ASSESSMENT OF RADIATION DOSE REDUCTION TO PATIENTS DURING BARIUM SERIES FLUOROSCOPY PROCEDURES

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EMMANUEL RWAGATARE

(10640006)

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DECLARATION

This thesis is the result of the research work undertaken by Emmanuel Rwagatare in the Department of Radiation Protection, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Prince Kwabena Gyekye and Dr. Stephen Inkoom.

Sign  Date 09/10/2020

Emmanuel Rwagatare

(Student)

Sign  Date 09/10/2020

DR. PRINCE KWABENA GYEKYE

(Principal-supervisor)

Sign  Date 09/10/2020

DR. INKOOM STEPHEN

(Co-supervisor

ABSTRACT

The current reference dose and dose reduction techniques have been assessed during barium series procedures at the Greater Accra Regional Hospital. The study used the kerma area product (KAP) meter fitted on the collimator of the GE fluoroscopy machine to estimate entrance surface doses of patients. The study focused on 120 patients undergoing barium swallow, barium enema and barium meal procedures. This was because previous studies in this area have proposed further dose optimization in barium enema procedure in particular. The self-consistent performance of the fluoroscopy machine was checked using the Piranha and Ocean quality control kit prior to data collection. Patient demographics (such as height, weight and age) and examination parameters (such as tube voltage, screening time, number of radiographs taken and beam projection angle) were collected for the estimation of organ doses using the PCXMC, a computational Monte Carlo based program. The mean KAP readings for barium swallow, barium meal and barium enema examination were 42.01, 4.56 and 9.53 mGy.cm^2 respectively. The patient effective dose for barium swallow, barium meal and barium enema examinations were 1.55, 1.94 and 0.43 mSv respectively. The breast (4.72 mGy), stomach (3.54 mGy) and gonads (0.95 mGy) received the highest dose for barium swallow, barium meal and barium enema examinations respectively. Barium swallow was found not to be optimized when the KAP values of this study were compared with previous studies. Further analysis on barium swallow examinations revealed that number of radiographs taken and screening time influences the KAP values. Also, body mass index and KAP values influences the organ doses. Therefore, a relationship between number of radiographs taken, screening time, body mass index and KAP readings was proposed for implementation at the Hospital to enhance dose reduction. Further studies into other factors influencing patient doses is recommended to enhance patient dose optimization at the hospital.

DEDICATION

This research work is dedicated to my parents Mr. Godefroid Nyamwasa and Mrs. Apollinarie Mukagashongore, my wife Mrs. Carine Kampire and my Children Reanne Bigwi, Jayden Gisa and Jaylen Rwema, also my Big Brother Jean Pierre Irakoze and young brother Jean Claude Bigirimana, encouragements, advice and support throughout my two years' master's program.

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LIST OF ABBREVIATIONS

DRL: Diagnostic Reference Levels

ICRP: International commission on Radiological Protection

ALARA: As Low As Reasonably Achievable

LDRL: Local Diagnostic Reference Levels

KAP: Kerma Area product

DAP: Dose Area Product

IAEA: International Atomic Energy Agency

FAO: Food and Agriculture Organization

ICRU: International Commission on Radiological Units and Measurements

IDRL: International Diagnostic Reference Levels

Gy.*cm2* :gray Centimetres Squared

µGy.*m2* Micro gray Metres Squared

mGy .MilliGray

FT :Fluoroscopy Time

BaS: Barium Swallow

BaM: Barium Meal

BaFT: Barium follow through

BaE: Barium Enema

NRA: Nuclear Regulatory Authority

SNAS: School of Nuclear and Allied sciences

RAMSRI: Radiological and Medical Sciences Research Institute

GAEC: Ghana Atomic Energy Commission

AEC: automatic exposure control

ABC: automatic brightness control

ESD: Entrance Surface Dose

OSL: Optically stimulated luminescence

DNA: Deoxyribonucleic acid

Sv: sievert

Gy: gray

TLD: Thermoluminescence dosimeters

BMI: Body mass index

CHAPTER ONE

1.0 INTRODICTION

This chapter gives a summary of the background, the statement of the problem the relevance of research and objectives of the research scope and limitations of study and organization of the study.

1.1 Background

Fluoroscopy is a very useful diagnostic tool which allows the assessment of dynamic functions of the human anatomy. Also, the fluoroscopy is a type of medical imaging that shows a continuous X-ray Video or images of a patient's body. However, it is generally used for medical techniques that guide physicians on extensive diversity of diagnostic and interventional examinations. During fluoroscopy procedure, an X-ray beam passes through the body and creates image on a detector, which is then transferred to a monitor for visualizing the human anatomy. In fluoroscopy examinations, real time images (part of human body) are seen through radio-opaque or a contrast agent technology. The most diagnostic fluoroscopy processes are performed without sedation of patients, some examples of the procedures are barium enema, barium meal etc. (Mantebia, 2015). Fluoroscopy procedures gives high doses to patients, the images created appear in real-time, allowing valuation of dynamic biological processes and guiding interventions which is a unique advantage. For some fluoroscopy procedures doses delivered to patients are very high creating localized reactions of deterministic Character. Patient doses have been identified to depend examination time and total number of radiographs.

In optimization of fluoroscopy procedures in hospital must be ensured in order to reduce doses to patients and the good quality image is achieved. In general, fluoroscopy examination of the patient involves continuous exposure to radiation for sometimes long screening time and a number of images taken during the procedure. The Current fluoroscopy kit gives the user chances to modify the image quality and the radiation exposure according to the needs for the real examination.

Therefore, for paediatrics undergoing fluoroscopy procedures, it is important to optimise their dose due to their sensitivity to radiation damage and potentially stochastic health risk that may manifest in the future. Additionally, if a fluoroscopically-guided procedures may be required during pregnancy, a consent statement must be given. This is because pregnant women and developing foetus are delicate group of concern during radiation exposure, due to their high radio sensitivities [(Ad den Boer et al, 2019) and (Wambani, 2019)].

As required for all medical procedures, benefits associated with fluoroscopically-guided procedure must offset the unforeseen exposure risks to the fetus and mother. Also, optimization (i.e. establishment of investigative reference levels etc.) of doses taking into consideration the image quality in radiology should be achieved according to the principle of AS Low As Reasonably Achievable (ALARA). The principle of ALARA is sustained accepted by several national and international bodies.

Barium series in fluoroscopy are numerous types of barium X-ray examinations of the gastrointestinal tract (GI). These include barium enema, barium follow-through, barium meal and barium swallow. Also, there are two series; one called upper gastrointestinal series include barium swallow, barium meal and barium follow-through and two called a lower gastrointestinal study or series include barium enema. In barium swallow, barium meal and barium follow-through (upper gastrointestinal series) barium sulphate is mixed with water and swallowed orally and barium

enema (lower gastrointestinal series) barium contrast agent is administered as an enema through a small tube inserted into the rectum. In barium imaging using fluoroscopy, the GI tract is coated with barium and imaged using live X-ray.

1.2 Statement of the Problem

Fluoroscopy studies [(Gyasi et al, 2016), (Mantebia, 2015) and (Gyekye et al, 2009 and 2012)] conducted on patients in Ghana over the decade has indicated that apart from technology innovations of the mode of screening (pulsating or continuous) of the machine, the radiation beam on-time, and number of radiographs interest taken per patient is a major contributing factor to patient doses. Continuous patient dose optimisation during fluoroscopy procedures has been recommended by all the studies under review particular emphasis with laid on the barium series (meal, enema (Gyekye et al, 2009) and swallow). Therefore, the study focused on investigating the impact of the number of radiographs taken and beam on-time on patient doses. Additionally, continuous patient dose optimisation was evaluated.

1.3 Objectives of the Study

The objective of this study is to assess the current patient dose profile for the selected procedures and assessment into patient dose reduction techniques for dose indicators proposed by previous studies in Ghana at the Regional Hospital in Accra. Emphasis was placed on two main procedures of barium meal and enema as reported by (Gyekye et al, 2009) as having high doses and therefore require dose optimisation. This was achieved by performing the following tasks:

Reviewing some proposed dose indicators;

Perform reference patient dose assessment at selected facility;

Assess dose reduction techniques; and

Propose dose optimization techniques for clinical trial.

1.4 Scope and limitation of the Study.

The study will focus on assessing typical radiation doses of patient and collecting dose indicator factors. The fluoroscopy procedures of concern are barium series and urethrogram. Patient selection will be at random and focus on people of 5 years and over of age. Dose assessments of patients will be done using PCXMC a Monte Carlo base computer program. This study was performed on the fluoroscopy machine at the Radiology Departments of Greater Accra Regional Hospital. The hospitals were chosen based on their its high throughput of patients.

The limitations of the study are:

Patients below the age of 5 years were not considered.

Other fluoroscopy procedures outside the scope of the procedures mentioned above were not considered.

Other hospitals with fluoroscopy machines were not considered for this study.

1.5 Relevance of the Research

The importance of this work is to provide the current status of patient dose optimisation techniques or examination protocol in Ghana. The information gathered is going to inform assessment clinical studies to further reduce patient doses as recommended by International Commission on Radiological Protection, (ICRP, 2008) and other studies [(Gyasi et al, 2016), (Mantebia, 2015) and (Gyekye et al, 2009 and 2012)] in the country. The collected typical doses will be compared with proposed DRLs by (Otoo, 2018).

The study will go a long way of projecting the current status of patient dose reduction techniques for clinical application in Ghana. The result of this study will provide information to the patient, staff and the scientific community for appropriate actions and decision taken in the field of interest.

1.6 Organisation of the study.

The study has been grouped into five main areas. Chapter one discusses the background of the study, statement of the study, objectives of the research, scope of the study and relevance of the research. Chapter two discusses the literature reviewed relevant to the study . Chapter three discusses the equipment used and the methodology used to address the objectives. Chapter four discusses the results of the study. Chapter five discusses the conclusion and proposed recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The chapter delivers the relevant literature with admiration or respect to what is known for the subject of study and the gaps in knowledge that must be addressed. This section sufficiently reviews the literature of the sub-sections as presented: Medical exposure, Introduction to fluoroscopy, radiation protection, patient radiation protection, dose optimisation, optimisation procedures in fluoroscopy, radiation dose estimation, dosimetry quantities, effects of radiation exposure, Monte Carlo estimation, and discussion on other studies conducted in the area.

2.2 MEDICAL EXPOSURE

Medical exposure is exposure incurred by patients for the purposes of medical or dental diagnosis or treatment. The use of ionising radiation for medical diagnosis (e.g. fluoroscopy examinations etc.) is extensive throughout the world. The medical radiation exposure is the main source of artificial ionising radiation, (UNSCEAR, 2000). In diagnosis, radiation is limited to an anatomical region of interest. The individual is only exposed to radiation if it is of direct benefit. Also, no patient shall be administered a therapeutic or diagnostic unless the exposure is approved by a Doctor, (IAEA, 2014). Maintaining the exposure of patients to the lowest possible is necessary to achieving the essential diagnostic or interventional objective. Therefore, optimisation is very important if we are to reduce dose to the patients, (IAEA, 2014).

The approach of radiological protection aims to control radiation risks without unreasonably limiting the possible benefits for individuals. The International Radiation Basic Safety Standards translates medical exposure to be exposure obtain by patients due to their personal medical diagnosis or treatment, (IAEA, 2014).

The medical exposure field over the years has profited extremely from the use of X-ray radiation with numerous new developments associated with diagnosis and therapy. The growth of high X-ray attenuating contrast media has ensued in diagnostic and therapeutic minimally invasive radiology. Dose constraints should only be used in medical exposure for optimising the protection of persons exposed in bio-medical research purposes or of persons other than workers who assistance in the care support or wellbeing of exposed patients. There is no request of radiation dose limits as it may limit the advantage of the application of radiation to the patient, (IAEA, 1996).

In justification, risks of available alternative techniques that does not involve radiation exposure must be considered. Medical exposure varies from occupational and public exposure in that persons (primarily patients) are purposely, directly and knowingly exposed to radiation for their benefit. In medical exposure, the benefits must offset the associated risks of the procedure.

Additionally, the equipment design considerations, safety requirement for radiation sources operational considerations and proper calibration of equipment, clinical dosimetry and quality assurance should be considered in order to achieve optimisation of medical exposure, (IAEA, 2014).

2.3 INTRODUCTION TO FLUOROSCOPY

Fluoroscopy is special X-ray imaging technique commonly used by radiologist and at times radiographers to obtain real time moving images of the internal structures of a patient. It is generally used for medical techniques that guide physicians on extensive variety of diagnostic and interventional examinations. The procedure is such that continuous X-ray beam passes through the body part existence examined and creates an image on a detector, which is then transmitted to television-like monitor for visualising the human anatomy. It is used not only by radiologists but similarly by an increasing number of clinicians, for example in interventional radiology. The interventional fluoroscopy technique enables real time images (part of human body) to be seen a screen through radio-opaque or a contrast agent technology, (Chehab et al, 2015). Fluoroscopy is similar to X-ray radiography in that it creates images using X-rays and difference is that radiography provides fixed still images on films whereas fluoroscopy provides real time images that can be stored. Most fluoroscopy diagnostic procedures are performed without sedation of patients, (Heidbuchel et al, 2014).

Basically, fluoroscopy consists of an x-ray source and fluorescent screen between which a patient is placed as shown in Figure 1. The fluorescent screen is attached to an electronic system that transforms and amplifies the glowing light into a video signal applicable for presentation on an electronic monitor. This is an improvement in the earlier version of fluoroscopy requiring the radiologist to stand in the direction of primary beam. Therefore, enabling optimisation options for at risk persons (peadiatrics, pregnant female patients and developing foetus). Fluoroscopy unit may have high, standard, and low dose modes. The high dose mode can deliver double the dose rate of standard mode , [(Ad den Boer et al, 2019) and (Wambani et al, 2019)].

The fluoroscopy may be performed to assess precise areas of the body alone as a diagnostic process or may be used in conjunction with other therapeutic media or diagnostic procedures. For example, barium series X-rays, where fluoroscopy is used alone to permit the radiologist or radiographers to see the movement of the organs example: stomach or intestines as the barium moves through them and allows the radiologist or radiographers to position the patient for spot imaging, (Golikov et al, 2007).

