

**DOSE REDUCTION IN GENERAL RADIOGRAPHY WHILE
MAINTAINING DIAGNOSTIC CONFIDENCE FOR SELECTED
EXAMINATIONS IN SELECTED HOSPITALS IN THE ASHANTI
REGION, GHANA**



EMMANUEL AMPONSAH

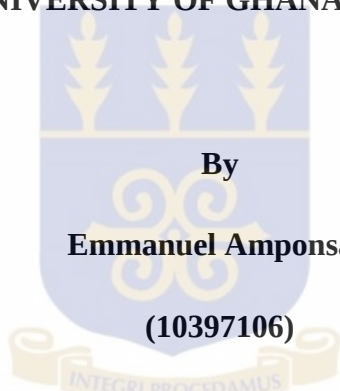
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DIAGNOSTIC CONFIDENCE FOR SELECTED EXAMINATIONS IN
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A thesis submitted to the:

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SCHOOL OF NUCLEAR AND ALLIED SCIENCES

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DECLARATION

This thesis is the result of the original research work undertaken by Emmanuel Amponsah in the Department of Nuclear Safety and Security, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Mary Boadu and Prof. Cyril Schandorf.

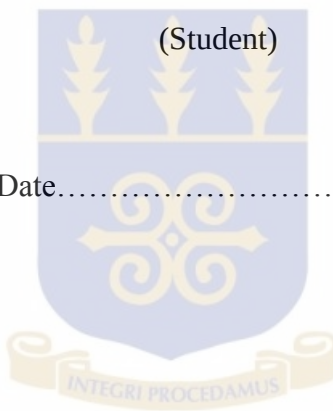
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DEDICATION

This work is dedicated to the Almighty God and my family and all my friends.



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I wish to express my profound gratitude to the Almighty GOD for his protection and strength up to this end.

I am extraordinarily grateful to the persons who guided me throughout my studies and the long hard process of the preparation of this thesis; my supervisors, Dr. Mary Boadu and Prof. Cyril Schandorf, for their patience, advice, support and thoughtful effort throughout my studies.

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LIST OF ABBREVIATIONS

ACR-SPR	American College of Radiology and the Society for Pediatric Radiology
AEC	Automatic Exposure Control
A _{FFD}	Area at Focus to Film Distance
ALARA	As low As Reasonable Achievable
AP	Anterior Posterior
BMI	Body Mass Index
COCL	Cocoa Clinic
DAP	Dose Area Product
DRL	Diagnostic Reference Levels
ESD	Entrance Skin Dose
FFD	Focus to Film Distance
FSD	Focus to Skin Distance
HVL	Half Value Layer
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
kV-mA-s	kilovoltage – milliampere – second
kVp/Kv	kilovoltage Peak / kilovoltage
LAT	Lateral
mAs/mA	milliampere - second / milliampere
mGy	milliGray
mSv	milliSievert
mGy.cm ²	milligray centimetres squared
μGy.cm ²	microgray centimetres squared

MMGH	Mampong Government Hospital
MNDH	Manhyia District Hospital
NCRP	National Commission on Radiation Protection
NEXT	Nationwide Evaluation of X-ray Trends
NRPB	National Radiological Protection Board
PA	Posterior - Anterior
PCXMC	Personal Computer program for X-ray Monte Carlo
QA	Quality Assurance
QC	Quality Control
SDLs	Suggested Dose Levels
SEDs	Suggested Effective Dose Levels
SID	Source to Image Distance
TLD	Thermolumiscent Dosimeter
UNSCEAR	United Nation Scientific Committee on the Effects of Atomic Radiations
US-EPA	United State – Environmental Protection Agency
RPI	Radiation Protection Institute
GAEC	Ghana Atomic Energy Commission

ABSTRACT

The objective of the study is to explore the potential for dose reduction in the selected X-ray facilities for the selected examinations and to ensure that images obtained after the reduction of dose are satisfactory for diagnosis. DAP were measured on a total of 327 patients for chest (PA), skull (PA/LAT), lumbar spine (AP/LAT), abdomen (AP) and pelvis (AP) examinations at COCL, MNDH, TAFH and MMGH. The effective dose incurred by patients per examination was estimated using a PCXMC version 1.5. In order to explore the potential for dose reduction, an anthropomorphic woman phantom was used. Seventy-five radiographs were obtained from the phantom studies at COCL, MNDH and TAFH for the image quality assessment. An experienced senior radiologist at the Korle-Bu Teaching Hospital performed the image quality assessment, which was based on the CEC 1996 image criteria. The range of the mean DAP and the effective dose recorded for the patient dose assessment for the selected examinations at the selected facilities is (21.1 – 752.1) $\mu\text{Gy.m}^2$ and (0.007 – 1.402) mSv respectively. The range of the DAP and the effective dose from the phantom studies were (15.1 – 200.1) $\mu\text{Gy.m}^2$ and (0.03 – 0.70) mSv respectively. In all, there was an overall average dose reduction of 49.7% in the DAP values for the selected examinations at COCL, MNDH and TAFH.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter is the introductory chapter to the work. It gives the background to the study, the research objectives, the problem statement, the relevance, and scope of the research work. The Arrangement of the work is also outlined in this chapter.

1.1 Background to the study

Medical application of ionizing radiation is over one hundred years now. Due to its huge benefits in both diagnosis and therapy, it has knowingly improved patient's care[1]. The use of ionizing radiation in medical diagnosis and treatment continues to grow rapidly in Ghana and worldwide. The exposure of patients to radiation requires that justification and optimization principle should be considered so that the radiation dose delivered to the patient is minimized while achieving the clinical objective of the exposure [2].

For diagnostic procedures the radiation dose should be the minimum required to provide the diagnostic information. Radiation protection of the patient, occupationally exposed staff and the general public are key requirements in the optimal use of ionizing radiation in medicine. The exposure of pregnant or potentially pregnant women and children are of a particular concern [2].

The use of X-rays in medical radiography has been continuously increasing and there have been technological advances in other modern imaging techniques. Though there are technological advances, many countries, especially developing countries such as Ghana, still use conventional radiography as the dominant diagnostic imaging tool [3]. In the year 2000, the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) indicated that the frequency of radiographic examinations over the preceding 5 years had roughly doubled and in some countries even tripled [3].

In radiographic image, a representation of the spatial distribution of tissue components as variations in the optical density of film is provided and the quality of the image can be quantified in terms of image characteristics; contrast (or density), sharpness (or resolution), and noise [4]

Radiographic quality is the ability of the radiograph to reproduce shadows on the radiograph that clearly represent the anatomical organs under investigation. The quality of the radiograph is dependent on radiographic density, radiographic contrast, and geometric factors affecting radiographic detail. Since radiographic density is a result of the number of photons that reach the film, it is also influenced by the tube potential (kVp), tube loading (mAs) and the forms of beam attenuation such as filters or grids.

Radiographic contrast refers to the observed differences in radiographic density between adjacent areas in the radiograph. These differences in film exposure permit identification of shadows on the radiograph and it depends on, subject contrast, inherent film contrast, kVp level, scatter radiation, and film fogging. Contrast is dependent on kVp range. Low

kVp produces high radiographic contrast while high kVp produces low radiographic contrast [4].

Contrast is a result of the penetrating power or the quality of X-ray beam in tissue; sharpness is the capability of the image to display small details; and noise refers to the random fluctuations across the image that tends to obscure the detail [4].

In medicine, X-rays for radiographic examinations is widely justified. However, from radiation protection point of view, the concerns are the balance between the quality of image produced in radiographic examination and the radiation dose incurred by the patient during the examination [5]. Despite these concerns, the radiation dose levels to patients in radiographic examinations are generally considered to be small as compared to the benefits derived from these examinations. [5-6]. It is well recognized that reduction in patient dose can have deleterious effects on the diagnostic information of the image and therefore, any action on dose reduction should be associated with ensuring that no diagnostic information is lost in the process [7]. In most cases, dose reduction can be achieved without any distortion in image.

Diagnostic radiology is recognized as the largest contributor to the collective dose from all man-made sources of radiation. There is a large difference in radiation doses from the same procedures among different X-ray rooms. This shows that there is a potential for dose reduction. Therefore, an exercise in dose reduction, while maintaining the quality of the diagnostic information in the image, is a genuine process of optimization associated with an improved use of the X-ray equipment. [8]. Because most procedures causing medical exposures are clearly justified and because the procedures are usually for the

direct benefit of the exposed individuals, less attention has been given to the optimization of protection in medical exposures than in most other applications of radiation sources [9].

In diagnostic radiology, the diagnostic confidence of a radiographic image means that the image should contain clinical information required from the examination and can be interpreted by the observer, but not the image being pleasing to the eye. The set of parameters describing image quality should give a measure of the effectiveness with which an image can be used for its intended purpose. These images should convey sufficient information to the clinician to allow a medical decision to be made with an acceptable degree of certainty[2].

An image is said to be of good quality if it has sufficient density/brightness to display anatomic structures, an appropriate level of subject contrast to differentiate among the anatomic structures, the maximum amount of spatial resolution and a minimal amount of distortion [4].

One of the requirements in diagnostic radiology is to reduce the radiation dose to the patient while maintaining the diagnostic quality of the image produced. This can be achieved not only by improving the parameters of the entire diagnostic equipment, but also by the examining the exposure parameters.

In diagnostic radiology, various dosimetric quantities and dose descriptors are used for patient dosimetry. Patient's dose may be determined in different ways. These include the measurement of the entrance surface dose (ESD) using TLDs (Thermo Luminescent

Dosimeters) chips, which is placed on the surface of the patient to measure the radiation dose to patients and a DAP (Dose Area Product) meter.

1.2 Statement of the problem

Radiography using film has been an established method for imaging the internal organs of the body and it is one of the most widely used imaging modality in Ghana. A background survey conducted to evaluate the trend in general radiography for skull, chest, abdomen, lumbar spine and pelvic examinations reviewed a significant increase in patient's throughput for the selected examinations. From the patient's registry, about 60 percent increase in patient throughput was observed (Patient's exposure registry of the selected hospitals) since 2008 to 2012.

Currently in Ghana, besides the increase in patients' throughput and the number of radiographic examinations in the selected hospitals, radiographers select their exposure parameters and even for the same examinations. For a standard sized patient, different exposure parameters were selected for all the imaging rooms visited. This shows that there is a wide range in patient doses for the same examinations in different hospitals. This therefore indicates that in many hospitals in Ghana, the radiation dose levels are much higher or lower than required to provide a sufficiently high-quality image for the radiologist to make a diagnosis. There is therefore the need to carry out a study to establish exposure parameters that will deliver a minimal radiation dose to patient while maintaining the diagnostic quality of the image produced in order to optimize patient protection.

1.3 Research objectives

The main objective of the study is to explore the potential for dose reduction in the selected X-ray facilities for the selected examinations and to ensure that images obtained after the reduction of dose are satisfactory for diagnosis.

Specific objective

The specific objectives of this study include:

1. To assess patient's dose from the selected examinations based on the exposure technique factors in beam measurement with DAP meter.
2. To use an anthropomorphic phantom studies to explore the potential for dose reduction following changes in the radiographic exposure factors, and to assess the image quality in the phantom studies.
3. Make appropriate recommendations for the minimization of radiation dose to patients undergoing conventional X-ray examinations addressed to:
 1. The Regulatory Authority
 2. The hospital authorities
 3. The scientific community

1.4 Significance of the study

The initial step in optimization process is the referral of a patient for diagnostic radiography [10]. In the United States, The Nationwide Evaluation of X-ray Trends (NEXT) program reported a wide range in patient doses for the same examinations in different hospitals [11]. It is also reasonable to assume that if the radiation doses to patients are reduced staff radiation doses are also reduced [12].

The significance of the study is to search for options and to develop exposure protocols to reduce the risk to patients from radiation doses incurred by patients in general radiography for various examinations while maintaining the diagnostic quality of the image. Effective use of the findings will go a long way in the strengthening the radiological protection of patient in conventional radiographic procedures in the selected facilities.

1.5 Scope of the study

This study was conducted in three conventional X-ray facilities in the Kumasi metropolis and Mampong Government Hospital, all in the Ashanti Region of Ghana. Chest (PA), skull (AP/LAT), lumbar spine (AP/LAT), Abdomen (AP) and Pelvic (AP) radiographic projections were used for the study because of the high patient throughput for these examinations. These facilities under study include:

- Cocoa Clinic (COCL)
- Manhyia District Hospital (MNDH)
- Tafo Hospital (TAFH)
- Mampong Government Hospital (MMGH)

There are various methods for dose reduction in diagnostic radiology. Some methods can be applied without having access to sophisticated equipment and may lead to considerable dose reduction. In this study, reviewing the exposure protocols (mAs, kVp and beam field collimation), which influence the effective dose to patients were considered as the method for dose reduction.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter reviews the related literature in diagnostic radiology in conventional X-ray imaging. It also reviews literature on medical exposure, basis of radiation protection, factors affecting image quality and patients dose in general radiography. The potential for dose reduction are also reviewed.

2.1 X-ray in diagnostic medical imaging

Uses of X-ray imaging equipment and facilities have been increased in medical practices. Diagnostic radiology is, so far, the largest source of man-made radiation and has the largest share of public dose from man-made sources. In X-ray diagnostics, radiation is partly transmitted through and partly absorbed in the irradiated object and these radiations are used to produce images for diagnosis. These images show the variations in transmission caused by structures in the object of varying thickness, density or atomic composition.

Currently, the annual number of diagnostic exposure stands at 2.5 billion and 78% of the exposure are due to medical X-ray procedures [13]. The annual collective dose from all diagnostic exposures is about 2.5 billion man-Sievert, which corresponds to a worldwide average of 0.4 mSv per person per year [14].

2.2 Selection of X-ray exposure factors in radiography

X-ray exposure parameters or technique factors include the tube voltage, tube current, and the exposure time that are selected on the control panel of the X-ray machine to produce the desired radiograph. The image density and contrast of the radiograph and the patient exposure are affected by these parameters.

Image density is blackening of the radiograph. Image density is controlled by the tube current and exposure time product (mAs) setting. Increasing the mAs will proportionally increase the number of X-rays reaching the patient and the image receptor. Underexposure (too low mAs) or overexposure (too high mAs) will result in a reduction in film contrast [15].

Tube voltage also affects image density in that increasing the tube voltage will greatly increase the exposure to the patient and the transmission of X-rays through the patient. The higher the tube voltage, the more penetrating the radiation beam and the darker the image will be. Other factors inclusive, selection of tube voltage is the primary method of controlling contrast in a radiograph. Image contrast is the difference in radiographic density of adjacent anatomic structures. The use of high tube voltage results in a reduction in contrast. The higher the kilo-voltage peak (kVp), the more penetrating the X-ray beam, hence the patient absorbs a smaller fraction of the beam, and the image contrast is reduced [15].

2.3 Overview of medical exposure in diagnostic radiology

Medical exposures are the exposures incurred by patients as part of their own diagnosis, treatment or as part of their health screening programmes. The exposure of patients or healthy individuals voluntarily for medical, biomedical, diagnosis or therapeutic research programmes are also classified as medical exposure [16].

It also includes the exposure of persons, other than those occupationally exposed, knowingly, while voluntarily helping in the support and comfort of patients undergoing diagnosis or treatment[17]. Usually, medical exposures of patients are intended to provide a maximum benefit to the exposed individual. Doses to patients will be as low as is compatible with the medical purposes only if the practice is justified and the protection optimized[13].

There are substantial features that differentiate medical exposure to radiation and other exposures to radiation. Generally, medical exposures are accepted to do more good than harm to the exposed individual and are usually voluntary [18]. Medical exposures typically involve only a portion of the body, whereas many other exposures involve the whole body.

Generally, medical practice involving exposure to ionizing radiation are categorized into three; diagnostic radiology, including image-guided interventional procedures, nuclear medicine and radiation therapy. Diagnostic radiology refers to the analysis of images obtained using X-rays procedures [18]. Diagnostic procedures are the widespread use of X-rays and are the most common application of ionizing radiation in medicine. The range of X-ray diagnostic procedures used today includes radiography, fluoroscopy, computed

tomography, interventional radiology, and bone densitometry [17]. Medical exposures are evaluated by assessing the annual frequency and types of procedure being undertaken and evaluation of the radiation doses for each type of procedure [18].

2.4 Framework for radiological protection of patients

In general, the main aim of radiation protection is to provide an appropriate standard of protection for human against the harmful effects of ionizing radiation, without unduly limiting the beneficial practices of such exposures. Two basic principles of radiological protection in medical exposures as recommended by the International Commission on Radiological Protection (ICRP) are justification of the practice and optimization of protection. These principles apply to the protection of the patient as well [19]. These basic principles of protection for medical exposures can be summarized as follows:

1. **Justification of medical exposures** - “Medical exposures should be justified by weighing the diagnostic or therapeutic benefits they produce against the radiation detriment they might cause, taking into account the benefits and risks of available alternative techniques that do not involve medical exposure” [20-21].
2. **Optimization of protection for medical exposures** - “The doses from medical exposures should be the minimum necessary to achieve the required diagnostic objective” [20-21]

These basic principles are incorporated in the International Basic Safety Standards against Ionizing Radiation and for the Safety of Radiation Sources [20] and the Radiation

protection and Safety of Radiation Source [21] and are the internationally accepted requirements for radiation safety.

The first step in radiological protection of patient is justification and it is accepted that diagnostic exposure is justifiable only when there is a valid clinical indication. Every examination must result in a net maximum benefit to the exposed patient. Once a diagnostic examination has been clinically justified, the next step is to optimize subsequent imaging process in order to obtain the required diagnostic information while minimizing the patient dose as low as reasonably achievable. Because the diagnostic medical procedures are usually for the direct benefit of the patient, somewhat less attention has been given to the optimization of protection in medical exposure than in other applications, which use radiation sources [19]. In the area of optimization in diagnostic radiology there is considerable scope for reducing patient doses without compromising the diagnostic information. The optimization of protection in diagnostic radiology does not necessarily mean the reduction of doses to the patient but image obtained should contain the diagnostic information required for clinical diagnosis [19]. This will reduce image retake or rejection of film to prevent unnecessary exposure to patient. That is optimization of patients protection is about managing the patient dose in order to fulfill the intended medical purpose [1]. The basic object of the optimization of radiological protection during medical diagnostic examination is to adjust imaging parameters and institute protective measures such that the required image is obtained with the lowest possible radiation dose while maximizing the net benefit of the exposure. That is, the ALARA (as low as reasonably achievable) principle should be taken into consideration for every examination. In optimization of radiological protection three

main aspects are involved; radiological equipment, ensuring adequacy of radiological equipment and technical parameters [1]. The optimization principle should also be applied on an individual basis in order to achieve image quality sufficient to provide diagnosis with the minimum dose to the patient [22].

