Cari Borrás *Editor*

# Defining the Medical Imaging Requirements for a Rural Health Center

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Cari Borrás
HTTG
Washington, DC
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# Foreword

The Health Technology Task Group (HTTG) was first proposed by the writer at the World Congress of Medical Physics and Biomedical Engineering at Seoul, Korea, in 2006. The idea was accepted by the International Union for Physical and Engineering Sciences in Medicine (IUPESM) with the election of myself as chair and Joachim Nagel as co-chair. In 2010, Joachim Nagel became chair and Cari Borrás, co-chair. Cari Borrás served as chair from 2012 to 2015, and it was under her chairmanship that this book was produced.

The HTTG is intended "to assist countries in defining their health technology needs, and identifying and rectifying health system constraints for adequate management and utilization of health technology, particularly through training, capacity building and the development and application of appropriate technology." One of the HTTG activities is the organization of workshops, and another is to publish the proceedings of these workshops. The workshop on palliative radiotherapy for developing countries was the first such venture.[1]

This current publication is based on the topics and recommendations of the Second Medical Physics HTTG Workshop, which addressed the medical imaging requirements for a health center. A group of experts in medical physics, consisting of physicists and physicians from many countries around the world, held scientific meetings during the 18th International Conference on Medical Physics: Science and Technology for Health for All, in Porto Alegre, Brazil, April 17–20, 2011. The conference was sponsored by the International Organization for Medical Physics (IOMP), the Latin American Association of Medical Physics (ALFIM), and the Brazilian Association of Medical Physics (ABFM). The program and the presentations made at that the workshop, as well as those for all HTTG Workshops from 2008 until 2015, can be found in the IUPESM Web site.[2]

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[1] Workshop on Palliative Radiotherapy for Developing Countries, Ho Chi Min City, Vietnam, 2008. Ed: Allen BJ, Rahman O. Vivid Publishing, Fremantle, Australia 2010.

[2] http://www.iupesm.org/health-technology-tas-group-httg/.

The idea of this book arose from the recommendations drawn at the Porto Alegre Workshop. It seemed that it was worthwhile expanding on the conclusions in a didactic manner. Cari Borrás, as editor, considered that the publication should emphasize rural health centers within resource-limited areas of developing countries. To ensure that the subjects are covered from that point of view, the authors were selected either from developing countries or from those having had extensive experience working in them.

This book differs from the usual approach, whereby most books on the subject start by explaining medical imaging modalities and then list what they are good for. Instead, this book starts by describing the health situations that present most often in a rural health center and then suggests how some imaging modalities, such as X-rays and ultrasound, can support the clinical diagnoses. With such limited resources, how can the center function well, what does the staff need to know, and who can be consulted? The role of telemedicine is expected to be of major importance in the integration of the rural service with the major hospital system, bringing specialist expertise to the smallest medical centers. These substantial challenges need careful planning if the centers are to achieve their objectives.

This book describes the crude reality of rural medical services in the emerging world. Even the clinical images shown in Chap. 2 come from medical facilities in remote areas. By sharing their experiences, the authors have imparted their knowledge and commitment to meeting the challenges facing rural medical centers. These challenges need to be addressed by thoughtful planning, careful equipment and imaging protocol selection, continuous staff training, and the implementation of quality control programs. This publication attempts to cover these issues; I commend it to the rural health centers of the world.

Prof. Barry J. Allen, Ph.D., D.Sc., AO
Past-President IOMP, IUPESM

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## About the Editor

**Cari (Caridad) Borrás**, **D.Sc., DABR, DABMP, FACR, FAAPM, FIOMP** a native of Spain went, as a Fulbright scholar, to the USA, where she worked as a radiological physicist in Philadelphia, San Francisco, and Washington, DC. There, she managed for 15 years the radiological health program of the Pan American Health Organization/World Health Organization and then, for two years, went to Recife, Brazil, as a visiting professor of the Federal University of Pernambuco. She chaired for nine years the Science Committee of the International Organization for Medical Physics and, for six, co-chaired/chaired the Health Technology Task Group of the International Union of Physical and Engineering Sciences in Medicine (IUPESM). For her scientific, educational, and professional contributions to medical physics, she has been given awards by the IUPESM, the Spanish (Sociedad Española de Física Médica), American (American Association of Physicists in Medicine), Latin American (Asociación Latino-Americana de Física Médica) and international (International Organization for Medical Physics [IOMP]) medical physics societies, by the American Board of Radiology and by the American College of Clinical Engineering. In 2013 the IOMP also included her among the 50 outstanding medical physicists over the last 50 years.

## Contributors

**Barry J. Allen, Ph.D., D.Sc., OA** is an internationally recognized expert on targeted alpha therapy (TAT) for cancer. He developed new targeting agents for the treatment of melanoma and prostate and other cancers, leading to world first trials of intralesional and systemic targeted alpha therapy for metastatic melanoma. Earlier major contributions were to neutron capture therapy (NCT) and in vivo body composition (IVBC). He initiated the Health Technology Task Group (HTTG) for developing countries. Professor Allen is a past president of the International Union of Physical and Engineering Sciences in Medicine (IUPESM), the International Organization for Medical Physics (IOMP), the Asia-Oceania Federation of Organizations for Medical Physics (AFOMP), and the Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM). His contributions were recognized when he was included in the 50 outstanding medical physicists at the 50th Anniversary Conference on Medical Physics in 2013 and his appointment as an officer in the Order of Australia in 2015.

**Patrick Cadman, M.Sc.** obtained his degree in medical radiation physics at McGill University. He worked for many years at the Department of Medical Physics, Saskatoon Cancer Centre, Saskatoon, Saskatchewan, Canada, from where he recently retired. One of his research interests explored the possibility of Cobalt-60 tomotherapy. He is a fellow of the Canadian Association of Medical Physics and of the Canadian College of Medical Physicists.

**Trevor D. Cradduck, Ph.D.** earned a Ph.D. at the University of Saskatchewan in medical physics. He spent many years at the Victoria Hospital in London, Ontario, and finished up there as professor and chairman of the University of Western Ontario's Division of Nuclear Medicine. In 1995, he was asked to manage the implementation of a metropolitan area network known as LARG*net, and in 1997, he moved on to ONet which, at that time, provided the Internet services to all the universities and colleges in Ontario. In 1999, he was invited to become the Director of Telehealth in Alberta where he remained for three years before retiring. The Canadian Society of Nuclear Medicine honored Dr. Cradduck with its 2014 CANM Emeritus Award, in recognition of the contributions made to the nuclear medicine community.

**William Hendee, Ph.D.** is a distinguished professor emeritus of biophysics, bioethics, radiology, and radiation oncology at the Medical College of Wisconsin. He is also a professor emeritus of radiology at the University of Colorado. Before his retirement in 2014, Prof. Hendee was editor of Medical Physics, the most widely distributed and read journal in medical physics and engineering in the world. He has written or edited 24 books in medical physics and is the author or co-author of over 450 scientific publications. Dr. Hendee has received gold medals from the Roentgen Ray Society, Radiological Society of North America, American College of Radiology, and the American Association of Physicists in Medicine.

**Kwan Hoong Ng, Ph.D., DABMP, MIPEM, CSc, FInstP, FIOMP, AMM, FASc** is a professor at the Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia. He has pioneered various innovative learning approaches in medical physics and actively promoted medical physics education, research, and professional practice. He has been honored as one of 50 outstanding medical physicists in the world by the IOMP. He is the founder and president emeritus of the South East Asian Federation of Organizations for Medical Physics and was a member of the HTTG.

**Marlen Perez-Diaz, Ph.D.** obtained a B.Sc. in nuclear physics and an M.Sc. degree in medical physics at the Institute for Nuclear Sciences and Technology in Havana, Cuba, and a Ph.D. in physics at Havana University. She is currently a professor for biomedical engineering at the Central University of Las Villas, Cuba, where she teaches undergraduate, master, and Ph.D. students and works in medical physics and image processing at the Study Center for Electronic and Information Technologies. She is a member of the Third World Organization for Women in Science (TWOWS), the American Association of Physicists in Medicine (AAPM), the Cuban Physics Society, and the Cuban Biomedical Engineering Society and is a regular associate of the International Center for Theoretical Physics in Trieste (ICTP). She is also a member of the scientific committee of the Cuban Bio-engineering and the Medical Physics Journal and was a member of the HTTG. Dr. Perez has received Cuban awards for her scientific contributions.

**K. Siddique-e Rabbani**, **B.Sc. Honours (Physics), M.Sc. (Physics), Ph.D. (Microelectronics)** joined the physics department at the University of Dhaka, Bangladesh, in 1978, where in 1988 he became a Full Professor. In 2008, he started the new department of 'Biomedical Physics & Technology' as its first Chairperson. Upon his retirement in 2016, he was appointed Honorary Professor. During his tenure, he organized a large group of young researchers contributing to indigenous development of essential healthcare technology for affordable and sustained service to the people in low-resource countries. He is a project director of the Dhaka University Telemedicine Programme, president of the Relevant Science & Technology Society of Bangladesh, Director of the International Center for Technology Equalisation—a center seeking global empowerment of technology and president of BiBEAT Ltd.—a non-shareholding company to manufacture and distribute medical equipment based on home-grown technology. He was a member of the HTTG.

**José Luis Rodríguez Monteagudo, MD** is a Cuban imaging specialist. He obtained his MD from the Medical University of Villa Clara, Dr. Serafin Ruiz de Zarate Ruiz, Cuba, and performed his radiology residence at the University Hospital Arnaldo Milian, Santa Clara, Villa Clara, Cuba, where he eventually became the head of the Imaging Services. After working for two years as a radiologist at the Polokwane Provincial Hospital in the northern province of the Republic of South Africa, attached to the University of Medunsa, he returned to Santa Clara, Cuba, to be the head of the Imaging Services. He taught undergraduate and graduate medical students at the Medical University of Villa Clara and has served as chief of the Provincial Imaging Group and president of the Imaging Villa Clara Chapter of the Cuban Society of Imaging. In February 2016, he began working as a specialist in radiology at the Cira Garcia Central Clinic and teaching medical students in the Faculty of Medicine, Dr. Finlay-Albarran, in Havana, Cuba.

**Hon. Prof. Slavik Tabakov**, **Ph.D., Dr. h.c., CSci, FIPEM, FHEA, FIOMP** was born and graduated in Bulgaria (M.Sc., Ph.D.). He worked at Plovdiv Medical University and later at King's College London, UK. He is currently president of

IOMP and is mainly known for pioneering of e-learning in medical physics and for leading the project EMITEL, which developed the first e-Encyclopaedia of Medical Physics and Multilingual Dictionary of Medical Physics (in 29 languages)—www.emitel2.eu. His current academic positions are as follows: director of M.Sc. of clinical sciences and of M.Sc. of medical engineering and physics, King's College London; co-director of International College on Medical Physics, ICTP, Trieste, Italy; consultant at King's College Hospital, Department of Medical Engineering and Physics, London; and co-editor in chief of the IOMP Journal Medical Physics International.

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**Jeannie Hsiu Ding Wong, Ph.D.** is a senior lecturer at the Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia. She has obtained her Ph.D. from the University of Wollongong, Australia, working on novel semiconductor radiation dosimeters. Her areas of interest are in medical radiation physics and radiation dosimetry.

# Introduction

This publication is based on the topics and recommendations of the Second Medical Physics HTTG Workshop "Defining the Medical Imaging Requirements for a Health Center," held in Porto Alegre, Brazil, in April 2011 during the 18th International Conference on Medical Physics: Science and Technology for Health for All. (The slide presentations made at the workshop can be downloaded from http://www.iupesm.org/health-technology-tas-group-httg/2nd-ws-presentation-slides/.) Although the technical aspects of the issues addressed there have been updated, the structure of the workshop has been maintained. The publication is structured in four parts: I. Medical and Public Health Needs of a Rural Health Center, II. Medical Imaging Modalities, III. Planning a Medical Imaging Service, and IV. Operational Considerations, and a set of Recommendations. The latest revision was done at the beginning of 2016.

Rural health centers are established to prevent patients from being forced to travel to distant urban medical facilities. The objective of this publication is to establish the criteria for the type of medical imaging services that should be made available to these centers, which are limited in technical and human resources. The emphasis is placed on rural health centers in resource-limited settings such as those encountered in developing countries.

The pathologies and/or health conditions that can be treated at such rural health centers are trauma, chest diseases (viral and bacterial infections such as tuberculosis), acute abdominal pain, diarrhea, kidney stones, gynecological problems, and also pregnancy. Medical imaging support can be provided by an all-purpose general ultrasound unit and a basic X-ray system, preferably using computed radiography (CR) or digital imaging (DR) with a simple interface to a computer. The technical specifications for these units given the reduced technical and financial resources available are described.

Other aspects considered are procurement issues of both ultrasound and X-ray units, building requirements, basic technical staff training elements, effective ways to develop and carry out quality control and maintenance programs, as well as international guidance on radiation protection and safety standards.

Since many of the professionals needed to carry out some of these procedures cannot be permanent employees of the rural health center, the required expertise has to be attained through telephone and internet consultations. How to compact/transmit digital images based on a telemedicine network or the possible options when this type of network is not present are discussed. The frequency of actual visits by various professionals, especially medical physicists and service engineers, is suggested.

To manage patients properly, the rural health center should be part of a regional and more complete system of healthcare installations in the country through a referral and counter-referral program, and thus, they should have the infrastructure for transporting patients to urban hospitals when they need more complex health care.

The coordination of all the activities is only possible if the rural health center has a strong and dedicated manager. This publication aims to provide this profession with information that will make her/his job effective and efficient. It will also be a resource for the physicians, medical physicists, and service engineers who provide virtual and physical consultations. It may also provide some insights to governmental, non-governmental, and religious organizations involved in the planning, establishment, and operation of medical facilities in rural areas.

# Part I

# Medical and Public Health Needs of a Rural Health Center

# Chapter 1
# Characteristics of a Rural Health Center

**Marlen Perez-Diaz, Consuelo Varela Corona and Cari Borrás**

**Abstract** “Rural health center” encompasses a variety of analogous terms that describe an establishment of ambulatory primary health care attention, placed in a rural location and generally distant from urban areas. Depending on the place and the complexity of the services offered, the staff may be comprised essentially of a medical doctor, a nurse, and a technician. This chapter addresses the health challenges faced by such facilities and emphasizes that rural health centers should define what pathologies and health conditions they can manage and which ones should be referred to a district or general hospital. It also introduces the view that medical imaging may be useful to corroborate clinical findings.

**Keywords** Rural health center · Rural health station · Rural health post · Rural health unit

In this publication, a rural health center is defined as an establishment of ambulatory primary health care attention, placed in a rural location and generally distant from urban areas. The characteristics of rural health care facilities are conditioned by many factors such as topography, demographics, economical resources, and cultural aspects, which are specific to each country. Even the name used in this publication, “rural health center” is not universal. For example, the World Health Organization designates the facility as “rural health post”; in Australia, it is called “rural health station”; in the

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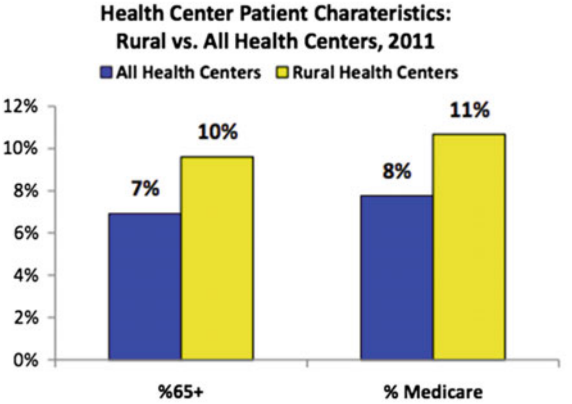
Philippines, "rural health unit." Some of the regions where these health facilities are located have a low density and dispersed population such as those in Kenya. Others are densely populated such as those in Bangladesh. The number of inhabitants that a rural health center can cover depends on the country or the region. Within each health service system, the criteria for the geographical placement of rural health centers should be determined by the government in accordance with its definitions of levels of care and taking into account accessibility issues. Often, rural health centers are established by religious or philanthropic non-governmental organizations (NGOs), eager to overcome health care accessibility issues of the local population. Ideally, within each health services system, the criteria for the geographical placement of rural health centers should be determined by the government in accordance with its definitions of levels of care and taking into account the existence of these NGO's facilities, which should be incorporated in the overall health care plan and provided support as needed.

In the United States, "Community, Migrant, Homeless, and Public Housing Health Centers" make up one of the largest systems of care for rural America, and are frequently the only source of primary and preventive services in their communities. Also known as Federally-Qualified Health Centers (FQHCs), about half (49 %) of the health centers are located in rural and frontier areas. These centers currently serve 1 in 7 of all U.S. rural residents. These centers serve patients regardless of insurance status or ability to pay and are usually located in high-need areas identified by the federal government as having elevated poverty, higher than average infant mortality, and where few physicians practice. Rural health center patients have low incomes (less than 200 % of the Federal Poverty Level), while two-thirds are uninsured or insured through a governmental program called Medicaid. Compared to all health center patients, patients of rural health centers are more likely to be over the age of 65 (Fig. 1.1), and thus, be more likely to be Medicare beneficiaries compared with all health center patients. Rural health center patients are also sicker than the general rural population. They are more than twice as likely to report being in fair or poor health and almost twice as likely to report limitations related to activity [1].

Unfortunately, comparable data for other parts of the world have not been found, but from anecdotal evidence, mainly gathered in Latin American and Caribbean countries, it seems the health situation in rural versus urban health centers is not too dissimilar. An exception is Cuba where an aggressive integral program that combines health services with educational, cultural, and agricultural activities in rural communities has not only diminished their difference with urban centers, but has yielded excellent health outcomes. A contributing factor to the results may have been the combination of western and traditional medicine [2].

Basically, a rural health center aims to preventing and protecting the health of people as well as solving the health problems they may present. The frequency of the health problems or situations that require attention varies with the sex, age, socioeconomic status, place, time, etc., of the population group in which they occur and the physical and social environment in which the group lives. For example, diarrheal diseases, gastroenteritis, and acute respiratory infections are more frequent in developing countries and especially in rural areas and the peripheral areas

**Fig. 1.1** Health Center Patient Characteristics [1]



Source: Bureau of Primary Health Care, HHS, DHHS, Uniform Data System, 2011.

surrounding large urban centers. These health problems can be treated through relatively simple means. However, in these communities there are also pathologies such as brain tumors and cardiovascular conditions that require more complex forms of treatment. In addition, accidents, violence, and injuries are significant causes of morbidity and have begun to displace other pathologies in the general epidemiological profile of these population groups as their living conditions and possibilities for survival improve [3]. Thus, it is critical that rural health centers define what pathologies and health conditions they can manage and which ones should be referred to a district or general hospital. Chapter 2 addresses these clinical issues and indicates whether medical imaging such as ultrasound or X-ray services can provide diagnostic support to the medical findings.

The decision on what services a rural health center is to offer depends not only on the clinical needs of the community but also on the human and technical resources available.

Depending on the place and complexity of the services offered, staff may be comprised essentially of a medical doctor, a nurse, and a technician. Some centers, for example in Cuba, include a pharmacy. And in the United States, emphasis is placed on physician assistants and nurse practitioners as health care providers for rural facilities, since recruitment of physicians—even less with any specialty—and registered nurses is very difficult.

WHO recognized that the success or failure in attracting health staff to rural facilities or retaining them in rural posts depends on health workers' preferences and choices and examined the extent to which health workers differ in their willingness to work in rural areas and the reasons for these differences, based on the data collected in Rwanda analyzed individually and in combination with data from Ethiopia [4]. It seems that non-wage job attributes, such as training opportunities, career development prospects, and living and working conditions, play a role in what health workers choose. Emerging survey evidence suggests that health workers with a rural background are more willing to work in rural posts and are more responsive to incentives to work in rural areas. Their religious faith affiliations also play an important part in their commitment. Countries as diverse as Australia, the United States, Indonesia, and Thailand have developed recruitment programs that target health workers who have particular reasons for being committed to rural service. This does not mean that wages or financial compensation are not important. The US Institute of Medicine (IOM) outlined key strategies and findings relating to rural health care workforce, in their report Quality Through Collaboration: The Future of Rural Health [5]. The report offers "a five-pronged strategy to address the quality challenges in rural communities:

1. adopting an integrated approach to addressing both personal and population health needs;
2. establishing a stronger health care quality improvement support structure to assist rural health systems and professionals;
3. enhancing the human resource capacity of health care professionals in rural communities, and the preparedness of rural residents to actively engage in improving their health and health care;
4. assuring that rural health care systems are financially stable; and;
5. investing in an information and communications technology (ICT) infrastructure, which has enormous potential to enhance health and health care over the coming decade."

Health care workers delivering services in rural health centers should realize that these type of facilities can play a very important role in promoting the integral development of the community, especially when they are located in poorly developed areas due to either socio-economical or cultural conditions or to their isolated characteristics.

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# Chapter 2
# Medical Imaging Needs in a Rural Health Center from a Clinical Point of View

**José Luis Rodríguez Monteagudo**

**Abstract** In a rural health center, certain health conditions may benefit from simple imaging technologies such as conventional radiography and ultrasound. Radiological and ultrasound findings can help diagnosing: Chest illnesses (e.g., viral and bacterial infections such as tuberculosis), trauma, degenerative diseases of the musculoskeletal system, acute abdominal pain, diarrhea, blunt abdominal trauma, kidney stones, pregnancy, and gynecological problems. Specific protocols should not be rigid and they should always be a complement of the clinical examination and other tests, such as laboratory exams, if available. Even though a radiologist may not be present, a general practitioner should be available in case a health problem arises during the examination. These practitioners, as well as imaging technologists and/or nurses working in the center, should have minimal medical and technical knowledge of conventional X-ray imaging and basic ultrasound, to decide whether the patient can be managed locally or referred to a higher health care level.

**Keywords** Infections · Trauma · Chronic diseases · Pregnancy · Rural health center

## 2.1 Introduction

Health systems are structured by health care levels according to the complexity of the health problems faced in each one of them. Those situations that affect health in a community determine the demand for services and their relative frequency, and they affect the growing complexity of the resources that need to be mobilized in the health care process. It is thus possible to relate the concept of levels of care to the

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geographic location of health care establishments or units, in order to systematize the supply of services according to the size, characteristics, and needs (or demands) of different population groups [1].

The general practitioner working in rural primary health care should contemplate the use of images in medical diagnosis as a support to clinical findings. Three basic requirements may be considered, i.e.

- Availability of technology
- Risk-benefit
- Cost-benefit.

These considerations will result in the rational use of technology including the use of adequate examination protocols. Imaging studies are a complement of clinical reasoning, which in turn is derived from the slow and painstaking observation of the patient.

The general practitioner working in a rural health area should have at least minimal medical knowledge of conventional X-ray imaging and basic ultrasound. Training may be obtained through graduate or postgraduate courses. Similarly, imaging technologists and/or nurses, who work in the same health care level, should receive training regarding the right acquisition and protocol management of the images. Training issues for the technical staff are addressed in Chap. 6. Even though a radiologist may not be present, a general practitioner should be available should a health problem arise during the examination.

In this regard, a mobile phone may facilitate an easy exchange of information among the medical staff. This is another way of implementing telemedicine. Consultations may be required especially in cases of dubious diagnoses. The possibility of photographing images of enough quality to provide diagnostic information should be assessed. Telecommunication issues are addressed in Chap. 7 . We intend in this chapter to develop a group of health conditions that may benefit from imaging using simple technology—conventional radiography and ultrasound—which can be available to general practitioners working in rural areas. Specific protocols should not be rigid and they should always be a complement of the clinical examination and other tests, such as laboratory exams, if available.

Imaging is not only useful for diagnosis, but also for patient follow up. Figure 2.1 shows that relationship.

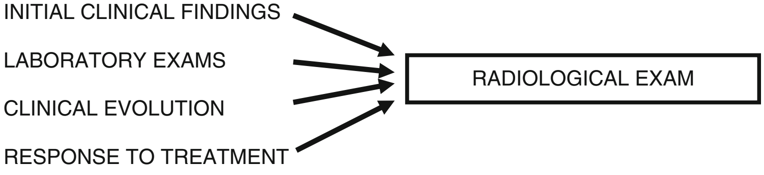

**Fig. 2.1** Relationship between radiological exam and another's clinical points

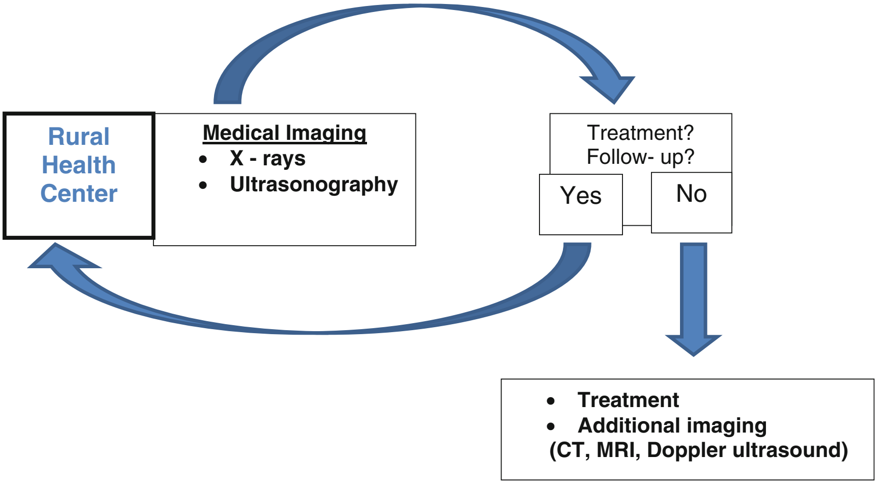

**Fig. 2.2** Flow diagram of patient management

Depending on the radiological findings, patients may be treated at the rural health center or derived to a secondary or tertiary health care level. Figure 2.2 shows a flow diagram of patient management.

The health conditions that may require imaging in a rural health center are

1. Chest diseases: viral and bacterial infections such as tuberculosis
2. Trauma
3. Degenerative diseases of the musculoskeletal system
4. Acute abdominal pain, diarrhea, blunt abdominal trauma
5. Kidney stones
6. Pregnancy
7. Gynecological problems.

## 2.2 Chest Diseases

Chest X-rays may be indicated in patients with respiratory problems such as colds, shortness of breath, cough, and associated fever especially during cold and/or humid months. Often the anxiety generated in patients with these symptoms results in excessive chest radiographs without clinical examinations.

### 2.2.1 Viral Lower Respiratory Infections (Common Cold)

When the viral infections, such as influenza and parainfluenza, after several days of fever, do not wear off with medication and, on auscultation, there are crackles or rales, there may be suspicion of viral/bacterial pneumonia or bronchopneumonia as a potential complication of the original infection. This is a frequent indication for a posteroanterior radiograph of the chest. Lateral projections are usually not necessary.

Radiological Findings:

The spectrum of images in viral respiratory infections varies with age. We can find [2]

1. An increase of the pulmonary radiotransparency (hypertransparency) as in cases of bronchiolitis in children.
2. Enlargement of the basal hilum pulmonary branches caused by peribronchovascular inflammation (commonly found in children and adults).

Cases in which the viral symptoms get complicated, lobar, or segmental radio-opacities of the lung may appear with the bronchogram sign typical of pneumonia (see Fig. 2.3). In pediatric cases, we may find opacity in masses, due to atelectasis produced by mucous plugs that lead to bronchial obstruction without the bronchogram sign. These cases can be treated in primary health care, without having to go to a higher level, by means of antibiotic therapy on an outpatient basis. It is important to monitor the patient's clinical evolution and response to treatment and to remember that the initial radiological findings disappear weeks after clinical improvement [2].

It is always important to follow-up previously diagnosed chronic lung diseases.

### 2.2.2 Bronchiectasis

Congenital or acquired bronchial dilatations are common reasons for recurrent respiratory infections. If there is any suspicion of a bronchiectasis re-infection, as is the case of Cartagener and Monier Kuhn Syndromes; one can perform a chest radiograph (posteroanterior projection) and treat the infection locally without sending the patient to another health care level [3].

Radiological Findings:

1. Normal radiography (the study is negative despite the existence of bronchiectasis without infection).
2. Depending on the shape, number, and location of bronchiectasis, we may find an opaque image, extending from the mediastinum to the diaphragm, with radiotransparent images inside (infected bronchiectasis).
3. Radiotransparent images with the shape of pigeon nests, preferably located in the lung apices; some of these images have fluid levels inside.

**Fig. 2.3** Pneumonia of the right middle pulmonary lobe as a complication of a lower respiratory tract viral infection

### *2.2.3 Pulmonary Emphysema (Bullous)*

Sometimes, in our consultations we have elderly or senior patients with an inveterate habit of smoking, who complain of respiratory distress. During auscultation, we detect hoarse and sibilant rales. The radiograph of the chest (posteroanterior projection) can be useful to determine if this patient has a respiratory failure that can lead to a cardiovascular complication (see Fig. 2.4).

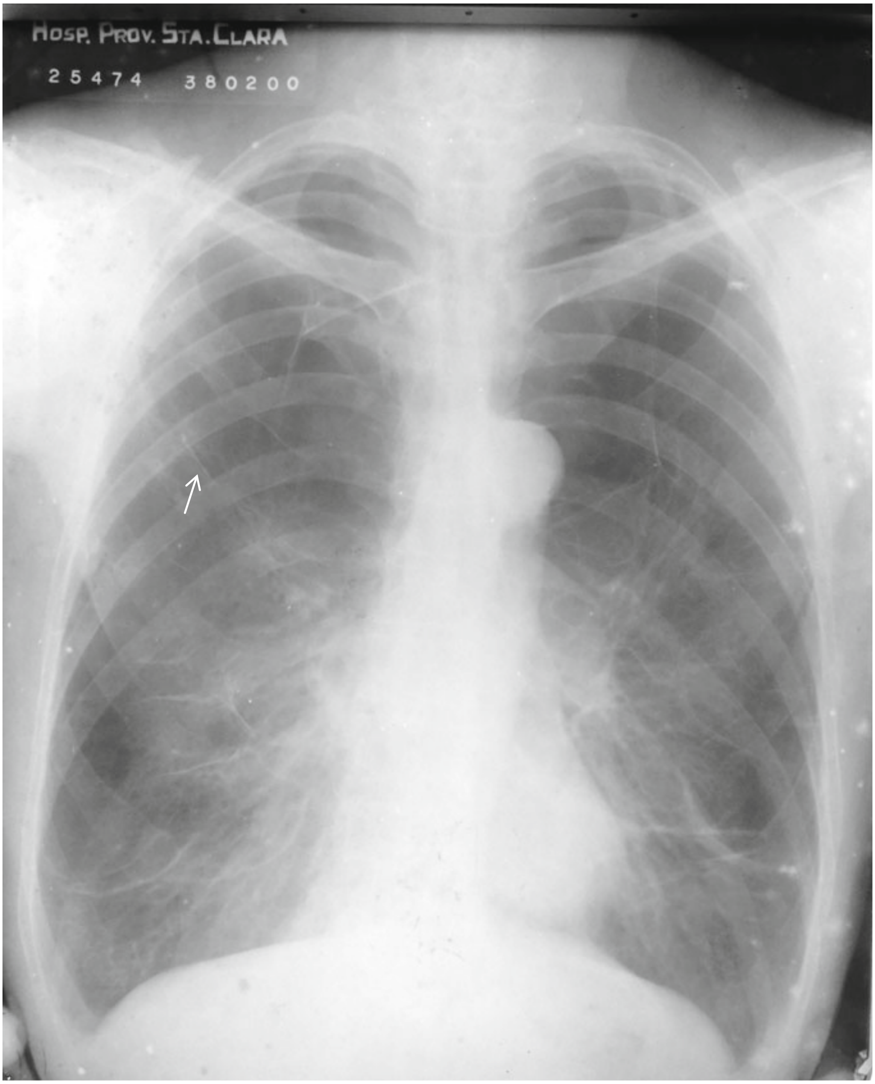

**Fig. 2.4** Bullous pulmonary emphysema in both upper lobes. Focal hyper transparency, with thin and incomplete walls as seen in the bullae (*white arrow*)

Radiological Findings:

Increased of the localized pulmonary hypertransparency, with a thin and discontinuous wall without pulmonary reticulum (emphysematous bullae), with or without indirect signs that depend on the extent of the emphysema and are independent of the patient biotype [3].

(a) Horizontality of the costal arches.
(b) Widening of intercostal spaces.

(c) Descent of hemidiaphragms.
(d) A heart with the shape of a drop.

### 2.2.4 Pneumothorax

A patient with sudden chest pain and shortness of breath can go to a health center for help, and after physical examination is performed, we may suspect the diagnosis of air within the pleural cavity; which can be confirmed by a chest radiograph (posteroanterior projection) (see Fig. 2.5).