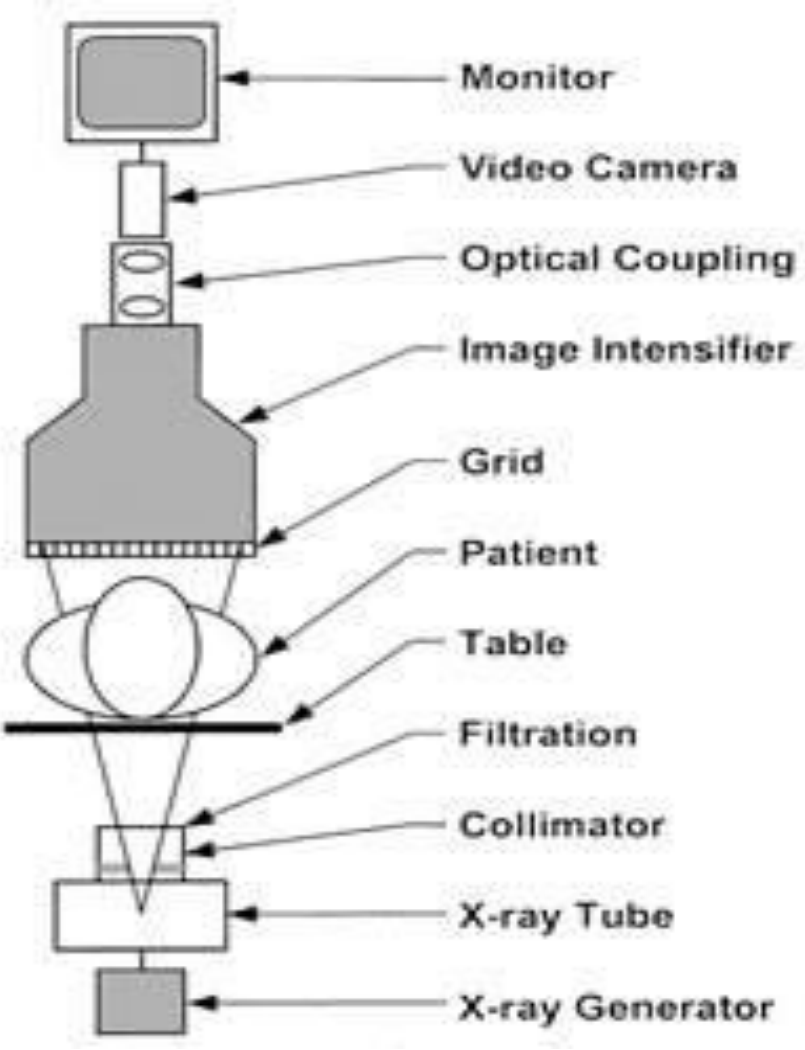


Figure 2.1: Schematic diagram of a fluoroscopic system using an X-ray image intensifier (XRII) and video camera.

2.3.1 Types of Barium Series in fluoroscopy

There are barium swallow, barium meal, barium follow-through, and barium enema are the barium series procedures under fluoroscopy. The barium swallow is a dedicated examination of the pharyns, esophagus and proximal stomach, may be performed as a double contrast study or single contrast study. The clinical symptoms are generally swallowing painful, difficulty with swallowing, abdominal pain, blood stained vomit and the clinical indications are alike to that of barium swallow but aims to look for problems in the stomach and duodenum such as ulcers, polyps and tumours. A barium meal is examination of the stomach using barium to coat the walls of the upper digestive tract so that it may be examined under X-ray and it shows the stomach and duodenum in double contrast techniques. A barium follow through is a single contrast study (oral contrast), and is similar to a barium meal but aims to look for problems in the small intestine, (Boland et al, 2013) and (Gyekye et al, 2009).

A barium enema implicates filling the large intestine with diluted barium liquid through the rectum while x-ray images are existence taken and a barium enema is used to look for problems in the colon (large bowel or intestine), such as polyps, inflammation (colitis), narrowing of the colon and tumours. Infusion of 500 to 1000 mL of barium sulphate suspension, depending on the patient, into the intestine is done through a duodenal tube. A barium series procedure will be examined by a consultant radiologist or radiographer and their findings will be sent to the referring doctor who will be able to assess the information, (Gyekye et al, 2009) and Horton et al, 1992).

2.4 RADIATION PROTECTION

Radiation protection aim is to protect people from the injurious effects of ionising radiation whiles allowing the benefit use to continue. The radiation protection is to control radiation risks without excessively limiting the possible benefits for individuals and society. Radiation dose measurement in diagnostic fluoroscopy is deliberated to be a critical factor for optimising radiation protection to the health care practitioners and the patient during barium series procedures. In fluoroscopy, personnel need training not only in occupational radiation protection, but also in patient radiation protection as the latter can impact occupational exposure. The fluoroscopy beam-on time is one of the primary factors that can be controlled to reduce patient doses (Gyekye et al, 2009). The minimisation of fluoroscopy examination time has demonstrated to be one of the most effective ways of reducing radiation dose to the patient during fluoroscopy examination. The radiation protection principle of As Low As Reasonably Achievable (ALARA) should guide decisions during fluoroscopy examination guided procedures. The fluoroscopy examination positioning of patient as far as possible from the X-ray tube and as near as possible to the image receptor reduces patient skin dose and improves image quality. The radiation protection key concepts are time, distance, and shielding and radiation protection in medical uses of radiation take place in a variety of settings, including hospitals, medical centres, health clinics, specialist clinics, and dental practices, (Gyekye et al, 2009) and (ICRP, 2008).

In justification, the benefits of using radiation must outweigh its consequences that may occur due to radiation exposure. Practices involving radiation exposure or potential must be considered when radiation detriment and the cost of practice have been included in the process of choice. There are practices that are not justified due to lack of sufficient benefits to offset its detriment, these

practices include deliberate addition of radioactive substances to food, beverages, cosmetics and products intended for ingestion or inhalation. The optimisation of protection and safety, when applied to the exposure of workers and of members of the public, and of carers and comforters of patients undergoing radiological procedures, is a procedure for ensuring that the magnitude of exposures and the number of persons exposed are as low as reasonably achievable.

The main aim is to ensure that the magnitude of individuals doses, the number of persons exposed and the probability of incurring exposure where they are not certain to occur are kept as low as reasonable achievable(ALARA), (IAEA, 1996) and distance, time and shielding are the major operator techniques that are employer wisely to achieve low doses, (Brown, 2008). However, diagnostic reference levels (DRL) are applicable for patient dose optimisation. The dose limits are used to guide the prevention of deterministic health effect and reduce the probability of stochastic effects for those occupationally exposed and members of the public due to exposures from authorized practices. Dose limits do not apply to medical exposures, exposures from natural sources, potential exposure and interventional, (IAEA, 1996). There are some areas of medical uses of ionising radiation, such as image guided interventional procedures, where, if good radiation protection practice is not being followed, there is a possibility of exceeding DRL. Dose limit is very important in radiation protection, because this serves as guidance for proper practices to reduce stochastic effect. However, diagnostic reference levels are not considered to be dose limits. Therefore, it is possible to exceed DRLs depending on clinical demands, (ICRP, 2008) and (IAEA, 1996).

2.5 PATIENT RADIATION PROTECTION

Radiation protection of patients is a necessary element of good medical practice. Dose limits do not apply to patients because the priority is always the clinical benefit, and radiation is only an 'instrument' to diagnose or to guide the procedure. Radiation protection reduce unnecessary exposure of patients is paramount by executing a radiation protection programme and committed activities and the programme should be oriented at the source and operational activities. Appropriate trained medical personnel, recurrent servicing of radiation equipment, and well documented working procedures are some of the ways of protecting the patient, (ICRP, 2006).

In fluoroscopy the use of shielding for patients can be effective but for processes performed in operational theatres the practicability of using patient shielding is a practical problem and it used shielding for protection of the patient's radio-sensitive organs, such as the breast, gonads, eyes and thyroid. The operator has responsibility to be well knowledgeable of dose levels in instruction to consider the risks or benefits of continuing a procedure. To augment patient protection, it is obligation that operator considers the doses to be incurred when choosing exposure parameters. The protection of the patient in medical exposure is not to give the lowest dose, but to deliver a dose to the patient that is equal with the intended medical purpose; meaning radiological medical practitioner must give the true dose to a patient for diagnose, (ICRP, 2006).

2.6 DOSE OPTIMISATION

In fluoroscopy, the dose optimisation is very important from the time when the process could lead to comparatively high absorbed doses in patients resulting in critical radiation harm, (Brown et al,

2000). During barium series procedure, the dose to patients are to be optimised to keep the exposure to the minimum essential to achieve the compulsory diagnostic or interventional objective. In dose optimisations using distance, time and shielding are the major operator techniques that are employed wisely to achieve low doses taking in to account economic and social factors. Proper of the patient positioning with admiration to detector and image quality of X-ray tube is of fundamental significance and radiation dose to the patient and good contrast resolution have provided the opportunity for enhanced optimisation with admiration to absorbed dose and image quality. At least there are two dose modes available: firstly is low dose mode, secondly high dose mode and in the most examination enough image quality is obtained using the low-dose mode, (Smiddy et al, 1996) and ((Brown et al, 2008) it is better to start fluoroscopy in low dose mode and if necessary switching off to a higher dose mode.

The fundamental safety principles, (IAEA, 2006) and the international basic safety standards for protection against ionising radiation (BSS) issued by the International Atomic Energy Agency (IAEA) necessary the radiation protection of patients undergoing medical exposures to go through justification and optimization of the procedures and distances, time and shielding are the major operator techniques that are employed wisely to achieve low dose. The aim of optimisation is to make sure that the greatness of individuals doses, the number of people exposed and the probability of incurring exposure where they are not certain to happen are kept As Low As Reasonably Achievable (ALARA), (IAEA, 1996).

The radiologist or radiographers using fluoroscopic machine can also have an effect on the radiation exposure of the patient as many inconstant associated with the procedure are controlled by the radiologist or radiographer and variables are selection of tube voltage (KV) values, field of

outlook, fluoroscopic time, use of limitation beam, and the use of particular imaging modes, (Ad den Boer et al, 2019). Hence, effective dose optimisation will require a collective effort of the radiographer, physicist and the radiologist.

2.7 OPTIMISATION PROCEDURES IN FLUOROSCOPY

During fluoroscopy examination, optimisation procedures is important from the time when the technique could lead to comparatively high absorbed doses both in patients and personnel. Optimisation procedures for fluoroscopy examination are as follows: reduction in fluoroscopy beam on-time, number of images, field size; usage of appropriate radiation entrance angle; operational consideration of patient size in parameters selection; minimisation of the use of continuous x-ray beam; and the consistent performance of x-ray machine. Also, automatic exposure control (AEC) should be activated to ensure automatic amendment of tube voltage and present to accommodate the varying attenuation of the patient, (Ad den Boer et al, 2019). During fluoroscopy examination, the patient table moves the patient to change the position of the examination e.g. in upright and horizontal position.

2.8 RADIATION DOSE ESTIMATION

The radiation dose estimation called dosimetry is the procedure of relating the administered quantity of radiation absorbed to organs, cancers or the whole body. The radiation dose estimation is used to record the radiation doses, which is the absorbed radiation energy amount in grays (Gy) or the equivalent dose amount in Sieverts (Sv), (ICRP, 2006). The operator evaluates the radiation

dose data all through the procedure of the process. The dosimetry is important for dose correlation with clinical results, and in some examples, for planning to avoid unnecessary exposure. The dosimetry system delivers individual dose estimates based on data regarding their exposure parameters, (ICRP, 2007).

2.8.1 Types of radiation dose estimation

There are two types of radiation dose estimation i.e. physical estimates of dose and biological estimates dose.

2.8.1.1 Physical Estimation Dosimetry Readings

Obtainability of readings personal dosimetry delivers the best amount of cumulative exposure, whole body exposure assuming from an external source. Borders of personal dosimeter identified are related to:

- Awareness of potential exposure and proper wearing of the device;
- The device type i.e. film badges, thermoluminescent or optical badges must be analysed in a laboratory, delaying the availability of results. However, immediate results can be obtained from electronic personal dosimeters;
- Incomplete body exposures due to proximity to the source (handling a source, for example, must result in a localised exposure), or shielding;
- Exposure from internal contamination is not successfully measured by personal dosimetry; and

- Does not account for biological differences in predisposition to the DNA damaging effect of radiation, which is the fundamental cause of the resulting morbidity and heightened cancer risk, (IAEA, 2001).

2.8.1.2 Biological Dosimetry Clinical Symptoms and Signs

Even as the signs and symptoms of radiation exposure are non-specific, the timing, severity and pattern characterise the dose received. The key disadvantage of biological dosimetry is the time necessary for symptoms and signs to grow. The total body exposures irradiation, the probable severity and timing of the manifest disease can be anticipated, particularly from the time of arrival of nausea and vomiting. Arrival of vomiting less than 4 hours after exposure is regular with evolution to haematopoietic syndrome. Onset of vomiting within 1 hour is characteristic of fatal exposures. Additional causes of vomiting, e.g. psychogenic, need to be excluded, (WHO, 2007).

2.8.2 Direct dose estimation

Direct dose estimation measures absorbed dose in the center of field at the surface of entrance of radiation to patient undergoing a diagnostic x-ray examination counting the backscatter factor. It is referred to as Entrance Surface Dose (ESD), it has been well established using different procedures, (IAEA, 2007) and (Compagnone et al, 2005). The most common technique in practice is to directly quantity the ESD on patient or whole-body anthropomorphic phantom using thermo luminescence dosimeters, (Jibiri et al, 2016) and (Sharma et al, 2013). The human health risks estimates are derived by identifying a large group of individuals having common exposure profile within each stratum and following the group over a long period of time, (Mamoru et al, 2017).

Approximations of the organ doses can be obtained using a Rando-Alderson anthropomorphic tissue equivalent phantom, (Kramer et al, 2008).

The direct dose estimation has been at the need and prospective for injurious outcomes as a result of radiation exposure during diagnostic evaluations and interventional techniques. Direct dosimetry of organs involves using lithium fluoride thermoluminescence dosimeters (TLD) inserted into a phantom material at specific locations to measure relative organ dose in a manner consistent with the literature standards, (Huda et al, 1984) and (Scalzetti et al, 2008).

2.8.3 Indirect dose estimation

The indirect dose estimation embroils using mathematical tools for dosimetry, [(Kramer et al, 2008), (Compagnone et al, 2005), (Ofori et al, 2014) and (Taha et al, 2015)]. Kerma-Area-Product (KAP) meters are large-area transmission ionisation chamber and associated electronics is one of the many ways indirect dosimetry can be estimated. In the use of the ionisation chamber, it is placed perpendicular to the beam central axis, (IAEA, 2007). Nano Dot optically stimulated luminescence (OSL) dosimetry are used for entry surface dose (ESD) dimensions in common X-ray diagnostics in free air without backscatter material (i.e. patient) in the primary beam of the radiation, (IAEA, 2007).

2.9 DOSIMETRY QUANTITIES

The International commission or radiation units and measurement (ICRU) has been reviewing radiation dose quantities since 1952. ICRU aim is to develop international accepted dose quantities and units of radiation and radioactivity to assure uniformity in reporting all over the world, (Bhatia,

et al, 1971). The dosimetric quantities developed by the ICRU of interest for this research are air kerma, absorbed dose, equivalent dose and effective dose.

2.9.1 Absorbed dose

This is the amount of ionizing radiation energy absorbed per unit mass, (Brown et al, 2008). Thus, it is used to express the concentration of radiation energy absorbed in a specific tissue, (Sprawls, 2000). The dosimetric quantity is also physical quantity and hence can be measured, (IAEA, 2006).

Dose= d $\bar{E}$ /dm

$\bar{E}$ is mean energy imparted by ionising radiation to matter of mass dm.

