is to be successfully implemented.

The goal for basic breast care programs is to increase the level of breast health awareness regarding outcome improvement with early detection and treatment. This can be assessed by comparing the number of women in the targeted population who have had a recent history and physical versus the number of women who have been evaluated and educated by the organized breast health program [24].

> BHGI basic resources goal: breast health awareness regarding value of early detection in improving breast cancer outcome.

Limited resources: In limited resource areas, public education and awareness should still be considered key factors to breast health programs. Organized campaigns encouraging women at highest risk of breast cancer (ages 50–65, or family history of breast cancer) to undergo a CBE are likely to be beneficial. A diagnostic ultrasound of any palpable abnormality and possibly a mammogram should be offered if local facilities have the resources needed. This should improve the outcomes of women who have clinically apparent and/or symptomatic breast cancer and may eventually downsize tumors that present for evaluation. Screening mammography or ultrasound may be offered to target populations if economically 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 [24].

BHGI limited resources goal: downsize symptomatic disease.

Enhanced resources: In LMICs where there are enhanced resources, screening mammography should be offered to targeted populations. There is also current research focusing on the feasibility of ultrasound-guided breast cancer screening given that ultrasound units are now more portable and affordable than ever. 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. If women between the ages of 40 and 49 are screened, the interval recommendation is every 12–18 months, given evidence that the sojourn time of a cancer (the period when a cancer is detectable by screening but still asymptomatic) is shorter compared to older women [24–28].

BHGI enhanced resources goal: downsize and/or downstage asymptomatic disease in highest yield target groups.

Osteoporosis

Lack of data from LMICs makes osteoporosis statistics unreliable, and testing for BMD using DXA or other more portable methods is scarce. According to the WHO, DXA and other forms of BMD measurement are highly specific but not sensitive, meaning that the risk of fracture with normal bone density is also real. The WHO suggests that patients should be evaluated for absolute fracture risk using internationally applicable clinical risk factors together with BMD measurements rather than BMD alone [19, 21].

In order to facilitate screening, the WHO developed a fracture risk assessment tool (FRAX®) using population-based cohorts on multiple continents. 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 40 FRAX® tools available based on country of patient origin due to a large variation in fracture risk worldwide [20]. The major impediment to screening for osteoporosis is the lack of affordable imaging equipment in most LMICs.

Program Quality Control

Breast Imaging

Program quality assurance is key to long-term sustainability of any population-based radiological screening exam. Both film-screen and digital mammography are technically challenging exams to perform and interpret correctly, and the quality of the images as well as the ability to refer women with abnormal exams for diagnosis and treatment will greatly affect program efficacy.

Several of the larger HICs, including the USA, Canada, and Australia as well as the European Union, have published guidelines for radiographers, radiologists, and physicists in an effort to standardize breast imaging, particularly screening and diagnostic mammography. In the USA, the American College of Radiology (ACR) offers a voluntary accreditation program that has become a national standard. The European Union passed a resolution of parliament calling on all EU states to make breast cancer a health policy priority, and a comprehensive quality assurance manual was subsequently published [37].

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 to determine how different components of a screening program were provided for and assessed. They evaluated equipment quality, image quality, training of technologists, radiologists and breast surgeons, policies for standardized nomenclature and reports, analysis of recall rates and cancer detection rates, impact on the population, and patient satisfaction. To date, external controls on quality assurance, including legislation requiring adherence to quality assurance guidelines, tend to be enacted in countries with national screening programs and these programs are usually more stringent than locally governed projects. The IBSN also determined that it is important to link screening programs to data reporting systems through cancer registries in order to better understand current trends and define program goals [38, 39].

Implementation of quality control programs for breast cancer screening in LMICs is necessary to provide women with a high standard of care. High quality mammography and breast ultrasound is required not only to achieve the goal of reducing breast cancer mortality but also to decrease costs and patient anxiety by decreasing the rate of missed cancers and false positive examinations. Attention to imaging equipment, technologist training, and physician training are all keys to optimizing image quality [37].

Image storage and transfer are also important parts of a screening program and must be carefully planned. This may include file rooms for film-screen images, hospital-based picture archive and communication system (PACS), or cloud PACS with established connections between mammography units if full-field digital mammography (FFDM) is available. Many countries employ centralized double-reading (two mammographers independently interpret images) of mammogram images to increase both sensitivity and specificity, and a well-designed PACS system can facilitate both double-reads of exams and multidisciplinary consultations [37].