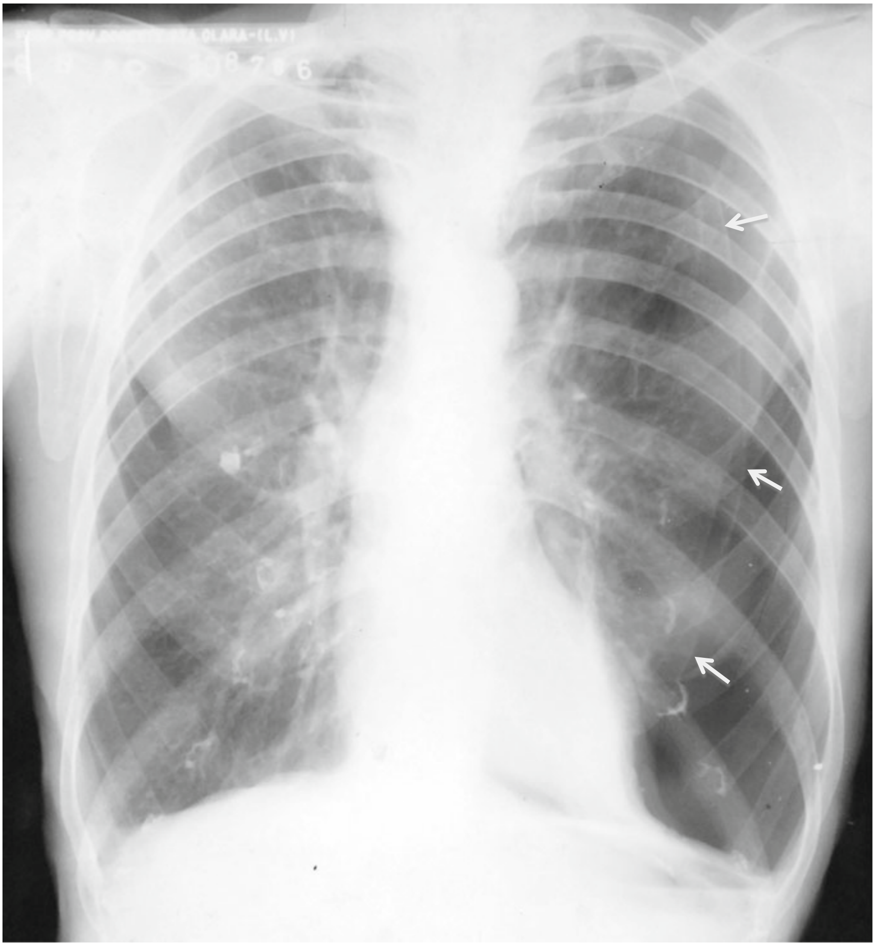

**Fig. 2.5** Right pneumothorax of 25 % presence of air within the left pleural cavity, without pulmonary reticulum and pleural line (*white arrows*)

Radiological findings:

1. Hypertransparency with absent peripheral lung markings.
2. Fine white line of the visceral pleura.

If the pneumothorax is large and there is a mediastinal shift away from the side of the injury, it is considered to be under tension. If left undetected, this can be rapidly fatal.

The association of blood with pneumothorax after any chest trauma, the finding of hypertransparent images mentioned before, is associated with blood collection inferiorly in the pleural spaces of the lung to form a subpulmonary opaque image. Whenever this condition occurs, the patient must be sent to a second level of health care.

### *2.2.5 Tuberculosis (TB)*

When an outbreak of respiratory signs and symptoms suspicious of tuberculosis reactivation occurs, the chest radiograph (postero-anterior projection) is useful to identify the existence of new tuberculosis activity and compare it to previous radiographic studies of the patient [4].

Radiological Findings:

1. Analyze how TB was cured in the previous images, assessing if there were calcifications, fibrous tracts, and apical sclerosis; if there was a cavern which no longer exists, etc.
2. Signs of tubercular activity, such as pleural effusion (discussed below). Tuberculous effusions may have septa with loculations.
3. Cavity with air fluid level.
4. Bronchopleural and tracheobronchial fistulas.

### *2.2.6 Pleural Effusion*

It can be found in a routine chest X-ray without any symptoms. There may be actually 250 ml of fluid present before it is detected radiologically [5].

Radiological findings:

1. An opaque image producing blurring of the costophrenic angle. This opacity may be found in shadows and masses. When the density is very high, the costal arches cannot be seen. In these cases, if there is any doubt, the thoracic ultrasound can be useful for the diagnostic difference between pleural effusion and thickening. The echolucent image, with or without septa, would confirm the diagnosis of fluid (see Fig. 2.6); the echogenic image would indicate pleural thickening.

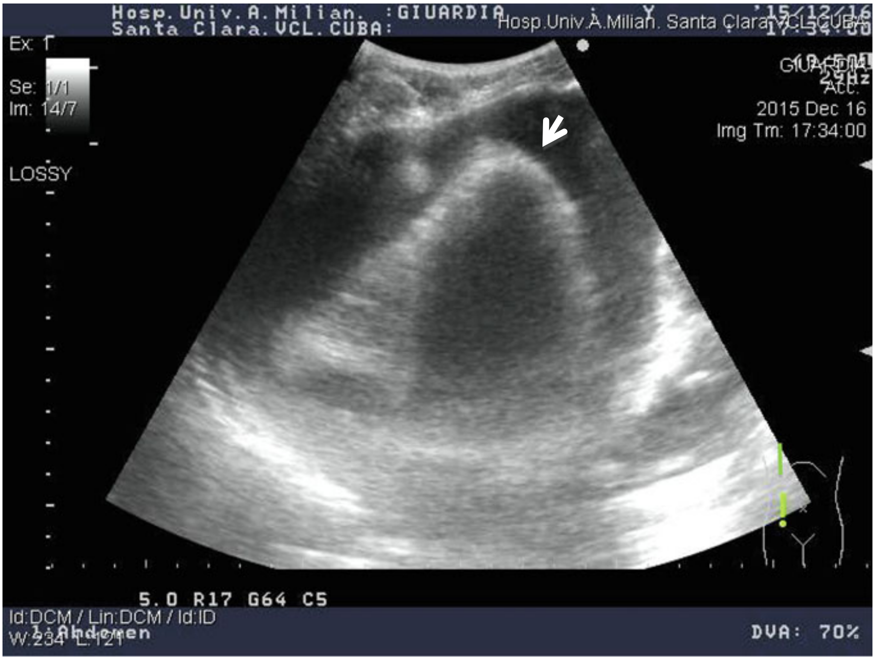

**Fig. 2.6** Thoracic ultrasonography (coronal plane) of the right lung base, with echolucent image and echogenic band consistent with pleural effusion and septum due to empyema (*white arrow*)

When there is little pleural effusion, a decubitus chest radiograph or chest ultrasonography is needed to confirm it. Depending on the clinical findings, it is not necessary to send the patient to another health care level, for example, if the patient exhibits little pleural effusion associated to any viral infections.

## 2.3 Musculoskeletal Conditions

### *2.3.1 Trauma*

Bone trauma is a frequent reason for immediate consultation with the doctor. Examples are minor accidents, with patients suffering from pain in the traumatic area or if there is suspicion of fractures in hands or feet.

When the general practitioner notes swelling, changes in skin color, also difficulty moving the injured anatomical area, there may be a doubt of a possible fracture. In these cases, a conventional radiograph of the affected bone structure must be done in at least two different positions (anteroposterior, lateral, or oblique projection). When the diagnosis is unclear, we recommend making the comparative radiograph with the contralateral structure.

Radiological Findings:

- **Radiotransparent line fracture**: It is very important to analyze the relationship between the fractured fragments of the bone and the form of the fracture line to see if it is possible to solve the problem in the rural health center, without sending the patient to another health care level.

Kids' bones are more likely to bend than break completely because they are softer. Fracture types that are more common in children include

- **Buckle or torus fracture**: one side of the bone bends, raising a little buckle, without breaking the other side
- **Greenstick fracture**: a partial fracture in which one side of the bone is broken and the other side bends (this fracture resembles what would happen if you tried to break a green stick).

Mature bones are more likely to break completely. A stronger force will also result in a complete fracture of younger bones [6].

A complete fracture may be a

- **closed fracture**: a fracture that does not break the skin
- **open (or compound) fracture**: a fracture in which the ends of the broken bone break through the skin (these have an increased risk of infection)
- **non-displaced fracture**: a fracture in which the pieces on either side of the break line up
- **displaced fracture**: a fracture in which the pieces on either side of the break are out of line (which might require surgery to make sure the bones are properly aligned before casting).

Other common fracture terms include

- **hairline fracture**: a thin break in the bone
- **single fracture**: the bone is broken in one place
- **segmental**: the bone is broken in two or more places in the same bone
- **comminute fracture**: the bone is broken into more than two pieces or crushed.

Always the fractures must be treated in a second heath care level by the traumatologists; uncomplicated fractures can be followed-up in rural health centers.

To take a plain film with at least two views (Antero posterior and lateral or oblique views) could be useful as a first step in the management of any trauma, as long as the clinical condition of the patient allows it (see Fig. 2.7a, b).

It is important to analyze the evolution of the consolidation of the fracture. To do that, conventional X-rays are very useful in rural areas. Table 2.1 shows the time a fracture in adult tubular bones takes to consolidate.

To determine the prognosis and proper treatment of fractures, it is important to know their classification. Fractures can be treated conservatively using a cast or

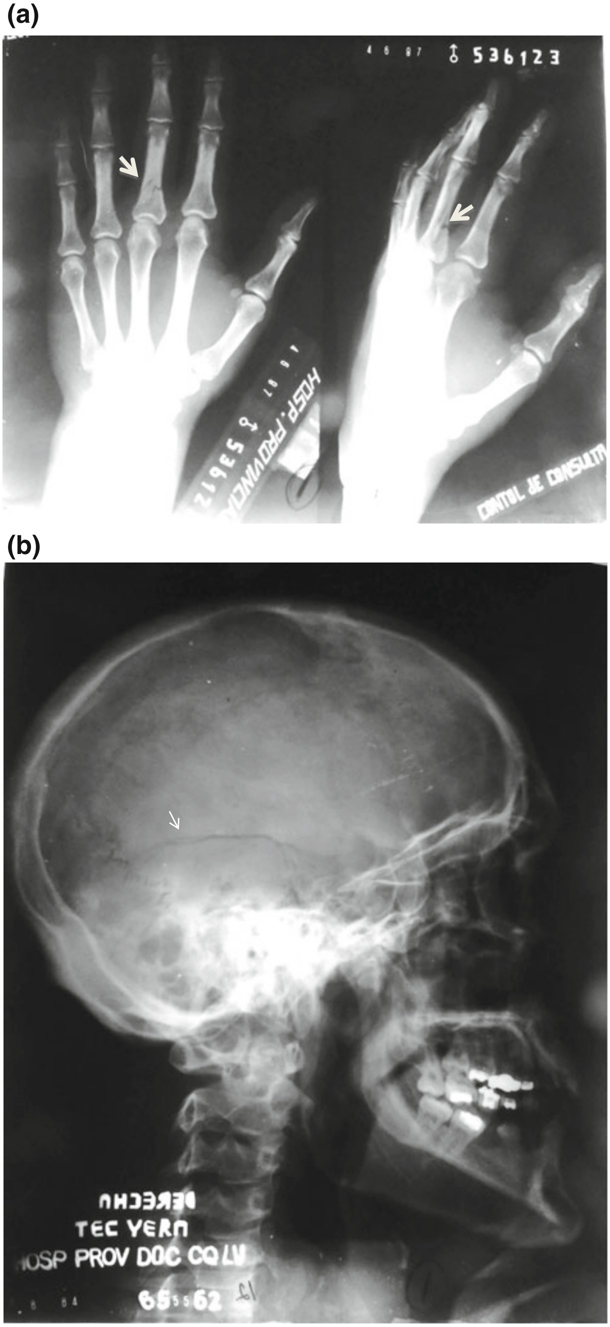

**Fig. 2.7** **a** Oblique transparent line of fracture in the third proximal phalange of the left hand, as it can be seen in AP and oblique views (*white arrows*). **b** Lateral skull projection with temporal line fracture (*white arrow*)

**Table 2.1** Time of fracture consolidation in tubular bones in adults [6]

| | Upper extremity (weeks) | Lower extremity (weeks) |
|---|---|---|
| Early callus | 2–3 | 2–3 |
| Late consolidation | 6–8 | 12–16 |

with the use of surgical internal or external fixation. The latter would require another level of assistance and not the rural health center.

If the fracture is incomplete, such as the greenstick fracture, reduction is usually easy and recovery is usually quick. On the contrary, compression fractures are rarely completely reducible.

The minor head trauma without neurological signs is of particular importance. From our point of view, a conventional skull radiograph (with anteroposterior, lateral, and Towne's projections) could be useful to assess any small fracture, together with the clinical observation that can be done within the first hours after the trauma (see Fig. 2.7b).

### 2.3.2 *Degenerative Osteoarthritis of Spine*

Low back pain is one of the most common causes of physicians' visits—with an enormous socioeconomic burden—as a result of degenerative processes such as osteoarthritis (see Fig. 2.8).

The spine is the most important and crippling area of the human anatomy that is affected by degenerative conditions, followed by hips and hands.

Lumbar and cervical pain, without any other symptoms, are the most common clinical conditions in patients complaining of increased pain early in the morning after waking up and whose symptoms improve during the day after the start of any daily physical activity [7].

The management of low back pain in primary heath care should be firm about not recommending radiography of the lumbar spine in patients with low back pain in the absence of indicators for serious spinal disease, even if the pain has persisted for six weeks. Unfortunately, though, patients undergoing radiography are more satisfied with the care they receive. The challenge for the primary care physician is to increase the satisfaction without recurring to radiography [8, 9].

The general practitioner may request certain exams to aid in the diagnosis of osteoarthritis of the spine. These tests include

- X-rays to look for bone damage, bone spurs, and loss of cartilage. However, X-rays are not able to show early damage to cartilage.
- Blood tests, mainly to look for rheumatoid arthritis, but also to exclude other diseases (not in rural health centers).

**Fig. 2.8** Cervical degenerative changes, with anterior osteophytes and narrowing of the intervertebral spaces as indirect signs of disc degeneration (*black arrows*)

Radiological findings:

1. Low bone density (high bone radiotransparency, cortical thinning, and wide medullar channel)
2. Vertebral osteophytes and facet joint osteoarthritis
3. Disc space narrowing (indirect sign of intervertebral disc disease)
4. Subcondral sclerosis
5. Vertebral fracture by osteoporosis can be found sometimes in women in their third decade of life.

The patients with minor symptoms could be treated in rural health centers. If the symptoms cripple the patient, it is necessary to ask for a second opinion in other health care level.

## 2.4 Acute Abdominal Pain

Symptoms of acute abdominal pain could be a common problem and we need to pay immediate attention to them and act quickly. The medical questioning could guide us in the images to confirm our clinical diagnosis.

### *2.4.1 Right Hypochondria Pain*

After rich fat meals, the symptoms in the right hypochondria are often a reason to visit the health care center looking for a general practitioner´s opinion.

Ultrasonography is a wonderful medical imaging tool to evaluate these symptoms. During the ultrasound exploration, the presence of gallstones could be the cause of pain exacerbation. Acute cholecystitis due to stones (see Fig. 2.9), would look like [10]

1. Echogenic images with acoustic shadow
2. Wall bladder more than 3 mm thick
3. In acute inflammation it is possible to see an echolucent fine line surrounding the wall, due to edema
4. Positive ultrasonography Murphy sign.

It is very important to recognize the normal anatomy of the gallbladder by ultrasound (see Table 2.2) to assess properly any ultrasonography pathology. Do not forget to check at the same time the pancreas and the biliary ducts, analyzing the size and changes in the echogenicity by pancreatitis as a complication of the presence of any stone in the main biliary ducts. In this case, the patient must be seen by a surgeon in another health care level, not in rural centers, for surgical or non-surgical treatment.

**Fig. 2.9** Acute cholecystitis. Echogenic image (gallbladder stone) with acoustic shadow (*white arrow*) and wall bladder thickness of 5 mm (*black arrow*)

**Table 2.2** Gallbladder normal ultrasonography anatomy

| Feature | Description |
|---|---|
| Location | Inferior to interlobar fissure |
| | Between left and right lobes |
| | Gallbladder can be used as a separating landmark for the lobes |
| Size | <4 cm transverse plane |
| | <10 cm longitudinal plane |
| Wall thickness | <3 mm (upper limit = 3 mm) |
| Lumen | Anechoic |
| Common variants | Phrygian cap (fundus folds on itself) |
| | Junctional fold in the neck |
| | Gallbladder may be intrahepatic just above the interlobar fissure |

In a routine abdominal ultrasound examination, the liver is the biggest gland in the abdominal cavity, and we should never forget to view it in different ultrasonography planes [11].

Before reporting any hepatic problem it is important to recognize the normal anatomy by ultrasound (see Table 2.3).

**Table 2.3** Liver ultrasonography anatomy

| Features | Appearance |
|---|---|
| Size | <15 cm (normal upper midclavicular length limits = 13–17 cm) |
| | The liver never overtakes the costal rim |
| Echogenicity | ≥right kidney |
| | <pancreas |
| | <spleen |
| Parenchyma | Homogeneous |
| Surface | Smooth |

## *2.4.2 Acute Abdominal Distention with or Without Pain*

The air distention of small or large bowels in elderly people with previous history of large periods of lying in bed, as well as constipation, could be a motive to visit the health center. Some times, some medications improve the patient's symptoms without the necessity to transfer him/her to another health care level.

Acute obstruction of the small or large intestine is an emergency all over the world and the patients must always be sent to another health care level, where they can be properly treated, but in the meantime, a plain X-ray will allow to make the diagnosis [12].

The recommended plain abdominal X ray (conventional views) are

1. Chest X-ray (Posteroanterior projection): looking for pneumoperitoneum, or any chest pathology that simulates acute abdominal picture.
2. Supine position (Posteroanterior projection): This image allows to analyze the abnormal air patterns of the bowels.
3. Standing views (Posteroanterior projection) looking for air fluid levels, as an occlusive picture.
4. Lateral view of the rectum: looking for air in it.

### 2.4.2.1 Paralytic Ileus

In a dynamic ileus, the lumen of the bowel remains patent but the loss of propulsive power and tone lead to focal or general distention with accumulation of gas and fluid within the paralyzed loops.

Radiologically this results in generalized gas and fluid distention, with gas predominance, involving large and small bowels and the stomach with air in the projection of the rectum [12].

Paralytic Ileus sometimes is associated to peritonitis, like appendicitis; for these cases another health care level is necessary.

**Fig. 2.10** Small and large bowel distention in a patient with paralytic ileus

The simple or complicated obstruction of the intestine cannot be treated in rural centers. Therefore, it is necessary to immediately evacuate the patient to another health care level where there is a surgeon for evaluation and treatment (Fig. 2.10).

<u>Radiological Findings</u> (In cases the patient stays long time in bed)

1. Enlargement of the large, small or both bowels loops, with air predominance and little fluid levels
2. Not significant thickness of bowel walls

3. Feces in the colon projection, including the rectum in lateral view.

Some decompressive maneuver can help in these cases, without transferring the patient to another health care level.

### 2.4.3 Diarrhea

For the patients with common diarrhea it is not necessary to use any medical images. The results of the clinical examination and previous history during the exam are the main factors that affect treatment decisions. Only in chronic diarrheal syndrome, the abdominal ultrasound is useful by looking for any gallbladder disease or liver pathology as focal echogenic lesions that may indicate metastasis or in cases where the general practitioner found a mass during palpation.

The procedures with barium are not necessary in rural areas. If the doctor has a clinical idea of any problems like tumors, ulcer, polyps, etc., for example, if the patient has heavy rectal bleeding, the endoscopy is the right procedure to do. However, that should be done in another health care level, in some cases with biopsy of the lesions.

Figure 2.11 shows an image of a barium enema.

### 2.4.4 Right Iliac Fossa Pain

If the practitioner suspects during the clinical examination the possibility of appendicitis, the abdominal ultrasound with full bladder as an acoustic window to make the exploration, is a right procedure to see any ultrasonographic findings such as

1. Enlargement of the appendix in a transverse plane that looks like a dartboard
2. Complex image surrounding the appendix or fluid around it
3. Blumberg ultrasonographic sign.

### 2.4.5 Splenomegaly

It is not a condition that the patient can be aware of, but sometimes it is an incidental finding during a routine ultrasonography exploration [13].

Splenomegaly exists when the measurement values exceed the normal limits in at least two planes (more than 14 cm in longitudinal measuring, overtaking the inferior pole of the left kidney and 6 cm in transverse diameter; see normal spleen anatomy (see Table 2.4).

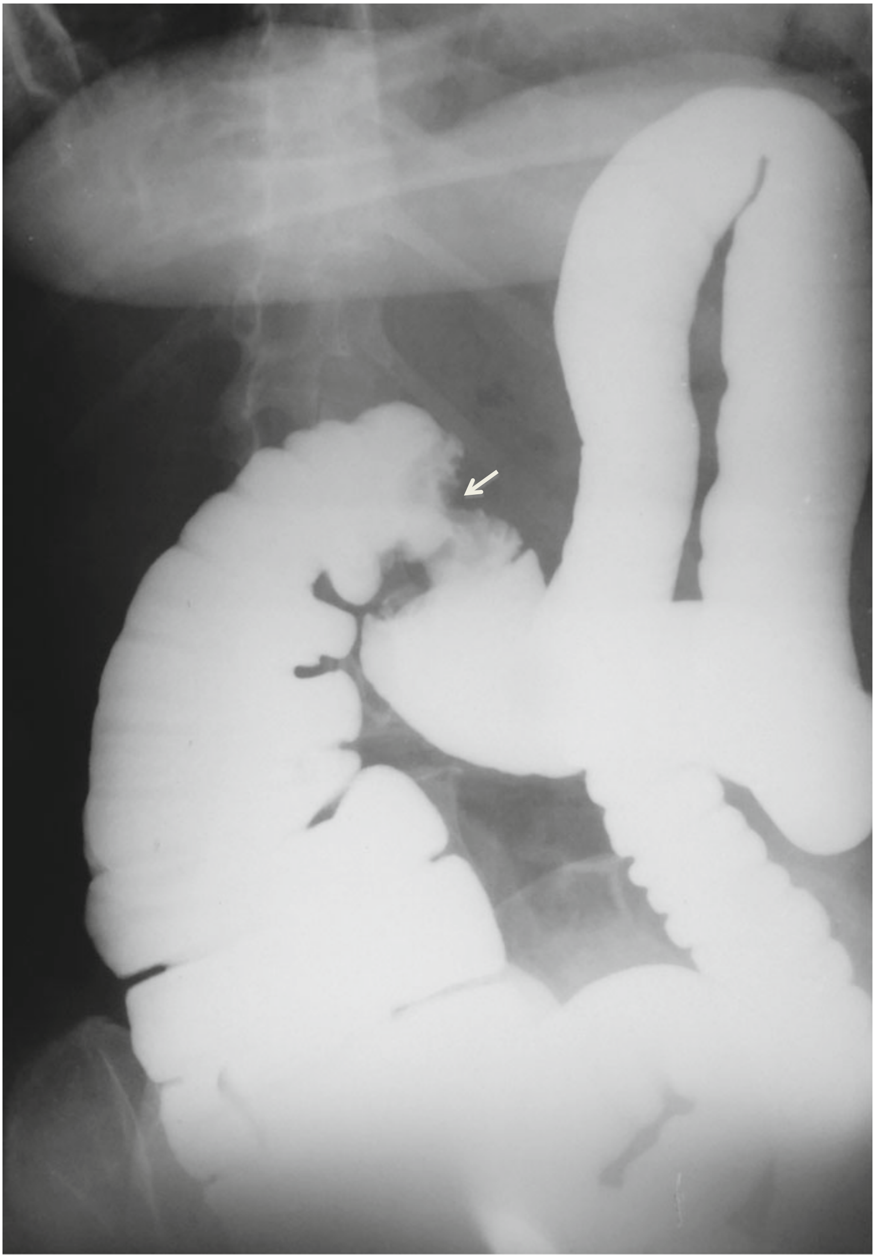

**Fig. 2.11** Problems like tumors (*white arrow*) can be seen in a barium enema, a procedure done at a secondary or tertiary health care level

**Table 2.4** Spleen ultrasonography anatomy

| Feature | Appearance |
|---|---|
| Size | ≤14 cm; ≤6 cm thick |
| Echogenicity | >left kidney; >liver; >/<pancreas |
| Echotexture | Homogeneous |
| Surface | Smooth |
| Shape | Crescentic |

As a clinical examination does not provide an adequate assessment of splenic enlargement, echographic size assessment plays an important role in the diagnosis and follow-up of these patients.

The numerous causes of splenomegaly range from infections and immunologic disorders, hematological diseases and benign or malignant infiltration of the spleen. It may appear in association or without focal hypoechogenic or echogenic nodular lesions.

- Infections usually lead to only moderate enlargement with the exception of tropical parasite infections; the symptoms may gradually disappear after the acute infection resolves.
- Cirrhosis of the liver and portal hypertension is also common causes of small splenomegaly.
- Splenic enlargement alone is an unreliable sign of diffuse myelo or lympho-proliferative infiltration.

Spleen enlargement always requires to be evaluated by a second health care level physician, who should identify the possible cause and apply the protocol for patient follow up; sometimes it is a necessary evaluation by a hematologist.

## 2.5 Urinary Tract Imaging

A probe of 3.5 MHz is generally used to do an ultrasound examination of the adult kidney. The kidneys are scanned in all planes. The patient should be placed in the supine or decubitus position.

Indications:

- Flank pain
- Hematuria
- Elevation of blood urea
- Acute renal failure
- Acute or chronic pyelonephritis and glomerulonephritis
- Diabetic nephropathy.

The renal capsule cannot be distinguished from the renal parenchyma, which is less reflective than the liver and spleen. The echogenic center of the kidney corresponds to the renal sinus, a space within the renal tissue; it contains the renal pelvis, the renal vessels, connective tissues, and fat.

### *2.5.1 Kidney Stones*

The prevalence and incidence of nephrolithiasis is reported to be increasing across the world. Changes in dietary practices may be a key driving force. In addition, global warming may influence these trends [1].

More men form stones than women. The sex ratios range from 2.5:1 in Japan to 1.15:1 in Iran [14, 15]. However, there are age ranges in some countries where this ratio is reversed. Data comparing stone disease differences between races within one country were available only for the United States [16]. Prevalence and incidence rates were highest for whites, followed by Hispanics, African Americans, and Asians.

Three studies published between 1991 and 2003 examined asymptomatic stone prevalence rates by performing ultrasonography on randomly selected subjects [17, 18].

Concretions within the renal pelvis typically appear as circumscribed changes. A stone is seen as a hyperechogenic focus with acoustic shadowing. Calculi which do not cause urinary tract obstruction and corresponding symptoms (colic, calyceal ecstasies) are generally situated in the zone of acoustic shadowing outside the central echo complex, and they are often incidental findings. Calculi of the order of 3 mm can be visualized under favorable conditions. Hydronephrosis is an important sign of possible concretions. The chemical composition of the renal calculi does not play an important role in echography, as opposed to radiology. Staghorn calculi are characterized by dense echoes from all calyces, which unite to form band-shaped, highly reflective zones in the renal pelvis (see Fig. 2.12).

Patients with kidney stones measuring less than 3 mm and without hydronephrosis or fever do not have to be sent to another level of health care. Such patients will need treatment for pain management and some medications to evacuate the stone. Follow up can be done by ultrasonography after few days, always when the clinical status of the patient allows it. However, if the patient has a stone in the urinary tract more than 3 or 5 mm on any side, and presents hydronephrosis and fever, it is necessary to send him/her to another level of health care. The stone could have resulted from complications due to a urinary infection, secondary to the obstruction, and the patient needs to be evaluated for future treatments, perhaps using minimal access procedures.

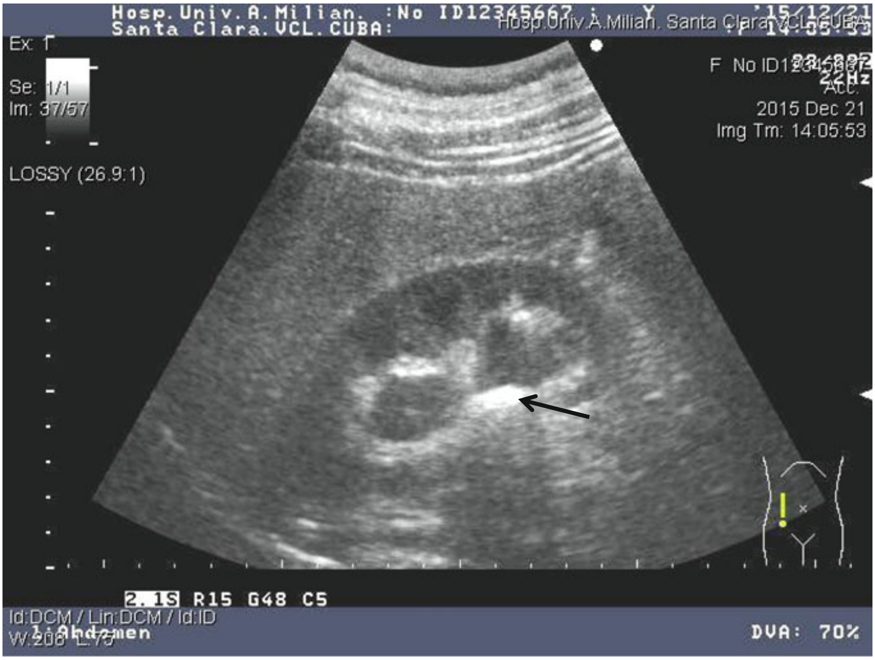

Fig. 2.12 Echogenic image with acoustic shadow in the renal pelvis of the right kidney and hydronephrosis, consistent with kidney stone (*black arrow*) and obstructive hydronephrosis

## 2.6 Pregnancy

### 2.6.1 *Gestational Age and Fetal Functions*

Ultrasonography is very useful for diagnostic evaluation and follow-up of pregnant patients if a proper transducer is used; intrauterine structures can be detected with sizes from 1 to 3 mm.

Ultrasound findings:

**6th week**: To assess the embryonic development, it is possible to evaluate the chorionic cavity (1–5 mm) on the 4th week of pregnancy after the last period (see Fig. 2.13).

**First trimester**: in addition to detecting the existence and location (ectopic or normal) of pregnancy, ultrasonography is performed primarily to assess the viability of the fetus (movement, cardiac action) and to determine the number of embryos (multiple pregnancy), and the gestational age and morphology (anomalies) of the fetus (towards the end of the first trimester). Ultrasound measurements are useful for determining the gestation age of the fetus or, if the gestational age is known, for assessing the development of the embryo and fetus [19].

**Fig. 2.13** 5-week pregnancy, where the gestational sac can be measured

These measurements include

**≤9th week**—diameter of the chorionic cavity.
**6th–12th week**—crown to coccyx length (CRL). See Fig. 2.14.
**≥9th week**—biparietal diameters (BPD) measured from the outer skull table to the inner skull table (see Fig. 2.15) and for the femoral length see (see Fig. 2.16).

Not only the gestation age can be estimated from measurements in the ultrasound images; ultrasound is also very useful to detect disorders that occur in early pregnancy. In the second and third trimesters, fetal development, and morphological anomalies can be assessed and detected with high reliability [20]; see Figs. 2.17, 2.18, 2.19 and 2.20 [2–4].

Intrauterine growth can be monitored using a normal curve with comparison data. The weight of the fetus can be calculated from multiple (2 or 4) measurements using empirical formulas. This provides a means of early detection of fetal retardation and hypertrophy [20].

Ultrasound can also be used to assess fetal function, e.g., for observation of fetal movement and behavioral patterns. Ultrasound monitoring of the placenta and umbilical cord is also an important part of pregnancy follow-up (location and structure; growth development; such complication as abruption placentae, hydrops, and tumors). Although fetal echocardiography must be done by specialists trained in other level of health care, it is possible to identify, at least, the cross of the heart (in four chambers view) see Fig. 2.21 [14]. This allows to determine a cardiac septum defect and also to see enlargements of cardiac cavities or any small congenital intracardiac tumor.