2.9.2 Equivalent dose

This is the sum of the dose (Gy) in a tissue or organ due to different types of radiation, each weighted by the corresponding radiation weighting factors since not all radiations are alike, (Bhatia et al, 1971). It was realised that for absorbed dose, different types of radiation may have significantly different level of radiation damage. Equivalent dose is given the symbol HT. Initially, quality factor was used to compensate for the difference in radiation damage by different radiation types but was not appropriate and therefore the introduction of the radiation weighting factor , (IAEA, 2006)) and (Gyekye et al, 2009). The mathematical formular for equivalent dose is:

$$H_T = \sum_R W_R D_{(T,R)} \quad (1)$$

Where:

HT is equivalent dose in a tissue or organ, T.

$D_{T.R}$ is the absorbed dose averaged over the tissue or organ, T, due to the incident radiation, R.

W_R is the radiation weighting factor.

2.9.3 Effective dose

This is the sum of the doses to body due to different radiosensitivity of organs or tissue, each weighted by their corresponding tissue weighting factors, (IAEA, 2006). The effective dose is the absorbed dose to the whole body. This is because different body parts have different sensitivities to radiation exposure, (IAEA, 2006). Tissue weighting factors (WT) recommended by (ICRP, 2007) give a correct whole body absorbed dose representation. The mathematical formular for effective dose is:

$$E = W_T H_T \quad (2)$$

Where:

H_T is equivalent dose in a tissue or organ, T; and

W_T is the tissue weighting factor of the tissue or organ.

2.10 EFFECTS OF RADIATION EXPOSURE

The effects of radiation exposure, radiation harm to tissue and/or organs depends on the dose of radiation received, or the absorbed dose which is expressed in a unit called the gray (Gy). The sievert (Sv) is the unit of effective dose that takes into account the type of radiation and sensitivity of tissues and organs. Ionising radiation has sufficient energy to affect the atoms in living cells and thereby damage their genetic material (i.e. DNA). There are two main types of radiation health effects i.e. deterministic (using threshold dose) and stochastic (no threshold dose) health effects. The ionising radiation, we are usually exposed to around us comes from nature, (ICRP, 2006).

The ionising radiation used in medicine, industry and research carries huge benefits to people when it is used safely. Radiation protection is practical to concepts, requirements and operations related to protection of people, for example: members of the public, radiation workers and patients against the harmful effects of ionising radiation, also is primarily worried with reduction of against radiation induced cancer and hereditary diseases, and prevention of deterministic effects, (ICRP, 2006).

2.10.1 Stochastic Effects

This effect may occur by chance when exposed to ionising radiation, generally occur without a threshold level of dose. The occurrence likelihood of stochastic effects is proportionate to the dose but the severity of the effect is autonomous of the dose received. The probability of cancer induction is dose dependent but the severity and hereditary effects occurring over a long time scale, (ICRP, 2006). The biological effects of stochastic health effects can be grouped into somatic effects (effects shown by the exposed person) and genetic effects (effects shown by the descendants of the individual exposed), (ICRP, 2006).

Low radiation dose to organs may result in modification of organs that can affect the usual functioning of tissues and organs. The modified daughter cells may cause cancer to the organ or tissue of the exposed individual. A latent period is seen between the time of exposure and the events to manifest, (UNSCEAR, 2000).

2.10.2 Deterministic Effects

Deterministic effects or non-stochastic health effects, tissue reaction may occur when the dose limits recommended in the protection systems is exceeded and in accident situations involving

radiation exposure. A threshold dose is applicable above which damage to the body and impairment of integrity of tissue and organs is observed, (ICRP, 2006). If the radiation exposure is above a threshold, there is a clinically observable damage to organs and tissues and the impairment of the integrity and functions of organs and tissues. Interaction of radiation with individuals that delivers high dose may cause death of cells. (ICRP, 2006)

2.11 MONTE CARLO BASE PROGRAMME PCXMC

PCXMC is a computer-based Monte Carlo program developed by the Finnish Radiation and Nuclear Safety Authority (STUK) for estimating patient organ doses in medical diagnostic x-ray examinations. The calculation of the x-ray conveyance is based on random mathematical simulation of the photon's interaction between and matter. Photons are emitted from an isotropic point source into an angle (determined by the main distance and the x-ray field sizes) for interaction with the phantom. The interaction process is based on the probability distributions of the physical processes (i.e. photo electric absorption, coherent (Rayleigh) scattering or incoherent (Compton) scattering). Other interactions occurring above 150 keV are not considered by PCXMC (Tapiovaara et al, 1997).

In soft tissues, electrons travel only a fraction of a millimeter and the energy of the scatter electrons is assumed to be absorbed at the photon interaction site (except for the dose estimations in bone marrow dose). A collection of individual photon histories generated are used to estimate the mean energy deposition in the various organs of the phantom (Tapiovaara et al, 1997). The energy deposition to organs at any interaction site is estimated and stockpiled. The photon sampling

direction, the interaction distance, type of atom, interaction and scattering angle are generated by multi-plicative linear congruential generator (Vattulainen et al, 1993). Each photon is followed until the following happens: it exits the phantom, its energy falls to less than 2 Kev and its weight reduces to less than 0.003. Russian roulette is used for the termination of the photon. It is terminated by a probability 0.75 and multiplied by a factor of four is it survives (Tapiovaara et al, 1997). Strom et al. 1970 generated cross sections for the photo-electric, coherent scattering and incoherent scattering were used. Hubbel at al. 1975 generated atomic form factors and incoherent scattering functions were used as well. The location of bone marrow in small cavities in trabecular has been taken into account in the estimation of doses (Tapiovaara et al, 1997). Therefore, the estimation of kerma is done in both the skeleton, active bone marrow and other skeletal materials by applying the method of Rosenstein (1976a) and (1976b) (i.e. dividing the absorbed energy in the whole skeleton into two parts). The increase in absorbed energy the active bone marrow resulted in equal quantity for reduction in other skeletal (Tapiovaara et al, 1997).

The PCXMC program can compute patient organ doses of patient of different ages and sizes in a freely adjustable radiography and fluoroscopy projections. PCXMC calculates the organ doses for monochromatic photons of 10, 20 up to 150 KeV energy in ten different consignments of each energy value. Another module in the progamme calculates the doses and their statistical errors for a practical X-ray spectrum of interest. The organs doses estimated PCXMC are in relation to the incident air kerma (Tapiovaara et al, 1997). Birch et al 1979 theory is used to calculate the X-ray spectra. The spectra are generated in terms of the tube voltage, the tungsten target and filtration of the x-ray tube. The conversion coefficients of the of International Commission in Radiological Units, (ICRU, 1992b) is used to calculate the air Kerma from photon fluence. Additionally, the

simulations time is dependent on the specifications of the computer and the set precision target (Tapiovaara et al, 1997).

2.11.1 Mathematical Phantoms

The human anatomy was represented by mathematical phantoms (Kramer et al, 1982; Cristy et al, 1987; Lee et al, 2006a and Schlattl et al, 2007) in the PCXMC simulations. Mathematical expressions derived from voxel-phantoms (CT and MR images) and computational models (Tapiovaara et al, 1997) were used for the phantoms. Mathematical hermaphrodite phantoms were developed for patients of different ages (i.e. new born, 1, 5, 10, to 15-year old and adult patients). The phantoms consist of mathematical expressions representing numerous organs and body (Tapiovaara et al, 1997).

The number of elements in National Radiological Protection Board (NRPB) phantoms (Jones et al, 1985) has been reduced by combining Na, Mg, P, S and Cl elements and treating them as phosphorus. Also, the atomic numbers of K or higher have been combined and treated as Calcium (Tapiovaara et al, 1997).

PCXMC used Cristys phantom models as the base for following changes in order to simulate the condition of X-ray examination better:

a. In order to estimate effective dose, the dimensions and location of the oesophagus in Zankl phantom was modelled (Zankl et al, 1992);

b. Christy phantom has no jaws so the frontal half of the neck of the phantom was modified (Kramer et al, 1982);

c. The breast material was represented as 50:50 mixtures of water and fat (Tapiovaara et al, 1997);

d. The height and mass of the phantom was modelled to vary (Tapiovaara et al, 1997).

2.12 OTHER STUDIES CONDUCTED

Generally, factors affecting patient doses for fluoroscopy examinations could be attributed to the varying radiological technique, the screening time and the number of images taken during the procedure. Radiographers and radiologists have been encouraged to use optimised technique factors to strengthen the protection of patients by minimising the screening time used and also minimising the number of images taken during a fluoroscopy procedure. Other fluoroscopy studies conducted on patients in Ghana, [(Gyekye et al, 2009, 2012) , (Gyasi et al, 2016) and (Mantebia, 2015)] over the decade has indicated that patient doses highly depend on the mode of screening (pulsating or continuous) or protocol of the procedure used ,(Gyekye et al, 2012); the experience of the operator of the fluoroscopy machine ,(Gyekye et al, 2012) the radiation beam on-time and number of radiographs of interest taken, [(Gyekye et al, 2009, 2012) and (Gyasi et al, 2016)] and the vulnerability of young adults to radiation exposure, (Mantebia, 2015).The barium swallow, barium meal barium enema, and urethrogram as considered in this study were investigated the decade studies in the country. Although some of the studies used different dosimetry approach i.e. free-in-air, thermos luminescence dosimeter and kerma area product meter. The objective of the

studies has generally focused on estimation of patient doses (dose-area product, organ dose, effective dose and entrance surface dose), (Gyekye et al, 2009).

The different fluoroscopy study examination categories were analysed, kerma-area product was resolute using a transmission ionization chamber. Organ dose and effective dose were assessed using knowledge of the examination and a Monte Carlo computer based programme, PCXMC, (Tapiovaara et al, 1997). For all the studies, the contribution of fluoroscopy to the total dose was greater than that from radiography. Kerma-area product from barium enema and meal procedures was higher than that obtained for other fluoroscopy procedures. A general recommendation identified was the need to consistently optimise the patient doses to strengthen their radiological protection, (Gyekye et al, 2009; Gyasi et al, 2016 and Otoo. 2018).

CHAPTER THREE

3.0 Materials and Methods

This chapter outlines the materials and the method used for the study.

3.1 Materials

This study was performed on the fluoroscopy equipment at the Radiology Department of Greater Accra Regional Hospital. The materials used for the study are the General Electric (GE) fluoroscopy system, Kerma Area Product (KAP) meter, PCXMC a Monte Carlo based program, weighing scale and measuring tape. Details of the equipment specifications and literature are provided below.

3.1.1 Medical system fluoroscopy machine at the Study Site

This is a GE Medical Systems fluoroscopy (serial number: 1603990 and IEC No.: 60522/1999) unit with a beam limiting device (serial number: R 302/A DHHS, and model: R 302 MLPI/A DHHS), a minimum inherent filtration of 1 mm Al/75, an over couch x-ray tube and under couch image intensifier connected to a monitor. The fluoroscopy system is powered by a generator manufactured in May 2016 in Italy (serial number: AM19646C16; and model number: VZW2930FD2-28). It has an alternating current (AC) volt of 400V, current of 155 amps, frequency of 50/60 Hz and a three-phase operating power. The X-ray rating is up to 150 kVp and direct current volts of 24 V/DC.

Fluoroscopy is special X-ray imaging technique commonly used by radiologist and at times radiographers to obtain real time moving images of the internal structures of a patient. The procedure is such that continuous X-ray beam passes through the body part being examined and creates an image on a detector, which is then transmitted to television-like monitor for visualising the human anatomy.

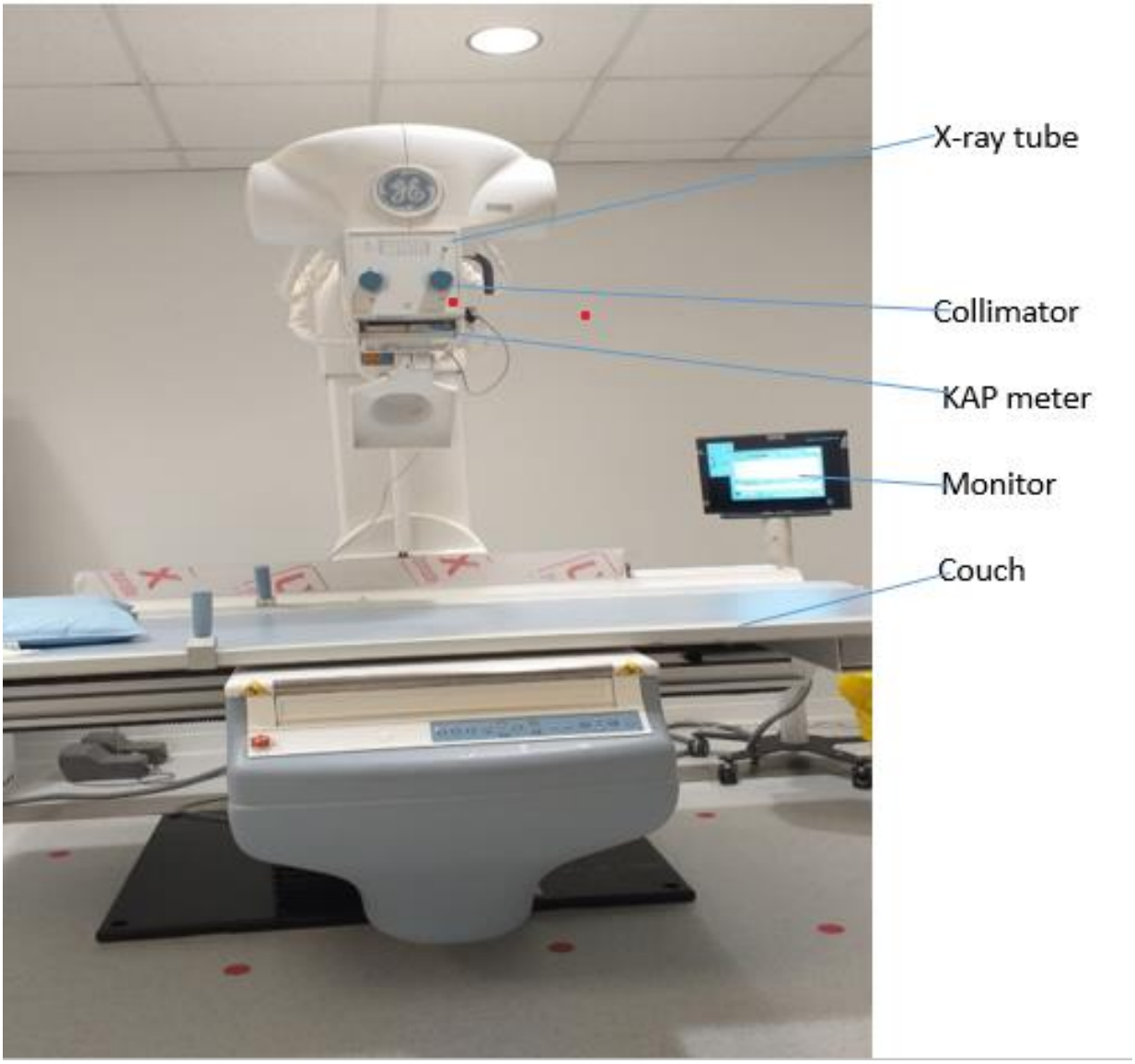


Figure 3.1: GE Fluoroscopy Machine at Greater Accra Regional Hospital

3.1.2 Kerma Area Product (KAP) Meter

The KAP meter collects patient entrance doses, as a function of photon energy at the Hospital. KAP meter measures using a transparent ionisation chamber mounted in the X-ray tube assembly between the collimators and the patient. The KAP-meter has been calibrated at well-defined radiation qualities. The calibrated KAP meter, KERMA X-plus iba dosimeter (serial number: 01A04042 and model: 120-131 HS) with aluminum holder, voltage: 15- 20 V and current: 80 mA connected to a display monitor (model: 120-210 and serial number: 01E004774) was used for the study.