In addition to image and program quality standards, screening programs in LMICs also need to consider available facilities and prerequisite training. Mammography equipment is sensitive to power fluctuations, vibration, dust, and extreme temperatures, and equipment calibration must be performed often to maintain image quality. Technologist and radiologist training regarding equipment calibration is key to achieving consistent high-quality images, and there are accreditation programs (i.e., from the ACR or EU) that can serve as models. The RAD-AID Learning Management System (LMS) is one solution to educational requirements for imaging quality and diagnostic skills required for accurate exam interpretations. Although breast ultrasound as a screening tool is still under debate, it may be considered in remote areas given the proven portability and stability of the equipment.

BMD Measurement

Program quality control efforts for DXA screening has been published by the International Society of Clinical Densitometry (ISCD) and the National Institute of Standards and Technology (NIST) through a workshop held in 2006. The publication identified major factors that limit DXA as a useful diagnostic tool, including inaccuracies and imprecision in BMD measurement across manufactures as well as between individual machines from the same manufacturer, 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 [40].

Cost of Screening and Follow-Up Care

Breast Cancer

Cost-effectiveness analyses (CEA) provide useful information that can guide breast cancer control program development and assist in allocation of precious resources, as well as identify efficient modes of delivery for diagnosis and treatment of breast cancer. Most analyses have been performed for HICs, but several estimates for large LMICs or underserved regions 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 to treat 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 $4,986 in Africa, $70,380 in North America, and $3,510 in Asia per DALY [41]. Thus, working to implement a screening program targeting stage I cancers is a reasonable first step for LMIC breast cancer detection programs. When soliciting government support for screening programs, the CERs may be used to demonstrate overall cost savings when disease is identified early. However, more comprehensive research on the lost household resources from late detection of breast cancer is necessary to better quantify the full economic impact 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. Several studies have attempted to estimate the cost of implementing CBE programs in LMICs using economic modeling in hopes of downgrading cancer stage at diagnosis. Studies in Malaysia, India, and Egypt suggest that performing CBE may be an effective way to downstage breast cancers at half the cost of mammography [35, 42, 43]. Tailoring breast cancer screening efforts to available and affordable treatments, as previously mentioned through the BHGI discussion, must be a major consideration when designing a screening program.

Osteoporosis

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 [44]. FRAX® computer modeling programs are available through the IOF Web site free of charge and may assist in building a sustainable screening program (www.osteofound.org).

The WHO risk prediction algorithm can be used to identify individuals with a 3 % or greater risk of osteoporotic fracture to facilitate cost-effective and efficient treatment [45, 46]. 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 [21].

Packaging Health care Interventions

Several studies have advocated packaging multiple screening interventions targeted at a specific population to improve cost-effectiveness, compliance, and acceptance. Breast and cervical cancer screening have been offered through trusted community clinics or via mobile screening camps. Linking breast health education to reproductive health and maternal/child care in order to reach women in the age range for premenopausal breast cancer, and as they approach screening age, has also been suggested. Education can be offered during antenatal and postnatal care encounters as well as during vaccination encounters for children [47–50]. 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. In any screening package, culturally appropriate patient education regarding the targeted diseases should be included.

Referral Patterns and Outcomes

Breast Cancer

After detection of screening abnormalities, it is crucial that women can be referred for further diagnostic testing with possible 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 ranging from breast surgery, radiation therapy, oncology, and palliative care. If basic treatments are not available to women, screening programs, however effective, will not decrease breast cancer mortality [51]. Systematic tracking of referral patterns and outcomes to monitor the success of breast screening programs is critical to evaluate for effects on mortality.

Osteoporosis

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

Breast Cancer

A general lack of awareness and education is perhaps the greatest barrier to breast care in most LMICs, as well as many HICs. 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 [24].

There are numerous other impediments to a successful breast cancer screening and treatment program including individual, interpersonal, organizational, community, societal, and global barriers. Several studies have shown that the best predictor of screening acceptance is socioeconomic status, particularly in HICs [52–54]. In LMICs, cultural taboos are often associated with illness, and women may be marginalized in the community after a diagnosis of cancer. Women often express fear over a possible cancer diagnosis and may decide against screening rather than confront a potentially expensive and painful medical problem. Often the women targeted for screening do not have the power to make their own health care decisions, and it is the male family members or mothers-in-law who must be educated about the need for screening.