In general, for the use of medical diagnostic radiation, the following criteria should be considered. Firstly, when a new diagnostic imaging procedure using ionizing radiation is introduced, it should produce a benefit to the exposed patient that will outweigh the risk from radiation exposure. Secondly, the exposure should be kept to the minimum necessary to gain the needed diagnostic information. In other words, there is no dose limit for medical exposures. Lastly, the exposure to other individuals who help in the support and comfort of the patient should be kept as low as reasonably achievable and should not exceed reference levels recommended by the National Council on Radiation Protection and Measurement (NCRP)[23].

2.5 Basis for radiological protection

The basis for radiological protection is about the biological effects associated with ionization radiation. In general, the biological effects of ionization radiation are mainly grouped into two types, namely deterministic effects (tissue reactions) and stochastic effects (cancer and heritable effects) [1]. Generally speaking, these biological effects depend on radiation dose and exposure time [24].

For deterministic effect, there is a practical threshold dose below which the effect is not evident and when the effect is present its severity increases with increasing the radiation

dose. The stochastic effects have a probability of occurrence that increases with dose. There is no threshold dose below which the effect will not occur. The severity of these effects is independent of the radiation dose [25].

Deterministic health effect is based on individual and the level of the threshold dose is characteristic of the particular health effect but may also depend, to a limited extent, on the exposed individual [24].

When ionizing radiation is incident on any material, it transfers energy to the material. When this energy is deposited in the living tissues, it changes the atomic structure of the tissue and the affected atoms that are essential for the normal functioning of a cell can be permanently damaged or killed. The larger the amount of energy deposited, the more the cell are damaged or killed [26]. At low doses below the threshold for deterministic effect, the probability of a stochastic effect attributable to the radiation increases with dose and is probably proportional to dose[26].

2.6 Radiation doses measurement in diagnostic radiology

Radiation exposure and dose in diagnostic medical radiology can be measured and estimated in a number of ways. Quantities that can be measured in medical diagnostic radiography include air kerma, entrance surface dose and dose-area product. Either absorbed doses to various tissues or organs can be estimated by using clinically validated anthropomorphic phantoms with internal dosimeters or Monte Carlo codes [27-31]. To estimate the detriment from cancer and hereditary effects, effective dose is used, which is the summation, over the whole body, the product of the tissue weighting factors and the

equivalent doses (in mSv) for various tissues [17]. Effective dose is expressed in sieverts and is a single dose parameter that reflects the risk of a non-uniform exposure in terms of whole-body exposure. Standard radiographic examinations have effective doses (and potential detriment) that vary widely by over a factor of 1000 (0.01–10 mSv) [32].

In radiography, the dose quantities that relates to the patients or phantom in X-ray examinations are the ESD, DAP and the effective dose (E). However, ESD and DAP are the dose descriptors that have a little biological significance regarding biological effects of the exposed patient [33-34].

The entrance surface dose (ESD) is the absorbed dose to air in the X-ray beam axis of the part of the body where the X-rays enter the patient. Measurement of the ESD includes the contribution of the backscatter radiation. The ESD can be measured using TLD placed on the patient's skin at the centre of the beam where the X-rays enters the patient's body or can be estimated by using the measured absorbed dose to air and the exposure factors for each X-ray projections together with the appropriate backscatter factor (BSF's) in literature.

The dose area product (DAP) in mGy.cm^2 for a given radiographic projection is the measured radiation dose to air multiplied by the area of the radiation beam. It takes into account the entire area of the X-ray beam and it takes the dose to the skin multiplied by the area exposed. The DAP is practically determined by mounting a transmission ionization chamber (DAP meter) underneath the X-ray beam collimator and the DAP reading are recorded on the display meter. The transmission ionization chamber of the DAP should be larger than the actual X-ray beam. The DAP reading is affected by the X-

ray exposure factor (kV, mA and exposure time) and the field size or both. During the DAP measurement, the position of the patient is less important since the DAP measurements does not interfere with the patient's examination [38].

Measurements and estimation of radiation dose to patients in radiography are of vast importance. Measurement of radiation dose to patients provides a means for setting standards for good practices. This will help to optimize patient's protection. Dose measurements also help to estimates the absorbed dose to tissues or organs in the body. These absorbed doses to tissues are needed for the determination of the risk to patients from the examination or the exposure. Dose measurements help to establish dose that is being delivered to the patients by the X-ray equipment and the technique used. These help in deriving national diagnostic reference levels (DRLs) for various examinations and it helps in the minimization of dose to patients[36-37].

2.7 Diagnostic Reference Levels (DRL's)

Diagnostic reference levels (DRL's) are dose levels in medical radio-diagnostic practices for groups of standard sized patients or standard phantoms and for broadly defined types of equipment. The DRL should be clearly defined and easy to measure or calculate. It directly indicates the dose delivered to the patient. It should also allow easy correlations with the technical parameters of the medical examination to be adapted to all types of radiological equipment for that examination. [38].

In diagnostic radiology, reference levels should be expressed in terms of quantities that can be easily measured or estimated, such as the entrance surface dose (ESD) or dose–area product (DAP) [39-40]

DRL values can be derived from relevant regional, national or local data and the mean or other appropriate value observed in practice for a suitable reference group of patients or a suitable reference phantom [40]

DRL is aimed to promote the attainment of an optimum range of values for a specified medical imaging protocol. [41]. To improve the medical procedure continuously, the DRL in a given institution for a given medical device should be monitored and make a comparison with other hospitals. It should be noted here that DRLs are not a dose limits and does not apply to a single individual. These levels are not expected to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied [38].

2.8 Best practices in general radiography

An increase in the range and capability of medical imaging modalities has resulted in greater demands for radiology services. Medical diagnostic imaging has been the domain of radiographers and radiologists. Diagnostic radiographers are health professionals who use a wide range of sophisticated and dedicated X-ray equipment to produce high quality images to diagnose a disease. Radiologists are medical practitioners who use imaging to diagnose, treat and monitor various disease processes. Radiologists are concerned primarily with the interpretation of the image and radiographers with its production [42].

At first, diagnostic medical exposure was not considered a problem and there was no evidence that exposure to low doses of ionizing radiation can increase cancer risk. The benefits of radiography have remained clear over the more than a century of diagnostic medical imaging's history. The critical role of radiographers in radiography is ensuring patient radiation safety during medical imaging procedures. Radiographers must apply the ALARA principle by keeping radiation dose as low as is reasonably achievable when performing radiography. When following the ALARA principle, radiographers should minimize patient exposure from radiography[43].

In conventional screen-film imaging, radiation exposure techniques are based on the specific screen-film system and the conditions under which the film is processed and the selection of exposure technique parameters. Paying careful attention during the conduct of the radiographic examinations will result in a considerable reduction of radiation dose to patients without a loss of the diagnostic value of the image produced. As a best practice, radiographers are charged with a great deal of responsibility on the understanding and appropriately performing the radiographic procedures even before the examinations begin. They must ensure that radiation protection and safety of patients is maintained and requires regular attention to several matters before capturing the images to minimize exposure of patients [43].

American College of Radiology and the Society for Pediatric Radiology (ACR–SPR) has developed practice guideline for general radiography and these guidelines are to provide assistance and guidance to practitioners in providing appropriate radiologic care for patients. The document defines the qualification and the responsibilities of all the

radiology staff and provides guidelines on the specification of the examination. This document also specifies that the diagnostic radiographic equipment and facility should meet all the applicable standards set by the regulatory authority and appropriate screen-film and grid combinations should be available to obtain diagnostic images of all anatomic areas to be imaged[44].

In United States, the Environmental Protection Agency (US-EPA) provides guidelines on radiation protection for diagnostic and interventional X-Ray procedures in the Federal Guidance Report NO. 14[45]. The achievement of the fundamental objective in performing an X-ray examination with minimum radiation dose but with adequate image quality requires the assurance of proper functioning and calibrated equipment, the equipment being operated only by competent personnel, appropriately preparing and positioning the patient, and the selection of appropriate equipment factors and appropriate protocols[45].

Knowledge and appropriate use of the radiographic exposure factors [e.g. focal spot size, filtration, focus to image plane distance, and the tube current–exposure time product (tube voltage, mAs product)] is essential since they have a significant influence on image quality, and this may have inferences for patient radiation exposure. Permanent parameters of equipment such as inherent tube filtration and anti-scatter grid characteristics should also be taken into consideration [1].

2.9 Image quality in projection imaging

In medical imaging, a good quality image is of great importance to make diagnosis and make accurate decision. A good quality image represents the exact anatomy of the patient; that is with the visibility of anatomy and signs of pathology. Spatial resolution, contrast resolution, and noise & artifacts are the most important characteristic of a quality radiograph [46].

Resolution is the ability of the image to separate two objects and visually distinguish one from the other. Spatial resolution refers to the ability of an imaging system to allow two adjacent structures to be visualized as being separate or to image small objects that have high subject contrast. That is the distinctness of an edge in the image. Conventional radiography has excellent spatial resolution[47]. In radiography, there may be losses in the spatial resolution of the image. These spatial resolution losses is caused by blurring which is caused by geometric, effective aperture size, and motion of the patient relative to the X-ray source and image receptor.

In screen-film (SF) conventional radiography, the determination of the spatial resolution is by the thickness of the screen. This is because the light produced when an x-ray photon is absorbed is emitted in all directions from that point; therefore, the thicker the screens the more distance for the light to spread before reaching the film and have poorer spatial resolution.

In radiography, any fluctuations in an image that do not correspond to variations in x-ray attenuation of the object being imaged is termed as noise. Image noise is dominated by the x-ray quantum noise. Noise in radiography can be defined as uncertainty or

imprecision of the recording of an image. That is the undesirable stochastic variations in the image [47]. Noise can cover or decrease the visibility of certain structures, which makes it the most disturbing effect on image quality and thereby on diagnosis. The loss of visibility is especially significant for low contrast objects. A significant cause of noise in X-ray images is related to the random manner in which the photons are distributed within the image[48].

Image contrast is proportional to the amount of the signal difference between the anatomic structure of interest and its surroundings in the displayed image [46]. It is the ability of the image to differentiate between different anatomic structures. It is expressed in terms of the difference in optical densities between two adjacent areas on the film. It is generated by the difference in the X-ray attenuation in tissues. The final image contrast is affected by the applied X-ray energy spectrum and the contrast resolution capabilities of both the detector and the display system[49].

Radiographic contrast is influenced by subject contrast and receptor sensitivity. In digital imaging, contrast in the displayed image can also be changed by the adjustment of display parameters independent of the acquisition parameters. Subject contrast is proportional to the relative difference in X-ray exposure on the exit side of the patient and is the result of the attenuating properties of the tissues under study. Attenuation is strongly dependent on the X-ray energy spectrum and is determined by the target material, kilo-voltage, and total beam filtration[50].

2.10 Methods for dose reduction

Dose reductions methods in diagnostic radiology are of primary concern from radiation protection point of view. This is because of the high dose contribution to the collective population dose from X-ray diagnostic procedures. These methods can easily be obtained by reviewing the parameters which have an impact on the effective dose. Some of these methods can be applied without having access to sophisticated equipment and may lead to substantial improvement in terms of dose reduction. [8]. To reduce the radiation dose to patients, the simple approach is to lower the X-ray tube current and tube voltage [51-52].

In diagnostic X-ray examination practice, increasing the beam filtration is also recognized as a method of reducing the patient dose is to increase X-ray beam filtration. Different absorber materials, usually aluminum and copper, are in use to absorb the soft X-ray component in the X-ray spectrum which would otherwise be absorbed in the body and would increase the patient dose without contributing to image formation [53].

Another known method to reduce radiation dose used in radiography is to apply high tube potential. Increasing the tube potential increases the beam energy, which in turn increases the penetrating power of the X-ray beam. In this hard-beam technique, Compton scattering dominate which increases the contribution of scattered photons to image formation which leads to contrast degradation. To reduce the scattered radiation to improve the image contrast anti-scatter technique is used [54].

Radiation dose can also be reduced by decreasing the tube current–time product (mAs) [55]. Methods for reducing the ESD influence the effective dose in the same proportion.

These methods include reduction of the mAs without modification of the beam quality. Modifying the beam quality, which includes increasing the kVp or tube filtration also reduces patients' dose. In this case, there is penetration and scattering inside the patient and these are modified so the reduction of the ESD does not imply a reduction in effective dose by the same factor [8].

2.11 Factors affecting radiation dose and image quality

Many factors affect patient's radiation dose in X-ray imaging. These include the beam energy, beam filtration, beam collimation, patient's size and film processing. In conventional radiography, patient's dose are also affected and determined by the selection of the exposure technique factors, the mAs and the kVp, that results in the diagnostic imaging.

2.11.1 Beam quality and beam filtration

In radiography, the kilo-voltage peak (kVp) selected and the beam filtration determines the beam quality and the penetrability of the X-rays. Increasing the kVp will change the ESD as the square of the kVp. Selecting higher kVp will increase the average energy of the X-rays and therefore more penetrating. The more penetrating the X-rays, this may allow for use of lower mAs and shorter exposure time thereby reducing the radiation dose to patients [56].

To absorb and filter out the low energy X-rays in the beam, diagnostic X-ray units are required to contain a total filtration of 2.5mm aluminum plus any added filtration. The absorbing material will filter out all the soft X-rays which does not contribute to the

image formation and are most likely to be absorbed in the patient and thereby increasing patient dose unnecessarily. The half value layer (HVL) is often used as a practical measure to describe beam quality [56-57]. Image formation requires that X-rays be transmitted through the patient during the exposure to expose the image receptor [57].

2.11.2 Radiation beam collimation

Another important factor is the radiation beam collimation. During examinations, only the part of the patient's body to be examined should be exposed. That is the radiation beam should be collimated to the area of clinical interest and this will reduce unnecessary exposure to patient. By collimating the radiation beam, scattered radiation that reaches the image receptor also decreases resulting in a better image quality [58].

2.11.3 Grid use

The use of grid reduces the amount of scattered radiation that reaches the image receptor resulting in images with improved contrast. Grids are provided to remove much of the scattered radiation than the primary X-ray and the dose are increased from two to five times than without using the grid. This is termed as the Bucky Factor, which represent the ratio of the dose with grid to dose without grid [49]. Using the grid, higher quality images are obtained and may results in fewer retakes and more accurate diagnosis.

2.11.4 Screen film combinations and film processing conditions

Using a faster screen film combination reduces the radiation dose. The use of rare earth up 600 speed is better. Faster screen film system will result in some loss of details [59].

During the film processing, it should be according to the film manufacturer's recommendations. The temperature, transport rate, or the replenishment rate should not differ significantly from the manufacturers recommendations because it can affect the image quality significantly. Poor quality image will lead to radiographic technique modification and this will affect the patient dose [57].

2.11.5 Patient's size

Depending on the type of procedure and the age of the patient, patient factors can be important to optimize protection prior to X-ray radiography. These patients factors includes the PA/AP and LAT thickness and the body mass index (BMI) need to be considered before the examination.

The amount of radiation incident on the patient depends largely on the thickness of the patient. A thicker patient requires much higher penetrating radiation to create an image of an acceptable quality [59]. It is useful to optimize the technique chart for various patient size and anatomic areas.

Patient Body Mass Index (BMI) is an important factor that determines the amount of radiation dose since the radiographer will increase the x-ray exposure to maintain image quality [60]. Fat or obese patients will be more exposed to higher doses of X-ray exposure during the examination and the X-ray scatter is also increased.

2.12 Potential for dose reduction in X-ray examinations

Based on the justification and optimization principle, radiographers have the responsibility to produce images of diagnostic quality at an acceptable cost to the patients. In medical diagnostic radiology, X-ray examinations are widely justified and therefore, the optimization principle implies that the margin of the benefits over the radiation detriment is maximized. By this, attention should be given to all aspects of radiographic techniques and the positioning of patients [61].

X-ray radiographic examinations in medical application require consideration of many factors. For any given radiographic examination, the understanding and application of each of these factors is essential in order to balance the radiation dose and the image quality. These factors include the exposure factors (tube voltage, tube current, and exposure time) which determine the basic characteristics of radiation exposure to the patient and image receptor. Equipment factors (focal spot size, grid use, x-ray generator design) and geometric factors (source-object distance and source-image receptor distance) also influence patient dose and the quality of the radiograph. Selection of radiographic technique often involves consideration of trade-offs between various measures of image quality and exposure [15].

In diagnostic radiology, the optimization process necessarily requires a balance between patient dose and image quality and that the diagnostic quality of the image is not lost in the cause of dose reduction. Images of unacceptable quality can result from unwarranted reductions in patient dose and this renders the images not good for diagnosis and ultimately leading to repeated examinations and higher patient doses. The clinical

problem will dictate the requirement for image quality and lower image quality might be acceptable in some circumstances. Inadequate examination/image caused by too low dose can also be harmful to the patient [62]. Some dose reduction options from various articles are reviewed below.

In radiography, kVp range in combination with other factors can be used to achieve optimization of patient's dose and /or image quality [63]. For screen-film radiography, reduction the ESD can be achieved without degrading the image quality for lateral projections of the lumbar spine radiography by using higher kVp (95kVp) and faster speed class (400) [64].

Many research papers have shown that simple adjustment of the radiographic techniques can affect the level of optimization positively. Reduction in ESD between 30% and 60% can be achieved in many examinations using rare earth beam filtration [65]. During lumbar spine radiographic examinations, in females, the ESD have been reported to be reduced by 44% if the source to image distance (SID) is increased by 30% [66]. In chest radiography, the ESD can be reduced by 32% when carbon fibre cassettes are used [67].