KAP meter is a dosimetric quantity that can be directly related to the patient dose and used for risk assessment associated with different x-ray examinations.

Figure 3.2 KERMA X-plus iba dosimeter (KAP meter)

3.1.3 PCXMC

PCXMC is Monte Carlo computer-based program used for the estimation of patient organ and effective doses in medical x-ray examinations of fluoroscopy or radiography. It allows a free modification of the x-ray projection, beam size, patient mass and height. The programme estimates the patient doses using mathematical phantoms and the recommendations of ICRP publication 60 and 103. The user is required to make all the necessary inputs to provide the desired output. Figure 3.3 illustrates the interface of the PCXMC that provides for patient information and examination data input. In summary, the following steps were followed: 1. Defining the examination conditions; 2. Performing the Monte Carlo simulation; and 3. Calculation the organ doses for a specified x-ray spectrum and patient input dose.

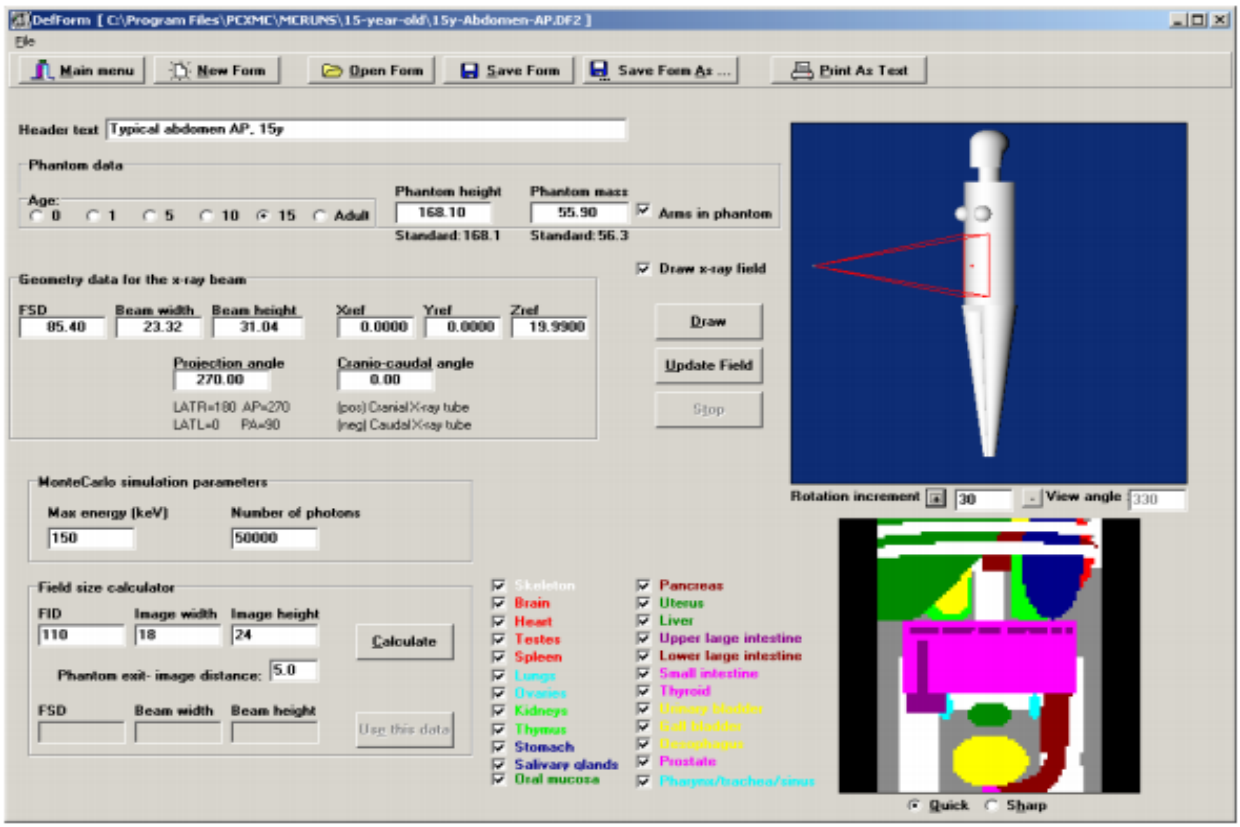


Figure.3.3: Examination Data and Patients Information input interface of the Monte Carlo Code (PCXMC)

3.1.4Weighing Scale

A weighing scale is an assessing instrument used for determination the weight of person or mass and it is among commonly used device by nurses, doctors and other healthcare. The scales are used medically the body weight to measure of human beings or patients for control purposes. Monitoring patient weight is an important part of patient care which among other things provides an indication of improvement or worsening condition. This scale features a rotating dial which indicates the weight. The simplicity and durability over a long time has been the biggest advantage of this machine and the main reason to be used in places where the device is continuously moved. The range of measurement is from 0 to 130 kg. The simple scale is cost effective and portable, it provides the patient the opportunity to step on it standing upright to provide measurements.

Figure 3.4: Weighing Scale

3.1.5 Measuring Tape

The measuring tape is used to measure distances in all directions. This type of measuring tape is made up of metal and flexible i.e. can be maneuvered to measure curves, it starts from 0 to 1.8m. The height measurement is used to measure the height of patients from their head to toe with the patient standing upright. Height measurement is an essential component of the assessment of the critically from head to foot for patient. The flexible measuring tape provides a means of assessing patients' body mass index for the assessment of well-being of the patient. However, accurate height is not easy to measure in the critical disease patient care setting.

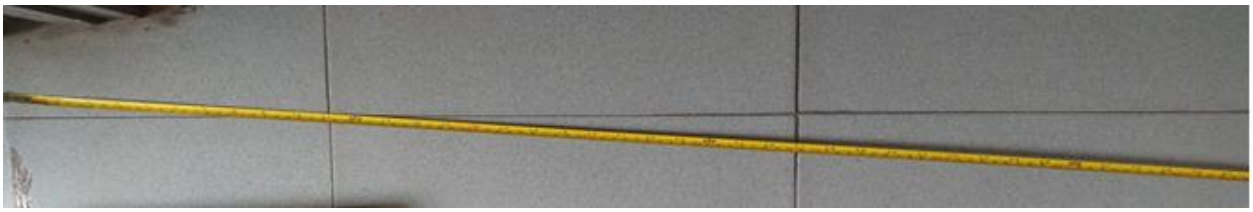


Figure 3.5: Portable Measuring Tape

3.1.6 Piranha Quality Control Kit and Ocean Software

This is a fast and easy x-ray quality control kit. The quality control kit Piranha is used together with the Ocean software was installed on a computer for your daily quality control test. Ocean can perform analysis immediate real-time during your measurements. Also, ocean when the work is done prepares a report in the background as you go. A tablet/laptop is used as both an interactive show during the measurements. . The Piranha can be used for the full complement of quality control test on fluoroscopy equipment.

3.2.0 METHODOLOGY

3.2.1 Study Location

The study focused on the fluoroscopy room at the Radiology Departments of Greater Accra Regional Hospital located on the castle road in the Accra. Figure 3.7 provides the google view of the hospital.

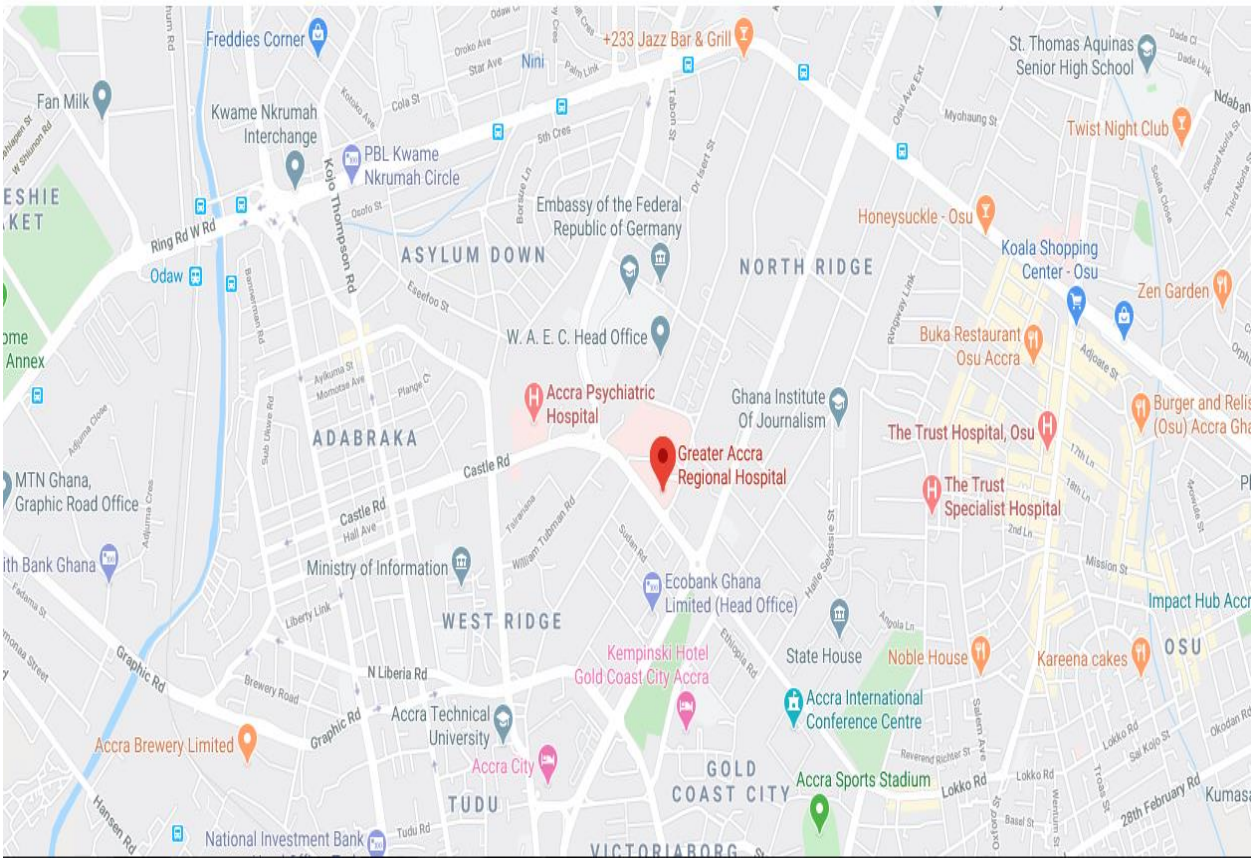


Figure 3.6: Location of Greater Accra Regional Hospital

3.2.2 Ethical Clearance

Ethical clearance was sort from the Accra Metropolitan Assembly and the Hospitals research ethical committee as shown in Appendix I. Patient confidentiality was ensured by using codes to

identify one patient from the other instead of their names. Therefore, the collected patient information (e.g. dose, age height etc.) cannot be related to a particular patient. It was also ensured that the collection of the data does not worsen the medial condition of the patient i.e. medical situation of the patient was of first priority before the research. A patient consent form was used to establish the agreement of the patient to partake in the research to aid improve the procedures at hospital.

3.2.3 Quality Control Measurement

Quality Control measurements were performed to ensure that the x-ray equipment was consistent in its performance. The procedures used have been described below.

3.2.3.1 Current-time Product (mAs) Linearity Test

The linearity of the current-time product of the fluoroscopy machine was checked placing the multiple purpose detector (MPD) on the patient couch with a distance of 100 cm from the focal spot of the x-ray tube. The MPD is then connected to the Ocean software on a laptop. The MPD is positioned at the center of the beam and the beam is collimated to the sensitive region. Selection of fixed tube voltages 120, 100, 80 and 60 kVp were chosen varying the current-time on 32, 16, 8, 4 for each of the voltages. The MPD measures the radiation output for each of the settings of varying mAs on fixed voltage for computation by the Ocean software. The Ocean software computes the current-time linearity by dividing the radiation output by its corresponding mAs. The results of the division for a fixed voltage is checked for linearity by using the formula i.e. $(Max - Min)/(Max + Min)$. The results of the linearity are checked for compliance using the acceptance criteria of linearity ≤ 0.1.

3.2.3.2 Half Value Layer

Using the same MPD arrangements in Section 2.2.1, the half value layer (HVL) of the fluoroscopy machine was estimated for 120, 100 and 80 kVp. A fixed mAs of 16 was selected for the exposures. The MPD was used to measure the radiation output for each of the settings for computation. The first measured radiation is when there is no thickness of aluminium sheet introduced in between the focal spot and the MPD. On the same exposure settings, aluminum sheets are introduced for each exposure until the output is reduced to half the initial output. A graph of aluminum thickness against the radiation output is drawn for estimation of the half value layer. The same procedure was repeated for 120, 100 and 80 kVp. The HVL was checked for compliance using the Nuclear Regulatory Authority's acceptable criteria at the various voltages.

3.2.3.3 Tube Potential Accuracy Measurement

Maintaining the same MPD arrangements in section 2.2.1, the tube voltage accuracy of the fluoroscopy machine was checked. The accuracies of tube voltages of 120, 100, 80 and 60 kVp were checked. The MPD was used to measure the voltage of the exposure and compared with that of the settings on the control console. Using this formula i.e. $\left[\frac{Indicated-Measured}{Indicated}\right] x\ 100\%$, the percentage deviation between the measured tube voltage and the indicated tube voltage on the control console is estimated. This was repeated for all the selected voltages. The accuracy of the voltage was checked for compliance using the acceptable criteria of percentage deviation $\leq \pm 6$ %.

3.2.3.4 Timer Accuracy Measurement

Maintaining the same MPD arrangements in section 2.2.1, the exposure time accuracy of the fluoroscopy machine was checked. The accuracies of exposure times of 100, 80, 20 and 6 ms were

checked. The MPD was used to measure the exposure time of the beam and compared with that of the settings on the control console. Using this formula i.e. $\left[\frac{Indicated-Measured}{Indicated}\right] x\ 100\ \%$, the percentage deviation between the measured exposure time and the indicated exposure time on the control console is estimated. This was repeated for all the selected times. The accuracy of the exposure time was checked for compliance using the acceptable criteria of percentage deviation ≤ ± 10 %.

3.2.3.5 Exposure, Time and Voltage Reproducibility

Maintaining the same MPD arrangements in section 2.2.1, the exposure, time and voltage reproducibility of the fluoroscopy machine was checked. A voltage of 81 kVp on an mAs of 10 was selected on the control console. The MPD was used to measure the exposure (dose), exposure time and the voltage. The exposure on the same settings was repeated five (5) times. The coefficient of variation (CoV) [i.e. $CoV = \frac{STDEV}{mean}$] of the values measured for the exposure, time and voltage were estimated. The reproducibility of the exposure, time and voltage was checked for compliance by using the acceptance criteria of CoV ≤ 0.05.