NGOs and other volunteer organizations must understand how information is disseminated in a community, as it may be most effective to use skits, songs, community meetings, and health care workers rather than pamphlets and commercials that have been successful in HICs. 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 [24, 52, 53, 55–57].

Patient navigators or trained health care workers, who can assist patients in understanding complex cancer screening services, have been incorporated into a multitude of HIC screening programs. Initiated by Harold Freeman, M.D., for colon cancer screening in New York City, the initial goal was to "assist patients… in navigating and, at times, circumnavigating… the hospital and human services bureaucracies to accomplish the follow-up and diagnosis of an abnormal finding…" [58].

Breast cancer navigation is particularly crucial given the known benefits of early detection and aggressive treatment and given the documented racial and socioeconomic disparities seen in most countries. 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 [59, 60]. Inclusion of patient navigators in LMIC breast cancer screening and treatment programs will likely improve both initial program success and long-term sustainability.

Osteoporosis

According to the IOF and WHO, the main barriers to prevention, diagnosis, and treatment of osteoporosis is 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 known clinical risk factors may facilitate BMD testing for patients at intermediate risk for osteoporotic fracture so that they can be prescribed appropriate therapy if needed [21].

Mobile Imaging

Mobile Breast Imaging

Factors that determine the acceptance of mammography have been studied in many HICs. Keys to acceptance of screening guidelines include older age (women over 50 are more likely to adhere to guidelines), higher education level, family history of breast cancer, adherence to other screening tests (such as cervical cancer screening), and recommendation by primary care physician. Factors that negatively impact screening include recent immigration, poor overall health, transportation barriers, perceived low risk, and previous poor mammogram experience. Cultural differences also affect acceptance of mammography. In general, it is clear that women tend to utilize screening more often when it is convenient; a group of women surveyed in the USA preferred mammography performed in a retail setting rather than a hospital setting due to convenience including easy parking and favorable operating hours [61–67].

Mobile health care 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. Portable ultrasound units are currently being developed to provide fast and accurate assessments in a multitude of settings, from battlefield injuries to prenatal screening. Other published mobile radiology solutions include mobile chest imaging (both radiography and CT) for tuberculosis and lung cancer screening, mobile MRI, and mobile interventional radiology suites [68, 69].

Mobile mammography can significantly increase the percentage of women screened in a community and this has been well documented in HICs such as the USA [70, 71]. It has been suggested that mobile mammography units can increase screening rates among minority and lower socioeconomic populations while providing lower average operational costs by capitalizing on economies of scale through high volumes and batch readings [72, 73]. It has also been shown that self-referring women under the age of 50 were more likely to use mobile mammography units, but that inherent problems associated with patient self-referral must be identified and overcome to provide these women with proper care and follow-up [74]. While it has been suggested that many mobile mammography units are not profitable, the use of mobile technology is on the rise in the USA in both academic and private practices to better serve communities.

Mobile mammography has been attempted in LMICs with varying success, but few accepted guidelines have been published in an effort to improve mobile breast cancer screening programs. Successful programs that include mobile mammography for screening have been implemented in Croatia, Uganda, Egypt, and Brazil [75–78]. 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, and competing government priorities for funding [36, 79].

If mobile mammography is to be attempted, imaging standards comparable to fixed-unit mammography must be maintained. Training of radiology technologists and radiologists to constantly assess and improve image quality must be emphasized. This can be facilitated through courses provided by experienced physicians and technologists from HICs and Internet educational resources. 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, service contracts with vendors are important.

Assessment of patient educational outreach and satisfaction with the screening and follow-up process should also be performed regularly, and phone or written patient surveys are an important source of data for program improvement [80]. This allows program coordinators to better understand barriers to care, and provide targeted, culturally sensitive community-specific interventions.

The addition of breast ultrasound to screening programs has been limited to date because of issues with ultrasound use to determine fetal gender, particularly in South and East Asian countries (India, China, Singapore, Taiwan, Hong Kong, and South Korea) as well as in former Soviet Bloc countries (Armenia, Azerbaijan, Georgia, and Serbia) [81]. India has passed legislation prohibiting the use of all technologies for the purpose of sex selection, restricting the use of ultrasound equipment to licensed and trained physicians [82]. In countries where this is less of an issue, use of portable ultrasound equipment can add value and improve efficacy by performing either targeted ultrasound for palpable masses or whole breast screening ultrasound. 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, and a younger screening population with increased breast density.