The use of Posterior-Anterior (PA) projections for abdominal, chest and lumbar spine examinations has been recommended to reduce patient dose. This is as a result of tissue displacement effect of the prone position and also, there is lower absorption in anterior organs when patients are in the prone position [68-69].

CHAPTER THREE

MATERIALS AND METHODS

3.0 Introduction

This chapter outlines the materials and the methods employed in this study. The chapter consists of two sections. The first section describes the materials and the participating facilities. The second section outlines the methods employed in the study. The methods used in the study include the radiation dose assessment, image quality assessment (for the phantom study), dose reduction options using phantom study. Dose measurement and effective dose per examination is also estimated in this chapter.

3.1 Materials

3.1.1 Participating facilities

Four hospitals in the Ashanti region of Ghana were selected for the study. These facilities under study were;

- Cocoa Clinic (COCL)
- Manhyia District Hospital (MNDH)
- Tafo Hospital (TAFH)
- Mampong Government Hospital (MMGH)

3.1.2 Radiographic Equipment details

Four radiographic X-ray machines in the four facilities under study were used. These X-ray machines were Philips medical System branded. The X-ray machines that were part of the study range from those that have been used from 1997 to 2009. They include high frequency generators to single-phase units. The summary of the X-ray machines used are given in Table 3.1.

Table 3.1 Specification of radiographic equipment used at each facility

Facility	Model Number	Serial Number	mAs Range (mAs)	kVp Range (kVp)	Year of Manu.	Manu.
MMGH	9848 500 29301	2635	0.5 – 850	40 - 150	1997	Philips
MNDH	9890 010	9701952	0.5 - 850	40 - 150	1997	Philips
COCL	9890 000 8521	224176	0.5 - 850	40 - 150	2009	Philips
TAFH	Emerald 125	AC07286	0.5 - 500	40 - 125	1998	Philips

3.1.3 Description of the X-ray machines

3.1.3.1 Philips medical Systems at COCL

Duo Diagnost system is an X-ray unit for conventional radiography and fluoroscopy (Model: 9890 000 85721, S/N: 224176) with an inherent filtration of 2.5mm Al. It conforms to the provision of the medical device directive (MDD 93/42, EEC (93)). It has a nominal voltage of 150kV and mAs range of 0.5-850 mAs. It is a Philip branded X-ray machine, which is powered by a three phase Optimus 50 high voltage (HV) generator and was manufactured on 2009 by Philips Medical System in Germany.

3.1.3.2 Philips medical Systems at MNDH

Bucky DIAGNOST is a Philip branded X-ray equipment (Model: 9890 010, S/N: 9701952) has an X-ray tube (Type: 9806 200 60002, S/N: 931 212) with inherent filtration of 2.5 mm Al equivalent. It has a maximum rating of 150 kVp and mAs range of 0.5 – 850 mAs. The X-ray tube is powered by three-phase Optimus 50 high voltage (HV) generator. The X-ray equipment was manufactured in Italy on June 1997 by Philips.

3.1.3.3 Philips medical Systems at TAFH

Philip Multi-Radiography System (Model: Emerald 125, Serial No: AC07286) is a conventional X-ray machine which is powered by a single-phase high voltage (HV) generator. It has a maximum kilo voltage peak rating of 125kVp and mAs range of 0.5 – 500 mAs. The inherent filtration is 0.6mm of Aluminum. It was manufacture on August 1997.

3.1.3.4 Philips medical Systems at MMGH

Bucky DIAGNOST is a Philip branded conventional X-ray equipment (Model: 984850029301, S/N: 2635) has an X-ray tube (Type: 9806 200 60002, S/N: 931329) with inherent filtration of 2.5 mm Al equivalent. It has a maximum rating of 150 kVp and mAs range of 0.5 – 850 mAs. The X-ray tube is powered by three-phase Optimus 50 high voltage (HV) generator. The X-ray equipment was manufactured in Germany on July 1997 by Philips.

3.1.4 Measuring devices

Measuring devices that were used during the study includes a height measurer and a caliper, which were used to measure the height (in cm) and the thickness (in cm) of the patient respectively. The height measurer and the caliper were graduated to 0.1cm. The weight of the patients was measured using a Personal weighing scale (LOT-2011A2) which was also graduated to 0.1kg. Calibrated dose-area product (DAP) meter Kerma XPlus Iba dosimetry (model 120-131 HS, serial number : 01A04042) was also used to measure the DAP per examination. Other materials include RAD-CHECK PLUS, RMI 240A GAMMEX RMI Multi-Function kVp meter and High purity aluminum sheets, that were used for the quality control test measurements.



(a)



(b)

Plate 3.1: (a) Transmission ionization chamber and (b) monitor of the DAP meter

3.1.5 Description of the phantom

The phantom used for this study was an anthropomorphic Rando woman phantom (Physics Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana), which was the only available phantom. It is considered equivalent to the human body of a standard sized patient. The Rando woman phantom represents a 163 cm tall and 54 kg female figure. The phantom is transected horizontally into 2.5 cm thick slices and each slice has a hole which are plugged with bone-equivalent, soft tissue equivalent or lung tissue equivalent pins which can be replaced by TLD holder pins. Plate 3.2 shows a Rando woman anthropomorphic phantom.



Plate 3.2: A Rando woman anthropomorphic phantom

3.2 Methods

3.2.1 Quality Control Measurements

In order to ensure that the fixed X-ray machines were performing consistently well, Quality control measurements were performed. Four basic QC test that were performed are tube output consistency checks, half value layer (HVL) measurements. The procedures employed have been detailed in the subsection below. The X-ray and the light beam congruence test and collimation test were also performed.

3.2.1.1 Tube Output Consistency

The output consistency of the fixed X-ray equipment was checked. This test was done by placing the RAD-CHECK PLUS on a lead block to standardize backscatter, in the central axis of the beam at a distance of 75 cm from the RAD-CHECK PLUS to the focus of the x-ray tube. The beam was collimated to the sensitive part of the RAD-CHECK PLUS. A fixed kVp and mAs values were chosen for each exposure and the output values were recorded from the RAD-CHECK PLUS. The procedure was repeated for kilo voltages of 50, 60, 70, 81 and 90 and the tube output (in mR) was divided by the current time product (mAs) to obtain an output ratio (mR/mAs). This output ratio was checked for consistency for the same tube kilo voltage. The output linearity was then calculated from the ratio's obtained using the formula $[(\text{max}-\text{min})/(\text{max}+\text{min})]$. The value obtained was checked for compliance with the acceptance criteria of ≤ 0.1 [70-72]

3.2.1.2 Half Value Layer Test

Maintaining the same settings on the RAD-CHECK PLUS and the X-ray machine for the output consistency test, the half value layer (HVL) of the beam was also measured. High purity aluminum sheets of varying thickness in millimeters were used. The tube voltage and current-time product was set at 81 kV and 16 mAs respectively. The output reading from the RAD-CHECK PLUS was recorded after exposure with this setting with no aluminum sheet placed in the direction of the beam. Two other readings were recorded with the same settings and the average calculated. An aluminum thickness of 1mm was placed in the direction of the beam and the exposure was made with the same kVp and mAs values. Three output readings were recorded after each exposure and the average

calculated. Additional aluminum sheets were added until the output readings from the RAD-CHECK PLUS fell below 50 % of the first reading recorded without aluminum sheet. The averaged Rad-check output readings and the thickness of aluminum sheets was plotted on a semi-log graph. From the graph the exact thickness of aluminum required to reduce the first reading (no aluminum) to half of its value is found [70-72].

3.2.1.3 Tube Potential Accuracy Test

A RMI model 240 multi-function kVp meter was placed at a distance of 100 cm from the focus the x-ray tube. Exposure parameters of 6.3 mAs and 50 kV were set on the control console. The peak tube voltage reading on the multi-function meter was recorded after exposure with the set parameters. Two other peak voltage readings were recorded after exposure with the same parameters and the average calculated. The percentage error between the set value on the control console and the measured value with the multi-function meter was calculated. The procedure was repeated for tube voltages in the range of 50 kV-90 kV. The deviation percentages were checked for compliance with the acceptance criteria of $\pm 5 \%$ [70-72].

3.2.1.4 Timer Accuracy Measurement

The time accuracy was also checked with the same set up as used for tube potential accuracy measurement. A button on the multi-function meter is switched from voltage readings to time readings and a range of indicted time on the console is checked with the measured time with the multi-function meter for accuracy. The deviation percentages

between the measured time and indicated time were calculated and they were checked for compliance with the acceptance criteria of $\pm 10\%$ [70-72].

3.2.2 Selection of facilities and radiographic equipment

The study was conducted in three hospitals in the Kumasi metropolis and one hospital in the Mampong municipality. In all the study was conducted in four hospitals. These hospitals were selected based on the availability of resources, including human resources, the age of the radiographic equipment and the patients' throughput. The radiographic equipment that were used in this study include those that were manufactured from 1997 to 2009.

3.2.3 Patient's selection and examination

The study group includes both female and male patients of varying height, size, weight, and age. They were selected randomly from a group of patients who were referred to the radiology and the X-ray unit of each of the participating facility. Adult head (AP/LAT), chest (PA), lumbar spine (AP/LAT), abdomen (AP) and pelvis (AP) examinations were chosen for the evaluation since they are the commonly performed examinations in the selected radiology departments. These accounts for a large collective dose to the population. Inclusion criteria was patients of ages of seventeen (17) years and above as considered as adult patients. Examination of paediatrics below sixteen (16) years and too sick patients were not taken since they required special positioning and projections.

3.2.4 Data collection

Data were collected on the conventional radiographic X-ray examinations in the selected imaging room in each of the participating hospitals, all in the Ashanti region of Ghana. The local ethical and institutional review boards at each participating facility approved the study protocols. Since the study was not directly related to the patient, the identity of the patient was treated as confidential and that the patients were identified patient's identification numbers and not names. Patient selection for the studies was done at random from a group of patients that were referred to each X-ray unit of the participating hospitals.

Data were collected for the following radiographic examinations; Skull (AP/LAT), Chest (PA), Abdomen(AP, supine or erect), Lumbar spine (AP/LAT) and Pelvis (AP). For each examination, the following patient's data were recorded: Patient's age, sex, height, mass, and the thickness of the part where the central axis of the beam enters the patient. For each imaging room, the mAs, kVp and time (except for Tafo Hospital) were collected from the control console of the X-ray machine. The focus to film distance (FFD) was measured and the beam collimation (field size) was recorded for each examination. The dose area product (DAP) per each examination were also recorded.

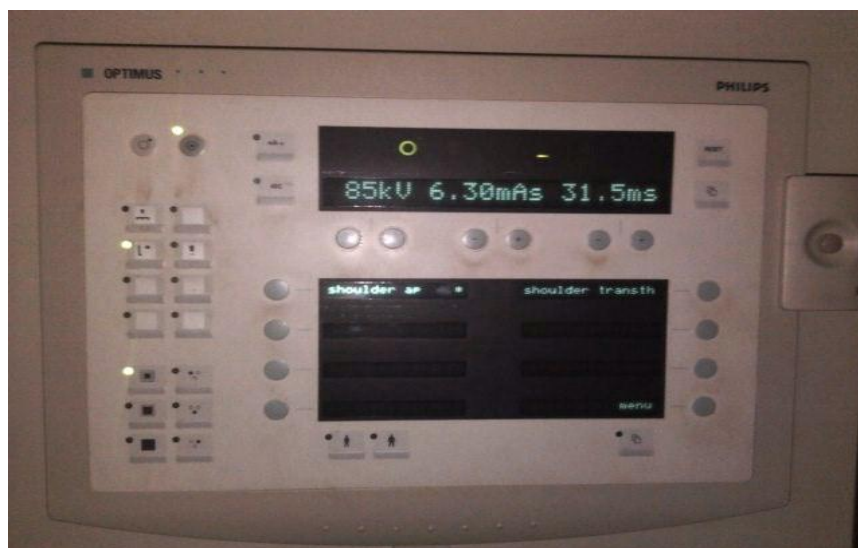


Plate 3.3: Control console of the X-ray machine at MMGH

3.2.5 Radiation dose measurement

Patient's dose measurement was conducted on the patients per examination and per radiograph during the four months study at the selected hospitals. The study group were patients of 17 years and above who underwent the selected examinations in the selected X-ray imaging rooms. The dose area product per examination was measured and recorded and the effective dose per radiograph and per patient was estimated.

3.2.5.1 Dose Area Product (DAP) measurement

A calibrated DAP meter, Kerma XPlus iba dosimetry (model 120-131 HS, serial number: 01A04042) was used to measure the DAP to patients in this work, since the radiation dose to patients cannot directly measured.

The transmission ionization chamber of the DAP meter, which is larger than the area of the X-ray beam was placed under the X-ray collimator to intercept the entire X-ray field. The radiation output depends on the thickness of the patient, the part of body being radiographed, the selected technique factors, and the number of radiographs taken per examination. The reading from DAP meter was displayed in real-time in $\mu\text{Gy}\cdot\text{cm}^2$ on a monitor and was recorded for each projection. The readings from the DAP meter were affected by either altering the X-ray technique factors (kVp, mAs and time) or by varying the area of the radiation field or both.

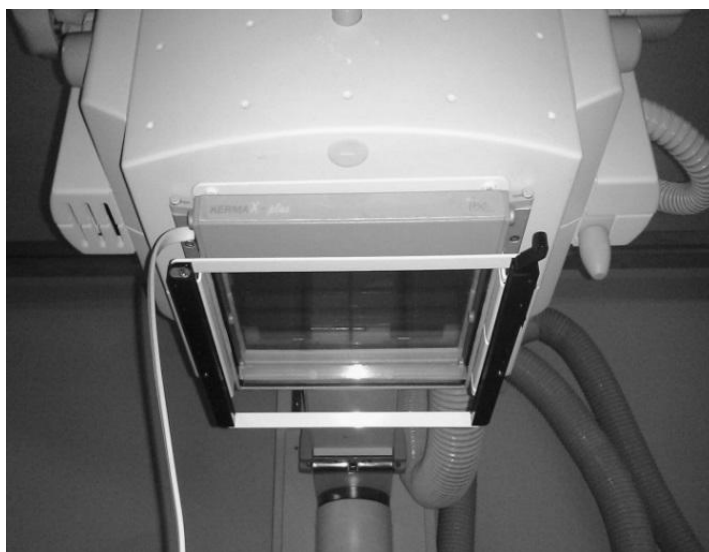


Plate 3.4: Transmission ionization chamber of the DAP meter fixed beneath the X-ray collimator

3.2.5.2 Estimation of the effective dose

The effective dose incurred by patients undergoing the selected examinations was estimated using PCXMC 1.5 dose calculation software. The PCXMC is a computer based Monte Carlo program for calculating organs doses and the effective dose in medical X-ray examinations (including fluoroscopy). The PCXMC 1.5 uses the tissue weighting factors in ICRP 60.

To estimate the effective dose to patients who underwent the selected X-ray examinations, the following parameters were entered into the program interface. The DAP (mGy.cm^2), tube potential (kVp), patient weight (kg), tube filtration (HVL = 2.5 mm Al) and height (cm). The film width, the film height and the FFD all in centimeters and the examination projection were entered.

To compute the dose, three steps were involved in the process;

1. Definition of the examination condition. This was done by using the examination data button. Patient weight and height were entered to develop a mathematical phantom to represent the patient. The FFD and the image size at FFD were entered to obtain the FSD and the image size at FSD. The examination projection was also entered to this interface. The developed examination data is saved for simulation.
2. In the simulation stage (second step), the saved examination data is called and simulated. This takes a few seconds.
3. After simulation, the third and the final step is to compute the organ dose and the effective dose (which is the summation of the equivalent doses to the organs

multiplied by their tissue weighting factors). This was done by using the Compute dose button. To compute the doses, the kVp and the tube filtration (HVL = 2.5 mm Al for all the centres) was entered to generate the X-ray spectrum for the examination. After generating the X-ray spectrum, the DAP (in mGy.cm^2) was entered and by clicking the Ok button, the doses to the organs (mGy) and the effective dose (mSv) were calculated and displayed.

3.2.6 Dose reduction options (Phantom studies)

This study attempts to find optimum exposure parameters that will deliver minimum radiation dose to patients without degrading the diagnostic image quality of the image produced. The DAP was measured for Chest (PA), Pelvic (AP), Lumbar spine (AP/LAT) and Abdomen (AP) projections using a Rando anthropomorphic woman phantom as an equivalent to the human body in X-ray absorption and scattering.

Exposure was made under with varying kVp and mAs values for each projection. Different mAs and kVp values were selected in each imaging room and it was based on the selection of exposure parameters for a standard built patient for each imaging room since different machines have different output.

For each projection, the mAs, kVp, DAP and field size were recorded as well as the focus to film distance (FFD). The selected exposure factors were based on the exposure parameters selected by radiographers in each imaging room for a standard sized patient. This was to ensure that there was a dose reduction with quality diagnostic image based on their normal exposure factors. Radiographs were obtained from each exposure for the

image quality assessment, which was based on the European Guidelines on the Quality Criteria for Diagnostic Radiographic Images (CEC 1996) [73].

3.2.7 Image quality assessment

The quality of the image relating to the X-ray equipment, exposure factors, and the processing condition was assessed. A senior radiologist at the Korle-Bu Teaching Hospital performed the image quality assessment. The image assessment was based on the European Guidelines on the Quality Criteria for Diagnostic Radiographic Images (CEC 1996). This document defines the diagnostic requirements for a normal basic radiograph, specifying image criteria and image details. It indicates the criteria for dose reduction to the patients and gives examples of good radiographic technique by which the diagnostic requirements and dose criteria can be achieved [73].

The perceptibility of the images was measured using the ranked scoring method. The ranked scoring assesses the observers level of confidence in the presence of abnormality in the image similar to the process used in clinical practice. This method has been widely used in image quality analysis [74]

Image assessment forms were developed and were given to the radiologist. This was to make a standardize assessment for all radiographs and to make the image evaluation easy and convenient to the radiologist. There were no restrictions on the reading time spent on each film and the observer was not aware of the radiation dose, and the exposure factors used to irradiate the films.