3.2.4 Patient Entrance Dose (i.e. Kerma Area Product) Assessment

3.2.4.1 Patient Selection and Exclusion Criteria

Patient selection was done at random focusing on the only those undergoing barium series examinations. Patients above the age of 5 years and are able to stand (i.e. for weight and height measurements) were considered for the study. Therefore, this suggests that, patients below the age of 5 years and can't stand i.e. in bed were not considered for the study. No particular focus was

given to the gender (i.e. male or female) as the aim was on all patients undergoing a barium series procedure.

3.2.4.2 The Data collection

The KERMA X-plus iba dosimeter (serial number: 01A04042 and model: 120-131 HS) flat panel ionization chamber was fixed on the beam limiting device (serial number: R 302/A DHHS, and model: R 302 MLPI/A DHHS) of the GE Medical Systems fluoroscopy (serial number: 1603990 and IEC No.: 60522/1999). The flat panel ionization chamber was fixed such that it fully intercepts the area of the beam being used for the procedures. The ionisation chamber was then connected to display monitor (model: 120-210 and serial number: 01E004774) positioned in the control area of the fluoroscopy room.

The height of the patients was recorded using a measuring tape. The weight of the patients was also recorded using the weighing scale. Other information as sex and age of the patients were recorded on a data collection sheet form the prescription slit of patients. The patients were selected at random but were older than 5 years old and able to stand for the height and weight measurements. Exposure parameters as the screening time, mean screening voltage and the KAP reading from the KAP meter were recorded for each patient procedure. These were recorded for only patients undergoing barium series (i.e. barium swallow, barium meal and barium enema) examinations.

All the required data was recorded on a prepared data sheet (Appendix: II), compiled and analyzed using Microsoft Excel spreadsheet.

3.2.4 Organ Dose Assessment using PCXMC

The physically collected data i.e. patient weight and exposure parameters were fed into a Monte Carlo computer-based program, PCXMC for calculating patients' organ doses and effective doses for each procedure. The dose calculation in PCMXC is in three stages:

- Defining the examination conditions
- Performing the Monte Carlo simulation, and
- Calculating the organ doses for a specified x-ray spectrum and patient input dose.

Based on the stages, the program menu includes the Examination data, simulate, compute doses, and Risk assessment (not utilised in this study).

3.2.4.1 The Examination Data Input

At this section, data that defines the x-ray and phantom to be used for the simulation is provided. Patient physical parameters such as age, height (cm) and weight (kg) was provided for the modelling of the phantom. The focus-image distance (which is fixed at 100 cm); the coordinate reference point for the x-ray beam; x-ray beam projection angle (90 in AP projections and 100 in LAT projections); the maximum simulation energy and the number of photons to be tracked (20,000) were provided in the PCXMC to appropriately define the beam. The above inputs were used to draw the x ray field and data saved for simulation. All the inputs are saved for simulation.

3.2.4.2 Simulation Phase

At this stage the saved data in the examinations data input phase is simulated using the Monte Carlo. The simulation speed is dependent on the defined number of photons to be tracked and the processing speed of the computer. After simulation, the output is stored for organ dose estimation.

3.2.4.3 Dose Estimation Phase

The patient organ doses for a particular examination is determined at this phase. The saved simulation output is used for the estimation. The tube voltage of the examination, anode angle of the x-ray tube and filtrations is provided to generate the required beam spectrum. After generating the spectrum, the KAP result for the examinations is provided for the PCXMC to estimate the dose to the organs. The study only focused on dose estimation of six organs (i.e. bone marrow, colon, breast, lungs, stomach and gonads) deemed to be most sensitive to radiation according to ICRP publication 103.

The organs doses were collated using Microsoft Excel for the estimation of their mean and standard error.

3.2.5 Assessment of Dose Indicators for Barium Swallow

Data collected on number of radiographs, fluoroscopy screening time, KAP readings and patient body mass index were assessed for proposed clinical dose optimisation using Microsoft Excel. A relationship between KAP readings and fluoroscopy readings was investigated for entrance surface dose optimisation. A graph of KAP readings against screening time and number or radiographs respectively was drawn suing Microsoft Excel. A relationship between KAP readings and patient body mass index was investigated for internal dose (organ dose) optimisation. A graph of KAP against body mass index was plotted for interpretation. Further investigation was conducted by keeping KAP readings constant and varying body mass index and vice versa.

CHAPTER FOUR

Results and Discussions

4.0 INTRODUCTION

This chapter describes and discusses the results from the research work conducted on the fluoroscopy machine and comparison of the results at the selected facility with results of works done by other researchers.

4.1 QUALITY CONTROL MEASUREMENT

Table 4.1: Summary of quality control test.

Parameters	Measured Deviation	Acceptable Deviation	Remarks
Voltage accuracy	4.04 %	Within ± 6.00 %	Pass
Exposure time accuracy	3.62 %	Within ± 10.00 %	Pass
mAs linearity	0.06	≤ 0.10	Pass
Voltage reproducibility	0.01	≤ 0.05 (coefficient of variation)	Pass
Time reproducibility	0.04	≤ 0.05 (coefficient of variation)	Pass
Dose reproducibility	0.03	≤ 0.05 (coefficient of variation)	Pass
Half-Value layer @ 80kVp	3.2 mm Al	≥ 2.30 mm Al	Pass

Table 4.1 shows the summary of the quality control tests conducted on the GE fluoroscopy system at the Greater Accra Regional Hospital. It is clear from the table 4.1 that the fluoroscopy machine is performing self consistently using the acceptable criteria of the Nuclear Regulatory Authority in Ghana.

4.2 EXAMINATION DISTRIBUTION

The number of patient distribution at the facility undergoing the selected examinations are 45 equal (37.50%) patients for barium swallow (BaS), 29 equal (24.17%) patients for barium meal (BaM), 7 equal (5.84%) patient for barium meal follow through (BaFt) and 39 equal (32.5%) patients for barium enema (BaE).

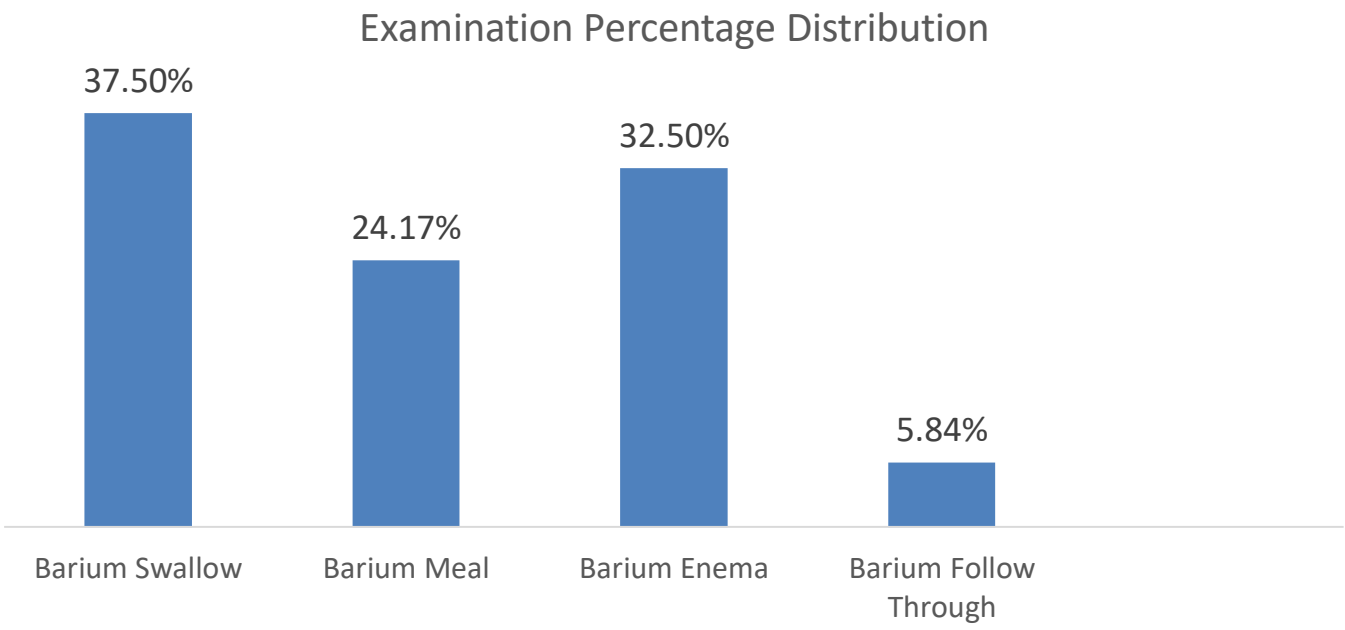


FIGURE 4.1: Percentage distribution of fluoroscopy examination types for the study.

It can be seen from figure 4.1 that during the month of collection of data, barium swallow examination was the most frequent and barium meal follow through the least frequent. In all data of 120 patients were collected.

4.3. GENDER PERCENTAGE DISTRIBUTION

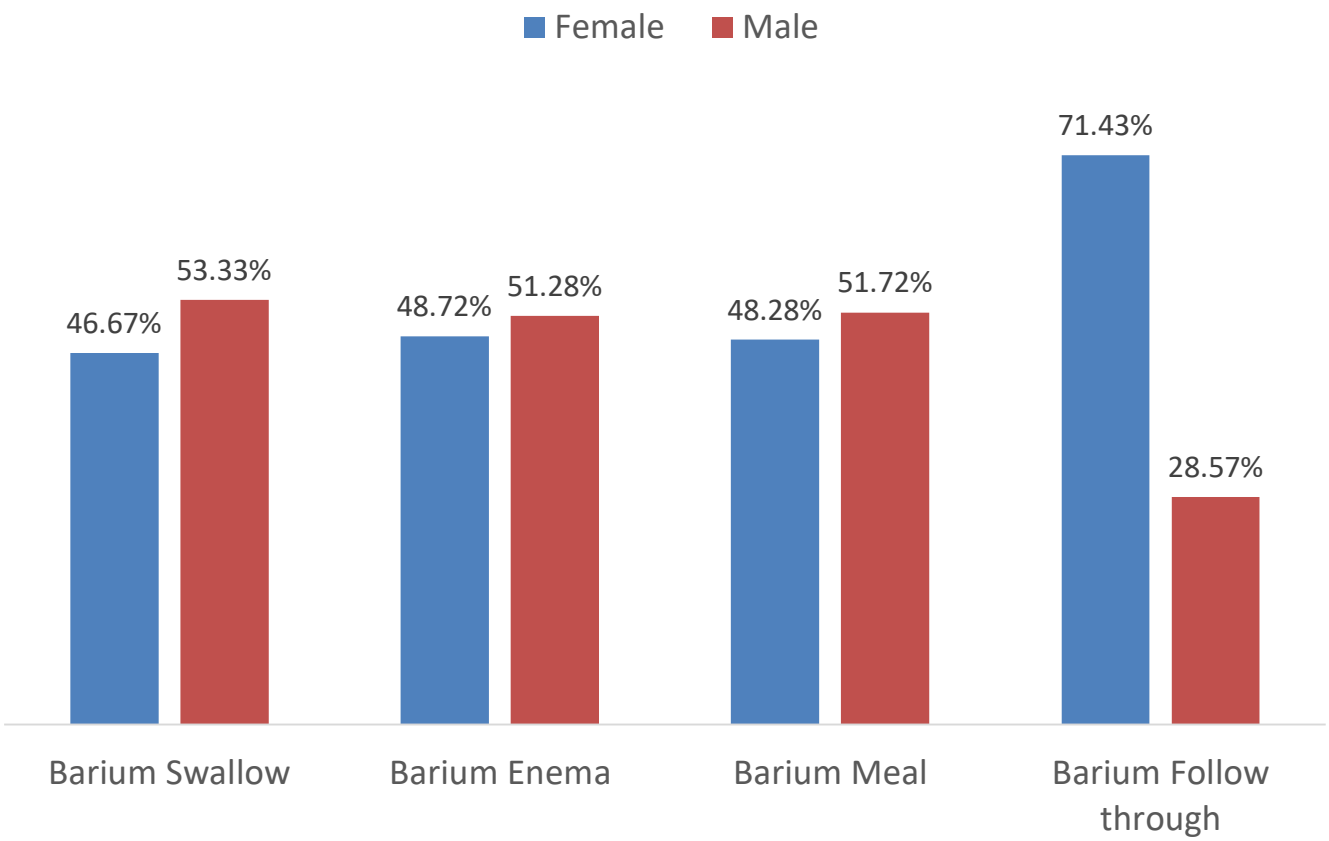


FIGURE 4.2: Gender Percentage distribution of for the examinations

Figure 4.2 shows the gender percentage distribution for all the examinations under study. It can be seen that there were more male patients than female patients for all the examinations except for barium meal follow through examination. Elaborate table has been provided in Appendix III.

4.4. PATIENT AGE DISTRIBUTION

Table 4.2: Age distribution of patients in this study

Examination	**Age Distribution (years)**
Barium swallow	5 - 81
Barium meal	5 - 70
Barium meal follow through	30 - 34
Barium enema	5- 27

Table 4.2 shows the age range per examination of the patients considered for the study. The patients undergoing barium swallow, barium meal and barium enema recorded the youngest age of 5 years. The oldest age of 81 years was recorded for a patient undergoing barium swallow examinations.

4.5 ESTIMATED MEAN KAP (Gy.Cm^2) VALUES FOR EACH EXAMINATION

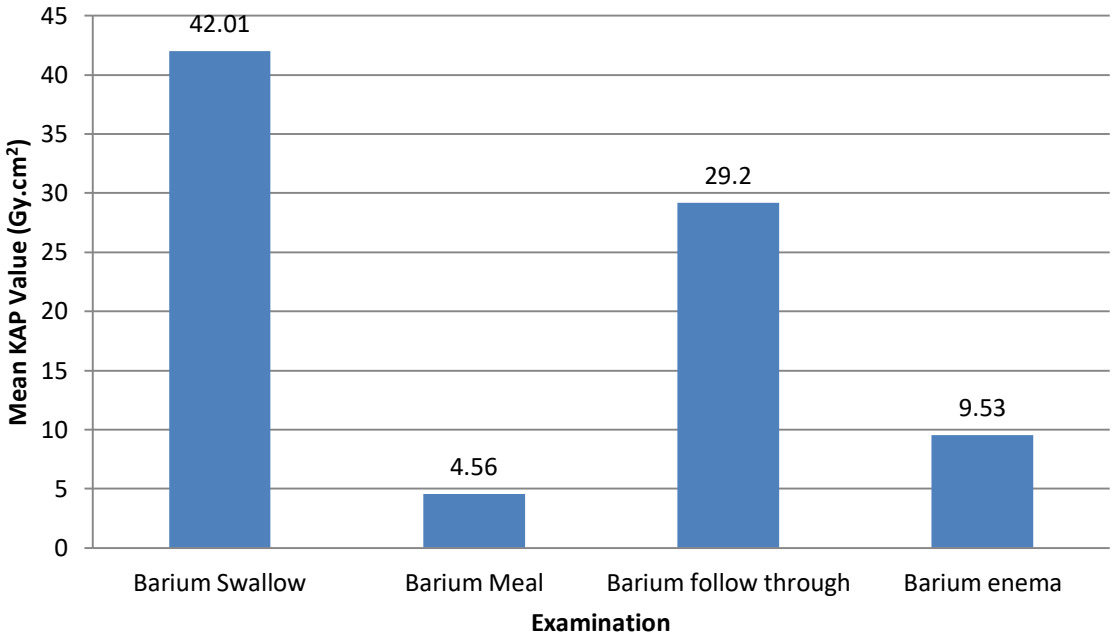


FIGURE 4.3: Mean KAP values for the considered examinations

Figure 4.3 shows the mean KAP values of barium series examinations. It can be seen that barium swallow recorded the highest value with barium meal recording the lowest. The second highest was barium follow through and then followed by barium enema. The difference in the KAP values for the examinations could be related to their varying screening time and number of radiographs taken. Elaborative table on the KAP values for all the examinations considered have been shown in Appendix IV.