Mobile Osteoporosis Screening

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 [83–85]. Published guidelines for a successful 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 [86].

RAD-AID's Experience with Women's Mobile Imaging

The concept of mobile screening is not new to India. Programs spanning primary care (Smile on Wheels, AmeriCares India), geriatric care (HelpAge India), and women's health (ROKO Cancer Campaign) have abounded, drawing international attention and fueling a debate about the effectiveness of mobile health care and screening. Beginning in 2010, RAD-AID and Project HOPE received funding from Philips Healthcare 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, China, Africa, and Haiti. The team identified women's health services, particularly for the poor in semi-urban and rural areas, as a key unmet need in India. The team then decided that local outreach was an important step in battling the cultural and logistical hurdles faced by women.

RAD-AID identified a local partner in the Postgraduate Institute of Medical Education & Research (PGIMER) of Chandigarh and 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*, meaning "ray of hope" in Hindi and Punjabi, is an innovative mobile women's health care outreach program. *Asha Jyoti* is designed to address women's health care needs including screening and follow-up care for cervical cancer, osteoporosis, and breast cancer (Figs. 22.1 and 22.2). This diagonal approach can offer multiple public health interventions to

Fig. 22.1 *Asha Jyoti* van arrived at PGIMER, Chandigarh, in April 2012

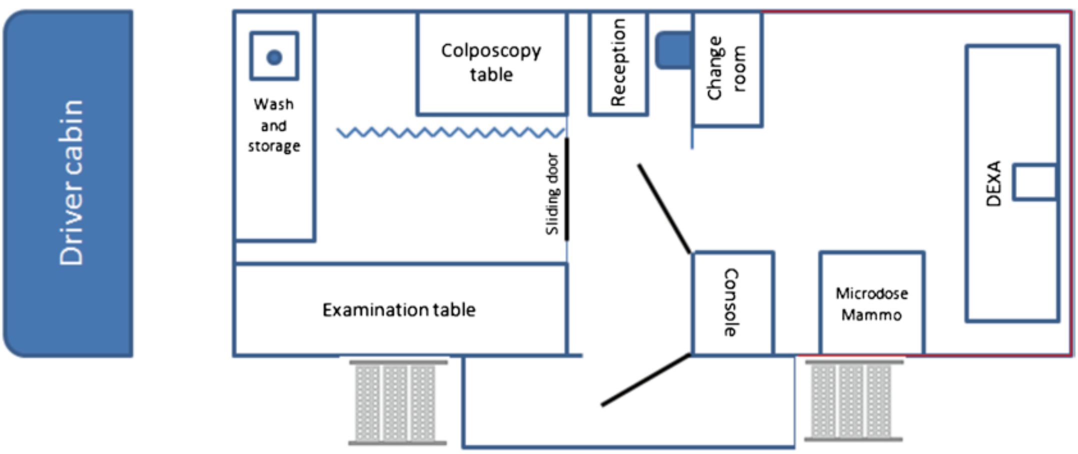

Fig. 22.2 *Asha Jyoti* van schematic

a targeted population in order to improve cost-effectiveness and community uptake and has been employed in other public health efforts targeting women [87].

This mobile health care model relies on three local groups. First is the PGIMER radiologists, technologists, and public health staff who operate the van, implement health awareness training, and survey patients daily for pre- and post-screening experiences. The second group is the multiple subspecialty medical departments at PGIMER that have committed to provide free medical care for women below poverty line (BPL) in accordance with the local government policies. The third group is the local charitable organizations that raise money to fund chemotherapy and medications not covered by the government BPL plan (Figs. 22.3 and 22.4).