The image criteria scores were ranked from 0 to 3 and interpreted as 0 (not seen), 1 (seen but not clear), 2(seen) and 3(clearly seen). The score for image criteria were clarified by summing individual scores for each radiograph and the total per radiograph were compared.

The important image details were scored as “+” or “-” as “Yes” or “No” for each radiograph. Each radiograph were assessed for density, contrast, sharpness and general radiographic remarks were given as A(High Quality), B(Good Quality), C(Medium Quality), D(Low Quality), E(Poor Quality) and F(Film Rejected). For rejected films, the observer was made to give the causes for the rejection.

The purpose of the image evaluation was to ensure that the techniques (including patients positioning and exposure technique factors) employed in various selected facilities provide clinical images that are acceptable for diagnosis and any modifications to these techniques to reduce dose to patients will not affect the diagnostic quality of the radiographic image. The image assessment form provides requirements that related to the techniques and the production of anatomical details against which the observer can judge an image. The evaluation was also to assess the basic aspects of quality for clinical radiographic image based on the technique used and the imaging performance. The image quality assessment form containing the image criteria was used for the assessment of the image quality is given in Appendix 1.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents the results of the study and discusses the results from the patient's dose and exposure technique factors collected at the conventional X-ray imaging rooms from the four participating facilities. Discussion of dose data with various imaging room and with DRLs and dose reduction methods and the assessment of image quality are also presented.

4.1 Radiographic examination details and Quality Control Test Measurements

The assessment of the physical operations of the X-ray equipment is one of the important aspects of optimization of patient's dose and image quality. The summary of the radiographic equipment used, the exposure setting, processing method of the exposed film, screen speed, and the quality assurance programmes in place are presented in the Table 4.1

Table 4.1: Details of the radiographic equipment and technique

Parameter	COCL	MNDH	TAFH	MMGH
Generator type	Optimus 50	Optimus 50	MRS Conv. Gen.	Optimus 50
Maximum voltage	150 kVp	150kVp	125kVp	150 kVp
Year of manuf.	2009	1997	1998	1997
Total filtration	2.5 mm	2.5mm	2.5mm	2.5mm
Focal spot size	0.6mm-1.2mm	0.6mm-1.3mm	0.6mm-1.2mm	0.6mm-1.3mm
Screen film speed	400	400	200	400
Grid	Yes	Yes	Yes	Yes
Exposure setting	Manual / AEC	Manual/AEC	Manual	Manual/AEC
Processing method	Automatic	Automatic	Manual	Manual
QA programmes	None	None	None	None

From Table 4.1, with the exception of TAFH, which uses a single-phase Multi-Radiography System conventional generator and a slow screen speed of 200 which contribute high exposure setting, all the facilities were using a three phase 12-pulse Optimus 50 high voltage generators and a screen speed of 400. With the exception of COCL, all the X-ray machines used in the three participating hospitals were older than 10 years. From Table 4.1, all the X-ray machines in all the hospitals were having a total filtration of 2.5 mm of aluminum. Table 4.1 shows that none of the participating facilities was having any QC programmes in place. This shows that there could be a significant dose reduction with an improved image quality if proper QC and QA programmes are in place in all the facilities. The summary of the quality control tests on the fixed X-ray machines at COCL, MNDH and TAFH are presented in Table 4.2.

Table 4.2: Summary of the Quality Control Test

Facility Parameter	Deviation of the X-ray machine (Measurements)			Accepted deviation (Value)
	COCL	MNDH	TAFH	
kVp Accuracy	1.50%	2.50%	1.80%	$\leq \pm 6.0\%$
Output linearity	0.02	0.03	0.04	≤ 0.10
Timer accuracy	6.10%	2.70%	N/A	$\leq \pm 10.0\%$
X-ray / Light beam (degree)	1.5^0	1.5^0	1.5^0	$\leq 3^0$
Collimation accuracy	3.0 mm	8.0 mm	5.0 mm	≤ 10.0 mm
HLV at 81 kVp	3.3 mm Al	4.2 mm Al	2.7 mm Al	≥ 2.3 mm Al

At the end of the quality control measurements on the fixed X-ray machines at COCL, MNDH and TAFH, the performance criteria of key equipment parameters were found to be within reference levels. The measured tube voltage at COCL, MNDH and TAFH were found to have maximum deviation from the indicated voltage on the console by 1.50 %, 1.50 % and 1.80 %, which were within the acceptable deviation of ± 6 %. From Table 4.2, the tube output was consistent and the output linearity in the three facilities were found to be below the 0.10 acceptable values. The timer accuracy test was not performed at TAFH because the control console was not displaying the exposure time. The measured exposure time at COCL and MNDH were also deviated from the indicated value by a maximum of 6.10 % and 2.70 % respectively, which are below the acceptable deviation of ± 10 %. The half value layer (HVL) of the X-ray beam at the three facilities were also found to be 3.3 mm Al, 4.2 mm Al and 2.7 mm Al at 81 kV for COCL, MNDH and TAFH respectively. This shows that there were enough filtration in all the machines to

remove the damaging low energy radiations for the X-ray beam. Table 4.2 shows that all the X-ray machines passed the X-ray / light beam congruence and the collimation accuracy test. Though most of the machines were older, they were performing self consistently.

4.2 Patients demographic and examination data

The mean and the range (in parenthesis) of the age, weight, thickness and the BMI are presented in Table 4.3.

Table 4.3: Physical characteristics of patients selected for the study

Examination		COCL	MNDH	TAFH	MMGH
Skull	Projection	-	PA/LAT	PA/LAT	PA/LAT
	Male	-	4	-	5
	Female	-	1	-	1
	Age(yr)	-	27(23-32)	-	39(25-68)
	Weight(kg)	-	70(61-86)	-	64(48-73)
	PAThickness(cm)	-	17(15-19)	-	17(15-18)
	LAT Thickness	-	14(13-15)	-	15(14-17)
	BMI(kg/m2)	-	26(20-38)	-	20(16-22)
Chest	Projection	PA	PA	PA	PA
	Male	7	54	22	30
	Female	18	57	20	24
	Age(yr)	49(23-60)	34(18-89)	44(20-85)	47(17-84)
	Weight(kg)	74(51-92)	64(39-132)	68(38-103)	63(41-104)
	Thickness(cm)	20(17-30)	17(14-30)	19(15-23)	20(15-25)
				21.9(12-	
	BMI(kg/m2)	26(18-34)	21(14-43)	36)	21(15-34)
Lumbar Spine	Projection	AP/LAT	AP/LAT	AP/LAT	AP/LAT
	Male	3	9	6	4
	Female	4	10	7	2
	Age(yr)	41(23-60)	42(17-61)	51(22-85)	47(28-75)
	Weight(kg)	78(52-93)	77(47-122)	77(56-108)	67(49-89)
	APThickness(cm)	27(17-30)	25(16-33)	26(18-31)	24(21-29)
	LAT Thickness	29(19-33)	28(21-33)	29(27-32)	27(24-30)
	BMI(kg/m2)	27(19-33)	26(18-40)	26(18-35)	22(16-27)
Abdomen	Projection	-	AP	AP	AP
	Male	-	0	2	3
	Female	-	3	0	2
	Age(yr)	-	57(40-67)	35(33-36)	41(32-44)
	Weight(kg)	-	96(82-109)	77(77-78)	68(58-78)
	Thickness(cm)	-	32(30-33)	4(22-25)	27(25-28)
	BMI(kg/m2)	-	32(30-35)	24(23-25)	21(15-34)
Pelvis	Projection	AP	AP	AP	AP
	Male	1	4	4	7
	Female	1	3	7	3
	Age(yr)	33(23-42)	49(27-66)	47(24-85)	38(18-67)
	Weight(kg)	88(87-89)	82(63-122)	70(40-93)	69(46-92)
	Thickness(cm)	22(18-26)	24(19-33)	20(13-25)	23(20-28)
	BMI(kg/m2)	31(29-33)	28(22-40)	23(12-30)	22(16-31)

Data were collected on 327 patients with 169 females representing 52% and 158 males representing 48%. The age range considered in this study was 17-89 years, which is considered as adult patients, which was within the age range considered in Malaysia (14-92) and United Kingdom (16-99) [74]. The average age and weight of patients selected for the study were 40 years and 68 kg. This average weight is less than the 70 kg mean weight considered in NRPB 2000 and 2005 [74]. The modest age group of patients who were included in the study was at the age of 18 years and most of the patients in this age group were students who were referred for chest X-ray examinations. According to ICRP 103 [74], an average standard (reference) man is of the age between 20-50 years with the weight and height of 70 kg and 175 cm respectively. This shows that average age in this study was within the ICRP 103 age group, but the weight and height were outside the range. The difference in the weight and height account for difference in the physical and physiological parameters for different race; including body size, weight and habit (pattern for food consumption)

The average thickness and the BMI of patients selected for the study are 20 cm (13– 30 cm) and 22.7 kg/m^2 (12 – 43 kg/m^2). The World Health Organization regards a BMI of a normal (healthy weight) person to be in the range of $18.5\text{-}24.99 \text{ kg/m}^2$ [75]. This also shows that the average BMI of patients selected for the study was within the WHO range. BMI values are age-independent and the same for both sexes. From Table 4.2, the patient the highest BMI shows a class III (very severe) obese with over 40 kg/m^2 .

Diagnostic procedures are the most common application of radiations in medicine. In Ghana, widespread use of X-rays in conventional radiography accounts for largest exposure of the population to radiations. Distribution of the selected examinations in the participating hospitals during the study period is presented in Figure 4.1 below.

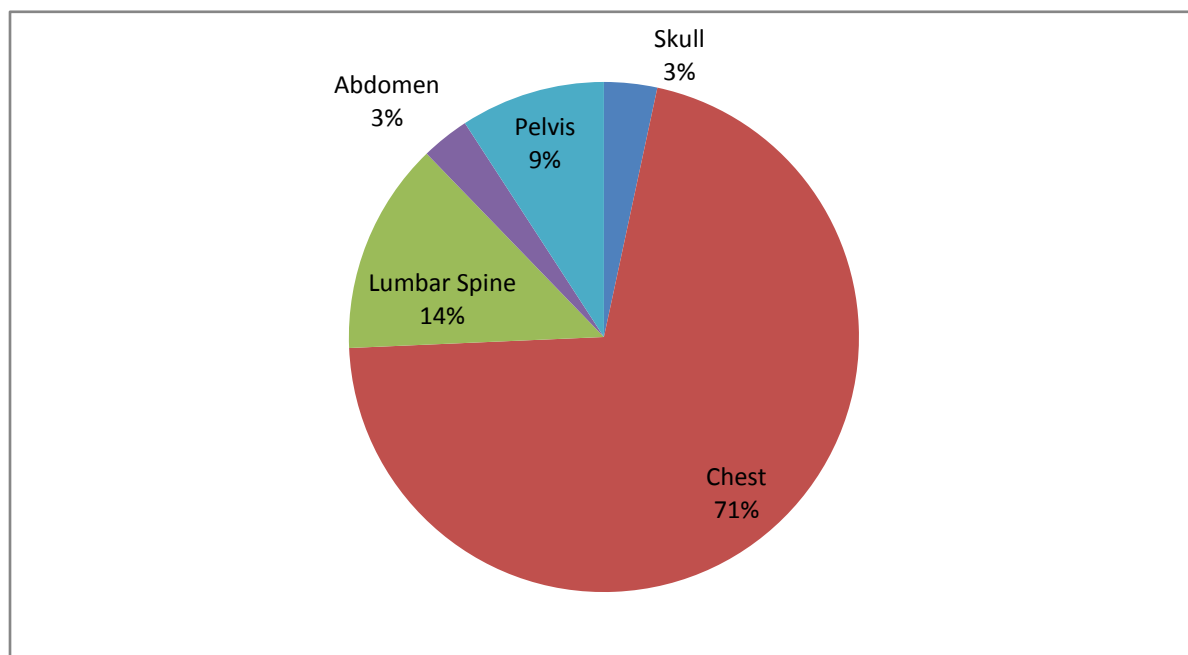


Figure 4.1 Distribution of the selected examinations in the participating hospitals

From Figure 4.1, about 71% of patients sample in all the hospitals underwent chest (PA) examinations. Pelvic and lumbar spine examinations also accounts for about 23% of the total sample of patients. Abdominal and head examinations were the least performed examinations. Abdomen (PA) and skull (AP/LAT) represent about 6% of the total sample used in this study. Figure 4.1 shows that Chest radiography remains a very common and most frequently performed X-ray examination in diagnostic radiology. It contributes to about 50% of the patients who are referred for X-ray radiography in Ghana. As seen in

Figure 4.1, chest (PA) examination remains the most frequently performed examination at any diagnostic radiology department.

4.3 Exposure parameters and radiographic techniques

The summary of the exposure factors (kVp and mAs) with the mean, range (in parenthesis) selected for various examinations at the participating hospitals are presented in Table 4.4. The most common values of the tube voltage (kVp) and the tube loading (mAs) selected are presented to the right of the range. The exposure techniques (FFD in cm and A_{FFD} in cm^2) are also presented in Table 4.4.

Table 4.4: Exposure factors and radiographic technique for the selected examinations at various centres

Examination		COCL	MNDH	TAFH	MMGH
Skull (PA)	Projection	NA	PA	NA	PA
	Tube voltage (kVp)		78(77-81)77		59(50-70)55
	Tube loading (mAs)		22(12.5-25)25		76(25-121)--
	FFD (cm)		100		100
	A _{FFD} (cm ²)		305		258
Skull(LAT)	Projection	NA	LAT	NA	LAT
	Tube voltage (kVp)		74(71-77)77		58(52-66)55
	Tube loading (mAs)		21(12.5-25)20		43(25-98)25
	FFD (cm)		100		100
	A _{FFD} (cm ²)		425		310
Lumbar spine (AP)	Projection	AP	AP	AP	AP
	Tube voltage (kVp)	83(70-90)90	83(77-90)85	83(80-90)80	74(60-81)77
	Tube loading (mAs)	33(16-63)32	38(22.5-63)25	54(30-80)50	34(20-85)25
	FFD (cm)	100	100	140	100
	A _{FFD} (cm ²)	789	839	825	626
Lumbar spine (LAT)	Projection	LAT	LAT	LAT	LAT
	Tube voltage (kVp)	92(81-102)90	91(81-125)85	93(90-100)90	84(81-90)81
	Tube loading (mAs)	37(25-63)32	63(25-107)63	80(40-90)80	31(25-40)32
	FFD (cm)	100	100	140	100
	A _{FFD} (cm ²)	717	758	915	760

Table 4.4 Continued

Examination		COCL	MNDH	TAFH	MMGH
Chest (PA)	Projection	PA	PA	PA	PA
	Tube voltage (kVp)	79(70-85)81	81(70-85)85	65(60-70)70	64(50-90)50
	Tube loading (mAs)	12(5.8-20)12.5	8(5-16)8	18(12.5-25)16	78(6.3-528)63
	FFD (cm)	180	180	140	180
	A _{FFD} (cm ²)	537	382	1117	302
Abdomen (AP)	Projection	NA	AP	AP	AP
	Tube voltage (kVp)		89(85-96)85	80(70-90)--	84(77-90)85
	Tube loading (mAs)		51(40-63)--	64	27(16-32)32
	FFD (cm)		100	140	100
	A _{FFD} (cm ²)		1571	1527	1136
Pelvis (AP)	Projection	AP	AP	AP	AP
	Tube voltage (kVp)	77(73-81)--	88(81-120)81	71(70-80)70	55(52-60)55
	Tube loading (mAs)	23(20-25)--	40(25-85)25	37(14-50)40	130(66-233)100
	FFD (cm)	100	100	140	100
	A _{FFD} (cm ²)	1505	1422	1257	1228

From Table 4.4, the range of tube voltage (50-125 kVp) mostly selected for all the radiographic examinations were within the range of tube potential selected in the UK (50-150 kVp). In the case of the tube loading (mAs), the range (5-528 mAs) was higher than in the UK survey (5-485 mAs). There is a wide range in the kVp (50-90kVp) and the mAs (6.3-528mAs) values used at MMGH. This is due to the usage of both the manual (kVp-mAs-s) and the AEC mode of exposure. The European Commission in its document, European Guidelines on Quality Criteria for Diagnostic Radiographic Images (CEC 1996) recommends the usage of high kV of 125 kVp for chest radiograph. From Table 4.4, all the facilities fell short to this recommendation. The range of the tube potential used for chest radiography is(50-90 kVp).

The range of FFD (in centimeters) used was (100-180 cm). This was within the optimum values (80-210 cm) required. From Table 4.3, there was a constant FFD of 140 cm for all the examinations performed at TAFH. This was due to a constant distance between the tube housing and the cassette holder. The other three facilities used a constant FFD of 180 cm for chest (PA) examinations and 100 cm for all other examinations.

The DAP is also affected by the beam size. Proper collimation of the beam field reduces the exposure area thereby reducing the DAP incurred by the exposed patient. The table shows that the lowest exposed area was 258 cm² for skull (PA) projection at MMGH and the highest was 1571 cm² for abdominal (AP) examination at MNDH. For chest radiography, TAFH used the widest exposure area of 1117 cm² as compared with MMGH of 302 cm², which was higher than MMGH value by a factor of about 3.6. This

shows that there could be a significant dose reduction if proper collimation is done. This will also improve the quality of the image produced by reducing the scattered radiation.

4.4 Patients radiation dose assessment before dose reduction

The average DAP (in $\mu\text{Gy.m}^2$) was computed for Skull (PA/LAT), Chest (PA), Lumbar spine (AP/LAT), Pelvis (AP) and Abdomen (AP) examinations for the selected X-ray rooms are presented in Figures 4.2.