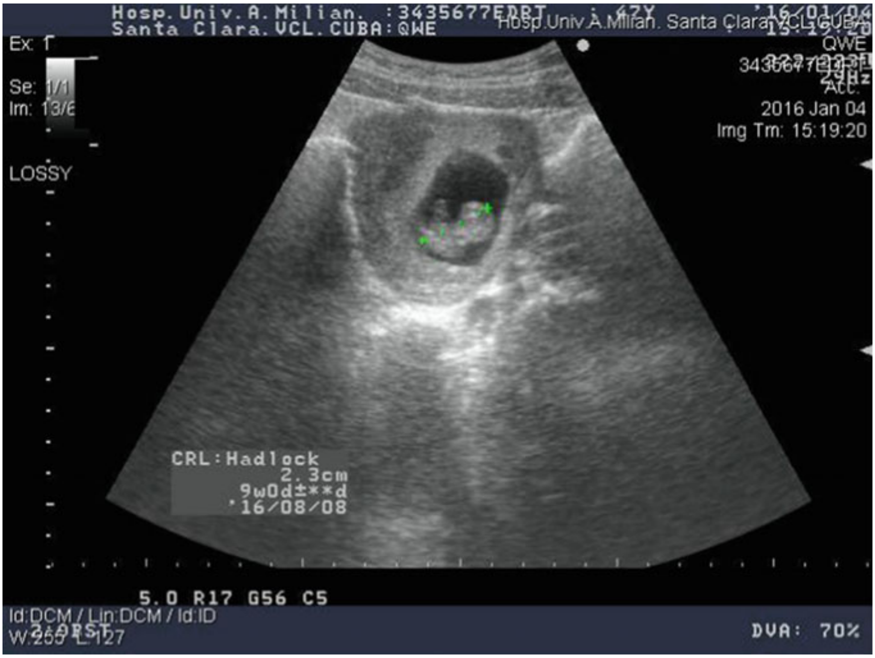

**Fig. 2.14** 9-week fetus with a CRL of 2.3 cm

**Fig. 2.15** Biparietal diameters can be measured from the outer skull table to the inner skull table

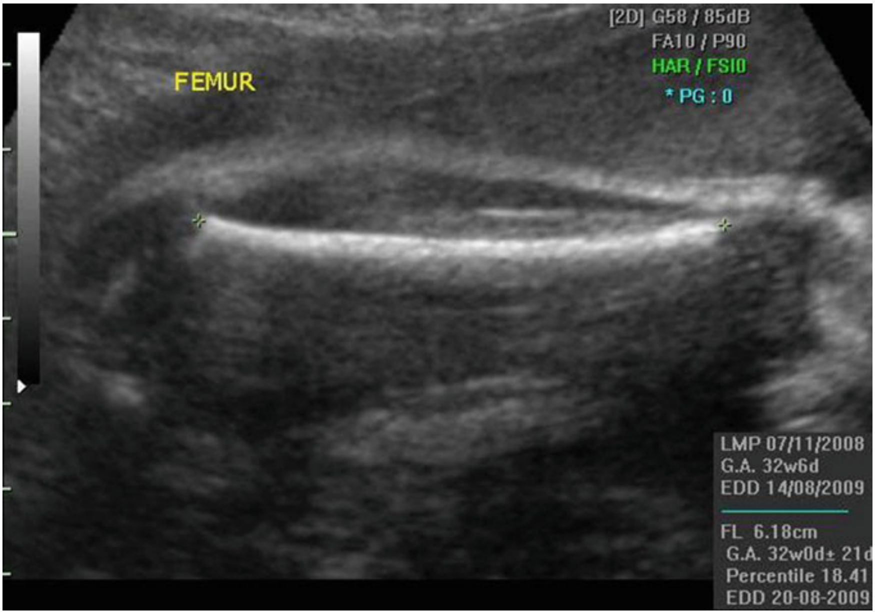

**Fig. 2.16** The fetal femoral length can also be measured in an ultrasound image

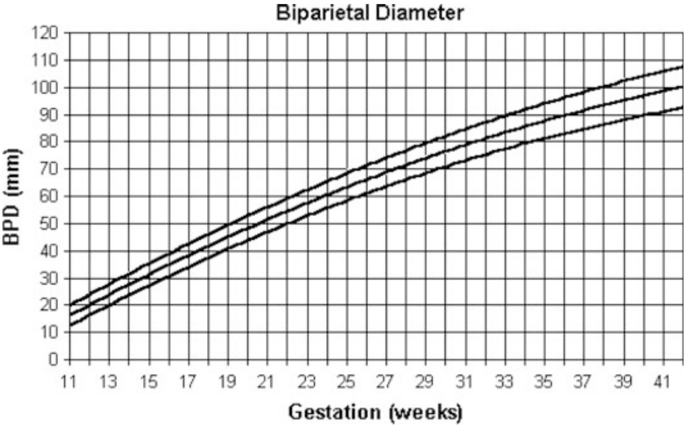

**Fig. 2.17** Variation of BPD versus gestation

The amniotic fluid can also be assessed by ultrasound as an important part of antepartum fetal surveillance. It may detect problems with the fetus, placenta, or another condition. It is important at least to know a simple method to evaluate it; the amniotic fluid index (AFI), or four-quadrant technique, has been suggested [21, 22].

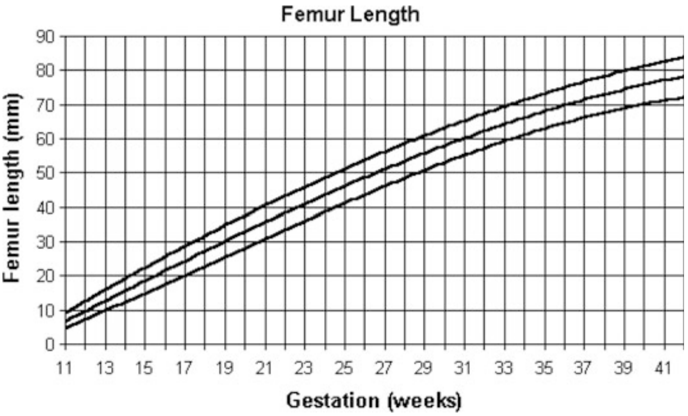

**Fig. 2.18** Variation of fetal femur length versus gestation

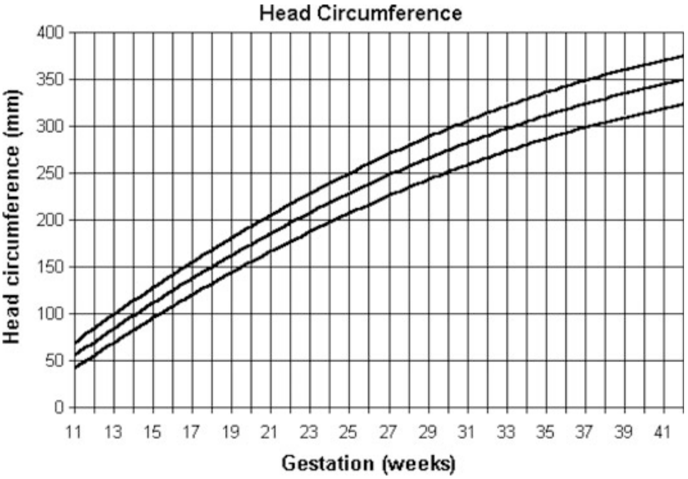

**Fig. 2.19** Variation of fetal head circumference versus gestation

1. All amniotic fluid studies can be done using a real-time linear array B-scan.
2. Amniotic fluid index (AFI) measurement with the modified four-quadrant technique (largest vertical pocket). In the third trimester, the AFI index is 16.0 ± 4.8 cm.
    (a) From 13 weeks' gestation, the AFI grows progressively until 26 weeks.
    (b) From then to 38 weeks, the AFI measurements demonstrate little variation.
    (c) After 38 weeks, the AFI appears to decline gradually.
3. High-risk pregnancies with an amniotic fluid index of $\leq 5$ cm appear to carry intrapartum complication rates similar to those of similar high-risk pregnancies with an amniotic fluid index of $>5$ cm [23].

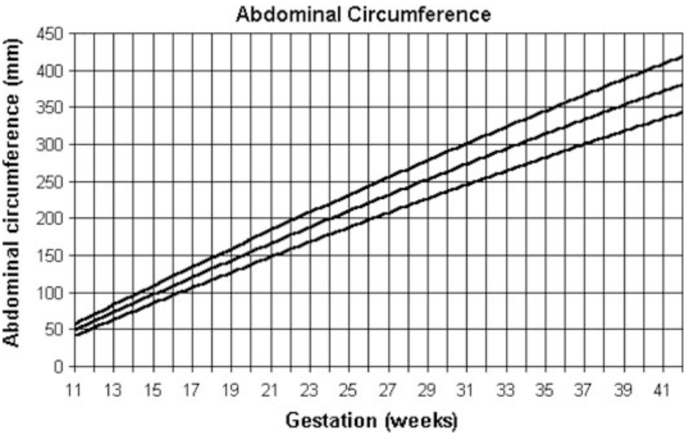

**Fig. 2.20** Variation of fetal abdominal circumference versus gestation

**Fig. 2.21** Normal view of the four fetal cardiac chambers

**Table 2.5** Normal and abnormal values of amniotic fluids levels (AFL)

| Methods to measure | Normal (cm) | Polyhydramnios (cm) | Doubtful (cm) | Olygoamnios (cm) |
|---|---|---|---|---|
| AFI | 8.1–24 | >24 | 5.1–8 | <5 |

Table 2.5 lists normal and abnormal amniotic fluid levels.

## 2.6.2 *Pregnancy Management*

Pregnancy assessment by ultrasound is necessary to have the basic tools to know when any problems may appear in a pregnant woman. It is important, however, never to forget the relation between the clinical symptoms and the ultrasound findings. For example, bleeding in a pregnant woman is not the same if it occurs in the first trimester or in the third one. In the first case, a possible abortion is the first diagnosis to make, with findings of irregular borders of the gestational sac, or to see the fetal pole without heart movement, or an echolucent image in the cervical canal. In such a case, the woman must be sent to a secondary level of health care, in order to remove the dead embryo and clean the uterine cavity. In the second and third trimesters, the physician must pay attention to the position of the placenta, and to any echolucent image between the placenta and the uterine wall; these findings may facilitate the diagnosis of either a low position of the placenta or of a retroplacentarium hematoma, with the consequent treatment at the secondary or tertiary healthcare levels. Also when the physician identifies abnormal amounts of amniotic fluid, it is important to always check if the stomach is present in the site of the abdominal fetal cavity, if the fetal urinary bladder is full, and also to identify the fetal kidneys. Never forget in the same situation to ask the patient for previous history of diabetes, and to measure the placenta, and assess if there is a single fetus. Ideally, pregnancy management should be done by an obstetrician. In rural areas such specialist may not be present and then the doctor (or midwife or nurse practitioner if a doctor is not available) will have to identify if the woman is pregnant or not and take the elementary measures, such as making the first ultrasound explorations, if the woman exhibits any acute symptoms that may be suspicious of complications, as explained previously. For a pregnancy with a normal evolution, the clinician in the rural health center should be able to evaluate fetal images and implement basic measures prior to the baby's delivery.

## 2.6.3 *Ectopic Pregnancy*

The ultrasonography appearances of ectopic pregnancy may vary greatly, particularly if other changes occur in the adnexa. In addition to a positive pregnancy test, one commonly finds an enlarged uterus without an embryonic cavity and adnexa changes. The diagnosis can be established only if the ectopic fertilized ovum is found with an intact embryo. Transvaginal ultrasonography is the diagnostic choice.

However, it is important to note that ultrasound not always allows to make the diagnosis of ectopic pregnancy. First, it is important to ask the patient when she had her last menstrual period, and if the physician has any doubt, a laboratory test for pregnancy should be carried out. If the test is positive and consistent with clinical findings, even though there are no positive ultrasonographic findings, the patient must be sent to the secondary level of health care.

Another situation is a woman with clinical findings of ectopic pregnancy and with ultrasonographic images showing an enlargement of the ovaries or any complex mass in any uterine adnexa, with or without an embryonic gestational sac, and with or without free fluid in the peritoneal cavity. In such a case, the patient needs to be sent urgently to another level of attention for surgical management.

## 2.7 Gynecological Problems not Related to Pregnancy

Common gynecologic symptoms in the medical room are presented by women who have missed their period or who have gynecological bleeding. In these cases, the ovaries could be evaluated first with ultrasound.

### *2.7.1 Normal Uterus Size*

The fluid-filled bladder can be used as the acoustic window for transabdominal ultrasonography of the uterus (and of all organs of the minor pelvis). However, transvaginal ultrasonography provides much more precise information [24]. Table 2.6 provides information of the size of the uterus versus age.

The uterus may be larger in multiparae and in women with poor involution after birth, and it is smaller again in older women. Ultrasound is able to provide a good topographic assessment (position, anatomical abnormalities such as double uterus) and can detect changes in the uterine cavity (particularly in the endometrium) during the course of the menstrual cycle (see Fig. 2.22). Additional echography is also useful for detecting uterine tumors and cystic lesions [24].

**Table 2.6** Size of the uterus

| | |
|---|---|
| Prior to puberty | 2–3.3 × 1 cm |
| Childbearing age | 5–8 × 1.6–3 cm |

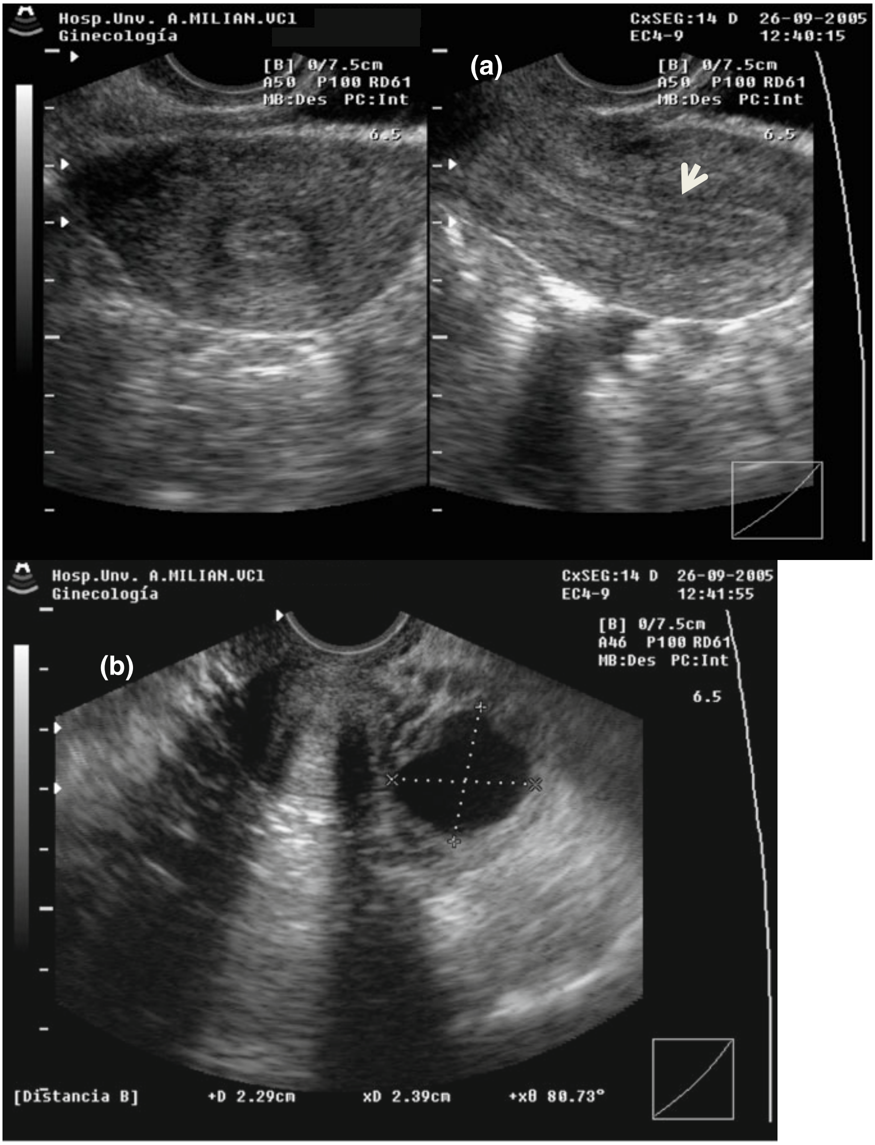

**Fig. 2.22** Normal trilaminar endometrium **a** with mature follicle in the left ovary (*white arrow*), **b** on the 14th day of the cycle

## 2.7.2 Uterine Myomatosis

Diffuse hyperplasia of the myometrium is normal in multiparae. In these women, the myometrium appears less reflective than the endometrium. This finding is considered pathological only when it coexists with menorrhagia. Circumscribed myomas are usually found in sub-serous positions. They have a polycyclic appearance and are smoothly demarcated from their surroundings. Degenerative changes may occur in myomas due to excessive growth or poor circulation, which gives them an irregularly spotted, hypoechoic appearance with plaque like foci of calcifications in some cases.

### *2.7.3 Ovarian Cysts and Tumors*

Simple cystic ovarian masses are a common finding; they usually correspond to corpus luteum cysts or retention cysts, and their appearance changes throughout the course of the menstrual cycle. Ovarian cysts are spherical unilocular masses with smooth walls, anechoic contents and dorsal acoustic enhancement [24]. Tumors may produce different images (see Fig. 2.23).

A particular tumor that requires special attention is the ovarian cystadenoma. This tumor may become quite large and contain septa, but the two types cannot be reliably distinguished by ultrasonography. The contents of ovarian cyst adenomas are usually echolucent, but the contents of mucinous ovarian cystomas are weakly echogenic. Mucinous types may be difficult to distinguish from endometriosis cysts or degenerated, pediculate (subserous) myomas that occur in uterine myomatosis [24].

Table 2.7 lists the echographic appearance of adnexal tumors.

**Fig. 2.23** Giant cyst of the right ovary, with thick septum and nodular wall, signs of a malignant cyst

**Table 2.7** Ovarian tumors

| Tumor | Cystic unilocular | Cystic multilocular | Solid cystic | Solid |
|---|---|---|---|---|
| Corpus luteum | + | | | |
| Cysts with hemorrhage | | + | + | |
| Desmoids | + | + | + | + |
| Endometriosis | + | + | + | + |
| Ectopic pregnancy | | + | + | |
| Ovarian fibroma | | | | + |
| Ovarian cystoadenoma | | + | | |

Echographic appearance of adnexal tumors

All the gynecological uterus and adnexal masses need to be evaluated by a gynecologist at the second level of health care to make the correct diagnosis, sometimes under laparoscopic view and biopsy. But at least, the ultrasound exam in rural areas is a tool to identify if the symptoms come from the gynecological structures and can rule out uterine and adnexal lesions, which the physician can see during the exploration.

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# Part II
# Medical Imaging Modalities

# Chapter 3
# Medical Imaging Equipment Characteristics at the Health Center Level: Overview

**William Hendee**

**Abstract** Those of us who live in developed countries often do not appreciate the severe limitations in health care experienced by persons in most parts of the world. Under these conditions, the care that is available usually is provided in facilities that are under-equipped, under-staffed, and inundated by requests for services. In many cases, these conditions can be alleviated to some extent by the deployment of technologies such as basic x-ray and ultrasound imaging, provided that such technologies are appropriate, accessible and affordable (the "Four A's"). Government agencies, policy makers and healthcare organizations should work together towards such deployment.

**Keywords** X ray imaging · Ultrasound imaging · Four A's · International collaboration

## 3.1 Assessment of the Challenge

Those of us who live in industrialized countries tend to take excellent health care for granted. We have access to well-educated physicians and nurses, highly-trained technical staff, and equipment that combine to yield exquisite diagnostic and therapeutic capabilities for patients suffering from a wide range of diseases and disabilities. The only thing limiting our ability to provide superb health care to all who need it is our willingness to pay for it.

Superb health care is, unfortunately, not the rule in most of the world. Instead, the majority of the world's population receives marginal health care at best, much of which is delivered in facilities that are poorly designed and equipped and that are often overwhelmed by many people seeking care for themselves and their family members. These so-called "health centers" are the access pathway for improving

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the health care of millions of people. The challenge is to identify ways to take advantage of this pathway by improving the care administered in health centers around the world. This is a challenge that the World Health Organization [1] is attempting to tackle, but unfortunately with far too few resources.

## 3.2 Contribution of Health Technologies

Although certainly not the sole answer to the world's problem of inadequate health care, health technologies, including medical imaging systems, can contribute substantially to improvements in the health status of people with illnesses and injuries. Whether a particular technology will make such a contribution depends on whether the technology is: (1) Appropriate; (2) Accessible; and (3) Affordable. These criteria are known as the four "A's". With regard to a particular health center, the challenge is to identify technologies that satisfy these criteria and that address the individual and public health needs of the population served by the health center. Unfortunately, far too often technologies are deployed that do not meet these criteria, or that cannot be sustained through proper installation and maintenance. Perhaps this is why 90 % of all medical equipment donated to health centers in developing countries fails in the first 5 years [1].

The issue of health technologies and their potential to improve the care of people at the health center level should be on the agenda of appropriate governmental bodies and policy-makers in both developed and developing nations. It should also be a topic of discussion in professional organizations, foundations, international health organizations, and large medical device companies. It will take all of these groups working together to achieve substantive improvements in the quality of care through expansion of health technologies at the health center level. The approach must be global, systematic and focused on the greatest good for the greatest number of individuals.

In developing as in developed countries, there is a fascination with technology that can sometimes result in decisions to acquire a sophisticated technology (e.g. a single computed tomography scanner) that will benefit a few people (as long as it is operating), rather than a less sophisticated technology (e.g. multiple ultrasound units) that will benefit many more for less cost. In making a decision about acquisition of a health technology, several issues must be considered. These issues include the four "A's" described earlier, together with how the technology will be used and managed, who will use it and how well they are trained, who will maintain the technology and fix it when it malfunctions, and how the equipment will be kept secure and operational. Some of these issues are discussed in Chaps. 5, 6, 7 and 8.

Government agencies, policy makers and healthcare organizations must address several major issues in deciding on the acquisition of a particular technology for a particular health center or patient population. These questions include: (1) Is this technology necessary for the patient population under consideration? (2) Is the technology justifiable in terms of how it will benefit the particular patients it is intended for, in terms of safety, expected outcomes, and cost-effectiveness? (3) Is the technology the most appropriate acquisition when compared with alternatives to the technology? (4) Is the technology equitable in its applications, or will it benefit only a subset of the population and, if the latter, is the subset identifiable by disease and disability, or by status and income? (5) Is the technology the most appropriate use of resources when the overall needs of the population are considered? An ideal technology will yield affirmative answers to each of these five questions.

To facilitate making decisions regarding their appropriateness, the Medical Devices Program of the World Health Organization is in the process of developing a set of minimum specifications and requirements that should be considered before starting acquiring medical devices. It is their belief, that "having this type of specification allows to improve access to medical devices of high quality, safety and efficacy, as well as planning adequately the financial, infrastructure and human resources, among others, to be considered in the implementation, functioning and decommissioning of the devices" [1].

For developing communities and countries, the most appropriate technologies to serve large populations of patients should be small scale, energy efficient, environmentally sound, simple to maintain and service, and well-matched to the educational level of the operators and the needs of the communities. In general, simple technologies that are labor-intensive are preferred over complex technologies that are highly automated. The technology should foster self reliance and responsibility in its operation and maintenance, and not require frequent service calls by vendor representatives.

Chapter 4 describes the technical specifications of ultrasound and X-ray units and Chap. 5 lists practical recommendations on the types of medical imaging equipment appropriate for a rural health center and discusses various ways of acquiring and installing the recommended systems.

## 3.3 Medical Imaging as a Desirable Technology

The World Health Organization has estimated that two-thirds of the world's population does not have access to even the simplest forms of X-ray imaging [1]. The operational need for imaging is one X-ray unit for every 50,000 people at the very least, which is a much more dense distribution of X-ray units than exists at present in most developing countries. The World Health Organization has attempted over the years to address this problem by assisting in placing new (especially the WHIS-RAD system described in Chap. 5, Sect. 5.2.2) and refurbished X-ray units in health centers in many locations. Unfortunately probably fewer than half of these units are operational. This dysfunction reveals that distribution of X-ray units is only part of the problem; sustainability of the units once they are distributed is also a part. The installation and operation of ultrasound units encounter similar problems. The equipment is less expensive than X-rays but the training of the operators is more difficult. Chapters 2, 6 and 9 discuss training issues.

Placing X-ray and ultrasound units in health centers and keeping them operational presents several challenges, including: (1) lack of knowledge to make appropriate decisions about the type of technology to be acquired; (2) inadequate education and training to operate the technology, obtain images of reasonable quality, and repair the technology when it malfunctions; and (3) inadequate skill to interpret the images properly. These challenges, often accompanied by a general lack of fiscal and technical resources, are formidable obstacles that must be overcome if imaging is to be employed successfully in support of improved patient care.

To address these obstacles successfully, the process of acquiring and sustaining imaging services should be integrated into the regional or national healthcare system and regulated according to standards developed at the international level. At the regional or national level, there should a commitment to improved technological services, and financial support to assist in the acquisition and maintenance of the services. A regional or national regulatory authority for radiation protection should provide oversight of the radiation exposures to patients and to technical and medical personnel. Ideally, a national plan should exist for deployment of technologies such as X-ray imaging at the health center level, which would include needs assessment and assistance in controlling radiation exposures, acquiring quality images, and interpreting them properly.

## 3.4 Partnerships for Acquiring Imaging Technologies

Several efforts have been established to form partnership to help under-developed countries acquire imaging technologies. The World Health Organization, International Atomic Energy Association [2], regional health organizations (e.g. the Pan American Health Organization [3]), and others have provided assistance to countries wishing to use imaging technologies to improve health care. Professional organizations (e.g. the American Association of Physicists in Medicine [4], International Organization for Medical Physics [5], Radiological Society of North America [6], and American College of Radiology [7]) have contributed to this effort through services to help site refurbished equipment and programs to educate operators in its use and maintenance. Manufacturers of imaging equipment have donated used and refurbished equipment to developing countries, and a few academic institutions have also been part of the effort to upgrade health care in developing countries. In addition, some organizations (e.g. the World Health Imaging, Telemedicine and Informatics Alliance [8], Imaging the World [9], and Medical Imaging Partnership [10]) have been formed specifically for the purpose of expanding the use of health technologies in developing countries. All of these organizations have websites that explain their programs of assistance.

## 3.5 Conclusions

Technologies such as ultrasound and X-ray imaging can contribute substantially to improved health and well-being of people in developing countries through their deployment at the health center level. To achieve this objective, several obstacles must be overcome, including but not limited to the availability of fiscal and personnel resources. Although the obstacles are formidable, there are pathways around them if the commitment to do so is present at the community and national levels.

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# Chapter 4
# Technical Specifications of Medical Imaging Equipment

Kwan Hoong Ng, Jeannie Hsiu Ding Wong and Sock Keow Tan

**Abstract** The two most basic and useful imaging modalities in rural healthcare facilities are ultrasonography and planar radiography. In this chapter, the basic technical specifications of the equipment, namely ultrasound units and X-ray units (both the screen-film system and digital radiography system) are listed along with selection recommendations. Clinical applications for which the equipment may be used are highlighted. Issues such as safety, training, maintenance, quality assurance are discussed briefly.

**Keywords** Digital radiography system · Imaging equipment · Radiography · Screen-film system · Technical specifications · Ultrasound imaging · X-ray imaging

## 4.1 Technical Specifications of Ultrasound Units

Ultrasound is an important diagnostic imaging tool especially in a resource-limited healthcare facility. It has the following attractive features, Non-invasive, does not use ionising radiation, relatively inexpensive to own and maintain, readily available, efficacy proven in many disciplines and is a cost-effective solution in health care. However, it is very much operator dependent and requires a rather steep learning curve.

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The original version of this chapter was revised: The spelling of the first author name was corrected. The erratum to this chapter is available at DOI 10.1007/978-981-10-1613-4_10

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In order to make a right decision to purchase a suitable ultrasound unit, this chapter explains the principles of selecting an ultrasound unit, the general requirements and the technical specifications.

### *4.1.1 Ultrasound Equipment*

Ultrasound images are formed by the emission of ultrasound pulses and detection of pulse echoes by the transducer. Basically, the ultrasound pulses generated from transducer propagate into the patient body, experiencing partial reflections from the tissue or organ interfaces, producing echoes and then reflecting them back to the transducer. The signals are then processed to form an image. This is known as the pulse echo method.

Hardware components consist of the beam former, pulse emitter, receiver, amplifier, scan converter/image memory and the display system which is used in the image formation. Images are stored in the picture archiving and communication system (PACS) or printed for the patient. A block diagram and photographs of ultrasound scanners are shown in Figs. 4.1 and 4.2.

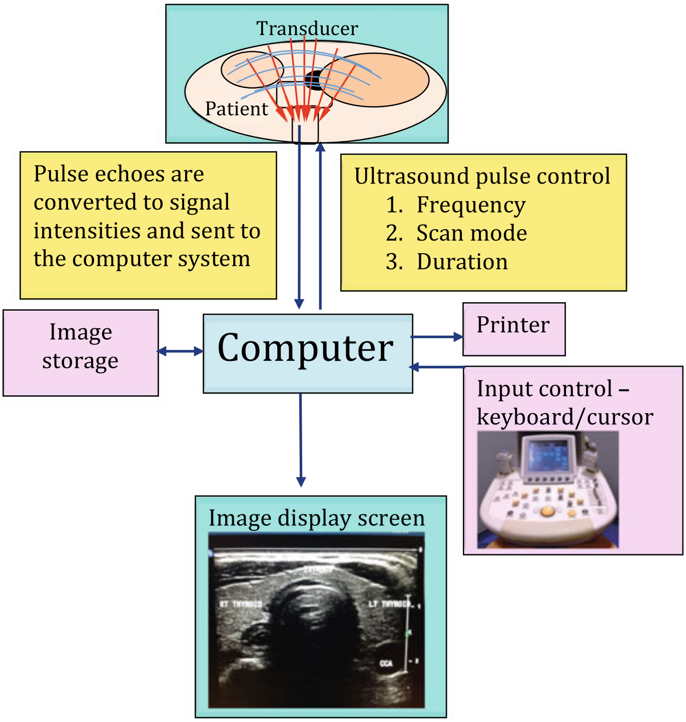


**Fig. 4.1** Block diagram of a general ultrasound scanner

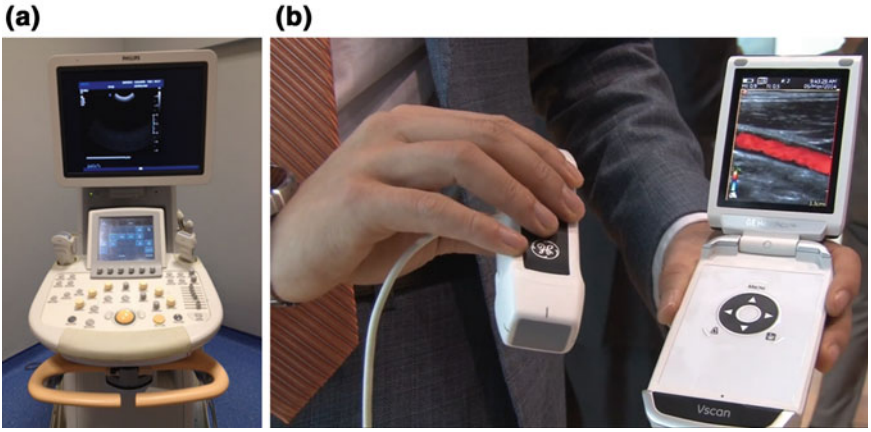


**Fig. 4.2** **a** A photograph of an ultrasound scanner (*Courtesy* of Philips Medical). **b** A photograph of a portable ultrasound scanner (*Courtesy* of General Electric)

#### 4.1.1.1 Selection of Equipment

The clinical applications and the relative workload in each application will determine the specification that is desirable or appropriate.

An all-purpose general ultrasound scanner in a busy general hospital to cover the entire range of common clinical applications (but mainly abdominal work), will require different specifications from that which is dedicated to musculo skeletal or vascular imaging.

A portable machine performing simple investigations will be required to meet basic specifications for imaging but should give priority to size and portability, rather than excellent image resolution and sensitivity.

### *4.1.2 General Considerations for All Equipment*

#### 4.1.2.1 Clinical Applications for Which the Equipment May Be Used

- Adult/Pediatric
- General Abdomen
- Obstetrics/Gynecology/Fetal
- Small parts/Breast/Musculoskeletal
- Vascular/Cardiac
- Biopsy/Interventional.

Chapter 2 discusses these applications in a rural health center.

#### 4.1.2.2 Transducer/Probe Required

Transducers and probes are generally described by the size and shape of their face known as its “footprint”. The appropriate selection of the right probe for the specific clinical situation is essential to obtain diagnostic quality images. There are three basic types of probe used: linear, curvilinear, and phased array. Linear probes are generally high frequency, better for imaging superficial structures and vessels, and are also often called a vascular probe. Curvilinear probes may have a wider footprint and lower frequency for trans-abdominal imaging, or in a tighter array (wider field of view) and higher frequency for endocavitary imaging. A phased array probe generates an image from an electronically steered beam in a close array, thereby generating an image that comes from a point and is good for imaging between ribs such as in cardiac ultrasound.

Both curvilinear and phased array probes generate sector or “pie-shaped” images, narrower in the near field and wider in the far field, while linear probes typically generate rectangular images on the screen.

Types of Probes (also called transducers)

- Linear
- Curved linear array
- Phased array/sector
- Endocavitary (Example: transvaginal)
- Intraoperative.

Additional features:

- Footprint size
- Biopsy guidance facility
- Depth range for each type of transducer:
  - Deep
  - Multiple
  - Superficial.

#### 4.1.2.3 Scanning Capabilities Required

Scanning capabilities depend on clinical applications. They range from the simple B-mode to the complex 3D imaging.

- B- and M-mode
- Color, Spectral, Power Doppler
- Tissue harmonic imaging
- Contrast agent imaging
- 3-D/ 4-D imaging.

#### 4.1.2.4 Physical Features

The desirable physical features depend on the clinical utility and the setting of the facility.

- Mobility (transportability): static, mobile, portable/emergency
- Screen size, positioning flexibility, foot print of the whole ultrasound machine
- Ergonomics of the work panel (up and down, side to side movements), siting of the buttons/controls.

### *4.1.3 Measurement/Analysis Features*

Standard measurements should include distance, area, circumference and volume. Specialized measurement/analysis calculations are needed for specific clinical applications such as vascular, obstetric or cardiac work.

### *4.1.4 Ultrasound Settings*

The common basic settings found in an ultrasound unit include:

- Magnification/Zoom facility (actual or digital)
- Cineloop review
- Adjustable number and depth of focal zones
- Adjustable signal processing facilities
- Customizable tissue specific pre-sets for individual clinical applications.

### *4.1.5 Annotation and Documentation*

#### 4.1.5.1 Display and Annotation

- Patient, center and date identification
- Text and anatomical site markings
- Ultrasound settings and indices.

#### 4.1.5.2 Documentation

There should be proper facilities for permanent recording and archiving of images. Various methods are available:

- Thermal printer (B/W)
- Color printer

- VHS or digital video recorder
- Connection to local laser printer
- Connection to local imaging network
- DICOM3 compatibility/print
- MO disk/DVD
- Flash memory drive.

## *4.1.6 Safety and Quality Assurance*

### 4.1.6.1 Ultrasound Bioeffects and Safety

Ultrasound is a high-frequency mechanical wave, thus it does not have the hazard associated with ionizing radiation such as X-ray.

There has been a very extensive research aimed at understanding the basic biophysics and evaluation of potential bioeffects. When ultrasound propagates through human tissue there are potential biological effects. Many studies are dose-effect studies and virtually all ultrasound-induced adverse bioeffects have occurred at higher intensities than diagnostic ultrasound.