Fig. 22.3 Asha Jyoti imaging room

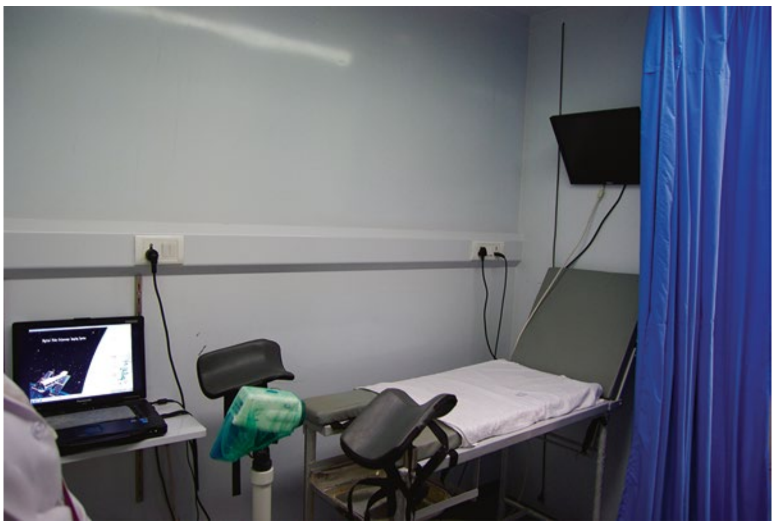

Fig. 22.4 Asha Jyoti colposcopy room

The goals of the *Asha Jyoti* program are to increase women's health awareness, provide a referral system for women into the public hospital system, and diagnose and treat cancers and osteoporosis. Additionally, the program features a breast imaging education exchange between PGIMER and the US clinicians, which encourages collaboration on best practices for imaging and has so far included collaboration between the lead *Asha Jyoti* radiologists and women's imaging radiology attendings, fellows, and residents from the top US hospitals, as well as a technologist educational exchange hosted by PGIMER and taught by the US RAD-AID technologist volunteers [88, 89] (Fig. 22.5).

In April 2012, RAD-AID and PGIMER began a 6-month pilot program to screen women in Chandigarh and its periphery, including slums, resettlement colonies, and surrounding villages. *Asha Jyoti's* goal is to define a model for sustainable integration of mobile health services into a large public hospital system, and the program

Fig. 22.5 Tulika Singh M.D., Asha Jyoti radiologist (*left*), and Anna Starikovsky Nordvig, Co-Director of RAD-AID, India (*right*), at the RAD-AID and PGIMER technologist training workshop in August 2012

received substantial governmental and media support upon the pilot launch. Punjabi, Hindi, and English reports in many Chandigarh newspapers as well as attendance of the inauguration by the Minister for Parliamentary Affairs boosted regional awareness of the program. Media reports emphasized the importance of cancer and osteoporosis detection "before the individual shows any signs or symptoms" [90–94].

Prior to the launch, one anticipated hurdle identified from research on previous mobile programs was the lack of public awareness or trust of a screening initiative. However, perhaps due to the strong local media support, patient turnout was strong and utilization of the van screening services was high during the pilot. Furthermore, regional awareness garnered requests from other rural regions for the screening services, allowing *Asha Jyoti* to test van functionality and outreach efforts in remote rural locations 300–400 km outside of the city. The pilot was created to carefully assess the program's potential in Chandigarh and rural areas, and based on the initial effectiveness, the program plans to extend to many rural areas of Punjab [95].

Although *Asha Jyoti* is a local program focusing on locally sustainable growth, lessons from the program launch could impact other mobile screening programs in India and worldwide. In September 2012, the Clinton Global Initiative (CGI) featured *Asha Jyoti* in the "Champions of Action" plenary session at the CGI 2012 Annual Meeting in New York [96–98].

Outcomes of the *Asha Jyoti* screening and public awareness are tracked by PGIMER's Department of Radiodiagnosis and the School of Public Health, respectively, and RAD-AID and PGIMER will meet biannually to assess program results, plan for future growth and improvements, and report translatable findings to the international global health community. Already in 2012, initial lessons from the *Asha Jyoti* pilot were presented by PGIMER and RAD-AID at the RAD-AID International Conference on International Radiology for Developing Countries, the largest conference on radiology global health in the USA, attended by over 150 radiologists, technologists, nurses, and public health experts and students. In the year following the pilot, *Asha Jyoti* hopes to expand screening to over 2,000 women, implement a wireless cloud PACS, and develop a "hub and spoke" model for expanding services into regional communities.

Conclusion

Efforts to provide radiological screening services to women in LMICs must be thoughtfully planned and organized to ensure that necessary infrastructure for screening, diagnosis, and treatment is available to the targeted population. The BHGI screening recommendations based on resource levels is a powerful tool for NGOs and governments interested in improving women's health care in LMICs. Community sensitization, patient education, program data collection, analysis of results, and adequate funding are key components for success. Long-term sustainability of screening programs may be achieved through NGO–government–private partnerships using mobile screening packages, thus allowing the most efficient use of scarce medical resources. RAD-AID implemented many of these key concepts during the development of the *Asha Jyoti* Women's Mobile Health Care Program, which may become a template for mobile radiological screening interventions throughout India and in other LMICs.

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