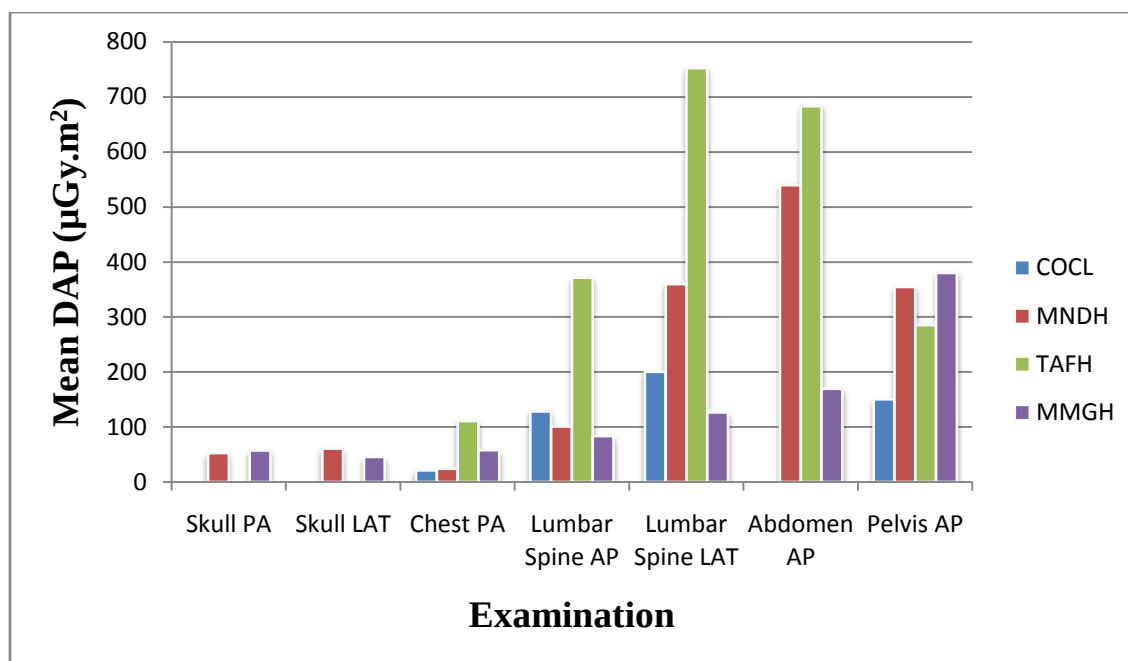


Figure 4.2: Average DAP for the selected examinations among the selected facilities

From Figure 4.2, TAFH recorded the highest mean DAP of $752.1 \pm 108.8 \mu\text{Gy.m}^2$ for lumbar spine (LAT) projection. This was followed by MNDH, COCL and MMGH with the mean DAP values of $359.5 \pm 32.8 \mu\text{Gy.m}^2$, $200.4 \pm 18.6 \mu\text{Gy.m}^2$ and $126.2 \pm 35.8 \mu\text{Gy.m}^2$ respectively. There was a wide difference of $625.1 \mu\text{Gy.m}^2$, which was by a

factor of 6 between the highest mean DAP recorded at TAFH and the lowest mean DAP recorded at MMGH. The difference between the mean DAP recorded at MNDH and MMGH was by a factor of about 2.8 which shows that the value record at TAFH was high for lumbar spine lateral examination. The higher mean DAP value recorded at TAFH may be due to the selection of high exposure factors which was also based on the patients thickness and BMI. Lack of proper collimation of the radiation beam field may also be a cause.

As illustrated from Figure 4.2, abdomen (AP) examinations accounted for the second highest mean DAP values with the highest mean DAP value of $682.9 \pm 15.2 \mu\text{Gy.m}^2$ recorded at TAFH, followed by MNDH and MMGH with the mean DAP values of $539.5 \pm 21.7 \mu\text{Gy.m}^2$ and $169.5 \pm 18.6 \mu\text{Gy.m}^2$ respectively. The difference between the mean DAP values recorded at TAFH and MMGH and between MNDH and MMGH were by a factor of 4 and 3 respectively. This shows that there can be further dose reduction at TAFH for lumbar spine (LAT) examinations since abdominal examinations require larger exposure area than lumbar spine examination.

For pelvis (AP) examination, Figure 4.2 shows that there was nearly equal mean DAP values recorded in all the centres. The highest mean DAP was recorded at MMGH with the DAP value of $380.1 \pm 12.6 \mu\text{Gy.m}^2$. This was followed MNDH, TAFH and COCL with the mean DAP values of $354.2 \pm 16.4 \mu\text{Gy.m}^2$, $285.2 \pm 20.3 \mu\text{Gy.m}^2$ and $150.1 \pm 11.1 \mu\text{Gy.m}^2$ respectively. There was a difference of $230.0 \mu\text{Gy.m}^2$, which is by a factor of 2.5 between the highest mean DAP recorded at MMGH and the lowest mean DAP recorded at COCL. The highest mean DAP recorded at MMGH may be due to the usage of the

AEC exposure mode since the magnitude of the DAP is also affected by the AEC mode. This is because during the AEC mode, the mAs depends on the exposure time. The longer the exposure time, the higher the mAs and therefore higher the DAP value. Pelvis (AP) examinations accounted for the third highest mean DAP since it also requires the exposure of wide area of the body. Pelvis examinations involve the exposure of gonads and therefore there should be an adequate protection for the patient.

For lumbar spine (AP) examination, again TAFH recorded the highest mean DAP of $371.1 \pm 40.5 \mu\text{Gy.m}^2$ with MMGH recorded the lowest mean DAP of $83.6 \pm 28.8 \mu\text{Gy.m}^2$. The difference was by a factor of 4.4. For lumbar spine (AP), Figure 4.2 shows that MNDH recorded the second highest mean DAP of $191.0 \pm 22.2 \mu\text{Gy.m}^2$ followed COCL with the mean DAP value of $128.2 \pm 26.2 \mu\text{Gy.m}^2$. The difference between the mean DAP values recorded at TAFH for both lumbar spine (AP) and lumbar spine (LAT) projections was by a factor of 2. This indicates that even for the same patient at the same X-ray imaging room, different exposure factors are selected for the same examination. This variation in the exposure factor selection may also be due to the size, thickness and the BMI of the patient being examined.

From the figure, chest (PA) projection account for the fifth highest mean DAP. The highest mean DAP value was $110.8 \pm 8.3 \mu\text{Gy.m}^2$ recorded at TAFH. This was followed by MMGH with the DAP value of $58.0 \pm 11.7 \mu\text{Gy.m}^2$. The mean DAP recorded at TAFH and MMGH were high as compared with the mean DAP values recorded at MNDH and COCL with $24.3 \pm 0.8 \mu\text{Gy.m}^2$ and $21.1 \pm 17.1 \mu\text{Gy.m}^2$ respectively. The higher mean DAP recorded at TAFH may be due to the selection of high exposure factors and loose

collimation of the radiation beam size. At MMGH, the high mean DAP could be due to the usage of the AEC mode with long exposure time and high mAs values.

From Figure 4.2, there were no examination data recorded for skull (AP/LAT) at TAFH and COCL. From the figure, there was a slight differences of $5.0 \mu\text{Gy.m}^2$ and $15.3 \mu\text{Gy.m}^2$ in the mean DAP values recorded for both skull (PA) and skull (LAT) examinations respectively at MMGH and MNDH. For skull (PA), MMGH recorded the highest mean DAP of $57.3 \pm 10.4 \mu\text{Gy.m}^2$ with MNDH being the lowest with the mean DAP value of $52.3 \pm 8.1 \mu\text{Gy.m}^2$. For skull (LAT), MNDH recorded the highest mean DAP value of $60.8 \pm 8.9 \mu\text{Gy.m}^2$ and MMGH recorded the lowest mean DAP value of $45.6 \pm 16.4 \mu\text{Gy.m}^2$.

From Figure 4.2, TAFH recorded the highest mean DAP values for most of the examination projections followed by MNDH. COCL and MMGH performed well by recording low mean DAP in most of the examinations. From Figure 4.2, there was a wide range of mean DAP values (21.1 ± 17.1 - 752.1 ± 108.8) $\mu\text{Gy.m}^2$ for all the examinations. The difference in the DAP values for among the centres accounts for the selection of different exposure protocols for the same examination used for the same examination at different X-ray rooms.

The range of the DAP values for each projection in each participating hospitals for the selected examinations are presented in Figure 4.3.

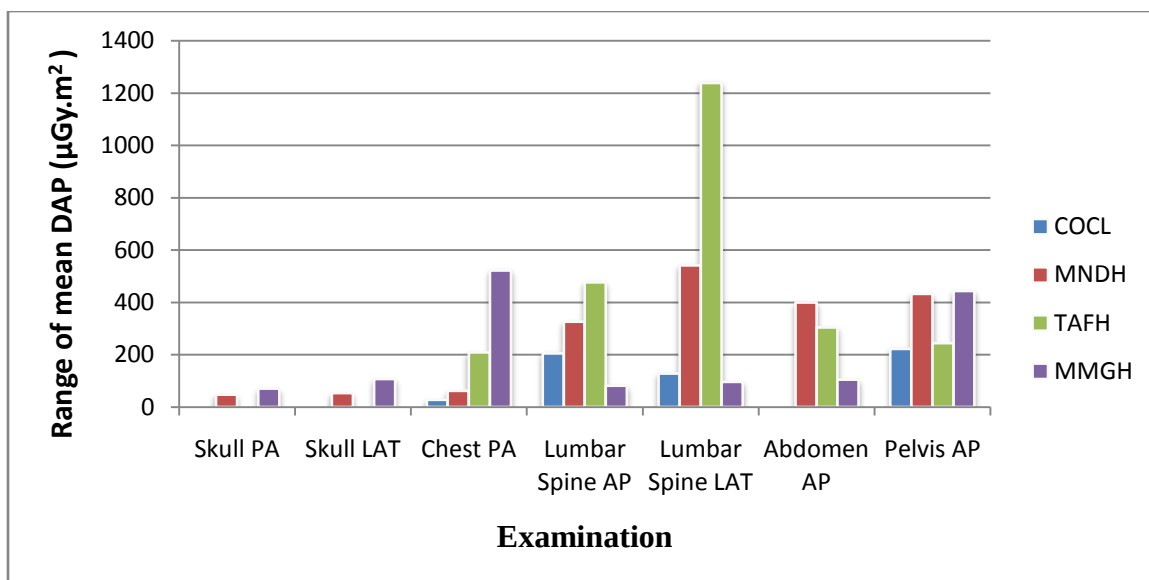


Figure 4.3: Range of DAP values for the selected examination at various hospitals

The range used in this study as in Figure 4.3 was determined by finding the difference between the maximum and the minimum DAP values recorded for individual examination and the range factors in Table 4.4 was calculated by finding the maximum-to-minimum ratios of the DAP values recorded for each radiographic projection and among the hospitals under study.

The results in Figure 4.3 show a large difference in the range of DAP values at TAFH. The widest range was 1238.6 $\mu\text{Gy.m}^2$ at TAFH followed by MNDH with the DAP range of 541.6 $\mu\text{Gy.m}^2$ for lumbar spine (LAT) examinations. This accounts for the usage of different exposure factors and techniques even for the same examination.

The range factor of the DAP values for individual examinations for each hospital and among hospitals are presented in Table 4.5.

Table 4.5: Range factors of DAP values for individual examinations for each hospital and among hospitals

EXAMINATION	COCL	MNDH	TAFH	MMGH	HOSPITALS
Skull PA	--	3.4	--	3.6	1.1
Skull LAT	--	2.4	--	6.5	2.7
Chest PA	3.4	8.6	6.6	68.6	20.2
Lumbar Spine AP	6.3	5.0	3.9	2.5	2.5
Lumbar Spine LAT	1.9	3.6	4.5	2.1	2.4
Abdomen AP	--	2.0	1.6	1.8	1.3
Pelvis AP	6.7	3.1	2.2	3.3	3.1

Table 4.5 shows that there is a large difference among the range factors for the DAP obtained for individual examinations and among hospitals. This indicates that there was a significant difference in the DAP values obtained for the same examination procedure for different patients at the same hospital and even the same patient at different hospital.

The wider variations in the range factors of the DAP values obtained for individual examination (1.2-68.6) and among hospitals (1.1-20.2) gives an indication that different exposure factors and exposure techniques were selected by the radiographers even for the same examination at different hospitals and even in the same X-ray imaging room for different patients. This suggests that there could be a significant reduction of radiation dose to patients from these examinations in the selected without compromising the diagnostic quality of the image produced.

To account for the total radiation harm to the exposed individual the effective dose, which provides a single measure of the dose that is directly related to the radiation

detriment, was estimated. The mean effective dose to patients from the selected examinations for participating hospitals is summarized in Figure 4.4.

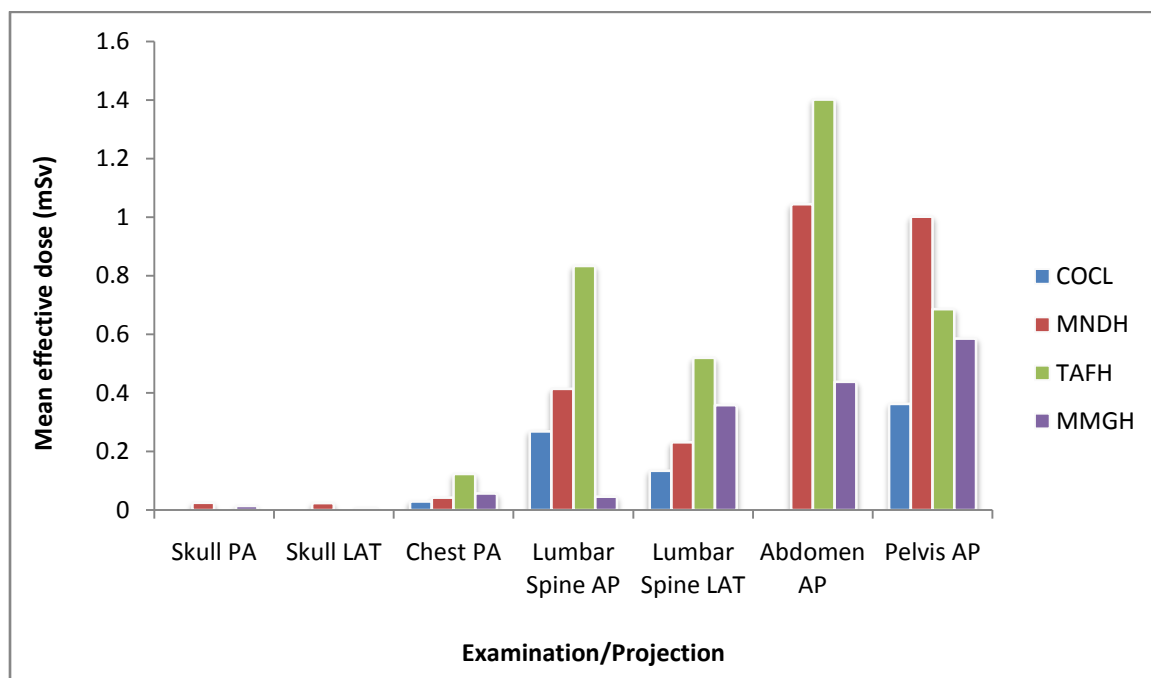


Figure 4.4: Estimated mean effective doses per projection per hospital

From Figure 4.4, abdominal (AP) examination accounts for the highest mean effective dose of 1.402 ± 0.55 mSv, 1.044 ± 0.20 mSv and 0.438 ± 0.05 mSv for TAFH, MNDH and MMGH respectively. The difference between the mean effective dose a TAFH and MNDH is by a factor of 1.3. MMGH recorded the lowest effective dose, which is about two times lower than at MNDH and three times lower than at TAFH.

Pelvis (AP) examinations accounts for the second highest effective doses. From Figure 4.4, the highest effective dose for pelvic examination was 1.002 ± 0.17 mSv recorded at MNDH followed by TAFH and MMGH with the mean effective doses of

0.685 ± 0.04 mSv and 0.586 ± 0.06 mSv respectively. The lowest effective dose was 0.363 ± 0.28 mSv recorded at COCL. The difference between the highest and the lowest mean effective doses was by a factor of about 2.8.

The third highest effective dose was for lumbar spine (AP/LAT) examinations. For lumbar spine (AP) projections, TAFH recorded the highest effective dose of 0.834 ± 0.03 mSv followed by MNDH and COCL with the mean effective dose of 0.414 ± 0.03 mSv and 0.269 ± 0.06 mSv respectively. The lowest mean effective dose was recorded at MMGH which was 0.046 ± 0.005 mSv. There was a large difference between the mean effective doses recorded at MMGH and the other three hospitals. For lumbar spine (LAT), TAFH recorded the highest mean effective dose followed by MMGH, MNDH and COCL respectively with the effective dose values of 0.520 ± 0.05 mSv, 0.358 ± 0.04 , 0.232 ± 0.02 mSv and 0.135 ± 0.02 mSv respectively.

Chest (PA) examination accounts for the fourth highest effective dose from the figure. The mean effective doses recorded at TAFH, MMGH, MNDH and COCL were 0.124 ± 0.007 mSv, 0.057 ± 0.008 mSv, 0.043 ± 0.001 mSv and 0.030 ± 0.002 mSv respectively. The difference between the highest mean effective dose recorded at TAFH and the lowest mean effective dose recorded at COCL was by a factor of 4.

Skull (PA/LAT) was the radiological examination that recorded the lowest mean effective doses. From Figure 4.4, there were no examination data on skull examination recorded at COCL and TAFH. For Skull (PA), MNDH recorded the highest mean effective dose of 0.025 ± 0.004 mSv followed by MMGH with the mean effective dose of 0.014 ± 0.001 mSv. For skull (LAT) projection, the effective doses recorded were 0.024

± 0.001 mSv and 0.007 ± 0.002 mSv at MNDH and MMGH respectively. The differences between the effective dose values for the two hospitals were by a factor of about 1.8 and 3.4 for both skull (PA) and skull (LAT) projections respectively.