4.6COMPARISON OF MEAN KAP (Gy.cm2) VALUES FOR THIS STUDY WITH OTHER STUDIES

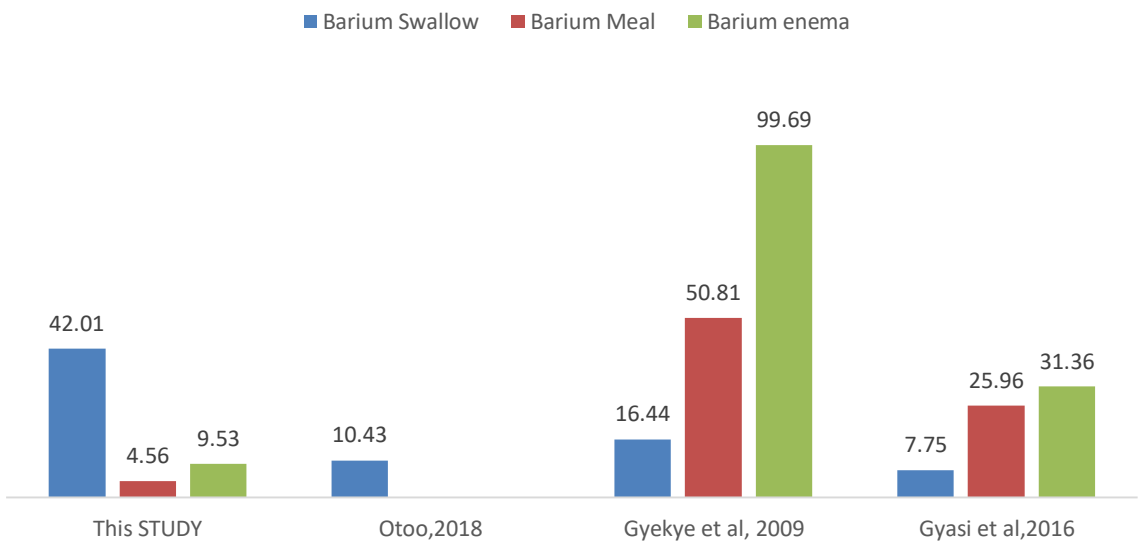


FIGURE 4.4 Comparison of the Mean KAP values of this Study with others.

Figure 4.4 shows the comparisons of the mean KAP values of this study with other studies. Generally, it can be seen that all the KAP values for this study were below that of the other studies except for KAP value of barium swallow. The KAP value for barium swallow of this study was more that of Gyekye et al, Otoo and Gyasi et al by a factor of 2.6, 4.0 and 5.5 respectively. The KAP values for barium meal of this study was less than that of Gyekye et al and Gyasi et al by a factor of 11.1 and 5.7 respectively. The KAP values for barium enema of this study was less than that of Gyekye et al and Gyasi et al by a factor 10.5 and 3.3 respectively. The variation in the KAP value readings in comparison with the other studies could be associated with difference in the techniques and protocols. However, it can be said that optimisation of doses to patients for these fluoroscopy procedures have improved except for barium swallow examinations.

4.7 ESTIMATED MEAN EFFECTIVE DOSE

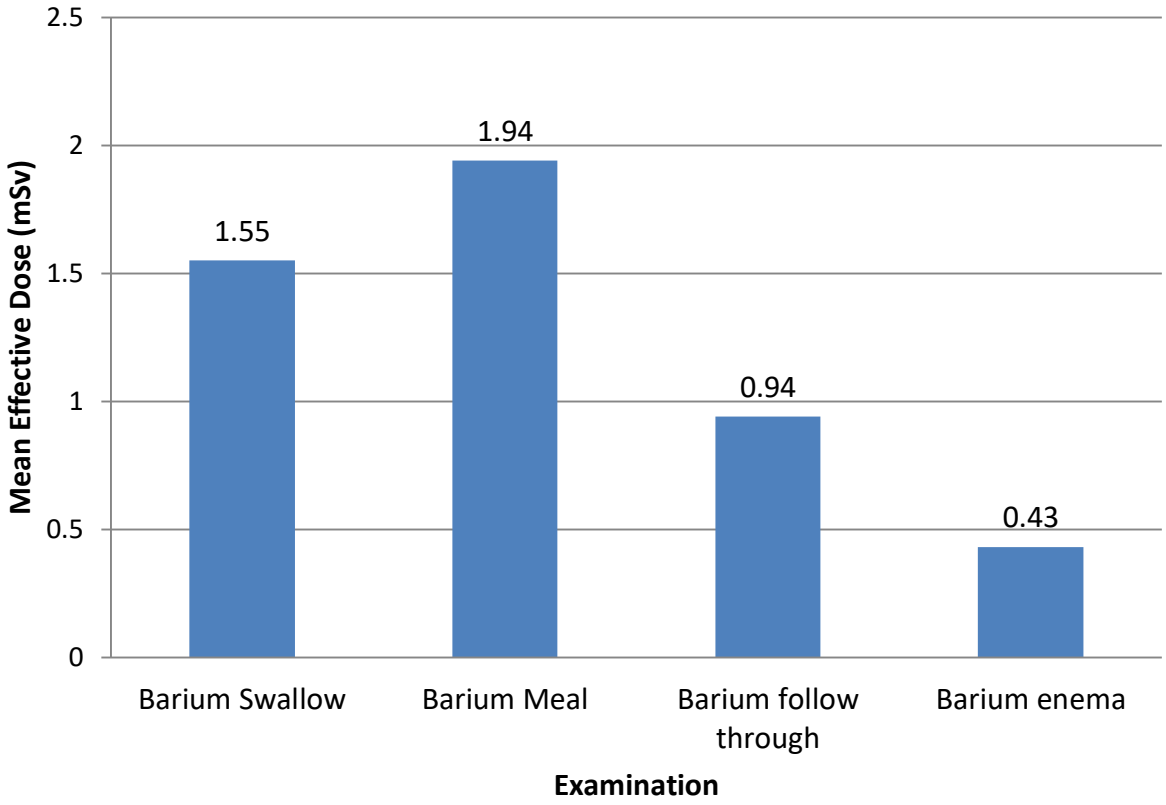


FIGURE 4.5: Mean Effective Dose for the considered examinations

Figure 4.5 shows the mean effective doses for the procedure under study. It is clear from figure 4.5 that barium meal recorded the highest dose with barium enema recording the lowest. The second highest was barium swallow followed by barium meal follow through. This indicates that patients undergoing barium meal have a high overall radiation effect than the other examinations. The variation in the effective dose values could be related to varying examination protocols for the fluoroscopy procedures. Elaborative table on the effective dose for all the examinations considered have been shown in Appendix V.

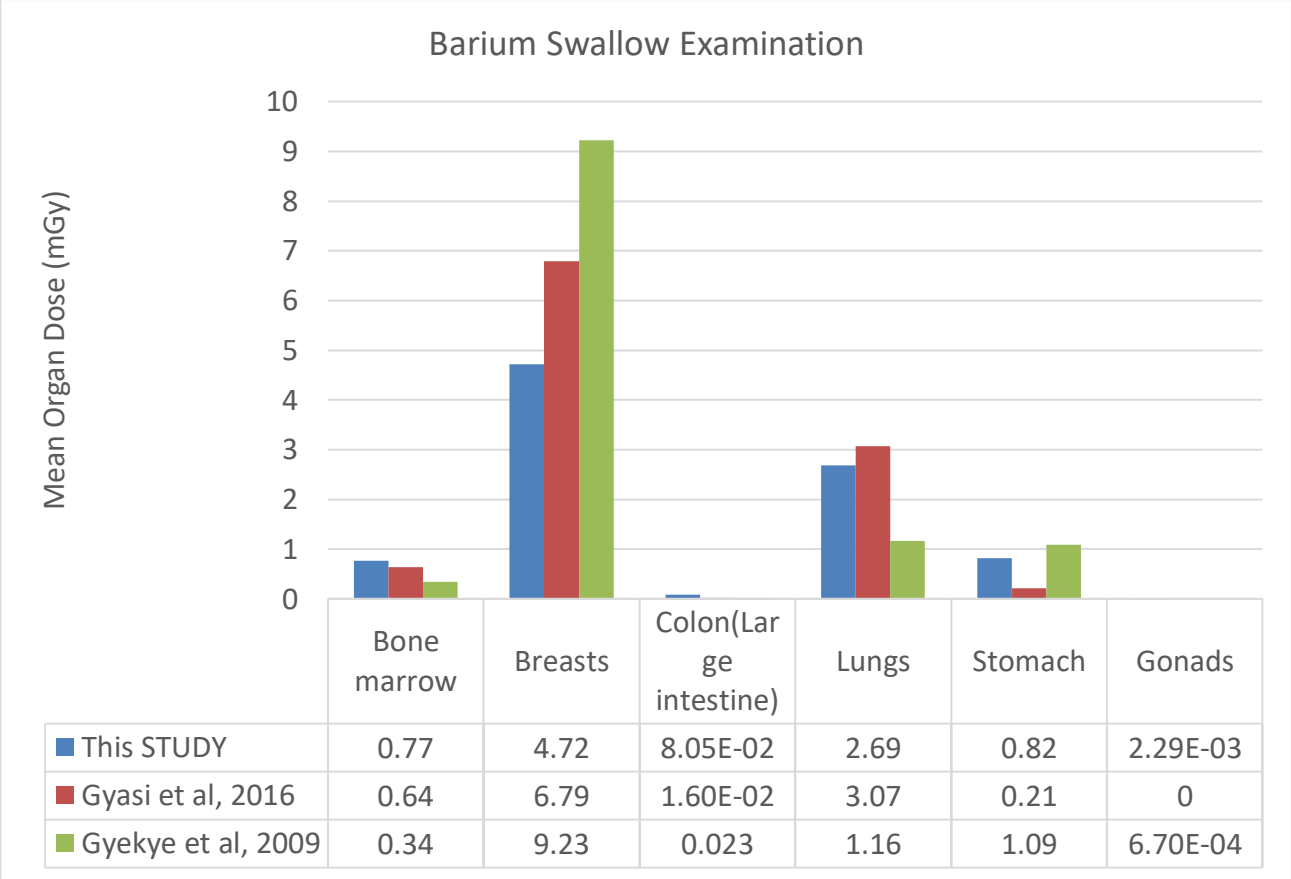
4.8 ESTIMATED MEAN ORGANS DOSES

TABLE 4.3: Organ doses of patients undergoing barium series procedures.

Organs	Organ Dose (mGy)			
	Barium swallow	Barium meal	Barium meal follow through	Barium enema
Bone marrow	0.77	0.91	0.49	0.25
Breasts	4.72	1.27	0.03	0.12
Colon (Large intestine)	8.05E-02	3.25	2.13	0.72
Lungs	2.69	1.22	0.07	0.19
Stomach	0.81	3.54	1.31	0.78
Gonads	2.29E-03	2.92	2.70	0.95

Table 4.3 shows the doses to the most sensitive organs of patients undergoing barium series procedures. These organs were selected based on the ICRP recommendations. It can be seen that the breast, stomach, gonads and gonads received the highest dose for barium swallow, barium meal, barium meal follow through and barium enema respectively. The organs that received the least doses are gonads, bone marrow, breast and breast for barium swallow, barium meal, barium meal follow through and barium enema respectively. It could be said that the variation of organ doses for an examination is associated with the proximity of the organs in the beam of the radiation and part of the body being exposed to radiation. The highest organs doses varied from procedure to procedure due to the varying protocol used and the part of the body being exposed to radiation.

4.9 COMPARISON MEAN ORGAN DOSES OF THIS STUDY WITH OTHER STUDIES

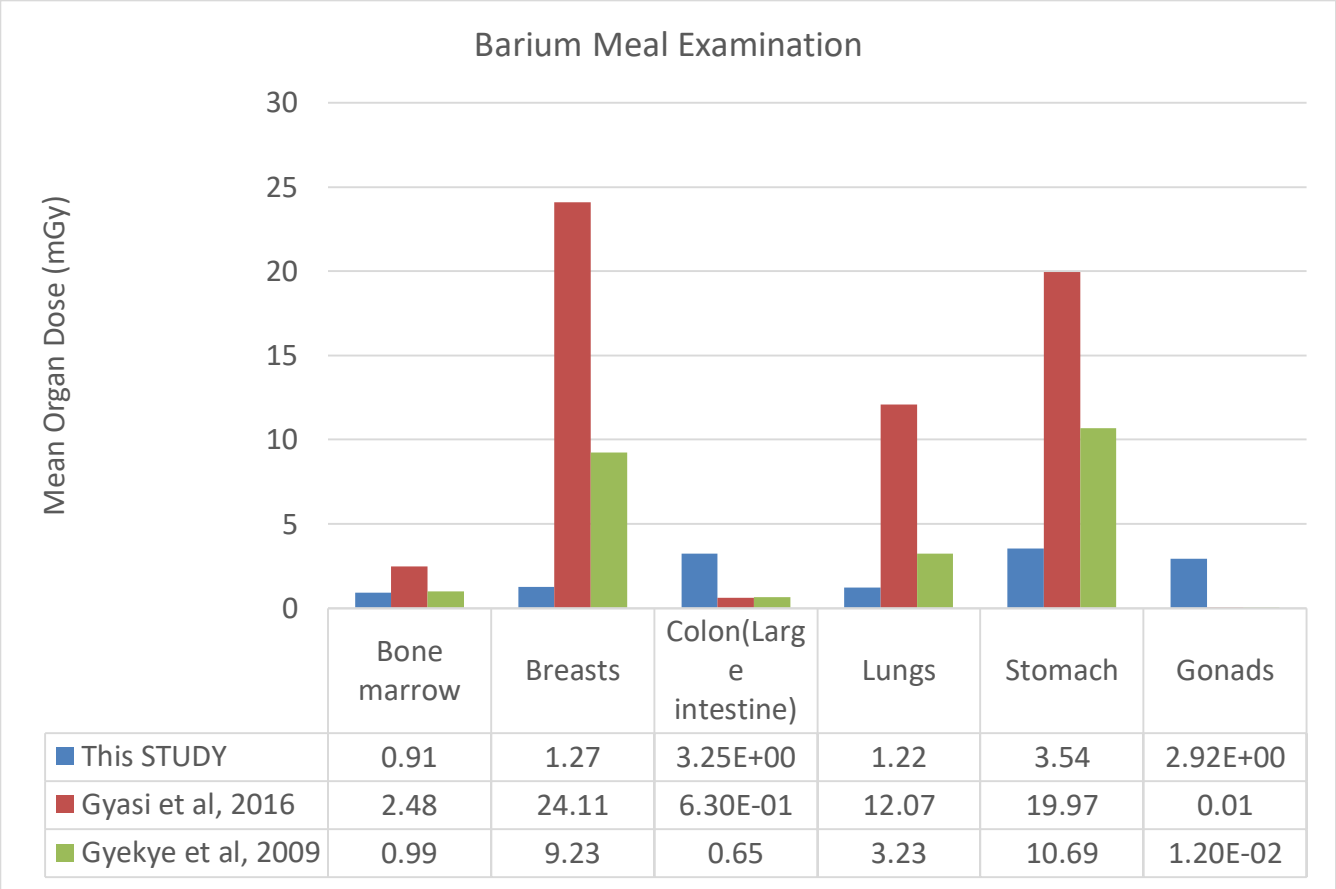


	Bone marrow	Breasts	Colon(Large intestine)	Lungs	Stomach	Gonads
This STUDY	0.77	4.72	8.05E-02	2.69	0.82	2.29E-03
Gyasi et al, 2016	0.64	6.79	1.60E-02	3.07	0.21	0
Gyekye et al, 2009	0.34	9.23	0.023	1.16	1.09	6.70E-04