The mechanisms by which ultrasound interacts with tissue are generally classified as:

- Thermal effects—heating of tissue as ultrasound is absorbed by tissue. Heat is also produced at the transducer surface;
- Cavitation—the formation of gas bubbles at high negative pressure;
- Other mechanical effects—radiation forces leading to streaming in fluids and stress at tissue interfaces.

### 4.1.6.2 Quality Assurance

In an imaging facility, quality assurance is a process performed to ensure that the equipment is operating consistently at its expected level of performance. During routine scanning every sonographer should be aware of any changes that can lead to suboptimal imaging that might require servicing. Quality assurance testing provides the confidence that image data, such as distance and area measurements are accurate and that the image is of the best quality for the scanning purpose.

A very common problem is wear and tear of the cable especially at the connections with the transducer. Cables should be robust with the protective casing one piece rather than with joints.

To establish a quality assurance programme would include the use of a general purpose imaging phantom and several test objects. There are several practical guidelines on ultrasound quality assurance such as the American Association of Physicists in Medicine (AAPM).

Basic tests include, but not limited, to the following:

- Transducer choice
- System sensitivity
- Photography and gray-scale hard copy
- Scan image uniformity
- Distance measurement accuracy
- Spatial resolution tests.

Quality assurance in ultrasound is further discussed in Chap. 8.

### 4.1.7 Equipment Trials and Training

Prior to the purchase of an ultrasound unit, it is highly recommended that the full range of clinical applications should be assessed. After installation, performance assessment should be evaluated. Application training for operators is an essential component of the successful and efficient implementation of the ultrasound service.

### 4.1.8 Equipment Review and Replacement

Rapid changes in technology and clinical expectations result in the need for frequent reassessment for possible upgrading or replacement. Software upgrades should be included when a purchase or maintenance contract is being negotiated.

Frequency and the type of array chosen should be appropriate for depth and penetration, therefore which body part or area is to be scanned (Table 4.1).

There are vascular focused and small parts probes. Most machines now have breast probes which are linear probes characterized by their wider foot print. Then, there are also multipurpose linear and curvilinear probes (Fig. 4.3).

Sector probes are the small conical shaped ones usually used in babies but also may be used for trans-temporal Doppler.

The transvaginal route allows the use of high frequency by applying the probe directly into the vaginal vault. It enhances the image resolution and clinical effectiveness. Table 4.2 shows the physical parameters of a transvaginal transducer.

**Table 4.1** Physical parameters of ultrasound transducers

| Transducer type | Frequency (MHz) | Body region | Axial resolution | Lateral resolution |
|---|---|---|---|---|
| Sector or curvilinear array | 3–6 | Abdomen | Moderate | Moderate |
| Linear array | 5–18 | Thyroid, carotids, breast, (other superficial sites) | Excellent | Very good |
| Curvilinear array | 5–10 | Paediatric abdomen/heart | Very good | Good |

| | |
|---|---|
|  |  |
| Linear array probe (5 to 17 MHz extended frequency range) (Courtesy of Philips Healthcare) | Transverse scan of the thyroid gland using a linear high frequency transducer (17 MHz). (Image courtesy of Sook Sam Leong) |
|  |  |
| Curvilinear array probe (1 to 5 MHz extended frequency range) (Courtesy of Philips Healthcare) | Transverse scan of the left lobe of the liver and the pancreas using a curvilinear transducer (5 MHz)<br>(Image courtesy of Sook Sam Leong) |

**Fig. 4.3** Photographs of linear and curvilinear probes and ultrasound images produced in a transverse scan

**Table 4.2** Physical parameters of transvaginal transducer

| | |
|---|---|
| Frequency | 4–9 MHz or higher wideband frequency imaging |
| Number of elements | at least 192 |
| Maximum depth | at least 140 mm |
| Maximum field of view | 170° |
| Array length | 32 mm |

Where there is limitation of choice or budget, the lower the frequency of the general abdominal probe the better, as it allows larger patients to be assessed. The priority is for quality of penetration rather than resolution (Table 4.3).

**Table 4.3** Specifications for general abdomen ultrasound unit

| Specification | Abdominal | |
|---|---|---|
| | Minimum | Optimum |
| *B-mode imaging* | | |
| Transducer:<br>Linear array (LA), curved linear array (CLA), phase array (PA) | CLA or PA | LA, CLA or PA |
| Frequency range (MHz) | 2–7 | 2–10 |
| Penetration (cm) | 15 | 18 |
| *Spectral Doppler* | | |
| Transducer:<br>Linear array (LA), curved linear array (CLA), phase array (PA) | CLA | LA, CLA or PA |
| Frequency range (MHz) | 2–5 | 1.5–4 |
| Calculation of waveform indices | Manual | Auto and Manual |
| Accuracy of range gate registration (mm) | <1 | <1 |
| Penetration (cm) | 10 | 15 |
| *Flow imaging* | | |
| Transducer:<br>Linear array (LA), curved linear array (CLA), phased array (PA) | CLA | LA, CLA, PA |
| Frequency (MHz) | 2–5 | 1.5–4 |
| Penetration | 10 | 15 |

### *4.1.9 Conclusion*

Ultrasound imaging is an indispensable diagnostic imaging tool. Its main advantages are its non-invasiveness and non-utilisation of ionizing radiation. Due to its relatively low cost and easy maintenance, it is readily available in most clinics and hospitals.

The clinical efficacy of ultrasound diagnosis has been proven in many disciplines. It provides a cost-effective solution to health-care in developing countries.

Selection of equipment and technical specifications depend on the clinical applications and the relative workload in each clinical setting.

## 4.2 Technical Specifications of X-Ray (Planar Radiography) Units

X-ray planar radiography is one of the mainstays of a radiology department, providing the front line screening for both acute injuries and suspected chronic diseases. Planar radiography is widely used to assess the degree of bone fracture in an acute injury, the presence of masses in lung cancer/emphysema and other lung pathologies, the presence of kidney stones, and diseases of the gastrointestinal (GI) tract. Chapter 2 discusses the uses this modality may have in a rural health center.

In order to make a right decision to purchase a suitable X-ray unit, this chapter explains the principles of selecting a general purpose X-ray unit, the general requirements and some technical specifications that are of interest.

### *4.2.1 X-Ray Equipment*

The basis of planar radiography is the differential absorption of X-rays by various tissues. For example, bone and small calcifications absorb X-rays much more effectively than soft tissue. X-rays generated from a source are directed towards the patient, as shown in Fig. 4.4. X-rays which pass through the patient are detected using an image receptor and then converted to a gray-scale radiographic image.

The digital image represents a two-dimensional projection of the tissues lying between the X-ray source and the detector. In addition to being absorbed, X-rays can also be scattered as they pass through the body, and this gives rise to a background signal which reduces the image contrast. Therefore, an 'anti-scatter grid' is used to ensure that only X-rays that pass directly through the body from source-to-detector are recorded. An example of a two-dimensional planar X-ray is shown in Fig. 4.4. There is very high contrast, for example, between the bones (white), which absorb X-rays, and the lung tissue (dark) which absorbs very few X-rays.

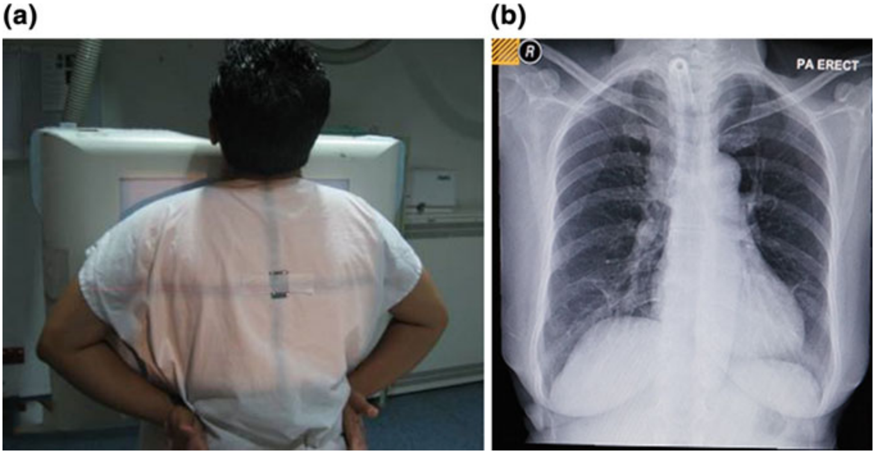


**Fig. 4.4** **a** Chest PA projection and its **b** radiograph image

The hardware component consists of the X-ray tube, a computer console, grid, image receptor, automatic exposure control (AEC) system, image storage and display. Figure 4.5 shows the block diagram of a general X-ray unit.

**X-ray tube** produces X-rays using a high voltage generator. For diagnostic imaging, the tube voltage used ranges from 40 to 150 kVp (kilo volt peak). The tube exposure is measured in mili ampere second (mAs). These are the two main exposure factors that are used to vary the X-rays energy and intensity. Nowadays, rotating anodes are often used so as to have a greater heat loading and higher X-ray outputs. Table 4.4 shows typical specifications for X-ray tubes.

**Couch**—supports patient positioning during examination. It may be flat or curved but must be uniform in thickness and as transparent to X-rays as possible. Carbon fiber couches are strong and absorb little of the X-Ray beam. This

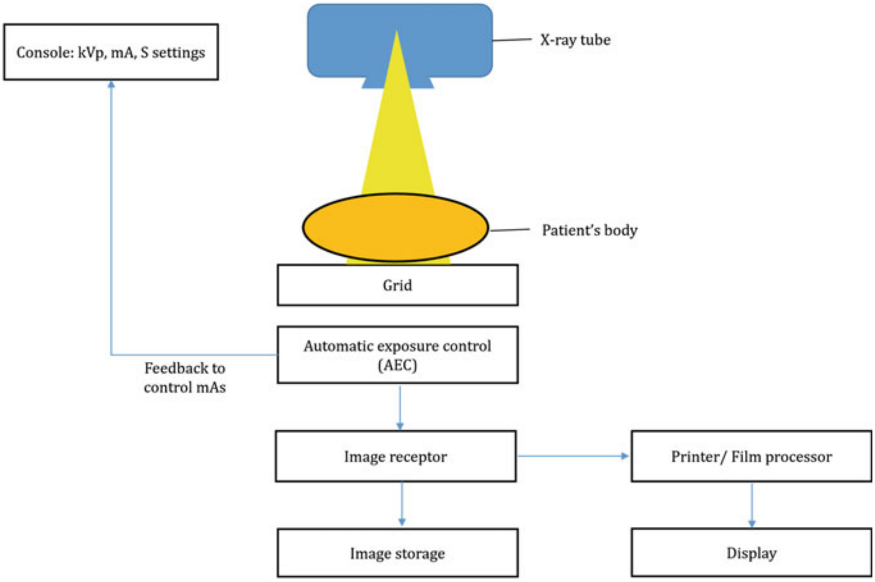


**Fig. 4.5** Block diagram of a general X-ray unit

**Table 4.4** Typical specifications for X-ray tubes

| Specification | |
|---|---|
| Maximum tube voltage (kVp) | 150 |
| Anode heat capacity (kJ) | 111–600 |
| Anode construction | Tungsten |
| Focal spot size (mm) | 0.3–0.6 (fine), 0.8–1.2 (large) |
| Target angle | 7°–20° (common: 12°–15°) |

contributes to reduced patient radiation dose. Most patient couches are floating, easily unlocked and are motor-driven. Just under the couch is an opening to hold a thin tray for a cassette and grid.

**Collimator**—A collimator consists of two pairs of lead shutters that are used to reduce the area of radiation exposure to the patient, thereby reducing unnecessary radiation dose. Collimator lamp and mirror projects a visible light field (which coincides with the X-ray beam) to help radiographers to delineate the area that will be exposed to radiation.

**Filtration**—Filtration refers to the effective change of X-ray beam spectra due to the presence of glass or metal envelope of X-ray tube and any additional metal filters (such as aluminium) that are placed in the beam line. For general-purpose tubes, the required total filtration is about 2.5 mm aluminium (Al).

**Cassette**—A cassette is a rigid holder that contains the image receptor. For screen-film (SF) radiography system, this will be the radiographic film and intensifying screens. For the computed radiography (CR) system, this will be the imaging plate. They are designed to be sturdy yet produce minimal attenuation of the X-ray beam.

**Bucky**—A Bucky also known as Porter-Bucky is a tray located under the X-ray table used to hold the cassette. Sensing devices in the tray identify the size and alignment of cassette. It also has a moving grid.

**Upright chest stand**—also called upright Bucky (Fig. 4.6a). It is used for the upright positioning of patient, e.g. for upright chest X-ray projections.

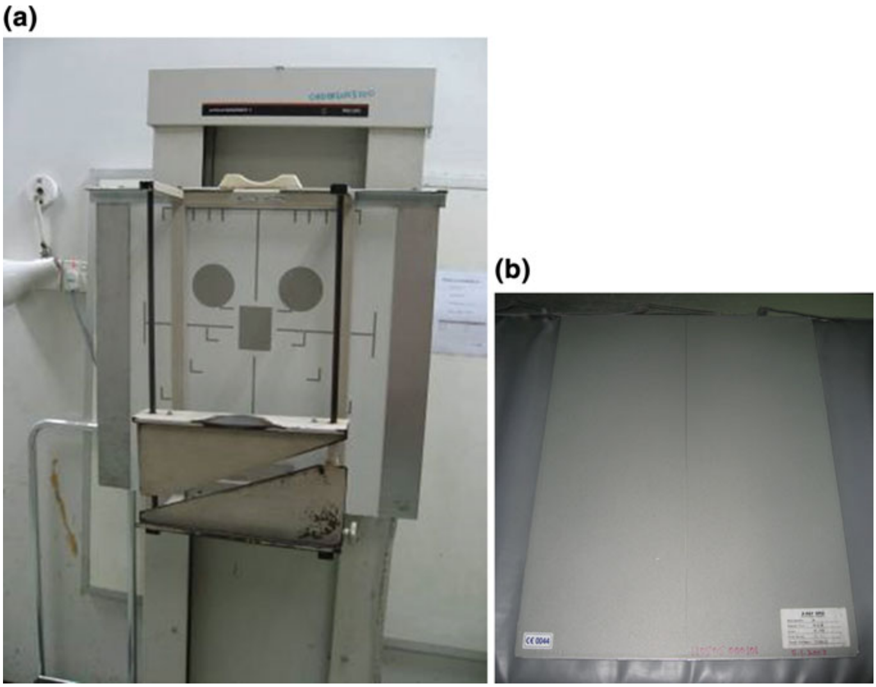


**Fig. 4.6** **a** Chest stand/vertical Bucky and **b** stationary grid

**Grid**—It is used to reduce the amount of scattered radiation reaching the image receptor (Fig. 4.6b). Large amount of scattered radiation reaching the receptor will reduce image contrast. There are two types of grid, the moving grid/Bucky's grid and the stationary grid. It is placed between the patient and the image receptor. There are different types of grid design, such as parallel, focused, and cross-hatched. Grids are mainly specified by the grid ratio. For general purpose use, grid ratios of 11:1 are recommended.

**Focal spot**—Most X-ray units offers two effective focal spot sizes known as the broad and fine focal spots. Common focal spot sizes are 0.8–1.2 mm for broad focal spot and 0.3–0.6 mm for fine focal spot. Fine focal spots are required for high spatial resolution imaging (such as extremities) at the cost of higher tube loading. Broad focal spots allows higher tube loading and enable the use of higher mAs.

### Automatic exposure control (AEC)

The AEC is a feedback system that is placed behind the image receptor. It uses an ionization chamber or other radiation detector to detect the amount of exposure required to produce sufficient darkening of the screen-film or detector. When the radiation dose to the detectors has reached a preset level, it automatically cuts off the tube exposure (mAs).

### Image receptor

Over the years, the technology of planar radiography has evolved from the conventional screen-film (SF) radiography system (Fig. 4.7) to computed radiography (CR) system (Fig. 4.8) and subsequently, direct digital radiography (DDR) system (Fig. 4.9). In all of these three systems, the main change was the technology of the

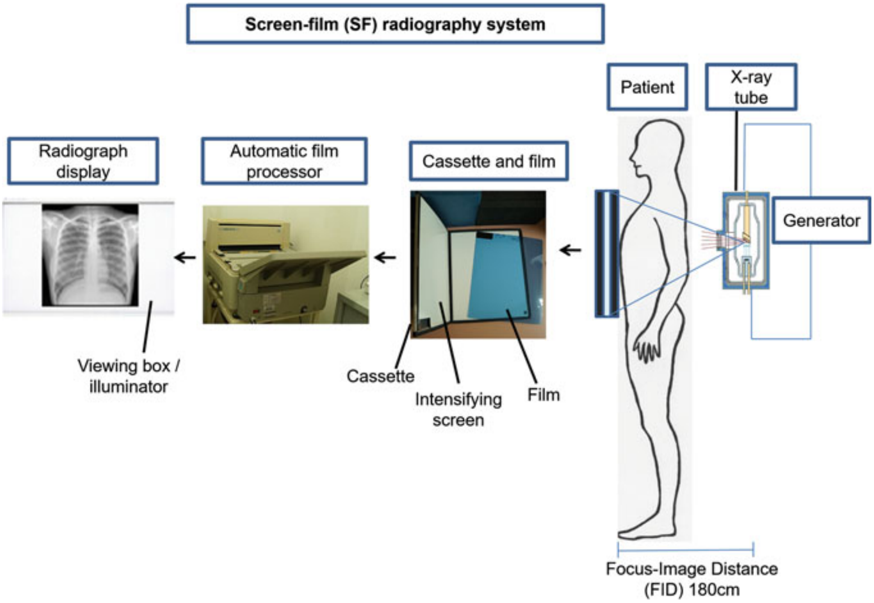


**Fig. 4.7** SF radiography system

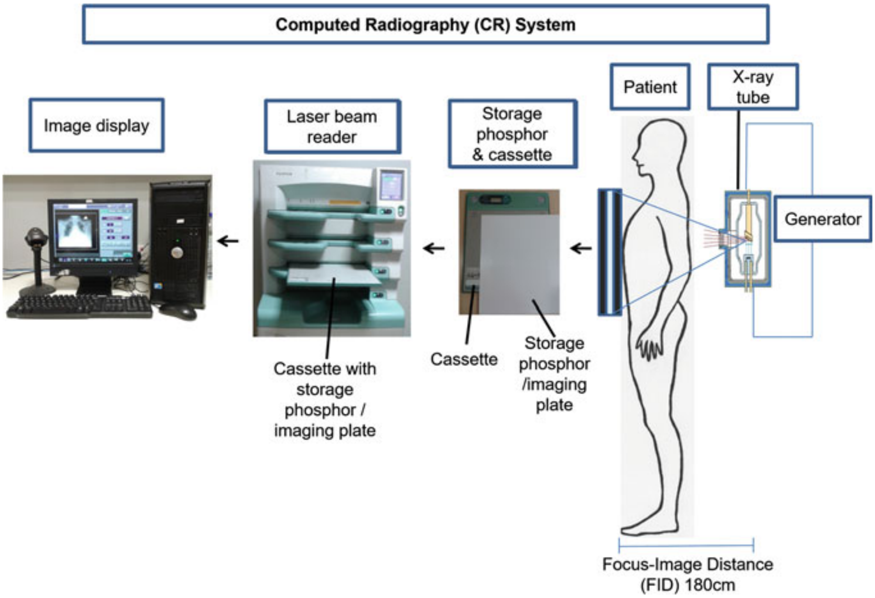


Fig. 4.8 CR system

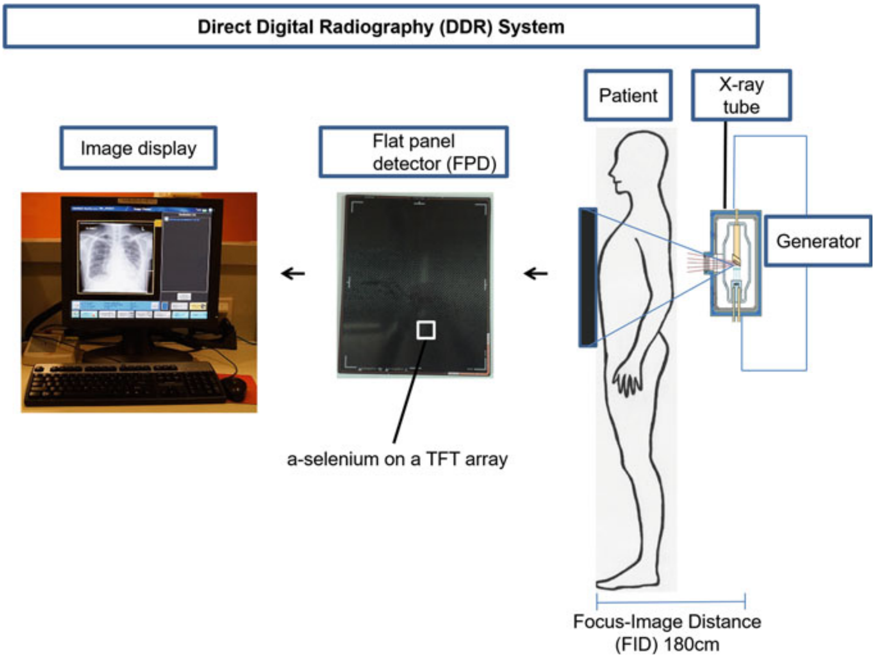


Fig. 4.9 DDR system

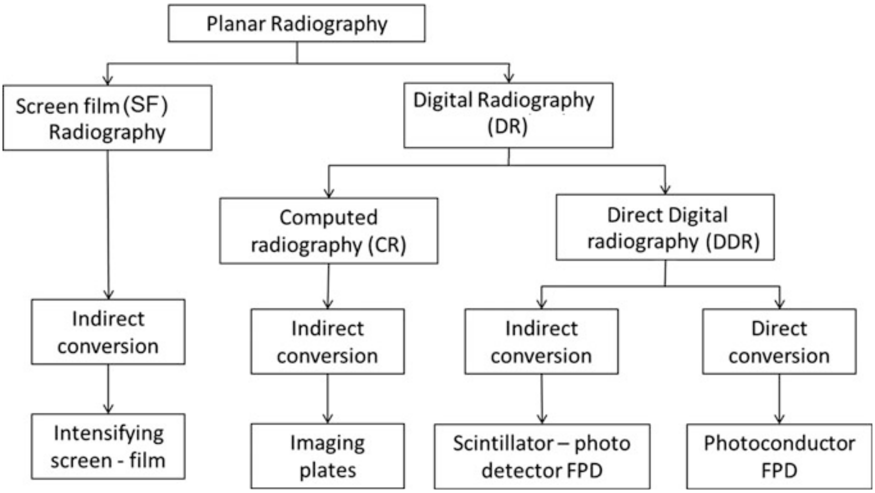


**Fig. 4.10** Chart showing the image receptors for SF, CR and DDR systems

image receptor. Further details of these three systems will be discussed in the following section. For now, it is sufficient to say that the image receptor or detector is a device that intercepts the X-ray photons transmitted through the patient body. The image information contained on the detector can be stored and retrieved instantaneously (in DDR system) or at a later time (in SF and CR systems) (Fig. 4.10).

## 4.2.2 Image Processing

### 4.2.2.1 Screen Film (SF) Radiography

SF radiography uses intensifying screens and a radiographic film sandwiched in a light tight cassette (Fig. 4.11). A dark room and a wet chemical processor is

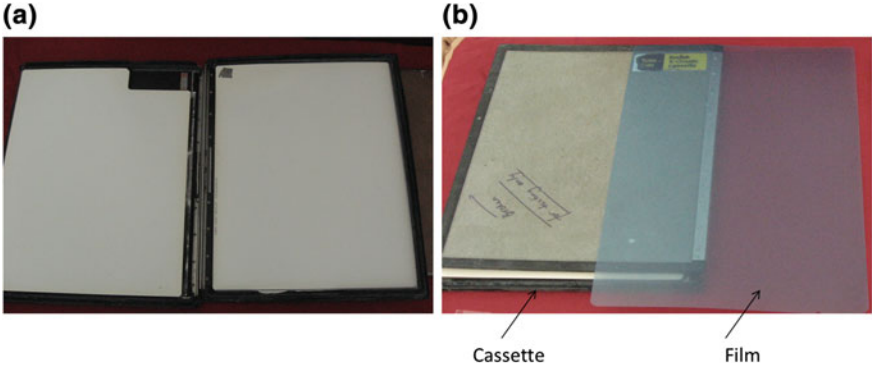


**Fig. 4.11** **a** SF cassette and **b** film

required to develop the radiographs. Exposure of X-ray radiation produces an invisible latent image within the film emulsion. The emulsion must be chemically processed to form visible and permanent information recorded in the latent image.

#### Film Processing

SF radiographs are processed and developed in a darkroom. A wet chemical processor is needed to perform this process. The processing cycle comprise of four main stages; development, fixing, washing and drying.

#### Darkroom

The area used for manual and automatic film processing is called a darkroom. This is an absolute necessity for the SF system but has gradually become obsolete with the advent of daylight imaging systems and electronic imaging systems. Table 4.5 lists some recommendations for the design and construction of a darkroom.

**Safelight**—Should provide sufficient illumination for handling and processing film in the darkroom.

#### Daylight Processor

The daylight processor automatically unloads the cassette, marks each film with patient's name or number, processes films and reload cassettes with fresh film. The entire unloading and reloading sequence only takes $\sim 15$ s.

### 4.2.2.2 Computed Radiography (CR)

A photostimulable storage phosphor (PSP), also known as imaging plate (IP), is the image receptor used in a CR system. The IPs are read using a CR reader (Fig. 4.12).

**Table 4.5** Set up recommendations for a darkroom

| | Recommendation |
|---|---|
| Location | • Centrally sited and services by hatches from adjacent imaging rooms<br>• Away from damp and hot areas<br>• Accessible in term of power and water supplies<br>• Adjoining a viewing area |
| Size | • Minimum floor size of 10 $m^2$ and ceiling height of around 2.5–3 m |
| Radiation protection | • If the darkroom is located beside an X-ray room, adequate shielding needs to be present in the wall to protect staff and radiographic films from radiation exposure/leakage |
| Floors | • Durable and easy to maintain<br>• Light-colored material for the low light working conditions<br>• Non-porous and non-slip material |

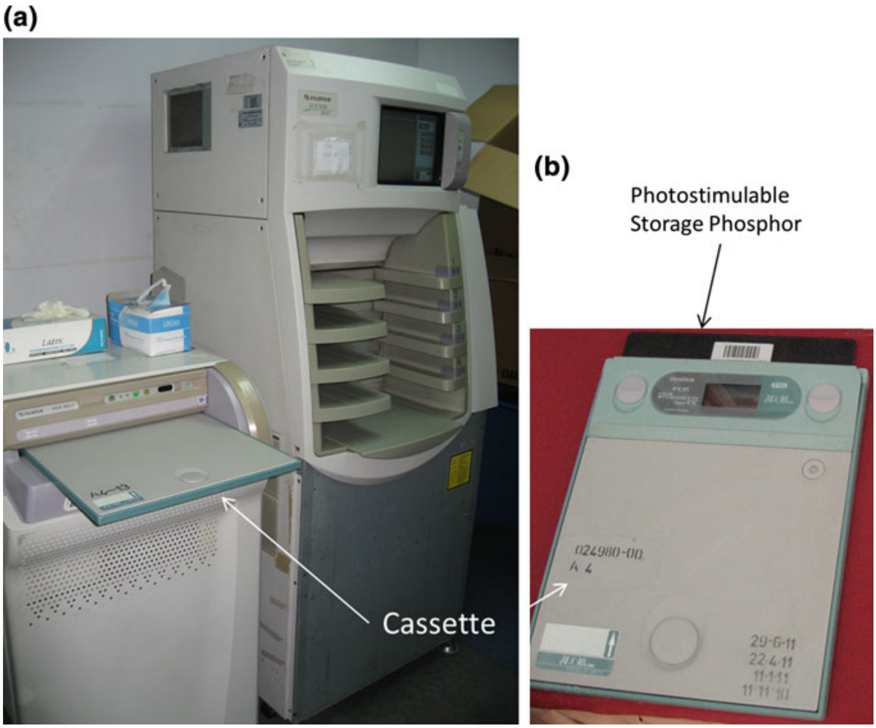


**Fig. 4.12** **a** CR reader and **b** imaging plate

The CR reader uses a red laser beam to scan the surface of the IP. This extracts the latent image from the IP which is then recorded in the computer for display. After the image is read, the residual signal on the IP is erased in the CR reader. The IP is then ready to be used for the next exposure. Table 4.6 shows the technical characteristics of some of the commercially available CR systems.

#### 4.2.2.3 Direct Digital Radiography (DDR)

DDR systems encompass a number of different technologies that are rapidly evolving. To date, the majority of DDR systems use thin-film transistor (TFT) arrays, commonly known as flat-panel arrays or flat panel detectors (FPDs). Figure 4.13 shows a photo of the image receptor of a DDR system.

Generally, there are two methods to produce the digital radiographic images, the indirect conversion and direct conversion method (refer Fig. 4.10). The indirect conversion method involves the use of an intermediate scintillator device which converts the energies of the X-ray photons to light photons. The light photons are then detected by photodetectors, which convert them into electrical signals. Common scintillators used are CsI(Tl) and $Gd_2O_2S$(Tb). Common photodetectors

**Table 4.6** Technical characteristics of selected CR systems

| Manufacturer | Fujifilm Medical Systems | Carestream Health | Fujifilm Medical Systems | Agfa Heathcare |
|---|---|---|---|---|
| Model | FCRProfect CS | CR975 | FCR Velocity | DX-S |
| IP type | ST-VI | GP | FP | HD |
| Phosphor type | Granular: BaFBr ($Eu^{2+}$) | Granular: BaFBr ($Eu^{2+}$) | Columnar: BaFBr ($Eu^{2+}$) | Columnar: BaFBr($Eu^{2+}$) |
| Phosphor thickness (μm) | 230 | 300 | 650 | 450 |
| Imaging area ($cm^2$) | 24 × 30 | 35 × 43 | 43 × 43 | 35 × 43 |
| Matrix | 2364 × 2964 | 2048 × 2500 | 4280 × 4280 | 3408 × 4200 |
| Pixel pitch (μm) | 100 | 168 | 100 | 100 |
| Image depth (bits) | 10 | 12 | 10 | 14 |

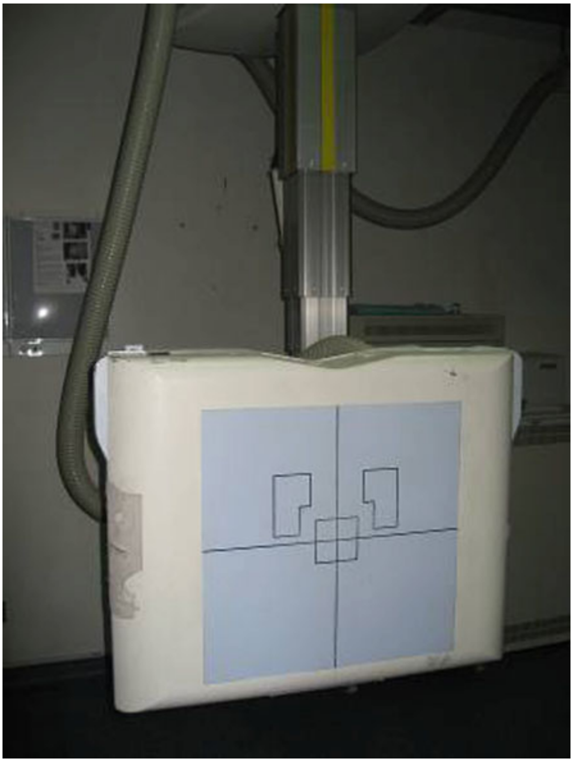


**Fig. 4.13** A photograph of a flat panel detector

**Table 4.7** Selected specifications of image receptors by various vendors

| Manufacturer | Konica Minolta Healthcare | Carestream Health | Canon | Toshiba | Toshiba | Philips Healthcare | GE Healthcare | Shimadzu Co. |
|---|---|---|---|---|---|---|---|---|
| Model | AeroDR HQ 1717 | DRX-1/DRX-1C | CXDI-401C/G | FDX3543 RPW | FDX4343 RP | Digital DiagnostVM | Revolution XR/d | RADspeed Pro V4 |
| Type of system | Indirect FPD (wireless) | Indirect FPD (wireless) | Indirect FPD (wireless) | Indirect FPD (wireless) | Indirect FPD | Indirect FPD | Indirect FPD | Indirect FPD |
| Converter readout | CsI (TI)<br>Active silicon | $Gd_2O_2S$(Tb)/CsI (TI)<br>Active silicon | CsI (TI)<br>Active silicon | CsI (TI)<br>Active silicon | CsI (TI)<br>Active silicon | CsI (TI)<br>Active silicon | CsI (TI)<br>Active silicon | CsI (TI)/ $Gd_2O_2S$<br>Active silicon |
| Detector size (in) | 17 × 17 | 14 × 17 | 18.4 × 18.4 | 14 × 17 | 17 × 17 | 17 × 17 | 16.4 × 16.4 | 17 × 17 |
| Pixel size (μm) | 175 | 139 | 125 | 140 | 143 | 143 | 200 | 139 |
| Matrix | 2428 × 2428 | 2560 × 3072 | 3320 × 3408 | 2466 × 3040 | 3008 × 3072 | 3001 × 3001 | 2048 × 2048 | 3052 × 3052 |
| Image depth (bits) | 16 | 14 | 14 | 14 | 16 | 14 | 14 | 14 |
| Image preview time | Approx. 2 s | Approx. 6 s | Approx. 3 s | Approx. 4 s | Approx. 4 s | Approx. 7 s | Approx. 5 s | Approx. 3 s |

are silicon detectors. Table 4.7 shows some examples of the specifications of image receptors by various vendors. In the direct conversion methods, the X-ray photons are directly absorbed by a 2D array of photoconductors (usually amorphous selenium) and then converted to electrical signals.