Results obtained from the selected institutions shows a significant variations in the DAP and the effective doses with TAFH and MNDH recording higher effective doses for most of the selected projections. The wide variations in the DAP and the effective doses are due to the techniques employed by the radiographers from these institutions. These differences could be attributed to the selection of exposure factors and the exposure technique used at each facility. Many factors affect the DAP which in turn affects the effective dose to the patient. The differences in exposure time, tube voltage, exposure geometric factors such as the FFD and the beam size are the exposure techniques that affect the radiation dose to patients. The patient's body mass index (BMI) and other factors such as design or type of the generator also affects the magnitude of the effective dose. The automatic control mode was used together with the manual exposure mode at MMGH for most of the examinations. This also affects the magnitude of the DAP and hence the effective.

The variations in the effective dose can also be attributed to screen speed, the film type and the processing conditions since the radiographic technologist consider all these first before the selection of the kVp and mAs is done. Some radiographic films required higher mAs and kVp, which affects the magnitude of the radiation dose. Weak processing chemicals also require high factors to be selected, which also affects the radiation dose.

Baggy collimation of the radiation beam size also affects the effective dose in that most organs are exposed to the radiations. The more radiosensitive tissues exposed, the higher the effective dose incurred. This accounts for the high effective doses for Abdomen (AP) and Pelvis (AP) examinations.

4.5 Comparison of results with other studies

Tables 4.6 compares the average DAP values for this study with the result from other studies [76].

Table 4.6: Comparison of DAP ($\mu\text{Gy.m}^2$) from this study with others studies

EXAMINATION	This work				Other works		
	COCL	MNDH	TAFH	MMGH	Iran	NRPB	UNSCEAR New Zealand
					2013 [76]	2005 [76]	2000 [76]
Skull PA	----	52.3 $\pm$ 8.1	----	57.3 $\pm$ 10.4	42	62	96
Skull LAT	----	60.8 $\pm$ 8.9	----	45.5 $\pm$ 16.4	39	51	57
Chest PA	21.1 $\pm$ 17.1	24.3 $\pm$ 0.08	110.8 $\pm$ 8.3	58.0 $\pm$ 11.7	22	9	17
Lumbar Spine AP	128.2 $\pm$ 26.2	191 $\pm$ 22.2	371.1 $\pm$ 40.1	83.6 $\pm$ 28.8	71	133	188
Lumbar Spine LAT	200.4 $\pm$ 18.1	359.5 $\pm$ 32.8	752.1 $\pm$ 108.8	126.2 $\pm$ 35.8	152	214	392
Abdomen AP	----	539.5 $\pm$ 21.7	682.9 $\pm$ 15.2	169.5 $\pm$ 18.6	129	216	267
Pelvis AP	150.1 $\pm$ 11.1	354.2 $\pm$ 16.4	285.2 $\pm$ 20.3	380.1 $\pm$ 12.6	111	190	237

From table 4.6, the mean DAP from this study are well comparable to the DAP values in New Zealand in most of the examinations. For chest (PA) the DAP recorded for this study were higher as compared with the mean DAP in Iran, UK and New Zealand [76]. The highest mean DAP was $752.1 \mu\text{Gy.m}^2$ recorded at TAFH for lumbar spine (LAT) as against $152.0 \mu\text{Gy.m}^2$, $214.0 \mu\text{Gy.m}^2$ and $392.0 \mu\text{Gy.m}^2$ recorded in Iran, UK and New Zealand respectively.

Table 4.6 shows that MNDH and TAFH recorded high mean DAP for most of the examinations, but COCL and MMGH have mean DAPs that are well compared with that in Iran, UK and New Zealand. The highest mean DAP recorded at MNDH and TAFH was due to the selection of exposure technique including the coning of the X-ray beam. For chest (PA), the mean DAP for all the facilities in this study were higher than in UK and New Zealand, but that of COCL was in good comparison with that in Iran. The highest mean DAP for chest (PA) was $110.8 \mu\text{Gy.m}^2$ recorded at TAFH. This was due to the selection of high kVp, mAs and lack of proper collimation of the X-ray beam. At MMGH, the highest mean DAP was recorded for pelvis (AP) which was $380.1 \mu\text{Gy.m}^2$. This was due to the usage of the AEC mode of exposure setting with long exposure time.

In general, a comparison of the DAP for this study made with other international studies shows that in most of the examination, the mean DAP from this study were higher than in the international reports. This may be due to the usage of high mAs and high kVp in most of the radiographic examinations. Lack of proper beam field collimation could also be a factor.

The mean exposure parameters (kVp and mAs) for the various examinations in various X-ray rooms are presented in Table 4.7 and compared with the mean exposure factors from other studies as reported by Shirin et al [76] and Akindele et al [77].

Table 4.7: Mean exposure parameters in various hospitals for the selected examinations compared with others studies

EXAM.	PARA.	This study				Other studies		
		COCL	MNDH	TAFH	MMGH	NRPB 2005 [76]	IRAN 2013 [76]	NIGERIA 2012 [77]
Skull PA	kVp	---	78	---	59	68	65	74
	mAs	---	22	---	76	20	36	53
Skull LAT	kVp	---	74	---	58	65	60	74
	mAs	---	21	---	43	16	26	53
Chest PA	kVp	79	81	65	64	84	65	65
	mAs	12	8	18	78	4	17	12
Abdomen AP	kVp	---	89	80	84	73	69	80
	mAs	---	51	64	27	93	43	80
L. Spine AP	kVp	83	83	83	74	76	70	---
	mAs	33	38	54	34	43	53	---
L. Spine LAT	kVp	92	91	93	84	87	80	---
	mAs	37	63	80	31	54	73	---
Pelvis AP	kVp	77	88	71	55	71	65	80
	mAs	23	40	37	130	193	38	75

From Table 4.7, the tube potentials used in this study were well compared with that used in Nigeria. For chest (PA), all the studies fell short in the usage of higher kVp of 125 kVp as reported in the CEC 1996 document by the European Commission. From this study, the lowest and the highest kVp were 55 kVp at MMGH and 93 kVp at TAFH for Pelvis (AP) and lumbar spine (LAT) examinations respectively. The lower kVp used at MMGH was due to the usage of the AEC exposure mode. The selection of the kVp and the mAs is also based on the thickness and the BMI of the patient being examined. The highest mAs was 130 mAs at MMGH for pelvis (AP) as against 193 mAs in UK for the same examination.

4.6 Film rejected at radiographers level

In order to optimize patient's protection and reduce unnecessary radiation dose to patient, information relating to the films that were rejected at the radiographer's level for the selected examination and other radiographic examination and the cause of the film rejection are analyzed and summarized in Figure 4.5. The result was analyzed for all the hospitals visited.

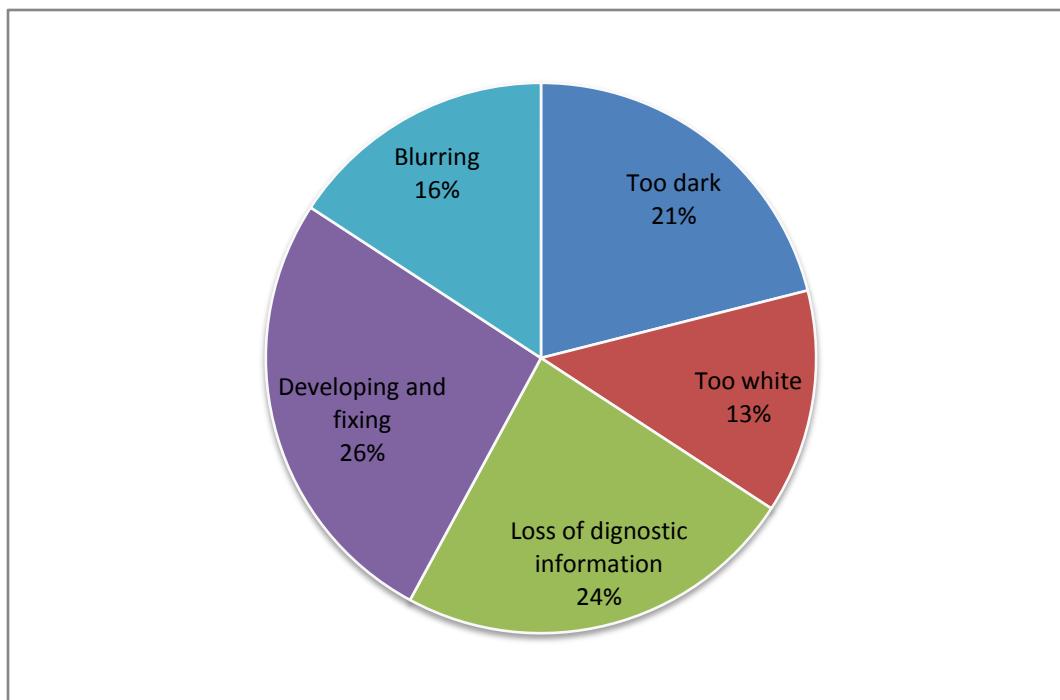


Figure 4.5: Films rejected at radiographers level

From Figure 4.5, 21% and 13% of the rejected films were too dark and too white respectively. Too dark and too white films are mainly due to the selection of kVp and low mAs. Improper selection of the exposure parameters for a particular projection causes the film to be rejected as too dark or too white. Loss of diagnostic information account for 24% of the total rejected films. The loss of diagnostic information was mainly caused by the adjustment of the collimator, which cut some part of the anatomical structure required for diagnosis. In addition, films that were rejected as not containing sufficient diagnostic information were also attributed to inaccurate request on the part of the referral medical doctor. Developing and fixing of the exposed radiograph is also a major cause of the rejected films. Weak processing chemicals, non-compliance with the film manufacturer's instructions, too long and too short processing time, and exposure of the exposed film to light during processing causes the film to be rejecting. Developing and fixing accounts

for about 26% of the rejected films in all the facilities during the study period. Blurring of the image was also a cause and it was mainly as a result of patient movement during the exposure.

4.7 Dose reduction

In order to search for options to optimize patient dose and the image quality, an anthropomorphic woman phantom was used by exposing with varying exposure protocols. The results from the dose reduction are presented and discussed in this section.

4.7.1 Image quality assessment with the phantom

Seventy-five (75) radiographs were obtained for Chest (PA), Lumbar spine (AP/LAT), Abdomen (AP) and Pelvis (AP) projections from the phantom studies for an objective image quality assessment. Image quality assessment forms were developed based on the CEC (1996) quality criteria. The image quality of the radiographs were assessed in order to investigate that the image produced after the dose reduction were good for diagnosis.

The results of the image quality assessment of the radiographs based on the scores on each quality criterion and the CEC dose criteria are summarized in Figures 4.6 – Figure 4.10