FIGURE 4.6: Comparison of organ doses of patients undergoing barium swallow examination

Figure 4.6 shows a comparison of the organ doses of patients undergone barium swallow of this study with other studies. It can be seen that this study recorded the highest dose to the bone marrow and colon in comparison with Gyekye et al and Gyasi et al. Gyekye et al recorded the highest dose to the breast and stomach in comparison with this study and Gyasi et al. Gyasi et al also recorded the highest dose to lungs in comparison with this study and Gyekye et al. Doses to the gonads were

significantly negligible. The variation in the organs doses among the studies could be associated with the varying KAP values and different patient demographics i.e. body mass index.

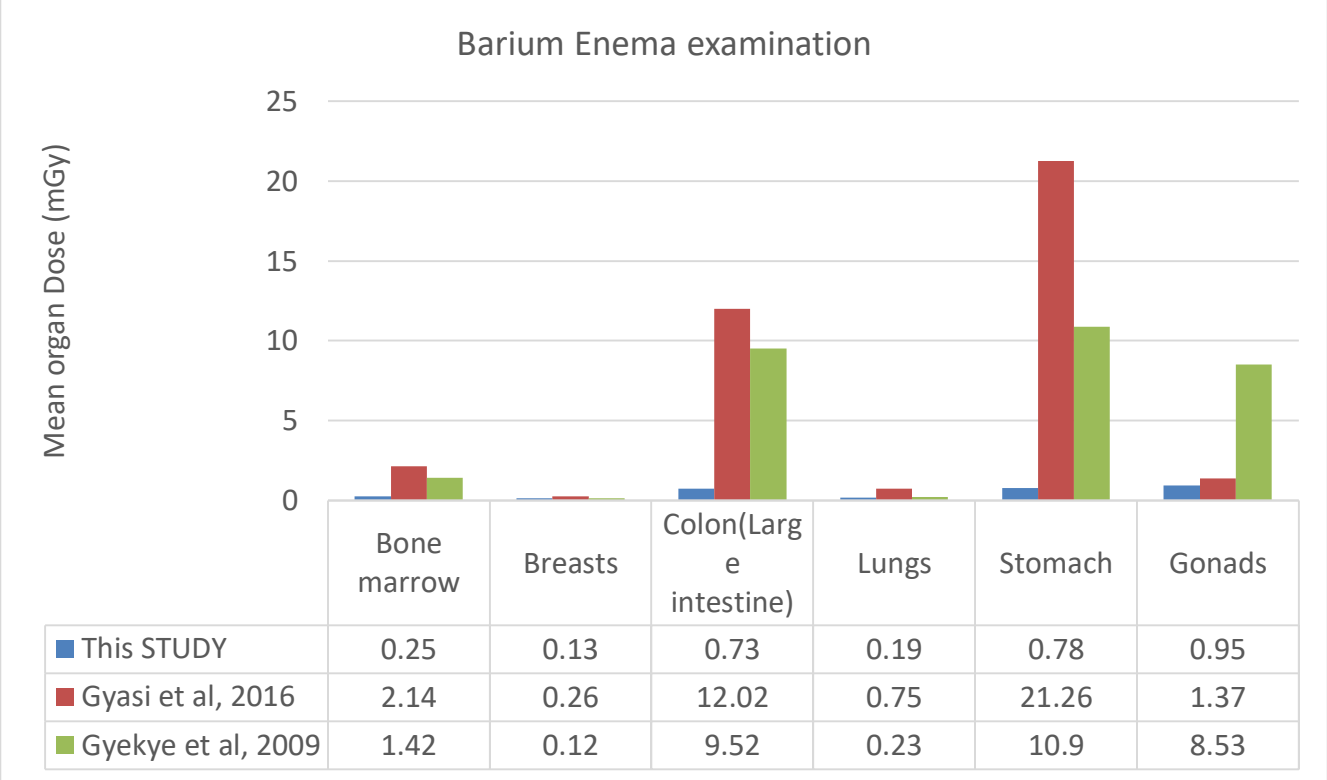


	Bone marrow	Breasts	Colon(Large intestine)	Lungs	Stomach	Gonads
This STUDY	0.91	1.27	3.25E+00	1.22	3.54	2.92E+00
Gyasi et al, 2016	2.48	24.11	6.30E-01	12.07	19.97	0.01
Gyekye et al, 2009	0.99	9.23	0.65	3.23	10.69	1.20E-02

FIGURE 4.7: Comparison of organ doses of patients undergoing barium meal examination.

Figure 4.7 shows a comparison of the organ doses of patients undergone barium meal of this study with other studies. It can be seen that this study recorded the highest dose to the colon and gonads in comparison with Gyekye et al and Gyasi et al. Gyasi et al recorded the highest dose to the bone marrow, breast, lungs and stomach in comparison with this study and Gyekye et al. Again, the

variation in the organs doses among the studies could be associated with the varying KAP values and different patient demographics i.e. body mass index.



	Bone marrow	Breasts	Colon(Large intestine)	Lungs	Stomach	Gonads
This STUDY	0.25	0.13	0.73	0.19	0.78	0.95
Gyasi et al, 2016	2.14	0.26	12.02	0.75	21.26	1.37
Gyekye et al, 2009	1.42	0.12	9.52	0.23	10.9	8.53

FIGURE 4.8: Comparison of organ doses of patients undergoing barium enema examination.

Figure 4.8 shows a comparison of the organ doses of patients undergone barium enema of this study with other studies. It can be seen that this study recorded the low organ doses in comparison with Gyekye et al and Gyasi et al. Gyasi et al recorded the highest dose to the bone marrow, breast, colon, lungs and stomach in comparison with this study and Gyekye et al. Gyekye et al recorded the highest dose to the gonads in comparison with this study and Gyasi et al. Again, the variation in the organs doses among the studies could be associated with the varying KAP values and different patient demographics i.e. body mass index.

Generally, it can be seen that barium meal recorded high organ doses than that of barium swallow and barium enema. The organ doses varied within a particular examination due to proximity of the organs to the radiation beam. Additionally, the organ doses varied within the examinations understudy due to varying protocols and patient demographics. A detailed table of comparisons of organs doses of this study with other studies for the various fluoroscopy examinations have been shown in Appendix VI.

4.10 MEAN FLUOROSCOPY SCREENING TIME FOR EACH EXAMINATION

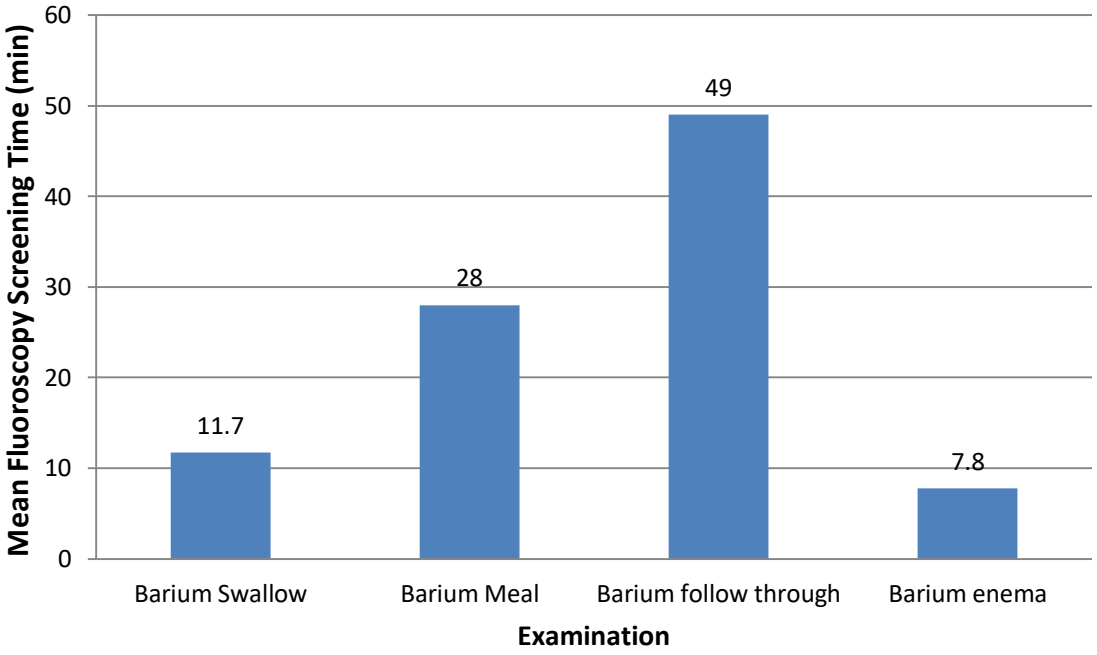


FIGURE 4.9: Mean Fluoroscopy Screening Time for the considered examinations.

Figure 4.9 shows the mean fluoroscopy screening time for patients undergoing barium series. It can be seen that barium meal follows through examination recorded the highest mean fluoroscopy screening time whilst barium meal examination recorded the lowest. The second highest

fluoroscopy screening time recorded was for barium meal followed by barium swallow. Comparing figure 4.9 with 4.3, it can be seen that barium meal follow through examination was recorded the second highest KAP value but recorded the highest fluoroscopy screening time. It can also be seen that barium meal examination recorded the second highest fluoroscopy screening time but recorded the lowest KAP value. The same variation of hierarchy can be seen for barium swallow and barium enema examinations. This was because of the varying examination protocols and patient data i.e. height and weight. Additionally, the observed trend also suggests that in addition to fluoroscopy screening time, there are other factors that contribute to the increase in patient entrance dosses during fluoroscopy examinations. A detailed mean fluoroscopy screening time for the various examinations has been shown in Appendix VII.

4.11 COMPARISON OF FLUOROSCOPY SCREENING TIME OF THIS STUDY WITH OTHER STUDIES

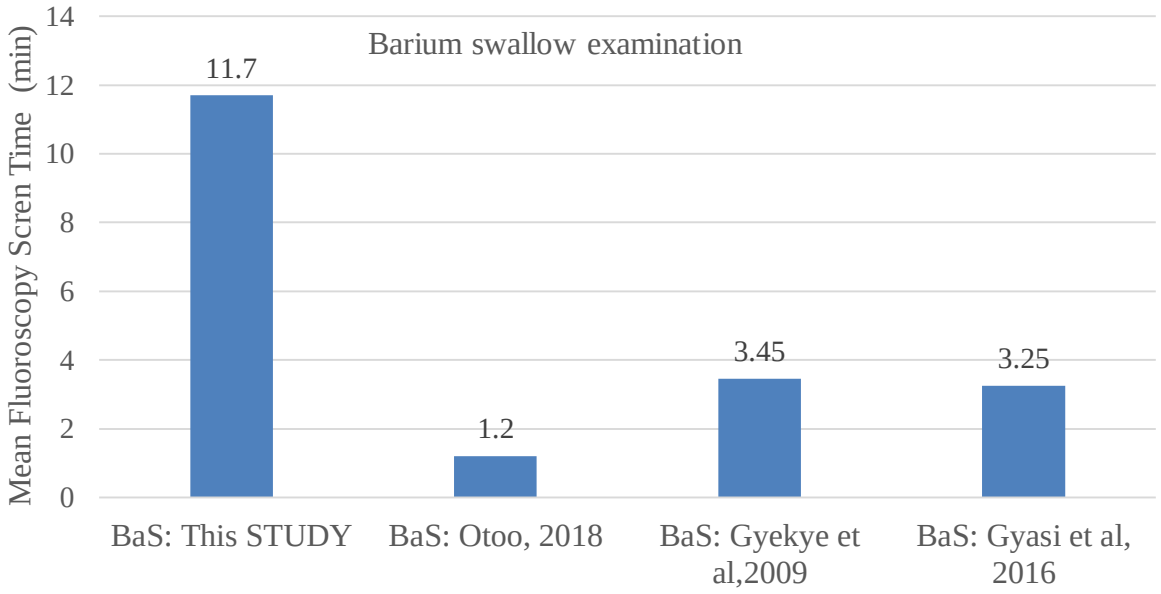


FIGURE 4.10: Comparison of fluoroscopy screening time for barium swallow examination

Figure 4.10 compares the screening time of this study with other studies for barium swallow examinations. The fluoroscopy screening time of this study was more than that of Otoo, Gyekye et al, and Gyasi et al by a factor of 9.8, 3.4 and 3.6 respectively. Comparing figure 4.4 and 4.10, it can be seen that the contribution of fluoroscopy screening time to the KAP value ($mGy.cm^2$) entrance dose was very clear and well demonstrated. This could be attributed to similar or closely related patient demographic dynamics for the studies