The DDR systems are also called cassette-less systems, whereas the CR system are also called cassette-based systems.

Digital images are comprised of large matrices of small picture elements, or pixels. Each pixel is represented by a numerical value relating to the brightness of the image. The advantage of digital images is that they can be post processed digitally using many of the computer software programs. The ability to perform image processing on digital images is a key feature and advantage of DR systems.

### *4.2.3 Image Display*

The viewing of the radiographs or images extracted from the image receptors differs depending on the technology. Screen-film (SF) radiography uses the conventional method of sticking the radiographs onto a diagnostic grade illuminator or viewing box. As for computed radiography (CR) and direct digital radiography (DDR) technologies, the images can either be printed using a dry printer and view via conventional view-boxes, or displayed on a diagnostic grade monitor. The advantage of a softcopy display is that it allows the radiologist to manipulate the contrast and brightness of the digital images when viewing them.

#### 4.2.3.1 Viewing Radiographic Films (SF Radiography)

In SF radiography, optimum displays of radiographs are closely linked with the choice of the intensifying screens and radiographic films used. Factors that must be considered when selecting screen-film combinations includes: contrast, speed, spectral matching, anti-crossover or antihalation dyes, and requirement for a safelight.

Different vendors produce radiographic films that are coated with different emulsions. The absorption of light is different depending on the emulsion. This is because in the manufacturing process, color sensitizers are incorporated into the film emulsion to control its spectral response. Film emulsion without sensitizer (also called monochromatic emulsion) is more sensitive to blue, violet and ultraviolet light. When a sensitizer is incorporated, the spectral response can be extended into green light (orthochromatic emulsion) and red light (panchromatic emulsion).

Intensifying screens are scintillators which convert the X-ray photons into light photons. The light photons then produce darkening of the radiographic films. The use of intensifying screens are necessary to reduce the amount of X-ray photons needed to produce sufficient darkening of the radiographic films, while reducing radiation dose to patients.

**Table 4.8** The color of the light photons produced by different types of intensifying screens

| Intensifying screen | Activator | Color |
|---|---|---|
| Gadolinium oxysulphide, $Gd_2O_2S$ | Terbium | Green |
| Lanthanum oxysulphide, $La_2O_2S$ | Terbium | Green |
| Ytrium oxysulphide, $Y_2O_2S$ | Terbium | Blue |
| Ytrium tantalate, $YTaO_4$ | Niobium | Blue |
| Lanthanum oxybromide, LaOBr | Thalium | Blue |

Conventionally, intensifying screens are made of calcium tungstate however nowadays intensifying screens that are commonly in use are rare-earth screens such as $Gd_2O_2S$, LaOBr, and $YTaO_4$ (Table 4.8). Rare-earth screens are more efficient (3–5× more efficient) than calcium tungstate in converting the X-ray photons into light photons. This means that with the same amount of radiation exposure, more light photons are emitted, increasing the radiographic speed and significantly reducing patient dose.

The correct matching of the intensifying screens with the spectral response of the respective radiographic films is important in order to achieve optimum performance of the film.

SF systems are often described by their "speed index" or sensitivity. Speed index is used to compare the relative exposure requirements of different receptors. Most speed numbers are referenced to a so-called par speed system that is assigned a speed value of 100. A higher speed index corresponds to a faster film. This means less radiation is needed to produce an image, although the radiograph will be noisier (more grainy). Table 4.9 shows the range of speed index available and general recommendation of their clinical applications.

Both film and intensifying screens could have variable speed. The speed index of a film screen combination is calculated using the following equation:

$$Total\,speed = \frac{Film\,speed \times screen\,speed}{100}$$

To achieve optimum speed, a correct matching of screens to films (spectral matching) is essential. Intensifying screens may emit blue (for conventional screens) and green (for rare earth materials) lights. The films to be used must be sensitive to the respective color of light photons emitted by the intensifying screens (Table 4.10).

**Table 4.9** Speed index and general clinical applications for each speed index

| Speed index | Comments | Clinical application |
|---|---|---|
| 100 | For imaging fine detail | Mammography |
| 200–400 | For imaging fine detail | Extremities |
| 400 | For general radiography | General radiography |
| 600–800 | | Lumbar spine and lumbar sacral joint imaging |

**Table 4.10** Different vendors with selected examples of their film and intensifying screen speed combinations

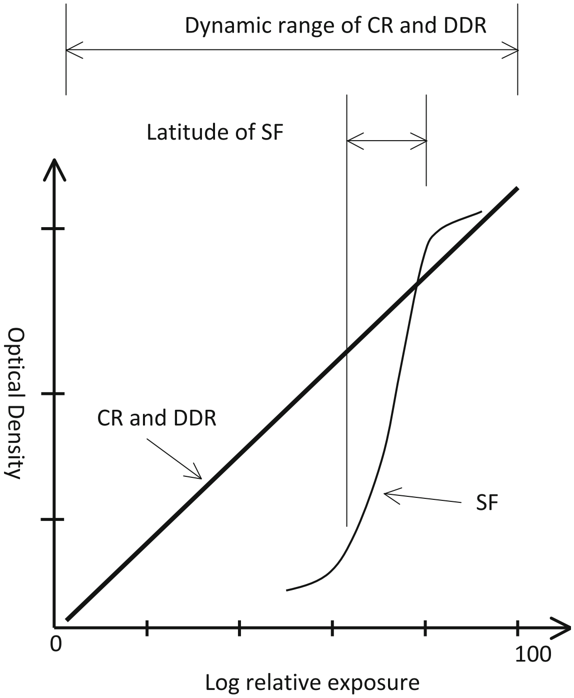
| Vendor | Film | | Intensifying screen | | System speed/speed class |
|---|---|---|---|---|---|
| | Model | Spectral response | Model | Spectral emission | |
| Carestream | X-Sight G/RA | Green | X-Sight | Green-emitting rare earth | 400 |
| | T-MAT G/RA | | Lanex | Green-emitting rare earth | 100 (Fine) |
| | | | | | 250 (Medium) |
| | | | | | 400 (Regular) |
| | | | | | 600 (Fast) |
| Fujifilm | Super HR-T/ Super HR-U | Green | HR screen | Green-emitting rare earth | 120 (HR Fine) |
| | | | | | 200 (HR Medium) |
| | | | | | 300 (HR Medium plus) |
| | | | | | 400 (HR Regular) |
| | | | | | 600 (HR Fast) |
| | | | | | 800 (HR Ultra Fast) |
| Agfa | Cronex10T | Blue (half speed) | CP-B 200 (Quanta Detail) | Blue-emitting | 100 |
| | | | CP-B 400 (Quanta Fast Detail) | | 200 |
| | | | CP-B 800 (Quanta Rapid) | | 400 |
| | CURIXHT-G | Green | Ortho RE 100 | Green-emitting rare earth | 100 |
| | CURIXHTL Plus | | Ortho RE 400 | | 200 |
| | | | Ortho RE 400 | | 400 |
| | | | Green RE 100 | | 600 |
| Konica Minolta | MGX-SR | Green | KF | Green-emitting rare earth | 100 |
| | MG-SR | | KM | | 300 |
| | MGL-SR | | KR | | 400 |
| | | | KS | | 600 |
| | MGT-SR | Green | KR | Green-emitting rare earth | 300 |
| | | | KS | | 400 |

(continued)

**Table 4.10** (continued)

| Vendor | Film |  | Intensifying screen |  | System speed/speed class |
|---|---|---|---|---|---|
|  | Model | Spectral response | Model | Spectral emission |  |
|  | MGV-SR | Green | KF | Green-emitting rare earth | 150 |
|  |  |  | KM |  | 400 |
|  |  |  | KR |  | 600 |
|  |  |  | KS |  | 800 |

**Fig. 4.14** Characteristic curves of a CR and a SF system



One of the major limitations of the SF system is that the radiographic film has a limited dynamic range or latitude to produce a diagnostic quality radiograph. Figure 4.14 shows the characteristic curves of a CR and a SF. The SF system characteristic curve has a sigmoid shape, with toe and shoulder regions that are flattened out. This indicates that these regions are not useful to display a change in the optical density (contrast), and hence the X-ray attenuation properly. If the SF system is exposed at these regions, the image would either be underexposed (too bright) or over exposed (too dark).

CR and DDR systems have characteristic curves that are linear, indicating that usable contrast is achievable throughout the entire range of exposure.

#### 4.2.3.2 Viewing Digital Images (CR and DDR Radiography)

The image extracted from the IP and digital FPD can be viewed on computer monitors or printed out using dry printers and viewed using the conventional view box.

However, in order to display diagnostic quality digital images, one needs to ensure that a good network system, i.e. a picture archiving and communication system (PACS) and medical grade monitor is in place. A PACS is a medical imaging technology which provides economical storage of and convenient access to images from multiple modalities. In order for digital images to be transferred on the imaging network between different vendors and modalities, it is often necessary for the image to be stored in DICOM (short for *Digital Imaging and Communication in Medicine*) format. The use of a medical grade monitor is also necessary in order to be able to display the full bit-depth of the image.

### *4.2.4 Implementation consideration in SF, CR and DDR*

| | Pros | Cons |
|---|---|---|
| SF technology | • Low initial cost to setup<br>• Conventional film technology allows us to detect mistakes; if overexposed the film is too dark and if underexposed the film is too bright | • Screen-film technology is not efficient in image formation<br>• Rather restricted film latitude and contrast<br>• Radiographers must be well trained to use the appropriate exposure parameters to obtain diagnostic image quality<br>• Higher retake rates<br>• Require darkroom and chemicals<br>• Require proper chemical waste disposal |
| CR technology | • Cheaper startup cost compared to direct DR system<br>• Since it is cassette technology, it can be retro-fitted to conventional radiography system easily<br>• Wider dynamic range thus lower retake rates<br>• Spatial resolution with imaging plate is lower than that with screen-film technology; however contrast resolution is higher. Thus overall image quality is equivalent or even better than screen-film technology<br>• Green technology—no chemicals needed<br>• Image quality may be inferior to direct DR systems | • Require workstation, display monitors and network to utilize the system more fully<br>• It is still a cassette-based system |

(continued)

(continued)

| | Pros | Cons |
|---|---|---|
| Direct DR technology | • Substantial increase in throughput and more efficient workflow<br>• Very low retake rates due to very wide dynamic range<br>• Electronic transmission of images<br>• Mass storage of image files in hard disks<br>• Softcopies of images allow post-processing and easy image manipulation<br>• Green technology—no chemicals needed | • High initial setup cost, require the installation of an entirely new system<br>• The image receptor is very expensive<br>• Over- and under-exposure can go unnoticed as image processing compensates and produces 'good' diagnostic images<br>• Movement of detector is inflexible thus certain radiography views are difficult to obtain<br>• Require workstation, display monitors and network to utilize the system more fully<br>• Careful handling of DR detectors is needed due to its fragile nature |

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## Useful Organizational Resources

1. American College of Radiology, www.acr.org
2. American Association of Physicists in Medicine, www.aapm.org.
3. Institute of Physics and Engineering in Medicine, www.ipem.org.uk
4. International Atomic Energy Agency, www.iaea.org
5. International Union for Physical and Engineering Sciences in Medicine, www.iupesm.org
6. World Health Organization, www.who.org

# Part III
# Planning a Medical Imaging Service

# Chapter 5
# Equipment and Physical Infrastructure

**Cari Borrás and K. Siddique-e Rabbani**

**Abstract** In the planning of medical imaging services, it is important to consider the minimum requirements of equipment and facilities. In this chapter, ultrasound and X-ray units considered appropriate for rural health centers are considered in terms of image quality, cost and tele-imaging capabilities. Equipment procurement issues such as acquisition schemes, development/review of technical specifications, warranties, and obsolescence issues are discussed. The need for the availability of operation and service manuals as well as replacement parts, accessories and software upgrades throughout the life of the machine is emphasized. Guidance is given on the actual process of acquiring a unit and the site preparations involved, including the various permits needed. Examples of ultrasound equipment for low resource settings and the possibility of having ultrasound probes connected to a personal computer are explored. WHO's efforts in promoting the development of a versatile, high quality, low maintenance and inexpensive X-ray unit are reviewed.

**Keywords** Equipment procurement · Ultrasound units · X-Ray units · Radiation shielding

## 5.1 Equipment Procurement and Acquisition

### *5.1.1 Planning of Medical Imaging Services*

Health care centers should be organized based on their technological complexity and should be incorporated within the general organization of health services depending on their stratification by levels of care. The criteria for the geographical

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and institutional placement of imaging services should be determined within each health services system in accordance with its parameters of accessibility and its definitions of levels of care. Prior to planning any service, it is essential to do a thorough analysis of morbidity and mortality in the community and to assess what impact the services may have in the overall patient management [1, 2]. The need for the services to be part of a patient-centered integrated health care system is further addressed in Chap. 9. There are three main considerations when establishing medical imaging services: equipment, facilities and staff. This chapter deals with equipment and facilities; Chap. 6 will discuss staff issues.

## *5.1.2 Equipment Procurement*

### 5.1.2.1 Acquisition Schemes

Ideally, equipment should be acquired new. However, resource-limited countries should be discouraged to acquire prototype medical devices, which have not have been fully tested clinically and have not been approved either by the US Food and Drug Administration, carry the CE mark or been authorized for use by the country's own National Authority, if there is one.

One possibility is not buying but leasing the equipment. This option can be attractive when compared to the high capital cost of some items, and it gives the vendor an incentive to keep equipment operational [3].

Another acquisition possibility is what is called the "turn-key" solution, when the whole service is acquired "ready-to-use" and it even includes the staff. However, this option can be very complex, as it still requires "careful contract planning, progress monitoring and acceptance checks" [3], and unless some local personnel is hired to work in the facility, there is no transfer of technology from the donor to the recipient.

An easier possibility is to acquire used equipment. This may have two advantages. One, clearly, is reduced cost, but another one, often overlooked, is the potential familiarity with the equipment that the physician or technician—who is going to be responsible for its clinical use—may have. This second factor may be very important, since it may guarantee a more effective and safe utilization of the equipment.

Second-hand equipment may be acquired through purchase or through donations. Guidelines referring to health care equipment donations have been addressed extensively by the World Health Organization (WHO) [4, 5], which states that because of economic constraints, in some countries, nearly 80 % of health-care equipment is donated or funded by international donors or foreign governments. Donors include corporations acting directly or through other organizations, individuals, nongovernmental organizations, and governments providing aid to other governments.

WHO's [4] four core principles underlying the guidelines are:

(a) A health care equipment donation should benefit the recipient to the maximum extent possible;
(b) A donation should be given with full respect for the wishes and authority of the recipient, and be supportive of existing government policies and administrative arrangements;
(c) There should be no double standards in quality: if the quality of an item is unacceptable in the donor country, it is also unacceptable as a donation;
(d) There should be effective communication between the donor and the recipient 'donations should be based on an expressed need and should not be sent unannounced'.

Part of this communication involves responsibilities of the recipient health facility before agreeing to accept a donation. For example [5],

- Check that the equipment conforms to national policy, and is suitable for the facility and staff.
- Confirm that the equipment only requires spare parts and consumables that can be afforded using available budgets.
- Check whether the equipment will come with its relevant accessories, consumables, manuals and some spare parts, so that it can function and be used.
- Confirm whether the donor will be responsible for covering the costs of transport, freight, insurance, import duties, customs clearance, and installation and commissioning costs, if applicable. If not, has money been put set aside for this?

Some of these issues are discussed in the following sections.

If the used equipment is not to be acquired through a donation but through a purchase, it may make a difference whether it is bought from a medical facility or from a commercial vendor, and in the latter case, whether the equipment has been refurbished, and what warranties are offered. WHO [5] suggests that "consulting and involving local vendors, where they exist, will help to establish beneficial relationships between the users and the vendors of equipment and can prove to be less expensive than donations". Regardless, when acquiring second-hand equipment, previous service records should be obtained and the availability of replacement parts, assessed. Issues specifically regarding refurbished and/or second hand equipment were discussed by Borrás [6].

#### 5.1.2.2 Development/Review of Technical Specifications

Equipment should comply with the original manufacturer's specifications, whether acquired new or used. For second-hand equipment, proof of compliance should be obtained before the equipment is acquired. If an original feature is no longer functional, but the equipment could still be used, this should be clearly indicated in the documentation provided by the donor/seller. The impact on the rest of the equipment of bypassing a particular feature should be carefully considered. Let's assume a rural health center is considering purchasing/accepting a conventional radiographic unit, where the automatic collimation (positive beam limitation) is no longer functional, but where the collimator scale indication, the light field and the radiation field sizes coincide with each other within acceptable tolerances. The unit may be acquired. On the other hand, if the temperature display in an automatic film processor is no longer operational—the right temperature is critical for image quality purposes—the unit should not be acquired, as immersing a thermometer in the developer tank to read the temperature is cumbersome.

The main problems with older equipment are usually not caused by electrical components which can be easily replaced, but by mechanical parts. There is something called "material's fatigue" which will eventually make the equipment operate outside tolerance. A typical example is the motion of the collimators of an X-ray unit, which may get stuck or may open asymmetrically.

### 5.1.2.3 Warranties and Obsolescence

New equipment always comes with warranties, but refurbished equipment can be sold also with warranties, usually for one year of operation. Whenever possible, such a warranty should be obtained. It is important to establish exactly whether it includes parts (X-ray tubes are very costly for example) and when actually the warranty starts. Ideally, it should start after acceptance testing. Criteria for good refurbishment practices have been published [7].

Even if the equipment is in good operating condition, and even if it meets the manufacturer's specifications, its acquisition may be not be warranted if the equipment is obsolete. The concept of obsolescence needs to be understood clearly. Because a piece of equipment was manufactured long time ago, it does not have to be obsolete. The equipment may be obsolete if it has been replaced by a different type which allows to reach the diagnosis of some health condition with significantly greater accuracy. This is particularly true for ultrasound units, which have improved tremendously over the years.

Because obsolescence should be decided on a clinical basis, it may not be understood by the health authorities, which—on the basis of reduced cost—may accept purchasing or receiving equipment that is functional but obsolete, with its potential detrimental effects on the health care system. Worse, such an acquisition may delay the purchase of a better unit.

### 5.1.2.4 Operation and Service Manuals

No piece of equipment should be acquired without operation and service manuals. These should available, as required by the International Basic Safety Standards [8], in "appropriate language understandable to users". This may be difficult if the language of the original owner of the equipment was different from that of the intended recipient and the equipment is no longer being manufactured. The possibility of having the manuals translated should be explored and such a cost, budgeted. If it is a donation, the donor may be asked to include the translation cost as part of the donation.

#### 5.1.2.5 Accessories and Replacement Parts

Some equipment cannot function without accessories. When acquiring second-hand equipment, it is important to assess whether the original accessories come with the main unit. It is also essential that replacement parts be available from the original manufacturer or a reputable distributor for the length of the intended use of the equipment. WHO recommends that manufacturer's support—including spare parts and accessories—be available for a minimum of two years and preferably four [4].

The recipient institution should investigate from the original manufacturer their intended time length to support the equipment and whether local distributors and/or third party maintenance organizations have spare parts and accessories in stock, for how long and at what cost. Ideally a donated medical imaging equipment should come with a maintenance contract, preferably for 10 years. WHO suggests that the donation of a used X-ray system includes a new X-ray tube to ensure availability of a working replacement [5].

#### 5.1.2.6 Software Upgrades

Nowadays software is as important as hardware. Equipment which uses some kind of software, especially if it is no longer manufactured, may have old software versions which may be out of date, or if nothing else, awkward to use. Computer programs have changed dramatically in the last years and their use is now easier than before. From a safety point of view, software should be "user-friendly" and their use, straightforward. Before acquiring any equipment, the availability of software upgrades should be explored from the original manufacturer and budgeted.

### *5.1.3 Equipment Acquisition Process*

#### 5.1.3.1 Obtaining Authorization from the Regulatory Authorities

The acquisition of medical imaging equipment needs to comply with national regulations. If the equipment emits ionizing radiation emitting, it should comply with radiation safety standards. Facilities of countries with radiation protection legislation/regulations need to seek approval of the Regulatory Authority before acquiring the equipment. The authorization process may require registering the equipment or licensing the installation [8]. Most manufacturers including refurbishing companies will not sell any piece of equipment to a foreign country until such documentation is produced. Regulatory authorities may require compliance with safety standards for the equipment per se, the building which is to house it and in regards to the radiation protection, a list with the qualifications of the personnel who is to operate it. Requirements may be more stringent if the facility plans to introduce new radiological practices, in which case it may also need clearance from other governmental entities such as the Ministry of Health which regulates medical practices.

In facilities of countries that do not have any radiation safety legislation, the facility manager has to assume the responsibility to ensure that the equipment and its use comply with international safety standards such as those of Ref. [8]. The compliance should be documented in writing and made available to the staff and to the patients and public if so required.

#### 5.1.3.2 Clearing Customs

If the equipment comes from a foreign country, importation permits are required and may have to comply with regulations other than radiation safety regulations. The facility manager should make sure of custom clearing processes well before the equipment arrives and have all the required documents ready.

#### 5.1.3.3 Site Preparation

It is very important that there be good coordination between equipment acquisition and site preparation. The facility manager should ensure all the arrangements have been made so that the room in which the equipment is to be housed is ready before its arrival, so that its installation can proceed smoothly. Too often in developing countries one sees expensive X-ray units in the middle of hospital gardens waiting for the facility to complete construction. In the case of ceiling-mount units, it is important to consider the minimum ceiling height and the load bearing requirements for the ceiling [5].

#### 5.1.3.4 Equipment Installation

Ultrasound units, even fixed ones, may be easy to move into their intended location within the health center, but the installation of X-ray machines may require cranes or other heavy machinery. The availability of all installation tools must be assured in advance of equipment arrival. Contractors and local staff must be properly protected and monitored if they can be exposed to ionizing radiation during their work. Accessories and supplies should be available at the time of installation to ensure that they are compatible and that the equipment can be operated in a safe manner.

### *5.1.4 Evaluation of Costs*

The costs involved in the provision of radiological services have a significant impact on the type of medical imaging modality the health center plans to offer. Special attention should be given to the replacement of technologies, for example the change from conventional to digital radiography. When evaluating costs, it is insufficient to just consider the price of the equipment; it is necessary to assess the cost of the whole medical imaging service and the time it will take the facility to amortize the expenses. The costs can be categorized as capital costs, installation costs, siting costs, operational costs and humanpower costs.

#### 5.1.4.1 Capital Costs

Capital cost is the price of acquiring the unit. WHO [4] cautions regarding new vs used equipment options. It states that:

> "Hospitals are typically paid 10 to 15 % of the original price for their used equipment by brokers and dealers. After the equipment is refurbished, it is typically sold for 45 to 60 % of its original cost. But new equipment can usually be purchased at discounts ranging from 95 % to 80 % of the list price. This means that buying equipment that is 5 to 15 years old and increasingly difficult to support usually costs one-third to two-thirds the cost of new equipment. In addition payment for used equipment usually becomes due in a lump sum on delivery, while leasing, rental, re-agent contracts, and other financial mechanisms for new equipment may often prove wiser than the purchase of used equipment. And new equipment often has safety and performance advantages, as well as better availability of spare parts and training".

In this chapter, Sect. 5.2 discusses specific issues related to ultrasound and X-ray units specifically designed for resource-limited health centers and the potential impact of cost on image quality.

#### 5.1.4.2 Installation and Siting Costs

Installation costs include all room modifications and equipment transportation. If the equipment comes from a clinical facility rather than from a refurbishing firm, there may also be costs involving the dismantling and packing of the equipment in the original site. The costs of transportation from there to the facility also need to be considered. Custom fees, when applicable, can also enter in this category. To contract a company that will take care of all the steps involved may be the best solution.

#### 5.1.4.3 Operational Costs

Operational costs include registration and license fees, which normally are required on a periodic basis, as well as utility consumption such as electricity and water, phone lines and internet connections. Supplies and consumables are also part of the operational costs. When considering acquiring second-hand equipment, the provision of consumables should be carefully budgeted. All too often, donated radiographic units lie idle because the recipient facility does not have money to buy X-ray film.

#### 5.1.4.4 Humanpower Costs

Humanpower costs are incurred at all stages of the acquisition process, from the time the facility decides to acquire the unit until it is placed in clinical use, when the equipment is in operation, and when it needs to be discarded. It is essential that before the acquisition decision is taken, the facility management is sure that there is or will be adequate personnel for its operation and maintenance.

#### 5.1.4.5 Hidden Costs

The health center should be aware that there are many hidden costs in the operation of a medical imaging practice. These are not only indirect costs such as facility and equipment depreciation, but unexpected fees arising from legal, accounting, clinical, architectural, engineering and medical physics consultations.

#### 5.1.4.6 Sustainability Considerations

Prior to equipment acquisition, facilities should ensure through appropriate budgeting that there is adequate and properly trained staff for its operation and that the equipment can be maintained during its projected life time. If the equipment is second-hand, it may require more corrective maintenance than a new equipment and thus the maintenance budget should be increased. Discarding the equipment at the end of its life cycle should also be contemplated and disposal costs, budgeted. A significant consideration in the planning process is to estimate the future procurement needs and to include in the budget the replacement cost of the equipment. For this, it is essential to estimate the useful life of each piece of equipment. “Planned replacement of equipment helps to safeguard patient safety, ensure quality of results and reduce the cost of repairing old equipment that is no longer supported” [3].

Additional relevant issues to procurement of medical devices can be found in WHO’s publication “Procurement process resource guide” [3].

## 5.2 Capital Costs Versus Quality of Medical Imaging Equipment in Low-Resource Settings

### *5.2.1 Ultrasound Equipment*

High quality standard ultrasound scanners are very expensive, upwards from $50,000. Even refurbished units would be in the price range of $20,000. In the future, most of the low resource countries will need tens of thousands of remote centers in the rural areas to cover all of their population. For example, Bangladesh [9] with a population of about 160 million has around 450 semi-rural hospitals with an average of 50 beds each and all of these are equipped with X-ray and ultrasound equipment together with pathological facilities. This is beyond the district level hospitals and tertiary care hospitals in the towns and cities which together number around 80. At the bottom of the ladder, there are about 12,000 community clinics having rudimentary facilities taking care of an average of 6000 people each. It is estimated that more than 18,000 such clinics will be needed to cover the entire rural population. Ideally all the 18,000 community clinics would be target stations for telemedicine, and this shows the huge costs involved in equipment terms. Therefore, even if the quality is not as high as that of the machines operating in advanced hospitals, one needs to go for a minimum cost for any equipment including tele-ultrasound, discussed in Chap. 7. However, the equipment should have adequate quality to give a doctor enough details for primary diagnosis of common disorders and for pregnancy, at least for screening purposes.

Figure 5.1 shows an ultrasound unit from a well known manufacturer priced over $20,000 for refurbished units (all costs are 2015 values). Even some claimed

**Fig. 5.1** GE Logiq 9 ultrasound equipment, general purpose [10]

‘low cost’ units developed by certain research groups in the industrially developed countries, aiming at the low resource countries, are not low enough. Some of them are priced at about $10,000, which is still very high. Some portable PC units are available from Chinese manufacturers costing about $1200–$2500. The price is still high, but so far, these are the lowest commercial devices available. Figure 5.2 shows a wireless probe that may be useful as it connects directly to a tablet PC or a smartphone which have the required software. The quality of the images is not as high as that of the high priced units, but for many primary diagnoses this may be adequate.

A recent (2015) innovation from Newcastle University of UK gives a very attractive proposition. It has developed a simple ultrasound probe that would cost around $50 and would require software to go into any PC. Produced in volumes, it offers a great potential in obtaining a low cost ultrasound equipment. Figure 5.3

**Fig. 5.2** Hand held wireless probe—connects to a tablet PC or a Smartphone with software [11]

**Fig. 5.3** The $50 ultrasound probe developed by Newcastle University, UK [12]

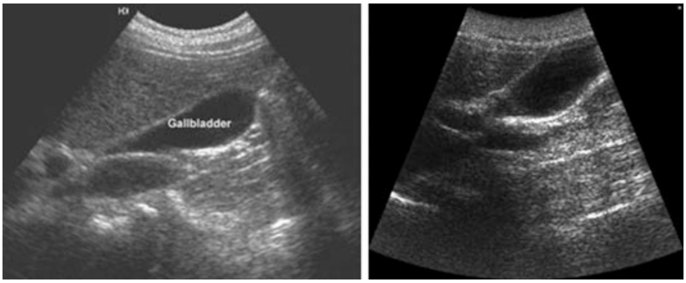

**Fig. 5.4** Image of a Gall bladder from a high-end scanner (*left*) and that using the low cost probe (*right*) [12]

shows a picture of the probe and Fig. 5.4 shows an example of a gall stone image, compared with the same image using a high end machine. The main approach taken for this astounding cost reduction is in the choice of the transducer and in the minimization of the hardware external to a PC. It has opted for a single fixed focus ultrasound transducer that rocks within a certain angular aperture, replacing the expensive multiarray ones used in the current commercial models. All the signal processing is done in the PC, using software. This gives a low speed, giving about 4 frames per second, and therefore would not be suitable for heart scanning. However, for most other applications including obstetrics, gynecology and abdominal scanning, this may be adequate.

### 5.2.2 The World Health Imaging System—Radiography

During the period 1975–1985, the Pan American Health Organization (PAHO) and WHO focused their efforts on the development of what they denominated the Basic Radiological System (BRS) in a concerted effort to provide developing countries with the much needed access to diagnostic imaging services [13]. The BRS consisted of a high frequency multipulse X-ray generator—a great novelty at the time—an X-ray tube with fixed aperture collimators that matched typical X-ray film sizes and a bucky with an antiscatter grid, rigidly joined to the X-ray tube in a U shape stand to ensure X-ray beam alignment. The source-detector distance was fixed at 1.4 m and a movable patient table, which could be substituted with a patient trolley, was part of the system. Aware of the electrical power limitations in most of the resource-limited regions for which the machine was developed, the generator consisted of battery-charged electrical storage units, capable of operating even if there was no power at the time of needing to take the radiograph. A critical requirement was that the unit could be easy to operate and to maintain.

To facilitate the work of obtaining, processing and interpreting the radiographs with such a system, WHO produced—in several languages—three training manuals: the Manual on Radiographic Interpretation for General Practitioners [14] the

Manual on Radiographic Technique [15] and the Manual on Dark-Room Techniques [16]. In addition, the manufacturer was expected to prepare and deliver with every machine a manual on maintenance and identification of failures. Trial tests were conducted in the America's Region, since PAHO had been the promoter of such a system, with very good results [13].

In 1993, WHO convened a consultation meeting at the University of Lund, Sweden, where it had a WHO Collaborating Center for General and Radiological Education which had served as the focal point for the development of the WHO-BRS since 1980. At the meeting, attended by radiologists, radiological technologists, radiological physicists and engineers, and representatives of the industry, enhanced specifications—based on actual field experiences in the use of the units—were proposed, mainly adding light field indication. The system was renamed *The World Health Imaging System—Radiography* [17], name that it has been retained until today. A typical system is shown in Fig. 5.5.

In spite of the modifications, and even though the system is very easy to use, its adoption by health services has fallen short of expectations. In 1997 there were only 39 of these units in nine countries of the Americas [1]. And in 2002, Vanden Brinken estimated that since 1975 only 1200 WHIS-RAD units had been installed worldwide [18]. One of the main reasons for its lack of acceptability in developing countries is that the machine was neither FDA nor CE certified. Thus, it was seen as an "inferior" product. The high cost was also a major barrier.

**Fig. 5.5** WHIS-RAD unit installed in a rural health center in Haiti, mid 1990s

In addition, some units had design flaws. In the mid 1990’s Borrás evaluated the problems associated with the installation in Haiti of 10 WHIS-RAD units, manufactured by two different X-ray companies. In one brand, it was found out that the generator failed to comply with the ease of use and maintenance required by the unit design, and repairs were conducted. The manufacturer in question actually exchanged the X-ray generators for others of more robust design and modular access for ease of maintenance. Still, by 1997, none of the units were working. The other manufacturer’s units fared a little better, mainly because of the efforts of a local X-ray company representing the manufacturer. The main problems stemmed from the technology design itself. The electrical supply units consist of batteries which—like car batteries—need to run to keep their charge. After a period of non-usage, the batteries become unchargeable. As Borrás reported “The problem that occurs most often is a blown fuse due to a power surge, so common in Haiti, which the poorly trained X-ray technicians do not know how to replace! As a result, the unit becomes inoperable, and after a certain time, the battery is discharged to a level that it can no longer be recharged!” [19].

Another problem common in all developing countries, is film processing [1]. So, as soon as computed radiography (CR) image receptors became available, efforts were made to use these detectors obviating the need for darkrooms and film processing. Rotary International facilitated and supported the deployment of WHIS-RAD/CR systems in Africa and Latin America. They even supported the publication of a 2011 on-line manual on diagnostic imaging for clinics and small hospitals in collaboration with PAHO [20]. This publication was followed with another one, “Radiation Shielding for Clinics and Small Hospitals with a WHIS-RAD 2013”, also available on the PAHO website [21].

Work on upgrading the WHIS-RAD design continues at WHO headquarters in Geneva. They are promoting a project led by an alliance, GlobalDiagnostiX, that has developed the protype of an inexpensive digital radiography machine adapted to the context of developing countries “without compromising on performance and quality” and “compliant with applicable international standards and regulatory directives”. The imaging system consists of a digital detector with a DICOM viewer that can be connected to a PACS system for teleradiology and telemaintenance access [22]. Compared to currently commercially available equipment, the prices of which are listed in Table 5.1, the product claims “to match the performance of standard digital X-ray machines on the market and is ten times less expensive than comparable designs when factoring in related equipment maintenance costs”. (The 2014 target was $50,000 including 10 years of maintenance.) Furthermore, part of the project includes training tutorials [22].