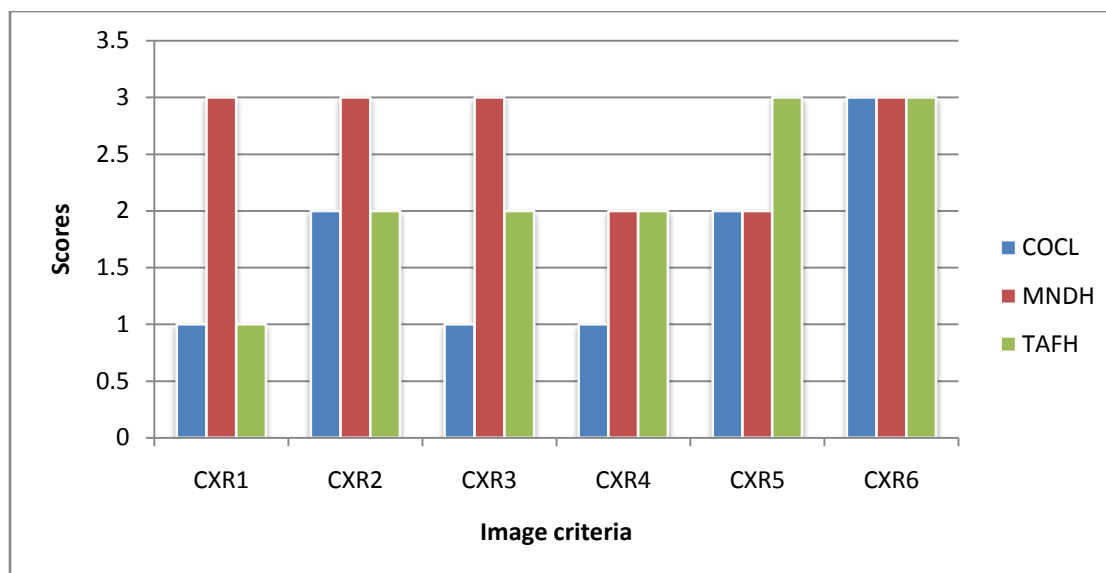


Figure 4.6: Image criteria scores for phantom chest (PA) radiographs

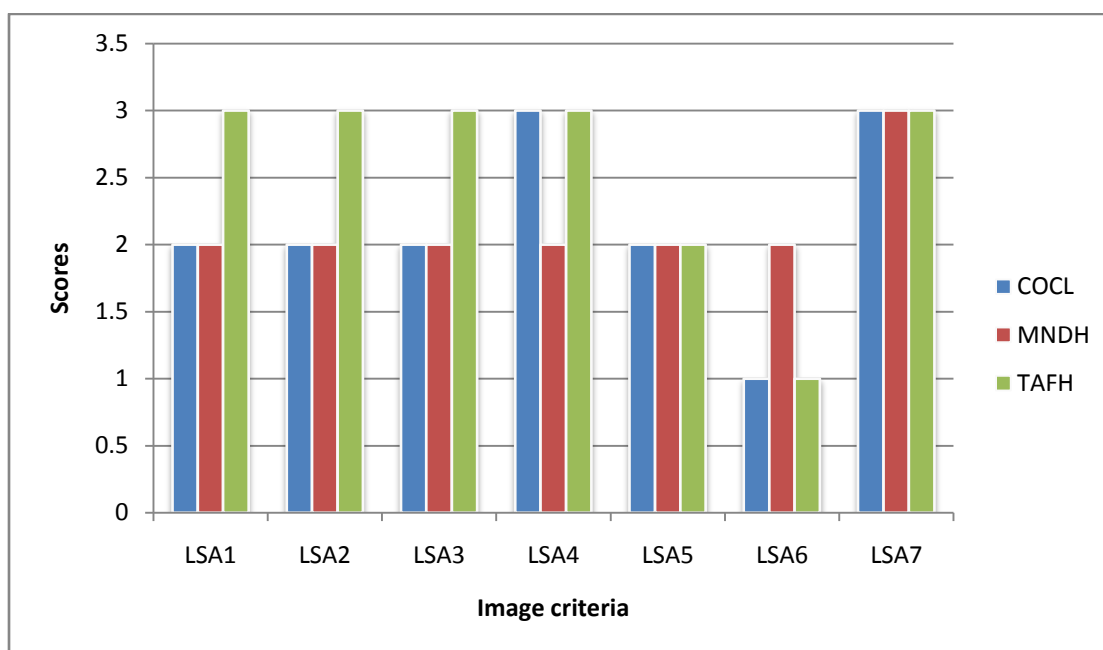


Figure 4.7: Image criteria scores for phantom lumbar spine (AP) radiographs

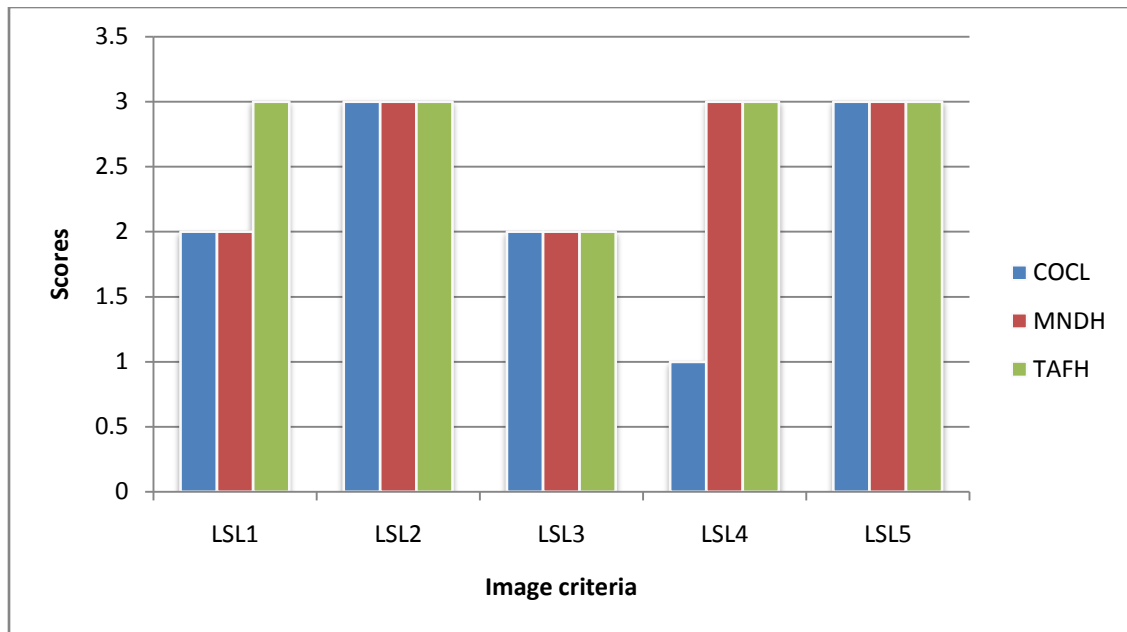


Figure 4.8: Image criteria scores for phantom lumbar spine (LAT) radiographs

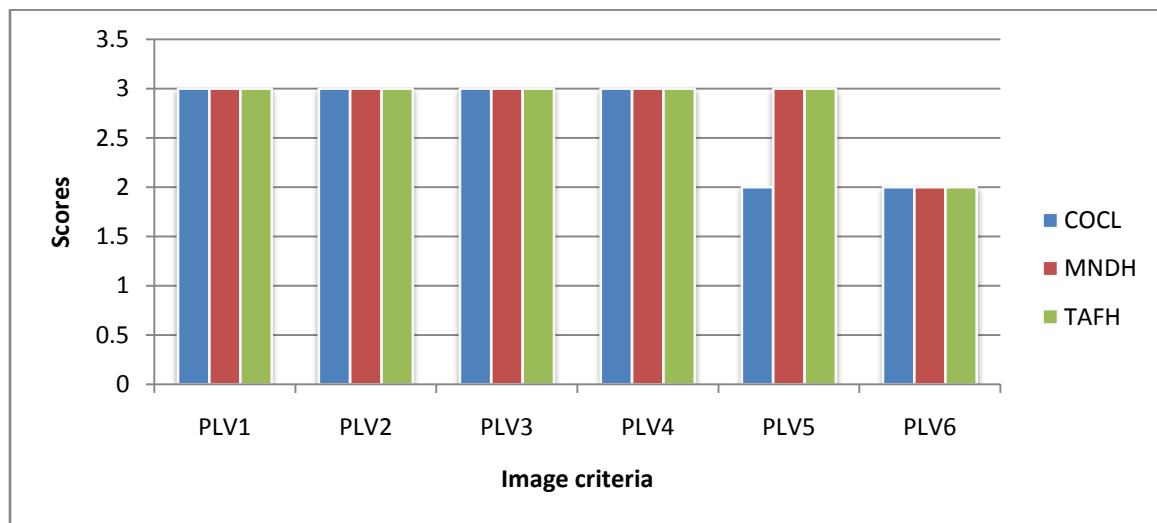


Figure 4.9: Image criteria scores for phantom pelvic (AP) radiographs

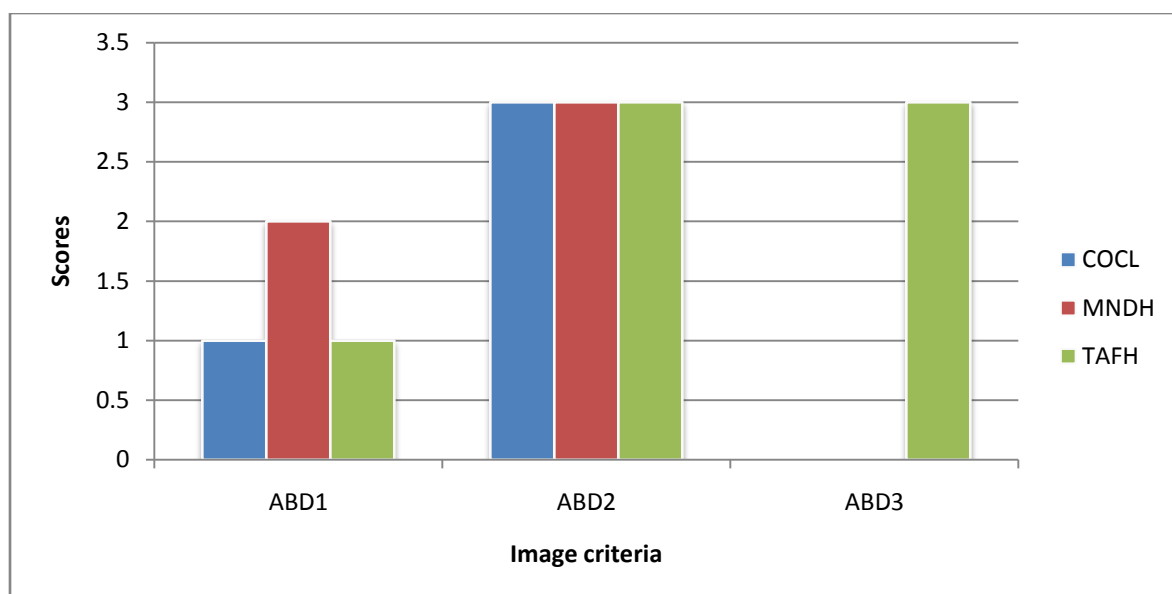


Figure 4.10: Image criteria scores for phantom abdominal (AP) radiographs

Results obtained in Figures 4.6 – 4.10 indicate that most the image criteria involving the reproduction and visualization of soft tissues were not suitably shown on most of the radiographs. For chest radiographs, criteria CXR1 and CXR3 were not clearly seen in most of the radiographs. For lumbar spine and abdomen radiographs, the criteria LSA6, ABD1 and ABD3 were also not clearly seen. This may be due to factors relating to the phantom and the selection of exposure parameters. In most cases, the radiographs selected from the image criteria evaluation had scores that can be used for diagnosis. This indicates that the anatomical structures in the image criteria were seen in the radiographs and that they could be used for diagnosis. Figure 4.9 shows that all the radiographs selected from the phantom pelvic examination passed the image criteria with the anatomical structure clearly seen in the radiograph. This was because all the criteria for the pelvis radiograph assessment were involving the bones.

The assessment of the radiograph was clarified by summing the individual criteria score and the results summarized in Figure 4.11

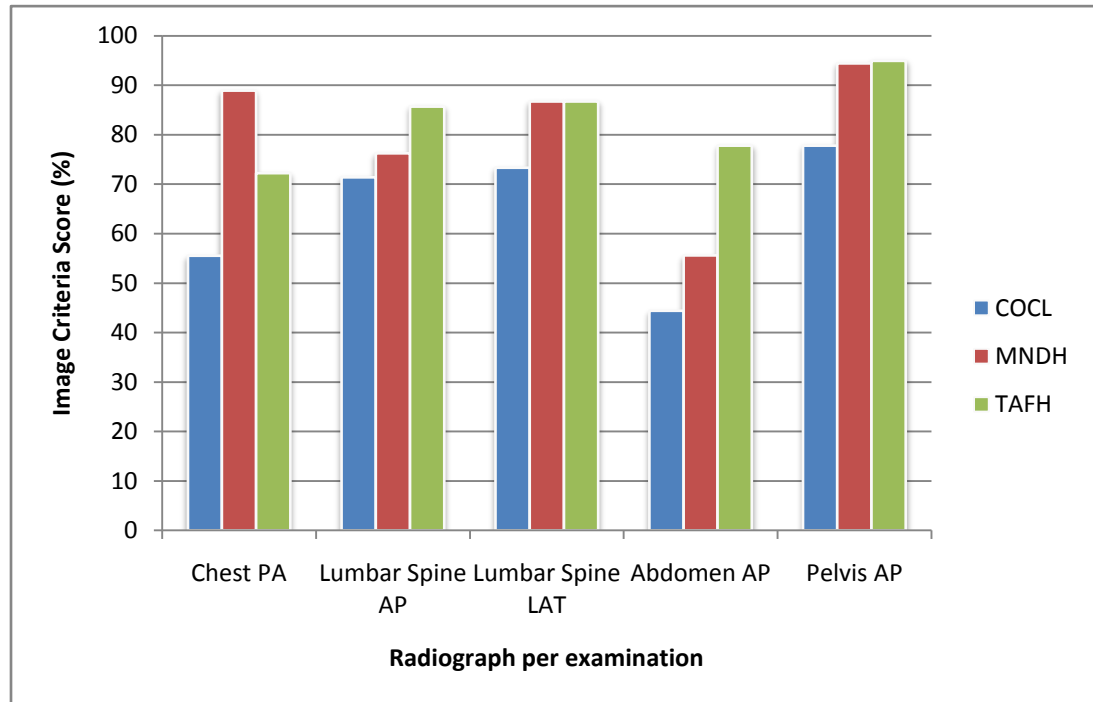


Figure 4.11: Summary of the image criteria score on the radiographs for each examination

The mean score values (in percentage), averaged over the selected x-ray examinations carried out in each hospital, was taken as the most significant numerical index to proceed towards the acceptance of the radiograph. The results of the technical evaluation of the radiographs and the acceptability of the radiograph are present in Table 4.8.

Table 4.8: Technical evaluation and the film acceptability of the radiographs

Facility	Examination	Film density	Contrast	Sharpness	Beam limitation	Film acceptability	
		%	%	%	%	Yes (%)	No (%)
COCL	Chest PA	66.7	83.3	66.7	100.0	83.3	16.7
	Lumbar Spine AP	77.8	55.6	77.8	100.0	77.8	22.2
	Lumbar Spine LAT	75.0	50.0	73.3	100.0	83.3	16.7
	Abdomen AP	77.8	77.8	77.8	33.3	66.7	33.3
	Pelvis AP	100.0	100.0	100.0	100.0	83.3	16.7
MNDH	Chest PA	91.7	100.0	83.3	100.0	91.7	8.3
	Lumbar Spine AP	100.0	83.3	86.7	100.0	93.3	6.7
	Lumbar Spine LAT	100.0	100.0	80.0	100.0	91.7	8.3
	Abdomen AP	73.3	91.7	77.8	33.3	66.7	33.3
	Pelvis AP	100.0	100.0	90.0	90.0	93.3	6.7
TAFH	Chest PA	66.7	83.3	50.0	66.7	66.7	33.3
	Lumbar Spine AP	91.7	83.3	75.0	66.7	77.0	23.0
	Lumbar Spine LAT	83.3	66.7	66.7	100.0	83.3	16.7
	Abdomen AP	83.3	66.7	66.7	100.0	66.7	33.3
	Pelvis AP	91.7	91.7	66.7	100.0	91.7	8.3

From Table 4.8, there was appropriate film density for most of the radiographs. There was a high score of 75% and above, with the exception of abdomen at MNDH. There were also low contrast for most of the radiographs at both COCL and TAFH, especially for lumbar spine and abdomen. The contrast is dependent on the mAs and kVp selected. The low contrast in radiographs at COCL and TAFH could be due to factors relating the exposure factors used. At TAFH, the low contrast could also be due to the performance of the X-ray machine.

There was a satisfactory (optimum) sharpness in the images produced at COCL and MNDH with sub-optimum sharpness for radiographs at TAFH. This accounts for the

performance of the imaging equipment. The age of the imaging machine and the X-ray tube, other factors, which include the HV generator pulse, pulse and the ripples of the waveform, focal spot size, also affects the sharpness of the image produced. For most of the radiographs, there was optimum field size adjustment. This indicates that the require area on the body was exposed to the radiations. At COCL and TAFH, the field size was small for abdomen (PA) radiographs. The field size is affected by collimation of the radiation beam size using the light beam diaphragm.

From Table 4.8, most of the selected radiographs were fully accepted with few of them, only accepted under limited clinical conditions. These were the radiographs that had poor demonstration and visualization of the soft tissues.

From Table 4.8, the percentages of the accepted films were high, although some soft tissues were not visualized in some of the images. Despite the limitations of some films, the general remarks on the selected radiographs were given as a good quality radiographs.

The percentage of the unaccepted films includes those that were having low quality and poor quality remarks. Rejected films were also included. The reported reasons for the rejection of these films were that the films were too dark with low contrast. This was caused by overexposure and the selection of high kVp, which made it difficult to delineate soft tissues and the bones.

The acceptance of the radiograph was based on its ability to display the anatomic structure (medical dimensions), ability to produce appropriate film density, optimum sharpness and film contrast (technical dimensions) and the appropriate part of the body

being projected onto the film (position dimension). To accept a radiograph as satisfactorily for diagnosis, the type of radiological information imaged on the film warrants its acceptability for diagnosis and because the medical outcome is far more important than technical and positioning considerations, primacy was exclusively given to the medical dimension. The general remarks made was that the selected radiographs were of good quality which make them accepted for clinical diagnosis.

4.7.2 Phantom dose evaluation

After the image quality evaluation, the radiation dose delivered to the phantom was based on the selected radiographs. Results obtained for the DAP and the effective dose from the phantom were compared with the mean values of the DAP and the effective dose obtained from the patient dose assessment. The result is summarized in Table 4.9 and Table 4.10 for the DAP and effective dose respectively.

Table 4.9: Comparison of the mean DAP (in $\mu\text{Gy.m}^2$) between patient dose assessment and the phantom studies

EXAMINATION	COCL		MNDH		TAFH	
	PDA	PHDA	PDA	PHDA	PDA	PHDA
Skull PA	----	----	52.3 $\pm$ 8.1	----	----	----
Skull LAT	----	----	60.8 $\pm$ 8.9	----	----	----
Chest PA	21.1 $\pm$ 17.1	15.1 $\pm$ 3.2	24.3 $\pm$ 0.08	27.6 $\pm$ 3.4	110.8 $\pm$ 8.3	72.4 $\pm$ 7.1
Lumbar Spine AP	128.2 $\pm$ 26.2	61.9 $\pm$ 6.7	119.1 $\pm$ 22.2	93.1 $\pm$ 20.1	371.3 $\pm$ 40.5	139.0 $\pm$ 17.3
Lumbar Spine LAT	200.4 $\pm$ 18.1	81.2 $\pm$ 5.4	359.5 $\pm$ 32.8	148.0 $\pm$ 5.8	752.1 $\pm$ 108.8	235.5 $\pm$ 43.9
Abdomen AP	----	133.1 $\pm$ 7.3	539.5 $\pm$ 21.7	193.0 $\pm$ 15.9	682.9 $\pm$ 15.2	169.4 $\pm$ 19.7
Pelvis AP	150.1 $\pm$ 11.1	88.6 $\pm$ 8.2	354.2 $\pm$ 16.4	179.9 $\pm$ 34.0	285.2 $\pm$ 20.3	200.1 $\pm$ 23.8

PDA – Patient Dose Assessment

PHDA – Phantom Dose Assessment

Table 4.10: Comparison of the mean effective dose (mSv) estimated from the patient and the phantom

EXAMINATION	COCL		MNDH		TAFH	
	PDA	PHDA	PDA	PHDA	PDA	PHDA
Skull PA	----	----	0.03 $\pm$ 0.004	----	----	----
Skull LAT	----	----	0.02 $\pm$ 0.004	----	----	----
Chest PA	0.03 $\pm$ 0.002	0.03 $\pm$ 0.007	0.04 $\pm$ 0.001	0.08 $\pm$ 0.02	0.12 $\pm$ 0.007	0.13 $\pm$ 0.02
Lumbar Spine AP	0.27 $\pm$ 0.06	0.15 $\pm$ 0.03	0.41 $\pm$ 0.03	0.25 $\pm$ 0.09	0.83 $\pm$ 0.07	0.37 $\pm$ 0.08
Lumbar Spine LAT	0.14 $\pm$ 0.02	0.09 $\pm$ 0.06	0.23 $\pm$ 0.02	0.18 $\pm$ 0.01	0.52 $\pm$ 0.05	0.27 $\pm$ 0.09
Abdomen AP	----	0.37 $\pm$ 0.04	1.04 $\pm$ 0.20	0.56 $\pm$ 0.06	1.43 $\pm$ 0.55	0.47 $\pm$ 0.08
Pelvis AP	0.36 $\pm$ 0.03	0.21 $\pm$ 0.03	1.01 $\pm$ 0.17	0.70 $\pm$ 0.11	0.69 $\pm$ 0.04	0.57 $\pm$ 0.16

PDA – Patient Dose Assessment

PHDA – Phantom Dose Assessment

Table 4.9 compares the mean DAP recorded during the patient dose assessment and the DAP recorded during the phantom studies. As seen from the table, there was a significant dose reduction in all the examinations at various centres, except for chest (PA) examination at MNDH. There was an increase in the DAP value by $3.3 \mu\text{Gy.m}^2$ which was about 13.6% increase. This accounts for the usage of high kVp and mAs values during the dose reduction.

Table 4.10, compares the effective dose estimated during the patient dose assessment and the phantom dose. There was no reduction in the effective dose for chest (PA) examination in all the centres. COCL recorded no change in the effective dose, but there were an increase in the effective dose at MNDH and TAFH. This may also be attributed to the selection of high exposure factors.

4.7.3 Dose reduction and the corrective actions used

The result from the dose reduction and the corrective actions used for each projection at each X-ray imaging room are summarized in Table 4.11.

Table 4.11: Dose reduction achieved by the hospitals and the corrective actions employed

EXAMINATION	Dose before reduction ($\mu\text{Gy.m}^2$)	Dose after reduction ($\mu\text{Gy.m}^2$)	% reduction (if any)	Corrective action used
COCL				
Skull PA	----	----	----	----
Skull LAT	----	----	----	----
Chest PA	21.1	15.1	28.4	↓mAs, ↑kVp, ↓Field Size
Lumbar Spine AP	128.2	61.9	51.7	↓mAs, ↓Field Size
Lumbar Spine LAT	200.4	81.2	59.5	↓mAs, ↓Field Size
Abdomen AP	----	133.1	----	----
Pelvis AP	150.1	88.6	41.0	↓mAs, ↓Field Size
MNDH				
Skull PA	----	----	----	----
Skull LAT	----	----	----	----
Chest PA	24.3	27.6	N/A	----
Lumbar Spine AP	119.1	93.1	21.8	↓mAs, ↑kVp, ↓Field Size
Lumbar Spine LAT	359.5	148.0	58.8	↓mAs, ↑kVp, ↓Field Size
Abdomen AP	539.5	193.0	64.2	↓mAs, ↓kVp, ↓Field Size
Pelvis AP	354.2	179.9	49.2	↓mAs, ↓Field Size
TAFH				
Skull PA	----	----	----	----
Skull LAT	----	----	----	----
Chest PA	110.8	72.4	34.7	↓mAs, ↑kVp, ↓Field Size
Lumbar Spine AP	371.3	139.0	62.6	↓mAs, ↓kVp, ↓Field Size
Lumbar Spine LAT	752.1	235.5	68.7	↓mAs, ↓kVp, ↓Field Size
Abdomen AP	682.9	169.4	75.2	↓mAs, ↓kVp, ↓Field Size
Pelvis AP	285.2	200.1	29.8	↓mAs, ↓Field Size

Dose before the dose reduction were the radiation recorded on patient's examination. During the phantom studies, after employing the corrective actions, the reduced radiation dose were compared with patients dose. Form Table 4.11, there were no dose reduction on chest (PA) at MNDH after the corrective actions were employed. This could be attributed to the selection of the exposure factors used. Concerning the increase in the kVp, for most of the examinations, a dose reduction was achieved by an increase in the

kVp with a decrease in the mAs. From Table 4.11, most of the dose reduction were achieved with an increase in the kVp and a decrease in mAs, especially at TAFH and MNDH. In all the cases, there were also a reduction in the radiation beam size. This was done by collimating the radiation beam using the light diaphragm to the area of interest. With regard to the kVp selection, no hospital adopted the high kVp technique for chest (PA) examinations.