**Table 5.1** Imaging equipment prices (USD)—2015

| | |
|---|---|
| General purpose X-ray unit (non-digital) | Basic system 100–150 k |
| General purpose X-ray unit—CR | Add 40–75 k to above |
| General purpose X-ray unit—DR | Add 60–110 k to the basic system |
| Ultrasound unit—fixed | 80–115 k |
| Ultrasound unit—portable | 30–60 k |

The latter is essential, especially in rural health centers where any imaging workstation will be challenged by the limited knowledge of the X-ray operators and by adverse environmental conditions such as unreliable power supply, extreme temperatures and high humidity. No matter how well designed the integrated system might be, no radiography system in the world will perform adequately, unless the X-ray technician fully understands the operation of the X-ray unit and the workstation; knows how to position the patient; what image acquisition parameters to select, and how to produce, store and transfer the diagnostic images. In addition he/she should be capable of diagnosing functioning issues and perform simple maintenance tasks. The key for the success of any X-ray system, including the WHIS-RAD, is operator training.

## 5.3 Building Space Requirements

Once it has been decided where the health center is to be located, what services is to provide and what equipment is to be installed, consideration should be given for what kind of facility is to be built, the construction materials and its size. The types of medical imaging services to be provided at a rural health center may be limited to ultrasound and diagnostic radiology. They should both be located on the ground floor of the building, near the Emergency Room, if there is one, accessible to casualty patients that may come by ambulance or by car. Adequate means of access into the room and to the patient couch should be provided. It should be possible to maneuver a patient trolley through the imaging room door to a position beside the patient examination table.

Ultrasound equipment may not need a dedicated room—an examination room may be adequate, but such a room should have a clearly labeled area where image accessories, such as probes, and consumables such as gel and print paper, are stored and, thus, can be easily found. On the other hand, X-ray services will need at least two rooms: one for the study to be performed, and another one for image processing. A third room for viewing and interpretation is desirable. If the facility is to use film/screens as image receptors, such a viewing area will have the viewboxes for film display and image interpretation. To process the films, a darkroom will be needed. If the volume of films is low or the processor is only used for a few days per week, manual processing may be preferable. Otherwise an automatic film processor is desirable. Darkrooms should be adequately illuminated using a color filter that should be compatible with the film/screen spectral response and must be installed with air ducts that permit ventilation to the outside to prevent the toxicity of the processing chemicals to affect health center workers. The dimension of the darkroom should be such that it allows to store small amounts of film in open packages; larger number of film packages should be stored in a dedicated storage area with humidity between 40 and 60 % and low temperature. Film should not be stored in areas where it may be exposed to ionizing radiation or chemical fumes. Additional considerations regarding the darkroom can be found in Chap. 4, Sect. 4.2.

Both the X-ray room and the dark room may need additional structural shielding to attenuate the radiation both for radiation safety purposes and to prevent film fogging. If the patient radiological workload is low, the conventional building materials used in ceilings, floors and walls may provide adequate shielding against both the primary X-ray beam and stray radiation. When existing structural material does not provide adequate protection, additional shielding will be required. This can be accomplished by using greater thickness of the building material or by adding lead to the walls, floor and ceiling of the existing facility. The shielding thickness and lead equivalence depends on patient workload, X-ray techniques used for patient examinations, room dimensions and occupancy factors. Particular attention must be given to the position of the X-ray technologist, who must stand behind a protective barrier from where he/she can energize the X-ray tube and at the same time observe the patient to be radiographed. Radiation shielding designs require calculations by radiation experts, usually medical physicists. Typical shielding design calculations are available from the literature [21, 23]. The adequacy of the shielding—taking into account patient, staff and public dose constraints—should be tested ideally during construction, or, at least, before the X-ray unit is put in clinical use, preferably by a medical physicist or by a radiation protection specialist.

If the image receptors are digital, there is no need to have a darkroom; the images may be processed at the image acquisition workstation which can be located within the control area of the X-ray room behind a protective barrier or just outside it. The latter requires a leaded window for patient observation. Although the acquisition workstation has software for image display that would allow the physician to interpret the images right there, the process is inconvenient, since it interferes with further examinations. It is best to have another workstation, the interpretation workstation, located in a viewing area for the physician to evaluate the images. The size of the rooms depends on patient workload and available resources; Hanson estimates that a 16 $m^2$ room is adequate to house a WHIS-RAD unit. A simple layout, adapted from Hanson's publication [21] is shown in Fig. 5.6.

In all cases, the facility needs to comply with local building codes regarding space, accessibility, floor loading capacity, electrical power (voltage, frequency, phase and heat dissipation), water volume, pressure and drainage, etc. Floor loading capacity may be a critical issue if an X-ray machine is to be installed in an already existing rural health center designed without structural shielding present. In that case the addition of such shielding in walls, windows and perhaps even ceilings and floors, may be more costly as the room dimensions are already fixed. The placement of the X-ray machine in an existing room within the health center will have to be optimized to take advantage of space and X-ray tube orientation. For example chest X-ray projections, which need the X-ray beam to be horizontal, may be aimed at an exterior wall, where instead of adding lead, one could plant thick shrubs that will impede human and/or animal access. The problem with these "cheap" solutions is that unless the facility has the radiation considerations properly documented, with time, the facility may build an adjacent room in that location and by then the fact that the wall is unshielded may no longer be remembered. In the long run, it may be better to put shielding everywhere to take into account future expansions.

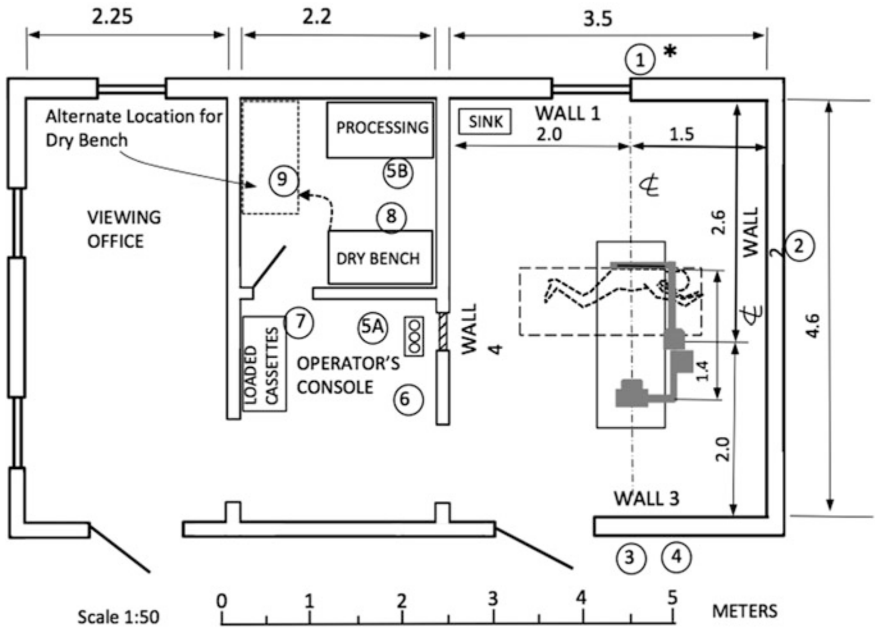

**Fig. 5.6** Simple layout for an X-ray installation in a rural health center. Adapted from [21]

In addition to shielding and ergonomics considerations, additional space may be needed depending on specific equipment needs. For example, most types of medical imaging equipment can only function well with a stable power supply. The need to purchase additional generators and/or UPS units should be addressed and budgeted. The location of these generators within the building is a consideration to be done at the planning stage. Another problem is the need of many units to have air-conditioning.

The biggest problem, however, especially in tropical countries, is the humidity. This will affect ultrasound units and X-ray machines. Electrical equipment just does not work well without proper humidity control. The requirements for both temperature and humidity should be known before the equipment is acquired. Room modifications should be implemented and plans for daily monitoring of the temperature and the humidity should be established before the equipment is put in clinical use.

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# Chapter 6
# Basic Training and Continuing Education of Technical Staff in Rural Health Centers

**Slavik Tabakov**

**Abstract** This chapter discusses the need and the possible organization of training for technical staff in Rural Health Centers (RHC). The entry training level could use a simple training structure, including Regional Referral Hubs (RRH), each coordinating several RHC. The organization of entry-level training for Medical Technology Maintenance (MTE) can take from several weeks to several months. A draft proposal for training curriculum is given, including 8 days training plus exit test for MTE technicians. The question for entry-level training for nurse-level staff, especially for operating the equipment, is also discussed. It is underlined that, in the field of medical imaging, development of user training for digital equipment is easier, compared with film processing. The chapter includes references to useful publications, e-learning materials, and to existing experience in the field.

**Keywords** Education · Training · Medical Technology Maintenance

## 6.1 Introduction

The rural health center is a healthcare unit, where the first diagnosis should be made and responsibility for providing integrated continuing care should lie [1]. In developing countries, such center could serve several thousands of population in remote villages and often is the only medical help available to the population from the region. The center has basic staff, sometimes without a medical doctor. Often some basic medical equipment is provided to the health centers. This equipment might come from various sources—ranging from official World Health Organization (WHO) programmes to second hand donations. The safe and effective use of this equipment is of great importance and special care is necessary for training the rural health center staff for this. Maintaining this equipment is a major problem and training staff for the purpose is not a lesser challenge. The most often

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scenario in the rural centers would be the existence of a person with nurse-level qualifications, without the support of a trained medical doctor or other specialists as radiographer/sonographer, service engineer or medical physicist. From this point of view the operation of the equipment in the rural health center will depend on this level of staff. Respectively the education and training we shall discuss here will be at the very basic level.

## 6.2 Pre-training Education

The pre-training education is in fact the school education obtained at local rural level. Often it is quite basic and elements related to sciences, physics, engineering, etc. cannot be taught to a satisfactory level. However in most developing countries good schools are available in the capitals and larger cities and these schools could provide the necessary science education.

Discussing the use of sophisticated e-learning and other web technologies for the education of the remote village pupils in developing countries is not practical at the moment. First, many of these pupils do not have the necessary information technology (IT) background/equipment to benefit from e-learning, and second, science education requires specific facilities and laboratories. However specific entry-level e-learning materials can be developed and transmitted over the Internet. They should be combined with pre-recorded lectures, as well as bi-directional life tutorials over the Internet; this will facilitate to explain some parts of the transmitted materials.

In all these educational activities, the language is of prime importance. Due to this reason possible tutors can be from the capital or other major cities of the country, where this rural health center is located.

One specific problem discussed at the World Conference on Physics and Sustainable Development (Durban, South Africa, 2005) was the need of more science/physics teachers for the developing countries. This shows that the solution of the problem with science education in developing countries will require many years and efforts at various levels.

## 6.3 Entry Level Training in Medical Technology

This training requires as pre-requisite completion of secondary-level school education. Strictly speaking Medical Technology training is a very complex issue. The complexity is related mainly to the great variety of medical equipment and its constant update. However, the limited technology in a rural health center simplifies the problem.

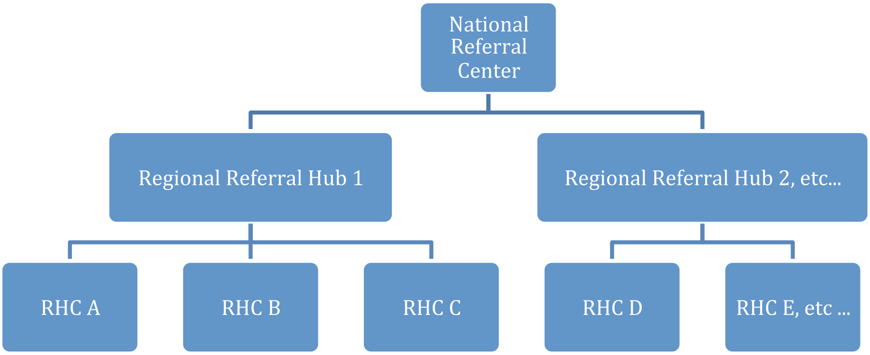

**Fig. 6.1** Possible structure of rural health center (RHC) in a country

In order to discuss the training we have to specify a basic training structure, which is also related to the operation of the rural health center. Such structure will link the many geographically-spread rural health centers to some type of Regional Referral Hub, to which the rural health center will refer on a regular basis (Fig. 6.1). Also, such structure offers two levels of advice.

Depending on the size and geography of the country, there might be two main scenarios. A larger country could have several Regional Referral Hubs, attached to a National Referral Center. A smaller country could have only one Regional Hub, serving also as National Referral Center. In all cases the National Referral Center should be staffed with medical and technical specialists, who can provide distantly the necessary advice to the rural health center staff. All these colleagues will have appropriate University education and we shall not discuss their training further. However they have to be fluent with the communication technology allowing them to link to the rural health center.

## 6.4 Entry Level Training in Medical Technology Maintenance at Hub-Level (e.g. Biomedical Technician's Assistant)

This training is mainly related to the Regional Referral Hub. In case of a small country, the Hub could be one of the rural health centers, which has better trained staff (e.g. this can be in the more-populated island of an archipelago). Such Hub will need to have at least a trained radiographer/sonographer and a trained technician. The level of training in general radiography and ultrasound is standard, however the training of the technical staff is not well standardized.

A team from Duke University, NC, USA has made a comprehensive study of several thousand pieces of out-of-service equipment in hospitals in developing countries. Based on this, a suitable curriculum has been developed [2] for a technician (named in the publication: Biomedical Technician's Assistant). This curriculum aims to allow secondary school graduates from developing countries to be trained to accomplish specific maintenance of medical equipment.

The programme proposed by the team from Duke University is for two years, including 6 months preparatory work in the hospital prior to the training. The actual training includes elements of acquiring mechanical skills, electrical skills, plumbing, etc. (see Table 6.1). It spans some 5–6 weeks, which is followed by 18 months of supervised work back in their hospital. The programme has been tested successfully in Rwanda.

The Duke University project shows the need of another level of training staff who would supervise the trainees, and, if such staff exist initially, one would assume that after several years the training programme could be self-sustained.

This excellent project presents curriculum for basic training. Additionally to it, in the case of additional imaging equipment, it has to include also a domain related to operation of X-ray equipment plus respective basic knowledge on Radiation Protection, as well as basic imaging quality assessment and related problems (see next section). Using the model of Duke University, this additional training can also be updated for Ultrasound equipment. However it will require a good Regional Training Center where the 18 months practical placements (supervised work) can be taken. It might be

**Table 6.1** Example from the Duke University paper [2], showing main knowledge domains and expanded skills related to the plumbing domain

| Knowledge domain | Unit | Skill |
|---|---|---|
| Mechanical | | |
| Plumbing | Leaking | Finding holes |
| | | Cutting tubes |
| | | Electrical tape |
| | | Epoxy |
| | | Superglue |
| | | Rubber patches |
| | | Melting tube |
| | Connections | Clamps |
| | | Hose barb with clamp |
| | | Threaded pipe connector |
| | Seal | Caulk |
| | | O-rings |
| | Filters | Cleaning |
| | Blockages | Routing |
| | | Cleaning |
| | | Descaling |
| Motors | | |
| Power supply | | |
| Electrical | | |

possible that only several Regional Training Centers are open for several developing countries (as per the common language used in the countries).

## 6.5 Training for Maintenance of Imaging Equipment

Medical Imaging Equipment includes some of the most complex equipment of our time. While training related to repair of simple medical equipment can be achieved at local level with moderate expenses, training for maintenance of imaging equipment is extremely expensive and does not exist even in some industrialized countries.

The question here is not related to CT, MRI, etc., but to the maintenance of X-ray radiographic equipment, which are the most complex equipment in a rural health center. Good documentation exists describing the WHIS—RAD equipment [3], and it can provide basis of such training. However it would be useful if the most common and simple faults would be identified and only these are taught to the technicians. Full maintenance of X-ray equipment requires work with high electric voltage and radiation, and is advisable to be performed only by specially trained industry personal. A similar situation applies to maintenance of ultrasound equipment, which is best done by specially trained personal.

On the other hand, tasks such as changing fuses, mechanical cleaning/lubricating, measuring the mains power supply, etc. can be performed by the local staff, together with basic radiation protection measurements where applicable. Acquiring of these skills can be included in the training curriculum.

Ideally, equipment quality control should be performed by specially trained technicians (or junior-level medical physicists). Currently, regular courses on this subject are carried by the College on Medical Physics and other related courses in ICTP, Trieste, Italy (The Abdus Salam International Center for Theoretical Physics) [4]. The Model Curriculum of the International Organization for Medical Physics (IOMP) and the new ICTP MSc in Medical Physics (a joint activity of the ICTP with University of Trieste, supported by the International Atomic Energy Agency (IAEA) and IOMP) will be very useful for the purpose [5]. Various activities on this subject of the IAEA and WHO will certainly help to build a good pool of experts. The issue of quality control is discussed in depth in Chap. 8. We have to mention also that specific quality control tasks are included (with detailed explanations and images) in the widely used e-learning materials EMERALD and EMIT—available free from: http://www.emerald2.eu/cd/Emerald2/ [6].

The trained local experts will be the future leaders of medical equipment training and education in their own countries. However these will be the advisors at the National/Regional Hubs, the training of the staff at the rural health center should be considered at a level possible for the staff of these Centers.

## 6.6 Entry Level Training on Medical Technology Maintenance at Rural Health Center-Level (e.g. Nurse-Level)

The higher level training (e.g. for Biomedical Technician's Assistant) could not be used for the staff at the rural health center, which will most likely be at the level of basic nurse medical training. Additionally to it, the rural health center staff will need to have basic training on the safe and effective use of the available equipment.

The model of rural health center maintenance/equipment training can be seen as an additional element to the required basic medical training of the rural health center staff. Developing a generic curriculum for such maintenance/equipment training depends on the type of basic equipment available at the standard rural health center. In our time is very difficult to assume that the basic imaging equipment will not be with digital imaging (we are considering here mainly basic X-ray and ultrasound equipment). Use of X-ray films is currently more expensive and unreliable. This is because it is related to chemical film processing, which is very much temperature development (what can be problematic for many rural health center's as most of these are in the tropical/equatorial geographical regions). Use of X-ray films will also require further skills from the rural health center staff to obtain sufficiently good images (after film processing). Also, special care would be necessary for the keeping/preparation of the processing chemicals, as well for storage of the films. Finally, eventual transfer to the Regional Hub of an X-ray film image would require further equipment and skills for the scanning/digitizing of the image. From this point of view, the training proposed here will be based on the use of digital detectors.

We have to again underline here that the proposed training is only related to the use of the equipment. Specific additional training will be required for the most basic medical interpretation of the imaging results. Training and experience requirements for the general practitioner who most likely will do the image interpretation are addressed in Chaps. 2 and 9.

## 6.7 A Draft Proposal for Basic Training on the Use of the Rural Health Center Imaging Equipment

This proposal is based on 8 days training period at a specific Regional Training Center, followed by a test.

Day 1—Type of equipment and its use. What is the difference between a good and a bad image

1a. Main parts of the X-ray equipment; Main parameters of the X-ray equipment related to image quality; Practical use of the equipment—3 h

1b. Main parts of the ultrasound equipment; Main parameters of the ultrasound equipment related to image quality; Practical use of the equipment—3 h

Day 2—Basic radiation safety and basic electrical safety

2a. Concepts/Need of radiation safety for patients and staff—3 h
2b. Basic safety related to use of ultrasound—1 h
2c. Concepts of electrical safety and first aid—2 h

Day 3—Basic checks of the equipment and basic problems with this equipment

3a. Basic use of specific/standard dosimeter in the rural health center—1 h
3b. Basic use of specific/standard X-ray test object in the rural health center—2 h
3c. Basic use of specific/standard ultrasound test object in the rural health center—1 h
3d. Main problems with the equipment (manifestation of the problem and possible staff actions)—2 h

Day 4—Sending images and information over Internet. Protocols on how to report problems

4a. Communication between rural health center and with the Regional Hub—1 h
4b. Specific software for sending images over Internet and its basic use—3 h
4c. Standard description of a problem (to be sent to the National/Regional Hub)—2 h

Day 5—Problem based discussion of various scenarios

5a. Interactive Problem-based session with X-ray equipment—3 h
5b. Interactive Problem-based session with ultrasound equipment—2 h
5c. Explaining the test after the training

Day 6 and Day 7—two days self-preparation for test, can be over the weekend

Day 8—Test

8a. Test—Practical use of the equipment and answer of questions—2 h
8b. Examiners mark the test and discuss the performance of students—3 h
8c. Announcing the results and feedback session with the students—1 h

In case of failing the test, another re-take of the training and/or re-assessment will have to be planned.

The materials for the training will have to be prepared as generic ones. This has to be based on the use of the specific equipment. Also the materials will have to be translated to the respective language. A specific training web-site could be developed to host these materials and their regular updates. This web-site can also be used for Continuing Professional Development, for example for further organisation of training, equipment maintenance, dealing with incidents, etc [7]. The period for re-training will also have to be specified.

## 6.8 Regional Training Centers

The effective development of such training programme would require setting of suitable Regional Training Centers. Such institutions can have their own staff and could have central funding—e.g. from WHO or a Non-Governmental Organization. Initial training at these institutions could also be delivered by experienced retired specialists, who could improve significantly the delivery of training and education. After certain level of development, the Regional Training Centers could develop specific on-line courses or web-libraries with specific problems and their solutions. This will facilitate the maintenance at local level.

At this stage it is very difficult to discuss eventual Certification of the Technicians who complete such training. As an example, the Certification of Clinical Technicians in the UK, a country with excellent education and systems for assessment, took several years and is still in development. However the international experience of the International Union of Physical and Engineering Sciences (IUPESM) and its Health Technology Task Group (HTTG) would allow for future development of an international system for validation of the skills obtained during the training (such system has already been developed in IOMP for the validation of MSc courses [6]).

## 6.9 Conclusion

The training of technicians working at rural health centers in developing countries, discussed at the HTTG Workshop in Porto Alegre [8], is complex and still awaits its solution. More complex training, such as X-ray equipment maintenance, can only be achieved through international cooperation for establishment of Regional Training Centers. Any project in this field should go in parallel with development of a system for employment of medical equipment technicians at various levels. IUPESM is in a good position to provide advice and help to solve this situation. The training of suitable medical equipment technicians will require the concerted efforts of WHO, IAEA, IUPESM and other related organizations.

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# Chapter 7
# Tele-Imaging and Networking

**K. Siddique-e Rabbani and Trevor D. Cradduck**

**Abstract** Tele-ultrasound, a typically hazard free medical imaging modality, is very useful for a rural telemedicine system. The speed requirements of the communicating network based on the typical data sizes of ultrasound images are discussed for still images, live video streaming and for 'store and forward' image transfer. In the low resource countries where high bandwidth is still not available, techniques for trade-offs have been discussed. Tele-radiology has a place in developing nations where the absence of qualified personnel may place constraints on the delivery of health care. Nevertheless there are several mitigating factors that must be considered. Probably the best solution provided here is the adoption of the WHIS-RAD system in combination with a CR system to transmit images for remote interpretation.

**Keywords** Tele-Ultrasound · Tele-Radiology · Communication network speed · Image transfer · Radiology · WHIS-RAD · JPEG · CR · Mini-PACS

## 7.1 Tele-Ultrasound

### *7.1.1 Introduction*

Digital x-ray, CT and MRI images that are used in medical diagnosis are mostly still images, therefore, data for these images can be transferred over a digital communication link using the 'store and forward' method for a doctor to see and analyse the images later. The speed of data transmission is not very important here and even slow communication links are adequate. On the other hand, many of the

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diagnostic ultrasound B-scan images require video ‘streaming’, that is, continuous transfer of video data while it is viewed at the other end in real time or ‘live’. This allows the specialist doctor at the remote end to see changes that are produced on specific movements or maneuvers of the patient following his or her instructions. For example in the detection of a gall bladder stone (Fig. 7.1a), the doctor wants to confirm the image of an apparent stone while the patient makes certain movements, on the doctor’s instructions. If it is a stone, it would most likely move, and that confirms the diagnosis. Otherwise the doctor will have to think on a different route. Again, if the movements of the heart valves and its walls are to be seen (Fig. 7.1b), it is not possible without a video. Of course there are situations where still ultrasound images are adequate and for transmitting such images through communication links, the same considerations as for the still images of CT and MRI apply.

Furthermore, ultrasound scanning, being non-hazardous, opens up the possibility of having a scan done at the patient end through an operator who may not have much training in anatomy or in the acquisition of ultrasound images. A doctor may give instructions to an operator to take images in certain ways through the video link. Therefore, this is a case of simultaneous training and diagnosis and this option should be kept in any tele-ultrasound system.

The speed of the video data transfer is very important to tap the maximum benefit of ultrasound scans through telemedicine. In the low resource countries where high bandwidth is still not available, we need to think of trade-offs for video transfers in telemedicine. The aim should be reducing the overall data size keeping a minimum acceptable quality of the images. Therefore, some discussions on the basic requirements for data size of the images and speed of data transmission would be useful at this point.

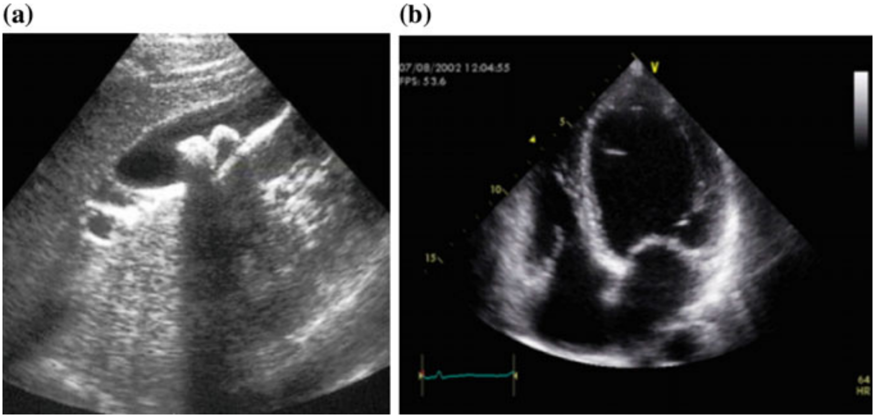

**Fig. 7.1** **a** Ultrasound B-scan of gall stone [1]. **b** Cardiac image [2]

## *7.1.2 Data Size*

### 7.1.2.1 Still Images

Ultrasound images are essentially of low resolution. A pixel size of 640 × 480, which is equivalent to approximately 0.3 MP is more than adequate for all ultrasound images. In fact even 320 × 240, equivalent to approximately 0.075 MP or 75 KP, may be adequate for some diagnostic purposes. However, in this article, the focus will be on the 640 × 480 pixel image. An uncompressed (bmp format) still image of size 0.3 MP or 300 KP will take a data space of about 300 KB for Monochrome (black–grey–white) images since the intensity of each pixel is given in 256 shades corresponding to a digital data of 8 bits (1 Byte) each. For color images using Red, Green and Blue pixels, the data size will be 3 times this. However, the former value will be relevant for ultrasound images since these images are basically monochrome. The images are usually compressed for data storage and transmission using different techniques, the popular formats being PNG, JPEG etc. Compression of a still image with the above pixel size will give a reduction of about 3–6 times in data size, depending on the details in the image; data sizes between 50 and 100 KB may be expected for monochrome images. A compression technique basically finds pixels with values within a narrow range of color and intensity and replaces them with a single value and stores the matrix position of these pixels. Thus, if large areas in an image have a narrow range of color and intensity, the compression technique gives a significant reduction in data size. On the other hand if the image has significant variations in color and intensity over much of the image, the reduction in data size is less significant. However, one should remember that once a compression is done, it is not possible to go back to the original data, small variations within a close range that have been replaced by single values cannot be restored back again.

### 7.1.2.2 Video

Any video consists of many still images, called frames, displayed sequentially at very small intervals of time. Therefore, in addition to the pixel size of the image, the data size also depends on the number of frames of images that are present. For considerations of the speed of transfer of data from a source to a recipient, the data size per unit time which is important is related to the number of frames per second (fps). Usually, for a smooth video, about 25 fps is chosen, and for a 640 × 480 pixel monochrome video without any compression, one comes up with a data rate of 7.5 MB/s (=300 KB × 25). In terms of bits (8 bits = 1 Byte), this corresponds to a data rate of about 60 Mbps. Obviously, this is an impractical size and compression techniques are employed in addition to the ones mentioned above for still images. In most typical videos the image in only a fraction of the image area is likely to change from frame to frame, the rest remaining unchanged. Video compression software will use this to advantage to reduce the data size further. Overall, these techniques bring a reduction of data size by a factor of more than 100 typically. Again, the compression ratio will change depending on the details as mentioned before for still images, and on how much of the image changes from frame to frame in a video.

To give an idea, for a typical color video of 640 × 480 pixel size and 25 fps with MPG compression, one may expect a data size of about 10 MB/min corresponding to about 170 KBps. For a monochrome ultrasound image it would be roughly one third of this giving about 60 KBps, equivalent to 480 Kbps. Just for comparison, a high definition color video of 1920 × 1080 pixels at 29 fps with AVCHD compression will have a data size of about 120 MB/min, or more than 10 times the size of the above. One should also remember that if audio is added, the data rate will increase slightly.

Coming back to the monochrome ultrasound video, if the position of the transducer is changed, or the patient is asked to move during a video, which is very common in most of the cases, the whole image changes from frame to frame and the compression expected from the above description no longer holds and one ends up with much larger data sizes.

#### 7.1.2.3 Effect of Frames Per Second on File Size

Another aspect to consider is the frame rate per second. For a smooth ‘movie’ or video, 25 fps or more are required. For example in viewing the movement of the heart valves, such frame rates are necessary. On the other hand when a doctor wants to see different views of a non-moving organ or a slow moving organ through a remote operator, lesser frame rates may be chosen to reduce the total data rate. Although the video will appear a bit jumpy, it may be adequate for a doctor’s information. In such cases, one may go down to slower frame rates, even down to 5 fps in some cases in order to reduce the data rate. However, the reduction in data rate is not proportional to the reduction in frame rate. For example, changing the frame rate from 25 to 5 fps, the reduction in data rate will not be given by a factor of 5, rather the factor is expected to be less.

### *7.1.3 Data Transmission Technology and Speed*

There are several methods using which data are transmitted over long distances that could be utilized in tele-ultrasound. Possible communication types, together with typically available data transfer speeds are given in Table 7.1.

It may be seen that there is a huge range of data transmission speed and it is obvious that higher speed comes at a cost. Besides, access to the highest speed links

**Table 7.1** Communication types and data transfer speeds

| Communication types and typically available data transfer speeds | | |
|---|---|---|
| (a) | Dial-up using telephone line | 2.4 Kbps–56 kbps |
| (b) | DSL—Digital subscriber line | 16 Kbps–9 Mbps |
| (c) | Broadband internet connection, cable | 200 Kbps–20 Mbps |
| (d) | Broadband link, optical fibre | 1 Mbps–40 Mbps |
| (e) | Internet over Satellite | 492 Kbps–512 Kbps |
| (f) | Mobile broadband, 2G | 10 Kbps–240 Kbps |
| (g) | Mobile broadband, 3G | 100 Kbps–16 Mbps |
| (h) | Mobile broadband, 4G | 5 Mbps–1000 Mbps |

is not available in most low resource countries, particularly in rural areas where telemedicine is required most. In recent times many of the low resource countries are setting up mobile phone networks that can be used for the mobile broadband links. Therefore, taking into consideration the above list, the practicalities of tele-ultrasound will be discussed below.

### *7.1.4 Practicalities of Tele-Ultrasound*

As mentioned earlier, if one does not mind delays in getting an image, transfer of still images is not much of a problem, even for a low data speed. For example a 640 × 480 pixel monochrome JPEG image may have a size of about 100 KB (=800 Kb) as mentioned earlier, and it will take about 80 s to transfer this image over a very slow line with a speed of only 10 Kbps. From a practical standpoint this delay may be acceptable in a low resource country.

However, for live video data transfer, the situation is more demanding. It was pointed out earlier that for a 640 × 480 pixel monochrome video, a data rate of about 480 Kbps is needed for live video transmission. From the above list it may be seen that 2G Mobile broadband, which is the most used communication link in the low resource countries, has speeds much less than this requirement. One needs at least 3G Mobile broadband, but even there are times when the speed falls below the requirements as the actual speed obtained fluctuates because of various reasons. Digital Subscriber Line and Broadband Internet Connection through Cable may be suitable if one gets the higher speed bands, not otherwise. It may be appreciated from the above list that only Fibre optical link, Internet over Satellite and 4G Mobile broadband offer speeds that suit the requirements for video for tele-ultrasound at all times, but only if monochrome images are considered. If ultrasound B-scan with color Doppler is desired, then the speed needs to be at least 3 times that for monochrome, i.e., about 1500 Kbps or 1.5 Mbps and one can find out from the above list the ones that are suitable.

Looking from a low resource setting having a coverage of 2G Mobile Broadband, or at least 3G, the practical modality should be ‘store and forward’, not live video streaming. For this, the technician at the patient end has to have some expertise in taking the ultrasound scans following the doctor’s advice. The technician saves the whole image file and then sends it to the doctor either through email, or uploads to a website with mutual access. However, if the speed allows some video conferencing like ‘Skype’, even if of low quality, the doctor may use it to guide a technician at the remote end to perform the scans as desired. In case the speed is not enough, the advice could be delivered through voice only, either through software like ‘Skype’ or even through mobile phone. In fact mobile phones offer a better voice quality and almost an instant response from the other end as the delays in transmission are much less than that through internet.

As mentioned earlier, an alternative of using lower frame rates is still possible if the transfer speed is somewhat less than 480 Kbps. Going for 5 fps, one may come up with a live streaming possibility with around 100 Kbps for which 2G Mobile Broadband may be adequate, or one can even go down to 1 or 2 fps to have useful information sent over to the doctor. Of course this would not be suitable to observe cardiac activity.

## 7.2 Tele-Radiology

### *7.2.1 Introduction*

Health Centers in Developing Nations tend, by and large, to be at some distance from the delivery points for specialized health care. Such geographic separation implies that to provide access to care for persons living in remote areas some form of telemedicine approach is necessary. This also implies that for adequate diagnoses to be made it is often desirable to have x-ray images of the patient available. Radiography in remote locations is bound by a number of constraints. Quite apart from the equipment to be deployed it is necessary to consider how the image can be transmitted to a radiologist for interpretation.

Although it was published in 2006, a Field Report by Hoaglin et al. [3] presents an excellent overview of the situation in South Africa at that time with recommendations that are equally pertinent today. The report recommends the adoption of computed radiography in conjunction with the WHIS-RAD equipment described in Chap. 5, Sect. 5.2.2. It also includes some comments regarding transmission and viewing of the images as well as consideration of technological alternatives.

The Swinfen Foundation [4] is one example of a mechanism providing a referral service to a number of countries. The intent of the service is to provide access to respected specialists for physicians who have difficult cases to resolve. It operates in a store-and-forward or asynchronous mode. The referring physicians or centers are provided with a digital camera, which allows them to take photos of wounds, rashes, deformities etc. and send these by email to the Swinfen Foundation which then places the physician in contact with a specialist. Although it certainly represents a very rudimentary form of teleradiology, the same digital camera can be used to take a photo of an x-ray film on a light box. Although a radiologist would not wish to make a diagnosis from such images, they (the images) can help the consulting specialist to form a better opinion than just reading a description in an accompanying email. Further details can be found in Telehealth in the Developing World [5].

Satellife [6] is a similar organization that has, for a number of years, provided assistance to health care providers in a variety of countries using both satellite and smartphone (at least 3G) technologies to provide information either loaded directly on the devices or transmitted by wireless connections. It is used primarily to improve nursing care, not to transmit images for second opinions as in the case of the Swinfen Foundation so, in the strictest sense of the word, is not a form of teleradiology.

## *7.2.2 Imaging Equipment*

### 7.2.2.1 Mitigating Factors

A number of factors play a role in deciding the equipment necessary for teleradiology in developing countries or, indeed, in remote locations in developed nations. In no particular order they may be listed as:

1. Limited funds for both capital outlay and on-going operations
2. Intermittent and unreliable electrical power
3. Lack of copper wire broadband infrastructure
4. Environmental conditions affecting the storage of chemicals and reagents
5. Limited training of personnel.

These mitigating factors imply that any system to be used for teleradiology needs to be simple to operate and maintain; should be largely immune to electrical power fluctuations and shall capture the images such that they can be transmitted, perhaps slowly, via a cellular telephone network. The WHIS-RAD system is ideal in this regard (see Chap. 5, Sect. 5.2.2 for a full description of the system and its historical development).

## *7.2.3 Digitizing the Image*

Film is increasingly expensive and becoming more difficult to obtain. The demand for film in many instances is low which further exacerbates the problem. In addition, the chemicals necessary for the processing of film represent an on-going operational cost and need to be replenished frequently if good diagnostic images are to result. Furthermore, when teleradiology is necessary to transmit the image for interpretation it is desirable to have that image in a digital format from the outset rather than needing to convert it from an x-ray film.

#### 7.2.3.1 Digital Image

##### Computed Radiography

Durable equipment is imperative in the environments prevalent in developing nations and computed radiography (CR) cassettes are more robust than digital radiography (DR). The CR cassette can be “read” by a local PC, viewed and stored on site while the image may be transmitted to a remote location for interpretation. The local PC may need a relatively large hard drive on which to store the images depending on the local demand. In addition, it would also be desirable to have a DVD burner included so that images can be safely archived. The advantage of such a system is that the images remain with the patient record. The System might be regarded as a mini-‘picture archiving and communication system’ (PACS). Formerly, when the film had to be sent off site for interpretation, that advantage was lost.

##### Image Formats

Digital images, if in their raw format, would take a long time to transmit to a remote location and also would quickly fill any storage medium. For this reason image compression is recommended. Although it is a lossy compression algorithm, JPEG compression is recommended.

#### 7.2.3.2 DICOM

DICOM is an open source imaging environment used in radiology and equipment capable of handling DICOM images are also capable of dealing with JPEG images. Several open source programs are available for PCs such that the PC can act as a mini-PACS. The role of PACS in the developing world as a means of increasing and improving radiology resources is promoted by international organizations such as RAD-AID [7].

#### 7.2.3.3 Scanner

Perhaps one of the more expensive components of the digital system is the CR scanner. On the other hand, the alternative of using film which must then be scanned by a flat-bed scanner represents greater operational costs in terms of film and chemicals so that the capital cost of a CR scanner is quickly overtaken by these operational costs.

#### 7.2.3.4 Photography

In those instances where a CR system does not exist or cannot be installed, the fall-back position for teleradiology is the use of a digital camera to photograph the x-ray image. This certainly has its disadvantages but a paper by a group based at the Brigham and Women's Hospital in Boston and published in the International Journal of Medical Informatics demonstrated that use of a digital camera and transmission of JPEG images, even those that are highly compressed, can provide radiologists with images sufficient for diagnostic purposes, at least in the case of chest x-rays. See: Diagnostic accuracy of chest X-rays acquired using a digital camera for low-cost teleradiology [8].

### *7.2.4 Transmitting the Image*

Teleradiology by its very definition implies images must be transferred from one location to another for interpretation. It is important this process not cause a degradation of the image but, by the same token, the image will, of necessity, need to be compressed if acceptable transmission time and costs are to be attained. An Internet connection that is at least 128 kbps is necessary and this can be achieved in most situations, even when satellite transmission is the chosen means of communication. Unfortunately the fibre glass or even copper wire infrastructure does not exist in most undeveloped nations. On the other hand cellular networks have found a place in the communications structure of these countries so that images may be transferred using that medium at reasonable speeds.

The image will be received at a suitable DICOM viewing center at which time a radiologist can provide an interpretation. Unfortunately the number of radiologists available to undeveloped nations is likely to be either non-existent or extremely limited so images may well have to be transmitted to major centers in developed nations. In the overall scheme of things it may well be the cost of that service itself that stands as a roadblock to the implementation of teleradiology.

When it is necessary to take a photograph of an x-ray film, that image can be sent as an attachment to an email. Once again, care needs to be taken to ensure the size of the digital image does not exceed either the sender or receiver's bandwidth limitations.

### *7.2.5 Information Security*

Transmission of patient data, whether it is text or images, requires due attention to privacy issues. This is usually a matter of the privacy legislation existing in the country of the patient's residence and could require the data to be encrypted. In most instances the very fact a health care service that would otherwise be absent is available tends to override considerations of privacy but organizations engaged in implementation and operation of teleradiology services need to be fully cognizant of the legislation that may be in place.

### 7.2.6 Power Considerations

The WHIS-RAD specifications recommend the x-ray system be battery operated in order to avoid the interruptions or fluctuations that may exist on the local power grid. Similar considerations also apply to the image collection, storage and transmission system. It may not be possible to power all of these components directly from battery power but it is imperative that they have some form of uninterrupted power supply (UPS) sufficient to sustain the system long enough to guarantee an orderly shutdown in the event of a power failure.

### 7.2.7 Conclusion

When considering the implementation of teleradiology in a remote location of a developing nation a number of mitigating factors must be taken into account. Not least of these is the cost of the installation, both capital and ongoing operating costs. The World Health Organization (WHO) has issued specifications for a simple, easy to use and relatively maintenance free radiological system known as the WHIS-RAD and this is now marketed by several of the major x-ray companies. By limiting the number of variables needing adjustment the system is designed to be used by personnel with minimal training. To mitigate against power fluctuations it is recommended the WHIS-RAD system be battery powered.

In order to reduce operating costs it is strongly recommended that computed radiography (CR) be the modality of choice over film, chemicals and the associated processing. With CR the image can be transferred to a local PC using a CR scanner which gives the added advantage that the image record is retained locally rather than being transported to some other location for interpretation. Also, the image is already in a digital format thereby facilitating its transmission to a remote location for a radiologist to review. The choice of communication link will depend very heavily on what infrastructure exists in the sending and receiving locations. At best a broadband or land-line connection may exist but it may be necessary to resort to cell phone or even satellite communications. The cost of each of these modalities will be a controlling factor but speeds as low as 128 kbps are acceptable given that the images to be transferred will be in the JPEG compressed format.

One cost that cannot be overlooked when establishing a teleradiology service is the reimbursement of the radiologist to whom the images are transmitted for interpretation. This may well constitute the largest component of operating expenses of the service.

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# Part IV
# Operational Considerations

# Chapter 8
# Quality Control, Radiation Safety and Maintenance Programs

**Cari Borrás**

**Abstract** To ensure quality of healthcare delivery, radiological equipment and personnel working in a medical imaging service require performance evaluation, including radiation safety assessments. It is necessary to establish and implement quality assurance/quality control (QA/QC), radiation protection and maintenance programs—the extent of which depend on the complexity of equipment and procedures. The programs should be established by professionals such as medical physicists or biomedical engineers but can be carried out by staff in the rural health center under the guidance (physical and/or virtual) of the professional experts. For the programs to function adequately, a person among the technical or nursing staff should assume the responsibilities for the QA/QC and maintenance programs. The same person may also function as a radiation safety officer, or such role may be entrusted to a clinical individual. This chapter outlines the elements of such programs and provides references to specific details.

**Keywords** Quality assurance · Quality control · Equipment maintenance · Radiation protection and safety

## 8.1 General Considerations: Concepts and Definitions

### *8.1.1 Quality Assurance/Quality Control*

Quality assurance (QA) is a management tool that in the medical field has as ultimate goal the improvement of patient care. 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. Regarding medical imaging, the World Health Organization (WHO) defined QA as: "All those planned and systematic actions nec-

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essary to provide adequate confidence that a structure, system or component will perform satisfactorily in service. Satisfactory performance in service implies the optimum quality of the entire diagnostic process, i.e. the consistent production of adequate diagnostic information with the minimum exposure of both patients and personnel" [1]. The main objectives of a QA program are to improve diagnostic accuracy without unnecessary radiation and to minimize costs by revealing problems at an early stage before they severely interfere with the clinical practice.

Regarding quality control (QC), the American Society for Quality defines QC as "the observation techniques and activities used to fulfill requirements for quality" [2]. In this chapter emphasis will be placed on the QC tests that are required to ensure effective and safe equipment performance. These tests can be developed based on the acceptance tests and on the data acquired during the commissioning; compliance criteria should be established to ensure that the units continue to perform adequately.

### *8.1.2 Acceptance Testing*

Acceptance testing is the process of determining if the unit meets manufacturer's specifications. The responsibility rests with the buyer. Acceptance tests are normally done between a person of the institution (ideally a medical physicist) and an engineer or technical representative of the manufacturer. For second-hand equipment, compliance with the original manufacturer's specifications can be tricky, unless it has been specified in the acquisition agreement. Safety tests are of paramount importance. If the equipment to be installed is used equipment, previous service records should be examined in detail and repaired or replaced components should be tested very carefully to assess whether they may compromise safety. Adjustment costs may have to be borne by the user, unless it is clearly indicated in the acquisition agreement that the institution or company providing the equipment is responsible.

Consumables such as X-ray film or printing paper should be available at acceptance testing time, to ensure that the tests can be done and documented. Accessories such as patient support items (table mats, sponge wedges, infant cradles, etc.) should also be tested during acceptance testing to ensure their use will not interfere with patient imaging.

Further guidance on acceptability criteria has been published [3].

### *8.1.3 Commissioning*

Commissioning is the process where the necessary operational data are acquired so that the unit can be used clinically. In medical imaging, this step involves setting all the programmable equipment features, such as patient imaging protocols, automatic exposure controls, software image manipulation, etc. While manufacturer's service personnel do the adjustments, the responsibility to ensure proper clinical use rests with the user. The process should be done preferably by a knowledgeable and competent medical physicist, and it should be more or less extensive depending on the complexity of the equipment. It is during commissioning that the base line values for the QC tests are set.

### *8.1.4 Preventive Maintenance*

Maintenance can be corrective or preventive. Corrective maintenance refers to fixing the equipment when there is a malfunction. Preventive maintenance consists of periodic procedures and interventions performed on equipment to reduce the possibilities of a malfunction and ensure its continuous, safe, and economical operation. Preventive maintenance also ensures that the equipment operates according to the manufacturer's technical specifications and in compliance with safety standards. The functional parameters of the equipment should be checked initially during the acceptance testing performed before the machine is put into service and subsequently following any repairs or modifications [4]. The QA/QC program and the maintenance program should be closely interrelated.

### *8.1.5 Radiation Safety*

If the rural health center has X-ray equipment, arrangements must be in place to ensure that patients, workers and the public are protected from the potential deleterious effects of ionizing radiation, regardless whether there are national and/or local radiation control regulations. Radiation protection and safety requirements for governments, health authorities, radiation protection regulatory authorities and users have been agreed by a consortium of international organizations, among them WHO and the International Labor Office (ILO). The requirements are periodically reviewed by the member states of the cosponsoring organizations and are published by the International Atomic Energy Agency (IAEA), which leads the review and revision processes. The latest revision of the "International Basic Safety Standards (BSS)" was published in 2014 [5]. To ensure compliance with radiation safety requirements, each rural health center should designate a person among its staff that will function as the "radiation safety officer".

## 8.2 Responsibilities

A medical imaging service cannot function without an adequate QA/QC program, encompassing radiation protection issues and maintenance considerations. The QA/QC program involves financial, administrative and technical aspects and must cover the physical infrastructure, the equipment and accessories and the human resources. The process may seem complex for a health center, short of medical and nursing staff. It is recommended that a medical physicist be contracted for its development. In this regard, the functions of the medical physicist include: develop/review purchase specifications, perform acceptance tests, evaluate diagnostic imaging equipment (both ultrasound and X-ray units), assess radiation safety levels, train the staff in radiation protection measures such as personnel dosimetry and patient safety, develop and supervise the QC program to be carried out by the health center staff, supervise the maintenance program and participate in a QA program, if one exists. To develop the QC program, it is necessary to define the parameters to be tested, the methodology to be used, the frequency with which the tests are to be done and by whom, the tolerance acceptable for all the measured values and the correction actions the health center is to be taken, if these tolerances are exceeded.

In a health center, QC activities may be shared by an imaging technologist performing the role of “QC Technologist” and by another person, who can be mainly responsible for the radiation safety aspects, and may be designated as “radiation safety officer”. The QC technologist will have as primary responsibility checking the equipment and interacting with the medical physicist as needed. Normally the data obtained during the commissioning should be repeated at least annually, since medical imaging units can change their characteristics and affect the result of patient diagnosis or therapy. Other tests should be done more frequently. Numerous guidelines on this process are available [6–11].

It is difficult to be prescriptive about QA and QC test methods and frequencies that are applicable in all situations in medical imaging. An automatic film processor may require monitoring on a daily basis, whereas it may only be necessary to check the tube filtration when an X-ray tube has been replaced. The tests to be done if the facility uses teleimaging may be quite extensive, depending on what equipment and communication system are used. QC tests may have to be developed for all the components of the teleimaging system.

In a publication of this kind it is impractical to describe in detail all the QA and QC tests that should be performed in a medical imaging service. But they all should include the evaluation of equipment and staff performance and the determination of image quality and patient, worker and public doses, if the facility has X-ray equipment.

## 8.3 Specific QC Tests for X-ray Units

Before performance parameters are tested and radiation characteristics are measured, the units should be checked for mechanical integrity, mechanical stability, electrical integrity, and electrical safety, in accordance with manufacturer’s specifications and national and/or local safety codes. Regrettably, fatal accidents have occurred as a result of equipment parts falling on patients, which could have been avoided had the necessary safety checks been performed. The initial testing should verify the accuracy of readouts (scales, meters, and digital displays) and the proper functioning of collision detection devices, emergency shut-off switches, and interlocks. Mechanical and optical tests should verify the proper functioning of all motions. The next step is to verify the alignment and limitation of the radiation beam, checking the congruence with optical indicators. Measurement of radiation characteristics involves the verification of generator settings, including tube potential, tube current, and exposure time. Beam quality determinations involve the measurement of half-value layers. Absorbed dose determinations require the dose to be measured with calibrated dosimeters either in air or in appropriate phantoms for each beam quality at the distances, field sizes and techniques (kVp, mAs) in clinical use.

Methods of testing image quality differ whether the system is analog or digital. For screen/film image receptors, the darkroom, the film processor and the film/screens tests are the most critical parameters to evaluate periodically. For film processors, whether manual or automatic, it is essential to maintain a daily log of developer and water temperatures, replenishment rate, water flow, and cleaning and maintenance procedures. The screens require regular inspection and cleaning and periodic testing for screen-film contact.

A very effective method for testing the quality of the films produced is to implement a film reject analysis program, in which the reasons for discarding films are periodically explained. Consistently overexposed films coming from the same unit may point to an improperly calibrated generator. Inadequate patient positioning or anatomical misses in films taken by the same technologist may indicate deficiencies in his/her training. In such cases, corrective actions can be easily implemented and can lead to significant reductions in repeat rates, with the consequential economic savings. More sophisticated film analysis involves periodic measurement with a densitometer of optical densities in typical radiographs.

Reject analysis is also vital for digital radiology, although the methodology for collecting rejected images is more complicated. Rejected images should be temporarily stored in a database from where the reasons for rejection can be analyzed. The process requires that no images be deleted from the system so that the ratio of rejected versus total number of images can be calculated. For digital images, a ratio of 5 % should prompt an investigation [12]. Table 8.1 lists standardized reasons for rejection.

There are other methods to assess image quality on an objective basis. Image quality may be quantified in terms of several parameters, namely: spatial resolution, which measures the ability of a system to discriminate high-contrast patterns; noise, which is affected by the granularity of the receptor, the quantum fluctuations of the radiation, and statistical sampling, if the image is digitally created; and contrast, which reflects the different responses of objects to the imaging process. These parameters may be quantitatively determined through the measurement of modulation transfer functions (MTFs), Wiener spectra, and contrast-detail diagrams. They require special phantoms and software programs.

**Table 8.1** Reasons for rejecting digital images [12]

| | |
|---|---|
| 1. | Positioning<br>a. Rotation<br>b. Anatomy cutoff<br>c. Incorrect projection<br>d. Incorrect marker |
| 2. | Exposure error<br>a. Overexposure<br>b. Underexposure<br>Grid error<br>Cutoff<br>Decentering<br>No grid<br>Grid lines |
| 4. | System error |
| 5. | Artifact<br>a. Detector<br>b. Foreign object (jewelry, clothing, etc.)<br>c. Contrast media<br>d. Table/support/X-ray tube |
| 6. | Patient motion |
| 7. | Test images |
| 8. | Study cancelled |
| 9. | Other |

Spatial resolution, noise, and contrast may be qualitatively assessed by the use of suitable phantoms that either mimic the tissue to be imaged or contain periodic patterns of different contrasts and/or spatial frequencies. A trained observer may reproduce his/her assessment of an imaging system by analyzing the image of a particular phantom and discerning all clearly visible ("resolved") patterns. An example of a QC phantom that incorporates quantitative and qualitative measurements is shown in Fig. 8.1, from Ref. [13].

Because the imaging device and the image receptor affect image quality, both have to be evaluated. In radiography the X-ray tube parameters to be tested are: beam quality (tube potential and filtration), focal spot size, source-image receptor distance, and tube current and time. The reproducibility of the factors selected for each radiographic projection need to be periodically verified to minimize exam repetitions due to generator or X-ray tube inconsistencies. This is particularly important when the system uses automatic exposure control. The tests to be performed on film/screens involve the determination of the screen/film characteristics: fog, contrast, latitude, and speed. The variation of these factors vis-à-vis radiation exposure is called the Hunter and Driffith (H&D) curve, and needs to be drawn for each type of screen/film combination during acceptance testing procedures. On a daily basis it may be sufficient to measure the optical density of the film at one exposure level. The automatic exposure control circuit also needs to be checked periodically to verify range and saturation. Contrast resolution and linearity, vignetting, and processing fidelity need periodic testing in digital systems.

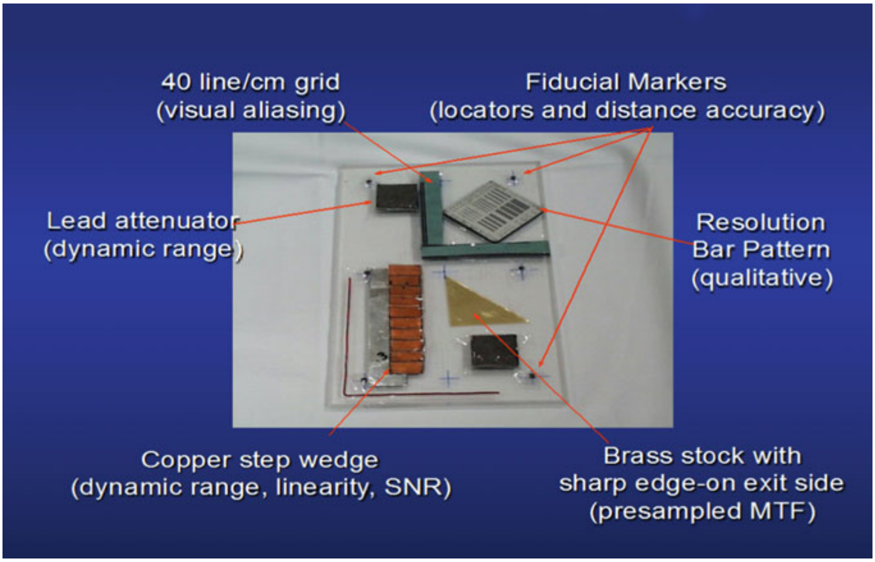

**Fig. 8.1** Example of QC test phantom (UC Davis) [13]

Digital systems such as computed radiography (CR) and digital radiography (DR) require careful validations of field uniformity and measurements of contrast-noise ratio. Spatial uniformity is a stringent requirement in CR and DR systems. In addition, both CR y DR systems should be checked for artifacts.

Some artifacts illustrated in the AAPM Report 151 are listed in Table 8.2 [12], to show that artifacts may be the result of faulty electronics or inadequate use of post-processing algorithms, but they also appear as a consequence of maintenance issues or operational carelessness.

For CR and DR systems, Seibert [13] recommends the QC tests listed in Table 8.3; they can be done by a technologist.

There have been numerous publications on QA and QC test methods and it is suggested that the reader refers to these manuals for further guidance [6–18].

## 8.4 Specific QC Tests for Ultrasound Units

Quality control (QC) testing of ultrasound scanners is important to verify the proper and consistent operation of these devices. The basics of ultrasound QC have been outlined thoroughly in the reports of AAPM Ultrasound Task Group No. 1 [19, 20]. The basic tests are listed in Table 8.4.

The American College of Radiology has selected a phantom for their accreditation programs that is well suited to perform such tests and has established tolerances [21]. The phantom can be handled by a technologist. However, the gel

**Table 8.2** Artifact causes in CR images [12]

| |
|---|
| Lead markers taped to the detector face left during maintenance |
| Scratches on the CR screen |
| White bands resulting from edge enhancement post processing |
| Inadequate positioning sponge |
| Dead pixels in a flat panel detector |
| Noisy image due to underexposure |
| Dust on the light guide of a CR reader |
| Shifting of the light guide |
| Patient motion |
| Bad linear amplifier in a flat panel detector |
| Quantitation saturation resulting from excessive post-processing |
| Grid lines |
| Latent images (erasure failure) |
| Electronics malfunctions |
| Image after flat panel image receptor was dropped |

**Table 8.3** QC tests for CR/DR systems [13]

| |
|---|
| • Daily<br>– Inspect CR/DR system and status and interfaces<br>– Erase image receptors<br>– Log image artifacts as they appear |
| • Weekly/Biweekly<br>– Review calibration monitor test image (AAPM TG-18 [14])<br>– Acquire QC phantom test images. Verify performance<br>– Check and clean IP's (if necessary) with recommended agents |
| • Quarterly<br>– Inspect cassettes. Clean with recommended agents<br>– Review image retake rate and exposure trends<br>– Update QC log. Review out-of-tolerance issues |

inside the phantom is susceptible to humidity and it should be kept in a dry environment. The test frequency should be established by a medical physicist, who should periodically (at least annually) review the QC Technologist results and advise regarding potential corrective actions.

Additional guidance on QA/QC for ultrasound units is available in Chap. 4, Sect. 4.1.6.2.

## 8.5 Maintenance

The goal of a maintenance program is not just that the equipment continues to function but that it does so ensuring that the manufacturer's specifications continue to be met years after years of clinical use and that its software is updated

**Table 8.4** QC tests for ultrasound units [19, 20]

| |
|---|
| Sensitivity and/or penetration capability |
| Image uniformity |
| Photography and other hard copy recording |
| Low country object detectability |
| Assurance of electrical mechanical safety |
| Vertical and horizontal distance accuracy |

periodically. After the warranty period is over, rural health centers are faced with difficult maintenance choices. And if the equipment is donated, the problems may be even worse, due to potential lack of spare parts and/or operation and maintenance manuals, or even because of the language of the written instructions and displays, which may have been written in the original donor's language and were never translated. An additional challenge is how to decide when equipment shall be discarded because of obsolescence or safety issues.

Depending on the technical capabilities of the maintenance personnel and the availability of instruments, calibration equipment, and technical information, as well as the technological complexity and amount of equipment and accessories, maintenance may be carried out by: staff of the institution; external maintenance personnel contracted through the manufacturer, the distributor, or a maintenance firm, or both internal and external personnel.

The pros and cons of each possibility were examined carefully in a Workshop of the International Union of Physical and Engineering Sciences in Medicine-Health Technology Task Group (IUPESM-HTTG) on Radiological Equipment Maintenance Issues and concluded that any of the solutions could be acceptable, provided the quality and the reliability of the services could be monitored and validated, preferably by an in-house program [22]. In the absence of such a resource, advice may be sought from a consulting service engineer who can advise on the best company to contract and how to prepare the maintenance contract. However, within the institution there should be personnel capable of exercising technical supervision of maintenance services provided by both internal and external personnel. To start with, the person or persons responsible for operating the equipment are also responsible for its upkeep and should promptly report any malfunctions to management in order to avoid major damage. They should also ensure that after the equipment has been serviced, the consulting medical physicist is alerted in case that additional tests and measurements are needed to ensure safety and efficacy.

A logbook should be kept in the rural health center in which all maintenance procedures, their costs and follow up actions are recorded. It would be good if the staff could also document problems in the rooms such as air conditioning break down, flood damage and power interruption, as well as mishaps with the equipment itself, which may have an effect on its performance, such as an ultrasound probe being dropped. Such logbook is to be periodically evaluated by the consulting service engineer and the consulting medical physicist, and their recommendations, followed.

## 8.6 Radiation Safety Program

### *8.6.1 Requirements*

According to the International Commission of Radiological Protection (ICRP), which the BSS follows, there are three principles of radiation protection: justification of the practice, optimization of the protection and radiation dose limitation. These principles apply to occupationally exposed staff such as the X-ray technologists (occupational exposure), the patients who are being radiographed (medical exposure), and the public that may be in the health center as visitors or for a diagnostic or treatment procedure that does not include radiography (public exposure). Table 8.5 summarizes the concepts implied in these principles and Table 8.6 lists the dose limits for workers and public. Both tables have been adapted from the BSS [5].

### *8.6.2 Methods for Exposure Reduction*

The reduction of exposure from a radiology facility may be achieved by a combination of three factors: Shielding, distance, and time.

Shielding involves placing attenuating material such as lead between the source of radiation and any individuals exposed. The need for structural shielding was addressed when discussing the planning of an X-ray room. Assuming that the rural health center is only going to do radiography, it is not necessary for the technicians to wear any protective vestment. The structural shielding alone, when properly designed, should take care of their protection to acceptable radiation levels. Ancillary shielding in the form of leaded aprons and gonadal and thyroid shields should be available to protect patients being radiographed and to persons helping infirm, elderly or pediatric patients while undergoing the X-ray examination. Such help should never be provided by the technologist him/herself [5].

**Table 8.5** Summary of radiation protection principles

| General | Medical exposure |
|---|---|
| *Justification of practices* | |
| Does the benefit to the exposed individuals or to society outweigh the radiation detriment? | Generic and individual. Consider benefits and risks of available alternative techniques that do not involve ionizing radiation |
| *Dose limitation* | |
| For occupational and public exposure | Not applicable to patient exposure |
| *Optimization of protection* | |
| As low as reasonable achievable (ALARA) | Management of the radiation dose to the patient commensurate with the medical purpose |

**Table 8.6** Dose limits for planned exposure situations (adapted from Schedule III of the BSS [5])

| *Occupational exposure* |
|---|
| For occupational exposure of workers over the age of 18 years, the dose limits are<br>(a) An effective dose of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years), and of 50 mSv in any single year<br>(b) An equivalent dose to the lens of the eye of 20 mSv per year averaged over 5 consecutive years (100 mSv in 5 years) and of 50 mSv in any single year<br>(c) An equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year<br>Additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breast-feeding (BSS para. 3.114) |
| For occupational exposure of apprentices of 16–18 years of age who are being trained for employment involving radiation and for exposure of students of age 16–18 who use sources in the course of their studies, the dose limits are<br>(a) An effective dose of 6 mSv in year<br>(b) An equivalent dose to the lens of the eye of 20 mSv in a year<br>(c) An equivalent dose to the extremities (hands and feet) or the skin of 150 mSv in a year |
| *Public exposure* |
| For public exposure, the dose limits are<br>(a) An effective dose of 1 mSv in a year<br>(b) In special circumstances, a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year<br>(c) An equivalent dose to the lens of the eye of 15 mSv in a year<br>(d) An equivalent dose to the skin of 50 mSv in a year |

Distance is a particularly useful method of reducing radiation exposures as a result of the inverse square law. If the distance from the source of radiation is doubled, the dose and dose-rate are reduced by a factor of four. While the inverse square law relationship is strictly applicable only to unattenuated primary radiation, increasing the distance from a source of scattered radiation will also greatly reduce the dose and dose-rate.

Exposures to individuals may also be reduced by reducing the time the individual is exposed to the source. Short exposure times will also improve image quality by decreasing blurring due to motion, especially when radiographing children.

Cost-effective methods should be considered and prioritized depending on the resources available [23].

## *8.6.3 Dosimetry*

### 8.6.3.1 Workers

For compliance with the dose limits, the personnel working with or in the vicinity of a radiation unit should wear radiation dosimeters, which should be changed on a quarterly basis, unless the patient workload is very high, in which case monthly monitoring may be best. Given the expense associated with this requirement, it is recommended that a personnel dosimetry service be contracted out. However, the person within the health center assigned with the function of radiation safety officer should check the dosimeter readings and assess that no one is receiving unacceptable radiation doses—the operational levels should best be decided by a medical physicist or a radiation protection specialist.

#### 8.6.3.2 Patients

Patient safety should be paramount and dose reduction techniques should be put in place and verified, as needed [5, 23]. The BSS requires the establishment of a comprehensive QA program for medical exposures. The most critical issue is to develop or adapt imaging protocols adequate to patient habitus, in particular when radiographing children [24]. The number of X-ray projections should be determined by the clinical need. The radiation field must be limited to the area under examination by proper positioning and adequate collimation. If the technology in use is analogic, the choice of film/screen combinations, the developer's temperature and processing time and the illumination of the viewboxes (in terms of luminance, uniformity and color) are significant. For both analog and digital systems, the choice of grid and the use of automatic exposure control if such circuit is available, are very important. Additional dose reduction may be obtained using organ shields as discussed above. Table 8.7 lists all the factors to be taken in consideration.

**Table 8.7** Dose reduction factors in radiography

| *Analog and digital* |
|---|
| Number of X-ray projections |
| Patient positioning |
| Radiation field size (collimation) |
| Use of anti scatter grid |
| Tube potential |
| Tube current |
| Exposure time |
| Automatic exposure control |
| Organ shields |
| Ergonomics of interpretation room |
| Physician experience and training |
| *Analog only* |
| Screen/film combination |
| Developer temperature |
| Processing time |
| Illumination of viewboxes<br>Luminance<br>Uniformity<br>Color |

Dose reduction techniques should only be implemented if the image has enough image quality for proper diagnosis. Even if acquisition protocols have been developed and validated by the physician in charge, they may have to be changed depending on the clinical needs. With film/screen technology, this may imply repeating the exposure using different technique factors, but with digital imaging the problem may be solved using post-processing software, as illustrated in Fig. 8.2**a**, **b**, taken from AAPM Task Group 151 [12].

Because patient dose depends on technique factors, technologists should document the techniques used for each patient, a task that current CR/DR systems can do automatically. In digital systems, particular attention should be given to the "exposure indicator" a metric used by the manufacturer related to patient dose, which is calculated differently depending on the manufacturer. At the time of acceptance testing, the medical physicist should evaluate the different exposures indices in terms of patient dose and together with the manufacturer representative instruct the X-ray technologist on their use for the different X-ray projections and body habitus [25].