4.8 Optimization of patient protection

In order to optimize the dose and image quality and reduce the risk of stochastic effects in the population exposed for diagnostic radiology procedures, the following Suggested Dose Levels and Suggested Effective Dose Levels, and exposure technique chart are developed in Table 4.12, Table 4.13, and Table 4.14 respectively.

Table 4.12: Suggested dose level (SDLs) for the selected examinations in $\mu\text{Gy.m}^2$

EXAMINATION	Based on the 3rd quartile values	Based on the phantom studies	NRPB 2005 (76)
Skull PA	65	----	62
Skull LAT	51	----	51
Chest PA	25	50	9
Lumbar Spine AP	223	120	133
Lumbar Spine LAT	432	192	214
Abdomen AP	397	181	216
Pelvis AP	354	190	190

Table 4.13: Suggested Effective Dose Levels (SEDs) for the selected examinations in mSv

EXAMINATION	Based on the 3rd quartile values	Based on the phantom studies	APRANSA[2]
Skull PA	0.02	----	0.10
Skull LAT	0.02	----	0.10
Chest PA	0.08	0.10	0.02
Lumbar Spine AP	0.47	0.31	1.50
Lumbar Spine LAT	0.34	0.23	1.50
Abdomen AP	1.14	0.54	0.70
Pelvis AP	0.78	0.64	0.60

In consultation with literatures and the guidance on national reference dose for common X-ray examinations, NRPB, the following SDLs and SEDs are established based on the patient dose assessment and the phantom dose evaluation. These were based on the third quartile values of the DAP and the effective doses from both the patients dose assessment and the phantom dose evaluation.

The SDLs are compared with the DRLs provided in the NRPB 2002 and the effective dose compared with APRANSA [2]. The SDLs established from the patient's dose were higher as compared with that of the phantom (except for chest PA projection) dose and the NRPB as in Table 4.12. From Table 4.13, the effective dose from the patient doses compared well with the reference dose by APRANSA, except for chest and abdomen examination. This could be attributed to the use of lower kVp for chest.

These suggested or reference dose levels are not intended to put a restriction on the radiation dose levels for various examinations, but doses above these dose levels gives an indication of abnormal higher doses. The dose levels are just suggested as the first step in

the optimization of patient dose. Doses above these levels call for investigation and corrective actions to be taken.

In the final stage of the study, the relevance of the dose reduction and the image quality assessment was to select the optimal radiographic technique and imaging protocols which would comply with both the diagnostic and the dosimetric requirement. For each X-ray projection type, the radiographic exposure protocols have been established with the reference dose criteria. Regarding the radiographic technique, only the manual (kVp-mAs-s) mode was considered. The established exposure technique and the imaging protocols are illustrated in Table 4.14

Table 4.14: Technique exposure protocols for the selected examinations

Examination	kVp	mAs	FFD (cm)	Grid	Filtration (mm)	Dose criteria $\mu\text{Gy.m}^2$	Protection
Skull PA [^]	75 - 85	16 - 25	100 - 150	Yes	2.5	<70	Standard Protection
Skull LAT [^]	70 - 80	12 - 20	100 - 150	Yes	2.5	<60	Standard Protection
Chest PA*	70 - 90	8 - 16	180 - 200	Yes	2.5	<50	Standard Protection
Chest PA**	100 - 150	32 - 40	180 - 200	No	3	<70	Standard Protection
Lumbar spine AP	75 - 85	20 - 40	100 - 150	Yes	2.5	<200	Gonad shield required
Lumbar spine LAT	77 - 90	32 - 40	100 - 150	Yes	2.5	<250	Gonad shield required
Abdomen AP	75 - 85	25 - 32	100 - 150	Yes	2.5	<250	Gonad shield required
Pelvis AP	75 -90	20 -32	100 - 150	Yes	2.5	<200	Gonad shield if possible
[^] Reference from CEC 1996 document			* Low kVp technique			** High kVp technique	

This technique exposure factors were developed from the phantom exposure after the dose reduction. The low kVp technique was use for chest (PA) examinations in all the examination rooms. This was because most of the X-ray machines used in the study could not deliver the high kVp. With the exception of COCL, all the other X-ray machines could deliver up to 100 kVp. Table 4.13 shows that the kVp and the mAs were given in range since patients of different BMI go for the examination.

The dose criteria provided for each of the selected examinations are expressed in terms of the suggested dose levels provided in this work in reference with the CEC criteria for radiation dose for a standard sized patient. These dose levels are intended to serve as a reference guide to increase the protection of patient and to aid optimization. The dose criteria are expressed in DAP which are practically, a direct and easy method of dose measurement using a DAP meter. Doses above these dose levels call for investigations and corrective actions to be taken.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the conclusions from the study and recommendations for the minimization of radiation dose for patients undergoing the selected radiological examinations in the selected conventional X-ray facilities in the Ashanti region of Ghana.

5.1 Conclusion

In this study, the method utilized in the optimization was the usage of optimal radiographic imaging protocols that deliver minimal dose to the patients without negatively affecting the quality of the image produced. The options employed in the dose reduction were the selection of the kVp and mAs and the collimation of the X-ray beam field. The effective dose incurred by patients who underwent the selected examinations was estimated using a PCXMC dose calculation software, version 1.5.

There was a wide range of the mean DAP values ($21.1 \pm 17.1 - 752.1 \pm 108.8$) $\mu\text{Gy.m}^2$ and the mean effective doses ($0.007 \pm 0.002 - 1.402 \pm 0.55$) mSv for the selected examination in the X-ray imaging rooms indicating the use of different exposure techniques parameters at different hospitals.

Concerning the selection of the exposure parameters, all the facilities selected different exposure factors for the same examination even for a standard sized patient. The lowest mean DAP of $21.1 \pm 17.1 \mu\text{Gy.m}^2$ was recorded at COCL for chest (PA) examination and

the highest mean DAP was $752.1 \pm 108.8 \mu\text{Gy.m}^2$ recorded at TAFH for lumbar spine (LAT) examination.

Comparison of the results in this work and other reported studies in the literature revealed that, the mean DAP and the mean effective doses recorded in this study were higher than the values reported in the NRPB 2005 report, but were lower than others. The range of the exposure factors used in this study was within the range used in the NRPB report.

To search for the optimum exposure parameters to reduce patients dose, an anthropomorphic woman phantom was used. Chest (PA), lumbar spine (AP/LAT), abdomen (AP) and pelvis (AP) examinations were included in the phantom studies. The dose area product was measured for each exposure in each X-ray room for the selected projections. Seventy five (75) radiographs were obtained from the phantom studies in all the centres and were subjected to an objective image quality assessment. Image quality assessment form were developed based on the CEC 1996 image criteria for the selected examinations. The image quality assessment was performed by an experience radiologist. The result obtained from the image quality evaluation indicated that the radiographs obtained from the phantom studies were fully accepted and were good for medical diagnosis.

Results from the phantom studies shows that there was an overall average reduction of 49.7 % in the selected facilities for all the selected examinations. The result shows that there were no dose reduction in chest (PA) projections, but there were a significant dose reduction for the other projections at various facilities as indicated in Table 4.11.

Although there were some limitations and difficulties uncounted in the search for options to reduce patient's dose, the results obtained from this work have shown that there can be a further dose reduction in the selected facilities for the selected examinations. This work has provided a platform for radiation dose reduction and has shown that there is a scope for dose reduction in diagnostic radiology, and can be achieved with simple and low cost method without the loss of diagnostic information required for diagnosis.

In order to reduce patient's dose while maintaining diagnostic confidence of the examination, suggested dose levels (SDLs) in DAP and suggested effective dose levels (SEDLs) have been established. A technique exposure chart has also been developed for all the selected projections. This chart presents the optimum kVp and mAs range with reference dose criteria to aid optimization of patient protection. This would ensure optimal protection of patient during radiological procedures in the selected facilities.

In conclusion, there were significant average dose reduction of 49.7% for all the selected projections in all the selected facilities.

5.2 Recommendations

To hospital management

It is recommended that a good communication medium be established between referring doctors, radiologist, and the radiographer in justifying and optimizing the procedure to improve patient protection.

Hospital Authorities should acquire and develop a proper dose management system to aid in radiation dose trend analysis. This will help the radiographers to review their exposure techniques to reduce patients dose and the dose to workers.

The referral doctor should briefly describe the examination or provide the history of the requested examination or information which the radiographic examination seeks to answer. This will help the radiographer to perform the right examination to provide the exact information that is required for diagnosis on the radiograph. This will reduce examination retakes and therefore reduce radiation dose to patients.

Diagnostic medical diagnostic exposures should be controlled and excessive radiation that do not contribute to the diagnostic objective must be avoided. It is therefore recommended to the hospital administrators that there should be a proper QC and QA programmes in place with regular maintenance and regular checking of the radiation output in order to avoid excess radiation.

To the Scientific Community

There are various methods to optimize patient's dose and image quality in diagnostic radiology. In this work, reviewing exposure factors (mAs and kVp setting) and the exposure technique (proper collimation) were employed. It is recommended to the scientific and the research community that further studies be conducted in the selected facilities employing other dose reduction options to further reduce patient's dose and optimize image quality for the selected examinations.

It is also recommended that further studies be conducted to include paediatrics dose assessment since children of various ages are frequently examined. The work should be extended to other district and private hospitals and other commonly performed examinations to establish national DRLs, which are important for protection against medical exposure.

Regulatory Authority (RA)

Patient dose optimization can be achieved with proper dose management system software and a proper established standard of practice for various examinations and projections. It is therefore recommended to the RA to set a standard of practice for various radiologic examinations and make it requirement for each radiology department to develop a standard exposure protocols for each projection, with the help from the radiation protection officer, in order to avoid inter-operator variations to avoid unnecessary and excess exposure to reduce patient dose.

The RA should make it a regulatory requirement for each facility to get a qualified radiation protection officer who will do proper checks on the X-ray machines to reduce excess radiation to patients and the occupationally exposed worker. This will help reduce the occurrence of stochastic health effects to the exposed patient and the worker

The RA should enforce a proper and effective dose recording system which aid the dose trend analysis.

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APPENDIX A

IMAGE QUALITY ASSESSMENT FORM

Image Assessment Form (Chest AP/PA)

Radiograph ID

Image criteria							
Visually sharp reproduction of the trachea and proximal bronchi (CXR1)							
Visually sharp reproduction of the borders of the heart and aorta (CXR2)							
Visually sharp reproduction of the diaphragm and lateral costo-phrenic angles (CXR3)							
Reproduction of the whole rib cage (CXR4)							
Visualization of the retrocardiac lung and the mediastinum (CXR5)							
Visualization of the spine through the heart shadow(CXR6)							
Total Score Radiograph							

Scoring: 3: Clearly Seen 2: Seen 1: Seen but not clear 0: Not seen PC: Area is obscure by pathological condition

Radiograph ID

Important Image Details

Small round details in the whole lung, including the retrocardiac areas: high contrast: 0.22 mm diameter low contrast: 2 mm diameter							
Linear and reticular details out to the lung periphery: high contrast: 0.3 mm in width, low contrast: 2 mm in width							

Scoring: +: Yes -: No

Radiograph ID**Radiograph Assessment**

Appropriate film density (blackening): *							
Contrast**							
Sharpness***							
Appropriate Beam limitation****							
Film acceptability*****							
General Remark*****							

Scoring:

* Film density: 3: optimum; 2: too much; 1: too little

** Contrast: 3: optimum; 2 : too high; 1: too low

*** Sharpness: 3: optimum; 2: sub-optimum; 1: unacceptable

**** Beam limitation: 3: optimum; 2: field size too large; 1: field size too small

***** Film acceptability: 1 = fully acceptable; 2 = only acceptable under limited clinical conditions; 3 = unacceptable (give reasons)

*****General Remark: A: High quality; B: Good quality; C: Medium quality; D: Low quality; E: Poor quality; F: Film rejected

Film No	Cause of Film rejection

Image Assessment Form (Lumbar spine AP)**Radiograph ID**

Image criteria							
Visually sharp reproduction, as a single line, of the upper (LSA1)							
lower- plate surfaces in the centred beam area (including T12 and S1) (LSA2)							
Visually sharp reproduction of the pedicles (LSA3)							
Reproduction of the intervertebral joints (LSA4)							
Reproduction of the spinous and transverse processes (LSA5)							
Visually sharp reproduction of the cortex and trabecular structures (LSA6)							
Reproduction of the adjacent soft tissues, particularly the psoas shadows (LSA7)							
Total Score Radiograph							

Scoring: 3: Clearly Seen 2: Seen 1: Seen but not clear 0: Not seen PC: Area is obscure by pathological condition

Radiograph ID**Important Image Details**

0.3-0.5 mm							

Scoring: + : Yes - : No

Radiograph ID**Radiograph Assessment**

Appropriate film density (blackening): *							
Contrast**							
Sharpness***							
Appropriate Beam limitation****							
Film acceptability*****							
General Remark*****							

Scoring:

* Film density: 3: optimum; 2: too much; 1: too little

** Contrast: 3: optimum; 2 : too high; 1: too low

*** Sharpness: 3: optimum; 2: sub-optimum; 1: unacceptable

**** Beam limitation: 3: optimum; 2: field size too large; 1: field size too small

***** Film acceptability: 1 = fully acceptable; 2 = only acceptable under limited clinical conditions; 3 = unacceptable (give reasons)

*****General Remark: A: High quality; B: Good quality; C: Medium quality; D: Low quality; E: Poor quality; F: Film rejected

Film No	Cause of Film rejection

Image Assessment Form (Lumbar spine LAT)**Radiograph ID**

Image criteria							
Visualization of the upper and lower-plate surfaces with the resultant visualization of the intervertebral spaces (LSL1)							
True lateral view with straight projection of the plates of the lumbar vertebral bodies (around central ray of L3 and L4) (LSL2)							
Posterior vertebral edges are fully superimposed (LSL3)							
Spinous processes well visualized (LSL4)							
Visually sharp reproduction of the cortex and trabecular structures (LSL5)							
Total Score Radiograph							

Scoring: 3: Clearly Seen 2: Seen 1: Seen but not clear 0: Not seen PC: Area is obscure by pathological condition

Radiograph ID**Important Image Details**

0.3-0.5 mm							

Scoring: + : Yes - : No

Radiograph ID**Radiograph Assessment**

Appropriate film density (blackening): *							
Contrast**							
Sharpness***							
Appropriate Beam limitation****							
Film acceptability*****							
General Remark*****							

Scoring:

* Film density: 3: optimum; 2: too much; 1: too little

** Contrast: 3: optimum; 2 : too high; 1: too low

*** Sharpness: 3: optimum; 2: sub-optimum; 1: unacceptable

**** Beam limitation: 3: optimum; 2: field size too large; 1: field size too small

***** Film acceptability: 1 = fully acceptable; 2 = only acceptable under limited clinical conditions; 3 = unacceptable (give reasons)

*****General Remark: A: High quality; B: Good quality; C: Medium quality; D: Low quality; E: Poor quality; F: Film rejected

Film No	Cause of Film rejection

Image Assessment Form (Abdomen AP)**Radiograph ID**

Image criteria							
Both domes of the diaphragm and the entire abdomen visualized completely and symmetrically (ABD1)							
Spinal column in the midline position (ABD2)							
Upper border of the symphysis demonstrated (ABD3)							
Total Score Radiograph							

Scoring: 3: Clearly Seen 2: Seen 1: Seen but not clear 0: Not seen PC: Area is obscure by pathological condition

Radiograph ID**Important Image Details**

0.3-0.5 mm							

Scoring: + : Yes - : No

Radiograph ID**Radiograph Assessment**

Appropriate film density (blackening): *							
Contrast**							
Sharpness***							
Appropriate Beam limitation****							
Film acceptability*****							
General Remark*****							

Scoring:

* Film density: 3: optimum; 2: too much; 1: too little

** Contrast: 3: optimum; 2 : too high; 1: too low

*** Sharpness: 3: optimum; 2: sub-optimum; 1: unacceptable

**** Beam limitation: 3: optimum; 2: field size too large; 1: field size too small

***** Film acceptability: 1 = fully acceptable; 2 = only acceptable under limited clinical conditions; 3 = unacceptable (give reasons)

*****General Remark: A: High quality; B: Good quality; C: Medium quality; D: Low quality; E: Poor quality; F: Film rejected

Film No	Cause of Film rejection

Image Assessment Form (Pelvis AP)**Radiograph ID**

Image criteria							
Completely and symmetrically view of the pelvis including the hip joint, trochanters and iliac wings (PLV1)							
Visually sharp reproduction of the sacrum and its intervertebral foramina (PLV2)							
Visually sharp reproduction of the pubic and ischial rami (PLV3)							
Visually sharp reproduction of the sacroiliac joints (PLV4)							
Visually sharp reproduction of the necks of the femora which should not be distorted by foreshortening or rotation (PLV5)							
Visually sharp reproduction of the spongiosa and corticalis, and of the trochanters (PLV6)							
Total Score Radiograph							

Scoring: 3: Clearly Seen 2: Seen 1: Seen but not clear 0: Not seen PC: Area is obscure by pathological condition

Radiograph ID**Important Image Details**

0.3-0.5 mm							

Scoring: + : Yes - : No

Radiograph ID**Radiograph Assessment**

Appropriate film density (blackening): *							
Contrast**							
Sharpness***							
Appropriate Beam limitation****							
Film acceptability*****							
General Remark*****							

Scoring:

* Film density: 3: optimum; 2: too much; 1: too little

** Contrast: 3: optimum; 2 : too high; 1: too low

*** Sharpness: 3: optimum; 2: sub-optimum; 1: unacceptable

**** Beam limitation: 3: optimum; 2: field size too large; 1: field size too small

***** Film acceptability: 1 = fully acceptable; 2 = only acceptable under limited clinical conditions; 3 = unacceptable (give reasons)

*****General Remark: A: High quality; B: Good quality; C: Medium quality; D: Low quality; E: Poor quality; F: Film rejected

Film No	Cause of Film rejection