From the knowledge of exposure factors and typical patient sizes, a medical physicist can estimate radiation levels per procedure and compare them with the so-called diagnostic reference levels [5], a radiation protection optimization tool described in the BSS and adopted by many countries [26–28]. When a technologist sees that technique factors for a specific patient deviate significantly (for example

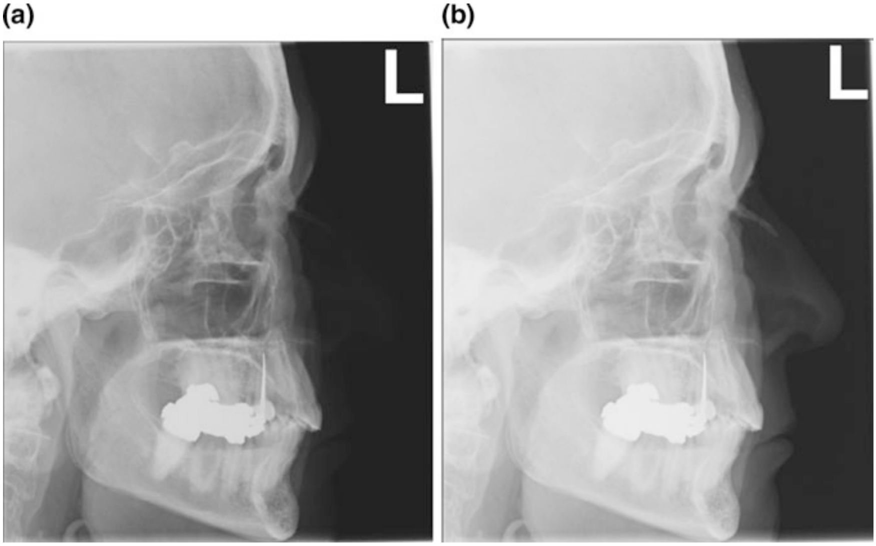

**Fig. 8.2** **a** Image post-processing correctly grayscales the skull, but the skin line and nasal bone are *black*. The clinical indication for the study was a suspected broken nose, and the radiologist requested help with the image. **b** Adjustment of post-processing settings resulted in suboptimal image appearance in the skull but excellent rendering of the nasal bone and skin line, allowing diagnosis to be made [12]

the mAs that has to be used is two times higher or lower than what the protocol suggests), the event should be documented for later review by the medical physicist. Dose should never determine whether a radiograph is to be taken or not. The decision is a clinical decision. Guidance on appropriateness criteria and referral patterns is available [29–32].

## 8.7 Management Considerations

It is possible to operate an imaging department in a rural health center without on site specialized personnel such as radiologists, medical physicists and maintenance engineers, provided the facility: (a) follows the clinical and technical protocols established by these specialists, (b) is in constant communication with them through scheduled and unscheduled visits and via telephone and Internet and (c) has a committed manager that supervises the financial, administrative and technical issues and insists on implementing and monitoring a rigorous QA/QC Program that includes radiation safety aspects as appropriate.

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# Chapter 9
# Patient Referral to Secondary and Tertiary Health Care Levels

**Cari Borrás and Patrick Cadman**

**Abstract** This chapter addresses the conditions for which a patient in a rural health center can be diagnosed or treated locally or has to be sent to a higher care level institution, and reviews the minimum knowledge health practitioners must have to arrive at such a decision, aided by medical imaging. Emphasis is placed on the importance of primary health care, where the majority of diseases can be prevented and diagnosed, and on the need of having services among the three or four health care levels well coordinated and interrelated. To ensure smooth referral and counter referral processes and guarantee continuity of care for patients who require it, functional links between centers of differing degrees of complexity must be clearly established. Recommendations regarding patient referral in resource-poor settings and an example of a system that functions very well in an industrialized country are presented and discussed.

**Keywords** Health care levels · Integrated health services · Imaging referral guidelines · Patient referral

## 9.1 General Concepts of Health Care Levels and Integrated Health Services

Medical imaging services in rural health care centers should be functionally interrelated within the overall system of health services in order to form a true subsystem of diagnostic support services, in which referral and counter referral of patients is possible and technical support is provided to the least complex centers. Both the World Health Organization (WHO) and the Pan American Health Organization (PAHO) have published extensively on the planning role governments

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have and how the coordination of public and private sectors improve health care delivery, especially at the primary health care level [1].

The term "levels of care" has been used in very different ways in different countries. In some cases, it has referred to the degree of medical specialization required or utilized in the delivery of a given service; in others, it has meant the units or institutional strata of organization and administration of health services. Sometimes the term has been used in relation to the quality of services; in these cases, reference is made to different levels of quality and it is assumed that specialized care, because it is more complex, is of higher or better quality. Quality, however, does not mean sophistication or complexity. Quality has to do with how the service is provided, not with where or with what type of equipment it is provided, nor with who provides the care.

The expression levels of care actually refers to the technological plane on which problems are solved [1]. According to WHO, there are three levels of healthcare. Level I is a basic level which includes promotion of health, early diagnosis of disease or disability, and prevention of disease. Primary health care should be "based on practical, scientifically sound and socially acceptable methods and technology made universally accessible to individuals and families in the community through their full participation and at a cost that the community and country can afford to maintain at every stage of their development" [2].

Level II is an intermediate level of health care that includes diagnosis and treatment, performed in a hospital having specialized equipment and laboratory facilities, such as local or regional hospitals. The radiological and laboratory services provided by hospitals should be directly available to the family doctor, thus improving and increasing the range of service.

Level III is a specialized, highly technical level of health care with specialized intensive care units, advanced diagnostic support services, and highly specialized personnel. It should support the population of a large region.

PAHO considered the possibility that certain countries may contemplate a higher level of care. This "level IV" might include diagnosis and treatment of infrequent diseases and of diseases unresolved at levels I, II, and III [1]. The medical facilities within this level would serve as national or international reference centers, often of a particular clinical specialty.

Disappointed by the fact that universal health coverage is not being achieved in spite of multiple past public health strategies, and that health care delivery is increasingly fragmented, inefficient and unsustainable, recently, WHO and PAHO are insisting on "integrated health services". These services "encompass the management and delivery of quality and safe health services so that people receive a continuum of health promotion, disease prevention, diagnosis, treatment, disease-management, rehabilitation and palliative care services, through the different levels and sites of care within the health system, and according to their needs throughout the life course" [3].

On the WHO website, there are two documents, one on the strategy itself and the other one on the evidence supporting it [4]. These background documents were summarized in an Executive Summary which was subjected to public consultation and can be found in Ref. [5]. Figure 9.1, taken from that Ref. [5], shows the conceptual framework for integrated people–centered health services.

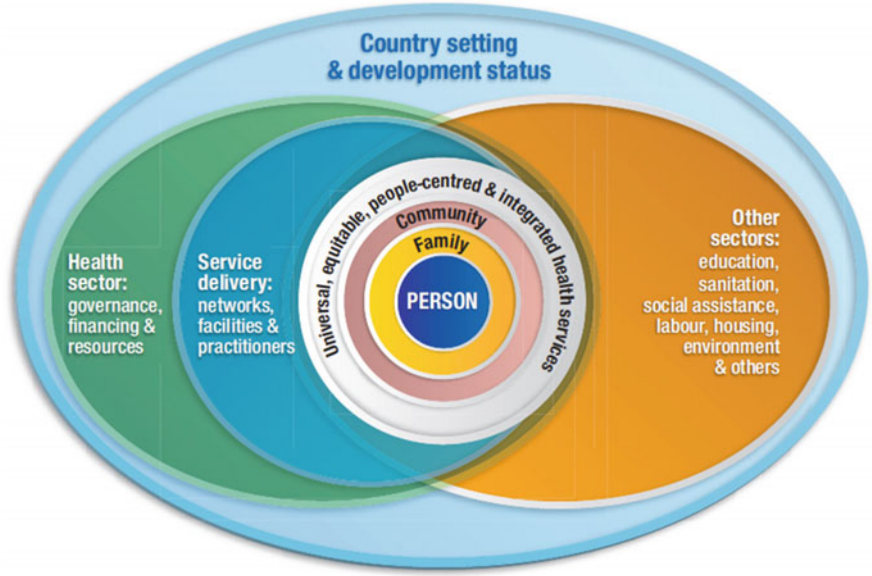


**Fig. 9.1** Conceptual framework for integrated people-centered health services [5]

WHO recommends five interwoven actions for health service delivery to become more people-centered and integrated, including:

1. Empowering and engaging people
2. Strengthening governance and accountability
3. Reorienting care models towards efficiency and effectiveness
4. Coordinating services around the needs of people, health-care provider integration and effective networks, and
5. Creating an enabling environment for change.

Item 4 relates directly to the subject of this Chapter. Coordinating services involves coordinating care around the needs and preferences of people at every level of care, as well as promoting activities to integrate different health care providers and create effective networks between health and other sectors. Coordination does not necessarily require the merging of the different structures, services or workflows, but rather focuses on improving the delivery of care through the alignment and harmonizing of the processes of the different services. One of the aspects it emphasizes is the need for a fully integrated and effective referral system [5].

There are three types of services coordination:

1. Coordinating care for individuals—through the following policy options and interventions:
    - Shared electronic medical record
    - Care pathways

- Referral and counter-referral systems
- Case management

2. Coordinating health programmes and providers—through the following policy options and interventions:
    - Regional or district-based health service delivery networks
    - Integrating vertical programmes into national health systems
    - Incentives for care coordination
3. Coordinating across sectors—through the following policy options and interventions:
    - Intersectoral partnerships
    - Merging of health sector with social services
    - Integrating traditional and complementary medicine with modern health systems
    - Coordinating with preparedness, detection and response to health crises.

Several review articles have analyzed published results of integrated health services by performing literature surveys. Wenke et al. [6] reviewed 21 peer-reviewed articles and 4 non peer-reviewed ones to assess the effect on quality and cost when integrating delivery services in the United States. They found out that while quality seemed to have improved, the evidence on cost reduction was very weak. A similar conclusion was reached by E.M. Rygh and P. Hjortdahl [7], who reviewed the continuous and integrated health care services in rural areas. The authors concluded that programs such as integrated and managed care pathways, outreach programs, shared care and telemedicine were relevant initiatives, which could be associated with greater equity in access to care, and more coherent services with greater continuity, but that they were not necessarily linked to reduced costs; and that in fact could in some cases, entailed additional expenses. Their final sentence stated “Such endeavors are, to a large degree, dependent on a well functioning primary health care system as a base” [7].

## 9.2 Changes in Disease Burden and the Importance of Health Care Level I

In 2008, WHO updated its 2004 Global Burden of Disease publication, showing the significant changes that were occurring regarding mortality and morbidity in the world. It projected selected causes of death (see Fig. 9.2) and leading causes of disability-adjusted-life years (DALYs) (see Fig. 9.3) to the year 2030 [8].

As the figures show, while deaths and disabilities from non-communicable diseases such as infections are decreasing, those of non-communicable diseases (NCDs) are rising. And the trend is not only true of industrialized countries. According to a 2015 World Health Organization report, “NCDs are estimated to kill around 38 million people per year, accounting for 68 % of all deaths worldwide, and the main NCDs (cardiovascular diseases, cancers, cardiorespiratory disease and diabetes), taken singly, are

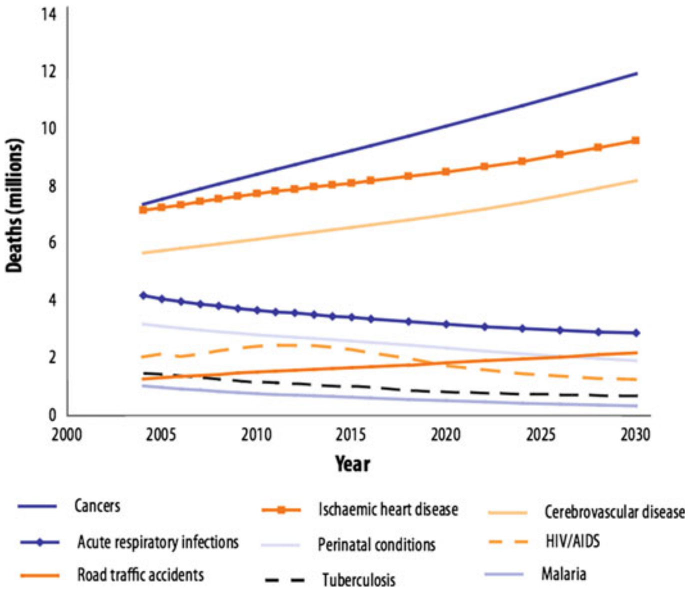
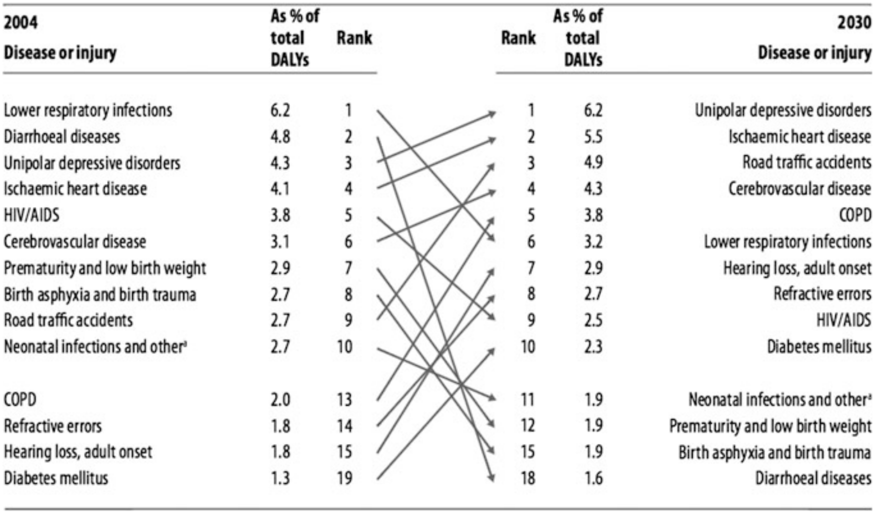


**Fig. 9.2** Projected global deaths for selected causes, 2004–2030 [8]



| 2004<br>Disease or injury | As % of total DALYs | Rank | Rank | As % of total DALYs | 2030<br>Disease or injury |
|---|---|---|---|---|---|
| Lower respiratory infections | 6.2 | 1 | 1 | 6.2 | Unipolar depressive disorders |
| Diarrhoeal diseases | 4.8 | 2 | 2 | 5.5 | Ischaemic heart disease |
| Unipolar depressive disorders | 4.3 | 3 | 3 | 4.9 | Road traffic accidents |
| Ischaemic heart disease | 4.1 | 4 | 4 | 4.3 | Cerebrovascular disease |
| HIV/AIDS | 3.8 | 5 | 5 | 3.8 | COPD |
| Cerebrovascular disease | 3.1 | 6 | 6 | 3.2 | Lower respiratory infections |
| Prematurity and low birth weight | 2.9 | 7 | 7 | 2.9 | Hearing loss, adult onset |
| Birth asphyxia and birth trauma | 2.7 | 8 | 8 | 2.7 | Refractive errors |
| Road traffic accidents | 2.7 | 9 | 9 | 2.5 | HIV/AIDS |
| Neonatal infections and other[a] | 2.7 | 10 | 10 | 2.3 | Diabetes mellitus |
| COPD | 2.0 | 13 | 11 | 1.9 | Neonatal infections and other[a] |
| Refractive errors | 1.8 | 14 | 12 | 1.9 | Prematurity and low birth weight |
| Hearing loss, adult onset | 1.8 | 15 | 15 | 1.9 | Birth asphyxia and birth trauma |
| Diabetes mellitus | 1.3 | 19 | 18 | 1.6 | Diarrhoeal diseases |

**Fig. 9.3** Ten leading causes of burden of disease, world, 2004 and 2030 [8]

among the top 10 leading killers. Nearly 80 % of NCD deaths—30 million—occurs in low-, middle- and non-OECD high-income countries, where NCDs are fast replacing infectious diseases and malnutrition as the leading causes of disability and premature death" [9]. (For specific health indicators, years and countries, the Institute for Health Metrics and Evaluation keeps updating statistical data on global burden of disease, accessible using interactive software [10]).

In developing countries, the cost of patient management at the various levels is a matter of particular importance. The 2015 WHO report shows that, although relatively decreasing, the out-of-pocket spending as a percentage of total health spending is greater for low income countries than it is globally [9]. Since the cost of treatment at the primary health-care level is usually only a small fraction of that at the third level, it is important to realize that the majority of diseases can be prevented and diagnosed at Level I [11]. And even though primary health care centers can meet over 90 % of the imaging needs of the population, given the forthcoming epidemiological changes, there is an increasing need to define strategies to improve access, quality and use of medical imaging equipment at different health care levels by ensuring a good referral-and counter-referral system.

## 9.3 Medical Imaging Referral Guidelines

Before a referral is considered, it is necessary to first establish which medical imaging procedures should be conducted at each level of health care. All medical imaging procedures should be chosen according to national or international referral guidelines to ensure the procedure is appropriate and in case of ionizing radiation, that radiation exposures are minimized. Such referral guidelines will help promote quality imaging and safer use of imaging procedures and prevent underuse or overuse of diagnostic imaging relative to the evidence base (i.e., appropriate with minimal cost). International guidelines applicable to developing countries have been drafted by the International Radiology Quality Network (IQRN), initiated by WHO [12]. National sources of referral guidance have been developed by professional societies in various countries [13–18] and are usually available for free consultation on the web.

If the rural health center capacities or capabilities are exceeded, then a referral for a specialist consultation may be required. All health center personnel should understand and acknowledge the capacities and capabilities of the health center for each common clinical situation. If these are exceeded or if there is doubt as to whether an investigation is required or which investigation is best, an appropriate specialist should be consulted.

**Table 9.1** Summary of recommendations for patient referral from a rural health center to a higher health-care level from Chap. 2

| |
|---|
| • Pneumothorax with blood collection |
| • Complicated fractures |
| • Advanced osteoarthritis |
| • Acute obstruction of the small or large intestine |
| • Appendicitis |
| • Heavy rectal bleeding with clinical suspicion of polyps, ulcers or tumors |
| • Enlargement of the spleen |
| • Kidney stones larger than 3 mm on one side with hydronephrosis and fever |
| • Abnormal pregnancy ultrasound images indicating aborted fetus |
| • Low position of the placenta or retroplacentarium hematoma |
| • Abnormal amniotic fluid |
| • Ectopic pregnancy |
| • Uterine lesions and adnexal masses |

## 9.4 Considerations Regarding Patient Referral in Resource-Poor Settings

In a rural health center, the critical issue is to decide when a patient can be managed locally or when he/she needs to be referred to a higher level of care. Chapter 2 described how to interpret common clinical situations that may be treated at the rural health center and when there is a need for either a consultation or a referral or both.

Table 9.1 summarizes the referral recommendations discussed in Chap. 2.

The issue, of course, is whether these pathologies can be diagnosed at the local level. For that, the person acquiring the images and the person interpreting them must have basic medical imaging knowledge. Chapter 6 addressed the basic training and continuing education of the technical staff in rural health centers, and Chap. 2 recommended that a general practitioner working in a rural health center should have minimal medical knowledge of conventional X-ray imaging and basic ultrasound. Such knowledge may be acquired in medical school and attending physical or virtual courses on X-ray and ultrasound. Nowadays, there are many on-line courses, some free of charge. WHO, aware that in rural health centers, general practitioners and not radiologists would interpret the medical images, did publish a "Manual on Radiographic Interpretation for General Practitioners" in 1985 [19]. Ten years later, recognizing that ultrasound interpretation presents many challenges, WHO published its first training manual in ultrasonography. As many WHO publications, the manual was translated into several languages and distributed widely. Given its success, in 2011 WHO published a second edition of the "Manual of Diagnostic Ultrasound", this time in two volumes; the first one deals with basics physics, image acquisition and covers basic ultrasound exams, while volume 2 includes paediatric examinations and gynaecology and musculoskeletal examinations and treatments. Both of them are available for free in the WHO website [20].

According to Dr. Jaume F. Mulet, a physician expert in rural health centers in Senegal [21].

1. The clinical practitioner must know the normal images of the examined anatomical region, and thus, be able to detect when an abnormality is present, even though he/she may not be able to reach a diagnosis.
2. Experience is paramount, since it will allow him/her—in addition of discovering the abnormality—to decide whether to refer the patient or not.
3. He/she must be able to describe the image accurately in case the consulting imaging specialist is not able to visualize it.
4. To perform the functions described above, the practitioner must have participated in a basic training course and should update his/her knowledge periodically through refresher courses—medical imaging technology evolves very rapidly.
5. The acquired knowledge will depend on multiple factors, both of personal nature (for example wanting to learn) as well as environmental issues, such as

**Table 9.2** Core conditions utilizing ultrasound in resource-poor settings [21]

| Type | Condition | Intervention | Skill level | Necessity |
|---|---|---|---|---|
| Abdominal | Cephalopelvic disproportion | Cesarean section | Advanced | Moderate |
| | Ectopic pregnancy | Surgical management | Advanced | Moderate |
| | Retained products of conception | Dilation and curettage | Advanced | High |
| | Abruptio placentae | Medical and surgical management | Advanced | High |
| | Peripartum hemorrhage | Medical management | Basic | Moderate |
| | Cholecystitis | Medical and surgical management | Advanced | High |
| | Tuberculosis (intra-abdominal) | Medical management | Basic | High |
| | Hydronephrosis | Medical and surgical management | Basic | High |
| | Abdominal trauma | Medical and surgical management | Advanced | High |
| | Abdominal masses | Medical and surgical management | Basic | High |
| Chest | Pleural effusion | Thoracentesis | Advanced | High |
| | Pneumothorax | Chest tube | Advanced | Moderate |
| | Hemothorax | Thoracentesis | Advanced | High |
| Cardiovascular | Deep vein thrombosis | Anticoagulation | Basic | High |

(continued)

**Table 9.2** (continued)

| Type | Condition | Intervention | Skill level | Necessity |
|---|---|---|---|---|
| | Cardiac failure | Medical management | Basic | Moderate |
| | Cardiac valve disease | Medical and surgical management | Advanced | High |
| | Pericardial effusion | Medical management and pericardiocentesis | Advanced | High |
| Orthopedic | Spine, skull trauma | Surgical management | Advanced | Moderate |
| | Pediatric osteomyelitis | Medical management | Basic | Moderate |
| | Rib, pelvis trauma | Surgical management | Advanced | Moderate |
| Neurological | Neonatal hemorrhage | Medical management | Advanced | High |
| | Neonatal infection | Medical management | Advanced | Moderate |
| Procedural | Intravenous access | Procedural guidance | Basic | Moderate |
| | Abscess | Procedural guidance | Basic | Moderate |
| | Arthrocentesis | Procedural guidance | Basic | Moderate |
| | Paracentesis | Procedural guidance | Advanced | High |
| | Thoracentesis | Procedural guidance | Advanced | High |
| | Pericardiocentesis | Procedural guidance | Advanced | High |
| | Foreign body | Procedural guidance | Basic | Moderate |
| | Lumbar puncture | Procedural guidance | Basic | Moderate |

**Table 9.3** Core conditions utilizing radiography in resource-poor settings [21]

| Type | Condition | Intervention | Skill level | Necessity |
|---|---|---|---|---|
| Chest | Pneumonia | Medical management | Basic | High |
| | Tuberculosis | Medical management | Basic | High |
| | Pneumothorax | Chest tube placement | Advanced | High |
| | Pleural effusion | Thoracentesis | Advanced | High |
| | Cardiac failure | Medical management | Advanced | Moderate |
| | Hemothorax | Thoracentesis | Advanced | High |
| | Chronic obstructive pulmonary disease | Medical management | Basic | Moderate |
| | Asthma | Medical management | Basic | Moderate |
| | Lung abscess | Medical management | Advanced | High |
| | Occupational lung diseases | Medical management | Basic | Moderate |
| Limb | Long bone fracture | Reduction and fixation | Advanced | High |
| | Small bone fracture | Reduction and fixation | Advanced | High |
| | Osteomyelitis | Medical and surgical management | Basic | Moderate |
| | Dietary deficiency diseases (scurvy, rickets) | Nutrient supplementation | Basic | Moderate |

availability of resources, clinical workload, support from other health professionals, geographical location and mobility access and Internet connections for on-line training. As a consequence, the acquired knowledge may be quite different from one center to another, but the basic knowledge is essential.

Maru et al. [22] listed the core conditions that certain exams and patient follow up were required by a general practitioner in terms of skill and necessity in resource-poor settings. Table 9.2 refers to ultrasound exams; Table 9.3, to X-ray studies. The skill level was chosen because the authors assumed in the resource-poor context that the generalist practitioner would be required to interpret the resulting image, and perform the indicated intervention. Necessity refers to the need for the imaging modality in diagnosis and management of the condition listed. In the case of ultrasound, it was assumed that the general practitioner would also perform the examination.

## 9.5 Patient Referral to Secondary and Tertiary Health Care Levels: Canadian Experience

Referrals from a rural health center to secondary or tertiary health care levels need to be appropriate, expedite and coordinated. This may present a significant challenge for regions with limited resources; however, fundamental philosophies which are employed by resource-rich countries might still be considered suitable.

Functional links between centers of differing degrees of complexity must be clearly established in order to ensure smooth referral and counter referral processes and guarantee continuity of care for patients who require it. These functional links may be realized by a call center oriented service designed to provide a single point of contact for physicians and health care providers to access appropriate and timely advice, referral, admission, discharge, repatriation and transportation for their patients.

An example which works very well is RAAPID (Referral, Access, Advice, Placement, Information and Destination), a service currently in operation in Alberta, Canada [23].

The main goals of RAAPID are to:

1. Facilitate critical and/or urgent transfers or consultations with tertiary care facilities or specialists;
2. Provide the right care at the right place, using real time capacity information, resulting in enhanced coordination to transport patients;
3. Return the patient to their sending institution or closest health care facility within their community following an acute episode, and;
4. Archive all calls to serve as a legitimate medical record.

RAAPID provides a single point of contact for coordinating seamless transitions of care. The coordinator (usually a nurse with Emergency Room experience) manages all consultations/transfers according to guidelines (and personal experience) and available real-time information (e.g. available beds, emergency room waits, etc.). The coordinator can set up a connection between referrer and specialist by available telehealth pathways (e.g. direct dial, teleconference).

RAAPID—example:

1. Health center physician contacts RAAPID regarding a patient having an acute episode;
2. RAAPID coordinator determines that a consultation with radiologist is required and that patient should be referred for an examination at tertiary care facility;
3. Coordinator arranges patient transport to tertiary care facility;
4. Coordinator sets up teleconference between referrer and radiologist to discuss results;
5. Coordinator documents initial call and is linked into the actual consultation by audio to capture the rest of the record. All information is entered into a data base to serve as a legitimate medical record;
6. The referring site documents the consultation and care at their end and is able to access RAAPID documentation;
7. Repatriation (patient transfer home, etc.) is managed by the Coordinator.

Although the RAAPID service described is a state-of-the-art initiative in an advanced economy, the basic philosophies might well be applied in a resource-challenged setting. The concept of centralized (intelligent) coordination for optimal use of available resources has universal appeal.

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# Erratum to: Technical Specifications of Medical Imaging Equipment

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## Erratum to:
## Chapter 4 in: C. Borrás (ed.), *Defining the Medical Imaging Requirements for a Rural Health Center*,
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The original version of Chapter 4 was inadvertently published with incorrect author name “Kwan Hong Ng” instead of “Kwan Hoong Ng”. The erratum chapter and the book have been updated with the changes.

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C. Borrás (ed.), *Defining the Medical Imaging Requirements for a Rural Health Center*, DOI 10.1007/978-981-10-1613-4_10

# Recommendations Made by the Participants of the Workshop "Defining the Medical Imaging Requirements of a Health Station", Porto Alegre, Brazil, April 2011

Part I: Medical and Public Health Needs of a Rural Health Center

1. The health conditions that need to be addressed are:
    a. Trauma
    b. Chest diseases: viral and bacterial infections such as tuberculosis
    c. Acute abdominal pain, diarrhea
    d. Kidney stones
    e. Gynecological problems
    f. Pregnancy.
2. Since medical doctors may not be available on a full-time basis, the nurse or nurse practitioners should receive special training to identify the potential health problems and seek appropriate consultation.

Part II: Medical Imaging Modalities

3. The medical imaging technologies need to be justified by the overall benefits achieved in terms of safety, health outcomes and costs, and need to be tailored to the specific health needs to be addressed.
4. Medical imaging technologies should be:
    a. Integrated into the national healthcare system
    b. Regulated according to international standards
    c. Appropriate to the level of the healthcare system
    d. Appropriate to the therapy capabilities available.
5. Given the health conditions to be addressed by the health center, the medical imaging modalities to be installed are basic X-ray systems and ultrasound units. They should be easy to operate and maintain.
6. A suitable X-ray system to deploy is the World Health Imaging System—Radiography (WHIS-RAD) that uses a battery-powered high frequency generator. It should have CR image digital capture with a single simple interface.
7. The ultrasound unit should be an all-purpose general ultrasound scanner mainly for abdominal work with Doppler capability and digital output.

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It should preferably be mobile, so that it can be shared among several health centers. A 3.5 MHz curved-linear array transducer should be the minimum specification.

8. Other medical imaging systems that may be suitable for rural health settings should be explored, but they should not be deployed until the technology has proven its value and appropriateness.

Part III: Planning a Medical Imaging Unit

9. Ideally, equipment should be acquired new. Costs should be negotiated with vendors who may facilitate bank loans. Schemes to reduce costs include public/partnerships and donations from non-profit corporations such as the Rotary clubs.
10. When acquiring second-hand equipment, either through purchase or through donations, it is essential that it still meets manufacturer's specifications and that spare parts, accessories and software upgrades are available for the period of planned use.
11. Refurbished equipment should come with at least one-year warranty.
12. Equipment maintenance for the planned period of use should be budgeted and, if necessary, paid at the equipment acquisition time.
13. The room that will house X-ray equipment must be shielded taking into account the workload, the location and orientation of the unit in the room and the potential occupancy of adjacent areas, including those above and below.
14. The placement of the patients' waiting room should be chosen in order to optimize the shielding.
15. If there is film processing, the film storage area must also be shielded.
16. Locally available materials should be considered for shielding to replace lead.
17. Staff training is an essential component in any health center with imaging modalities. It should include three capabilities:
    a. To obtain patient images and record areas of clinical interest, including potential pathology
    b. To perform basic maintenance for both ultrasound and X-ray equipment and to communicate with service technicians off-site
    c. To send images to the consulting clinician and decide examination outcome.
18. Local/Regional Training Centers can be developed, using existing teaching facilities, such as local universities.
    a. This approach will be less expensive if funded by a specific international program
    b. It will need about 3 years of train-the-trainer courses up-front
    c. The Center will need long term support (c. 10 years before it becomes self-sustainable)
    d. The Center (and profession) will have to be attractive for local people.

19. Equipment manufacturers or donors should be enticed to provide a package: equipment + training for 2 people + maintenance/test tools.
20. E-learning either using CD-ROMs or via Internet should be available to all staff in the health center.
21. Digitally acquired images need to be displayed locally and transmitted for interpretation using telemedicine. There are three modes of operation: telediagnosis, teleconsultation, and telemanagement.
22. If the health center has Internet access, images may be directly transferred or streamed, depending on the software being used. The following caveats apply:
    a. Tele-imaging is not appropriate if the available system does not provide images of sufficient quality to perform the indicated task.
    b. Lossy and lossless compressions are possible, with varying degrees of loss of information, which may be acceptable depending on the modality and the clinical situation.
23. Assuming that there is a mobile telephone network, the simplest tele-imaging device is the mobile phone camera, which may acquire still pictures and video frames. A "smart phone" or equivalent can render adequate images for tele-consultation.
24. Image storage and retrieval may be done on line or locally depending on the situation.
25. Patient confidentiality should be preserved at all times.

Part IV: Operational Considerations

26. Prior to installation, acceptance testing and commissioning of new equipment should be done by a medical physicist, who should then set up a quality control program and train the local staff to carry it out.
27. For ultrasound units, the essential tests are image quality and caliper calibration.
28. X-ray units require testing not only of image quality, but of radiation safety, including patient dose assessment. If the facility uses film, the darkroom and the film/screen combinations need to be tested as well.
29. Image viewing and transmission fidelity for both ultrasound and X-ray units have to be monitored periodically to ensure they meet the standards set up at installation time.
30. The quality control program should be the responsibility of the health center manager and should include 3 aspects:
    a. Maintenance Program
        i. Mechanical/electrical checks done locally
        ii. Follow up periodic preventive maintenance visits.

   b. Medical Physics Program
      i. Tests done locally
      ii. Follow up medical physicist recommendations.
   c. Radiation Safety
      i. Periodic local safety checks
      ii. Reports to the Regulatory Authority, should there be one.

31. Integration of radiation protection and quality assurance/quality control programs is essential for good results.
32. Personnel working with X-ray equipment need to have adequate basic training and regular updating in radiation protection.
33. Staff exposure should be monitored every three months using TLD or OSL badges.
34. At least one protective lead apron (well kept) should be present; to be used also by helping relatives.
35. Local rules regarding justification of exposures and optimization of protection should be established. If the program is part of a surveillance network, it can be regularly checked.
36. In health centers of countries that do not have any radiation safety legislation, it is the responsibility of the facility manager to ensure that the equipment and its use comply with international radiation safety standards.
37. All medical imaging procedures should be chosen according to national or international referral guidelines to insure the procedure is appropriate and radiation exposures are minimized. International guidelines applicable to developing countries are being drafted by the International Radiology Quality Network (IQRN), initiated by the WHO.
38. Health center personnel should understand and acknowledge the capacities and capabilities of the health center for each common clinical situation and develop local guidelines, which indicate when an appropriate specialist should be consulted.
39. Consultations that result in patient referral to secondary or tertiary health care levels should be coordinated to ensure continuity of care.
40. The Government should establish a referral and counter referral mechanism such as a call center oriented service designed to provide a single point of contact for physicians and health care providers to access appropriate and timely advice, referral, admission, discharge, repatriation and transportation for their patients.