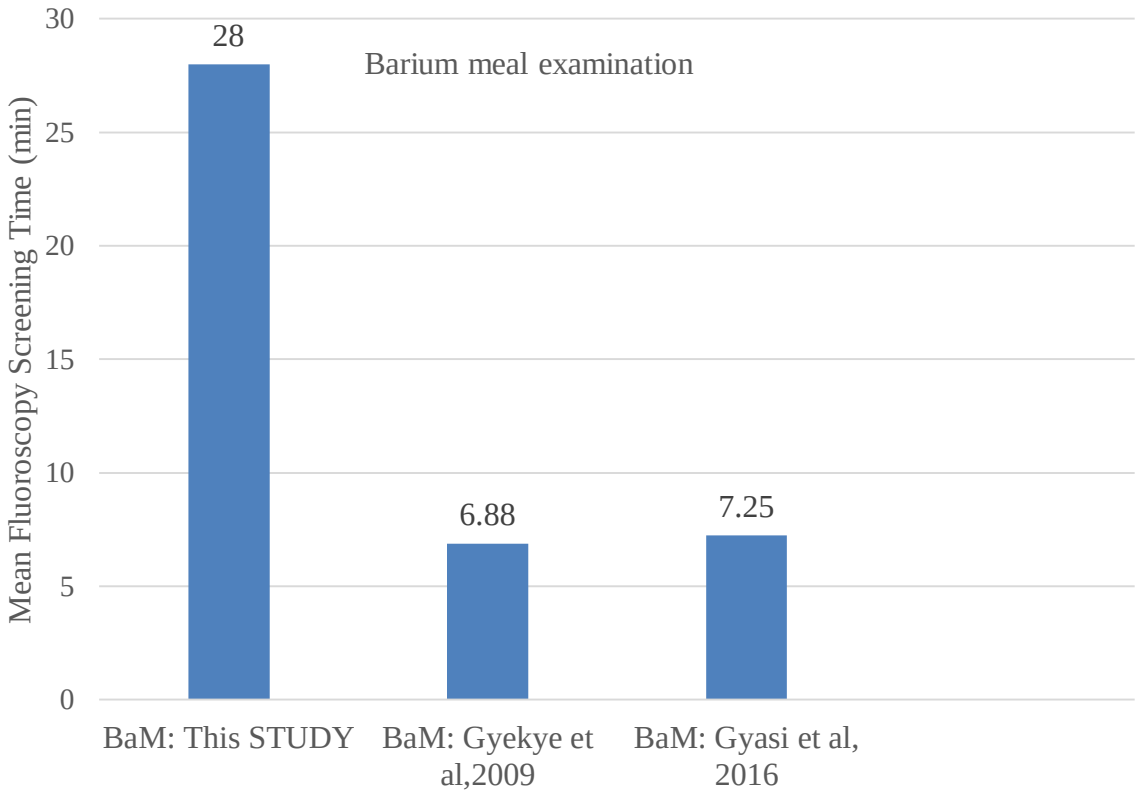


FIGURE 4.11: Comparison of fluoroscopy screening time for barium meal examination

Figure 4.11 compares the screening time of this study with other studies for barium meal examinations. The fluoroscopy screening time of this study was more than that of Gyekye et al, and Gyasi et al by a factor of 3.4 and 3.9 respectively. Comparing figure 4.4 and 4.10, it can be

seen that the contribution of fluoroscopy screening time to the KAP value (mGy.cm^2) entrance dose was not evident as this study recorded the lowest KAP value (mGy.cm^2). This could be attributed to the other contributing factors to patient dose i.e. unrelated patient demographic dynamics and different examination protocols (e.g. number of radiographs taken).

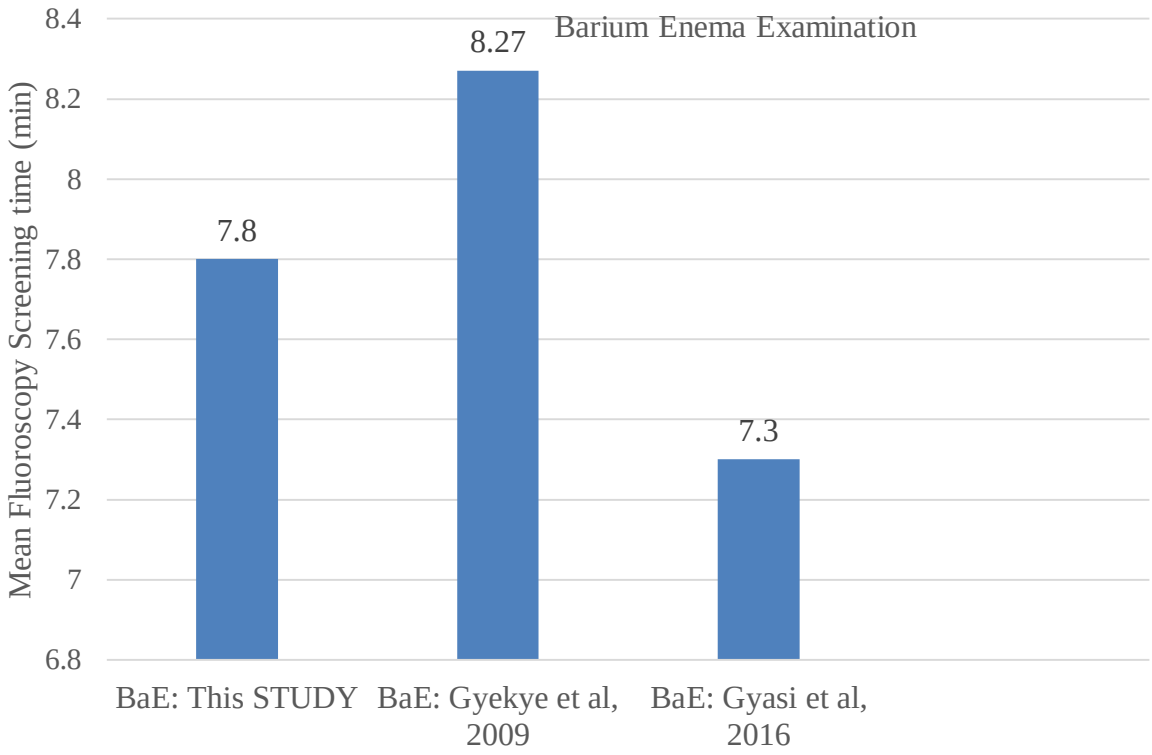


FIGURE 4.12: Comparison of fluoroscopy screening time for barium enema examination

Figure 4.12 compares the screening time of this study with other studies for barium enema examinations. The fluoroscopy screening time of this study was more than that of Gyasi et al by a factor of 1.1 and less than that of Gyekye et al by a factor of 1.1. Comparing figure 4.4 and 4.10,

it can be seen that the contribution of fluoroscopy screening time to the KAP value (mGy.cm^2) entrance dose was not evident as this study recorded the lowest KAP value (mGy.cm^2) . Again, this could be attributed to the other contributing factors to patient dose i.e. unrelated patient demographic dynamics and different examination protocols (e.g. number of radiographs taken).

Generally, it was seen that fluoroscopy screening time is not the only contributing factors to patient entrance doses. Fluoroscopy screening time for barium meal is more as compared with barium swallow and barium enema.

4.12 NUMBER OF RADIOGRAPHS PER EXAMINATION

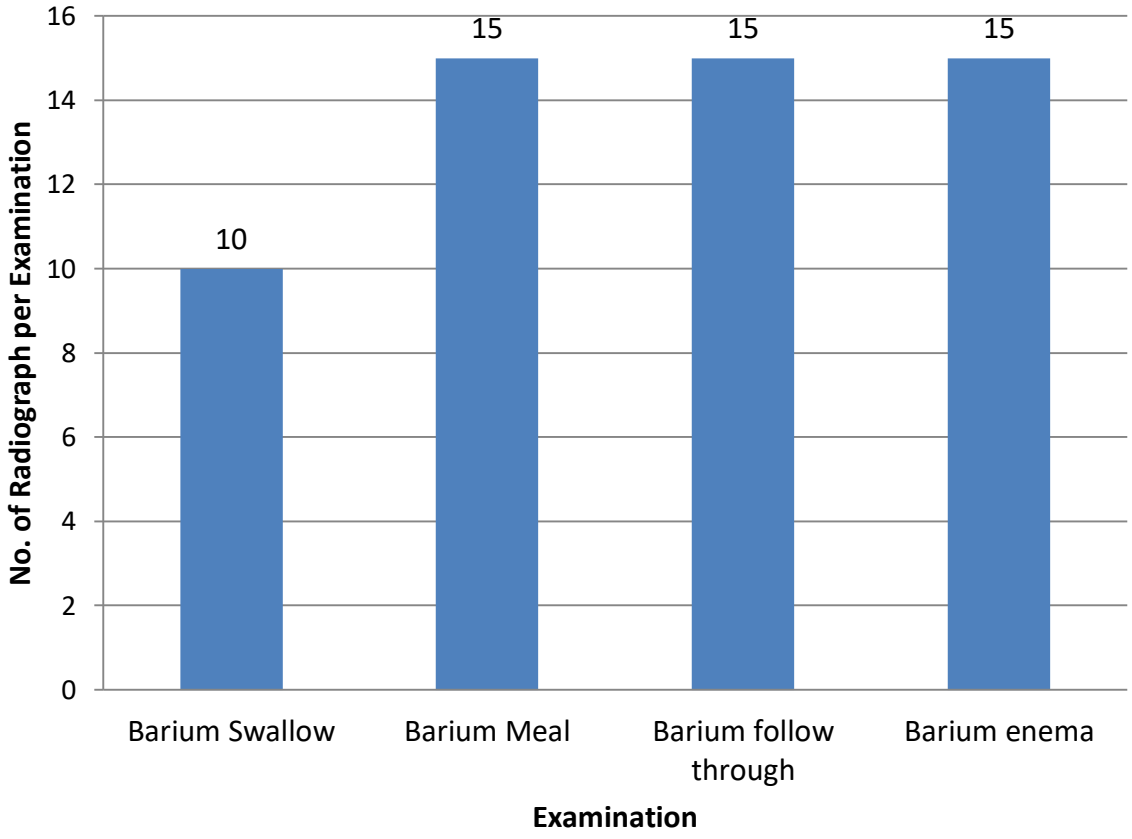


FIGURE 4.13: Mean number of radiographs per examination

Figure 13 illustrates the mean number of radiographs taken per examination for barium series procedures of this study. It can be seen that barium meal, barium meal follows through and barium enema recorded the highest mean number of radiographs taken with barium swallow recording the lowest. Comparing figure 4.13 and 4.3, it can be seen that within the different examinations under study, there is no correlation established between KAP value (mGy.cm^2) and number of radiographs taken. This could be attributed to the different technique used by the radiographers or the radiologist's and the patient demography. A detailed number of radiographs taken per examination for the various examinations has been shown in Appendix VIII.

4.13 COMPARISON OF NUMBER OF RADIOGRAPHS TAKEN PER EXAMINATION OF THIS STUDY AND OTHERS STUDIES

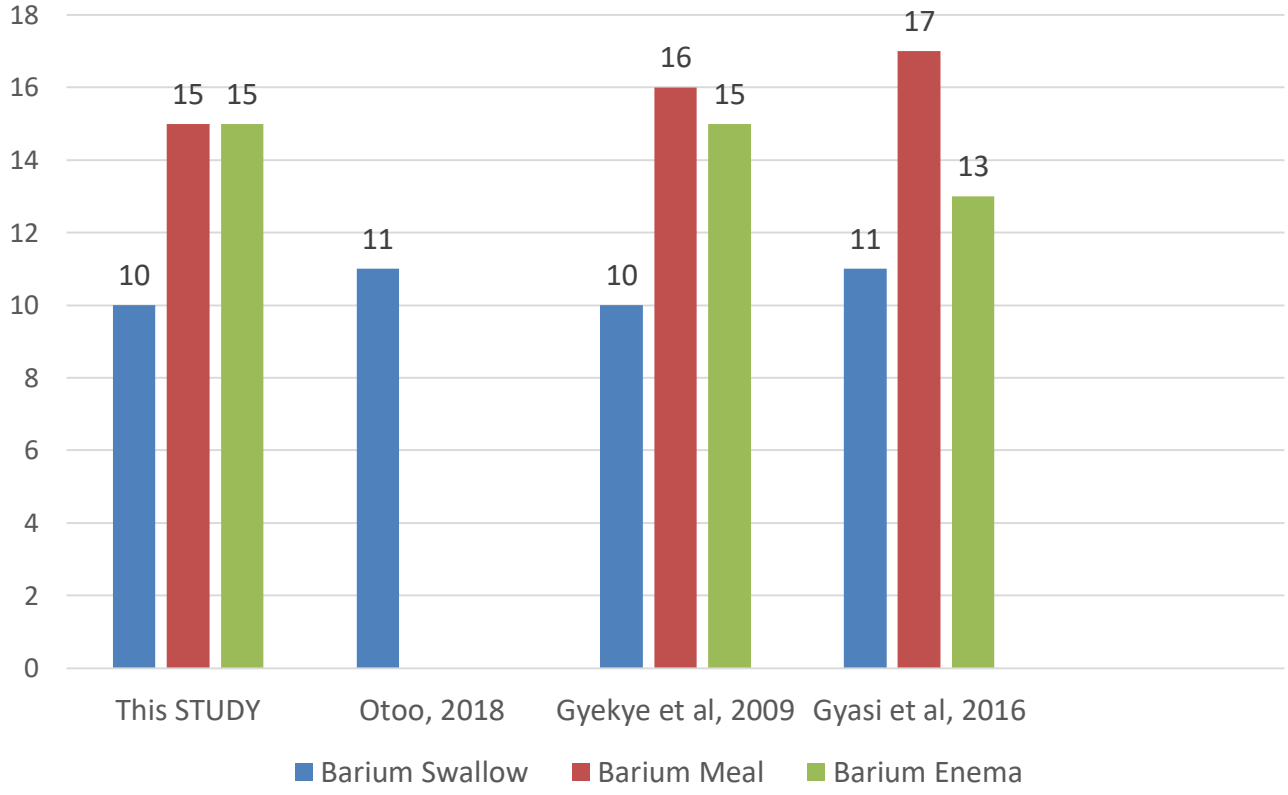


FIGURE 4.14: Comparison of mean number of radiographs taken per examination.

Figure 4.14 illustrates the comparison of the mean number of radiographs taken per examination of the studies under investigation with that of other studies. It can be seen that for barium swallow examination, the number of radiographs taken per examination for this study was the same as that of Gyekye et al but was less than that of Otoo and Gyasi et al by a factor of 1.1, and 1.1 respectively. For barium meal examination, the number of radiographs taken per examination for this study was less than that of Gyekye et al and Gyasi et al by a factor of 1.1 and 1.1 respectively. For barium enema examinations, the number of radiographs taken per examination for this study was more than that of Gyasi et al by a factor of 1.2 but same as that of Gyekye et al. Comparing figure 4.3 with figure 4.14, it can be seen that barium swallow recorded the highest KAP value ($mGy.cm^2$) but recorded the lowest number of radiographs taken per examination. Also, it can be seen that barium enema recorded the third highest KAP value ($mGy.cm^2$) but recorded the highest number of radiographs taken. It goes to suggest that in addition to the number of radiographs taken per examination contributing to patient dose as published, there are other factors. These factors could be patient demographics and examination protocol.

Generally, the variation in the number of radiographs taken per examination could be attributed to the different examination protocols within the same examination and other examinations. Barium meal and barium enema have the same highest number of mean radiographs taken per examination. Additionally, other factors in addition to number of radiographs taken per examination contribute to entrance patient doses.

4.14: RESULTS OF DOSE CONTRIBUTING FACTORS ASSESSMENT FOR BARIUM SWALLOW

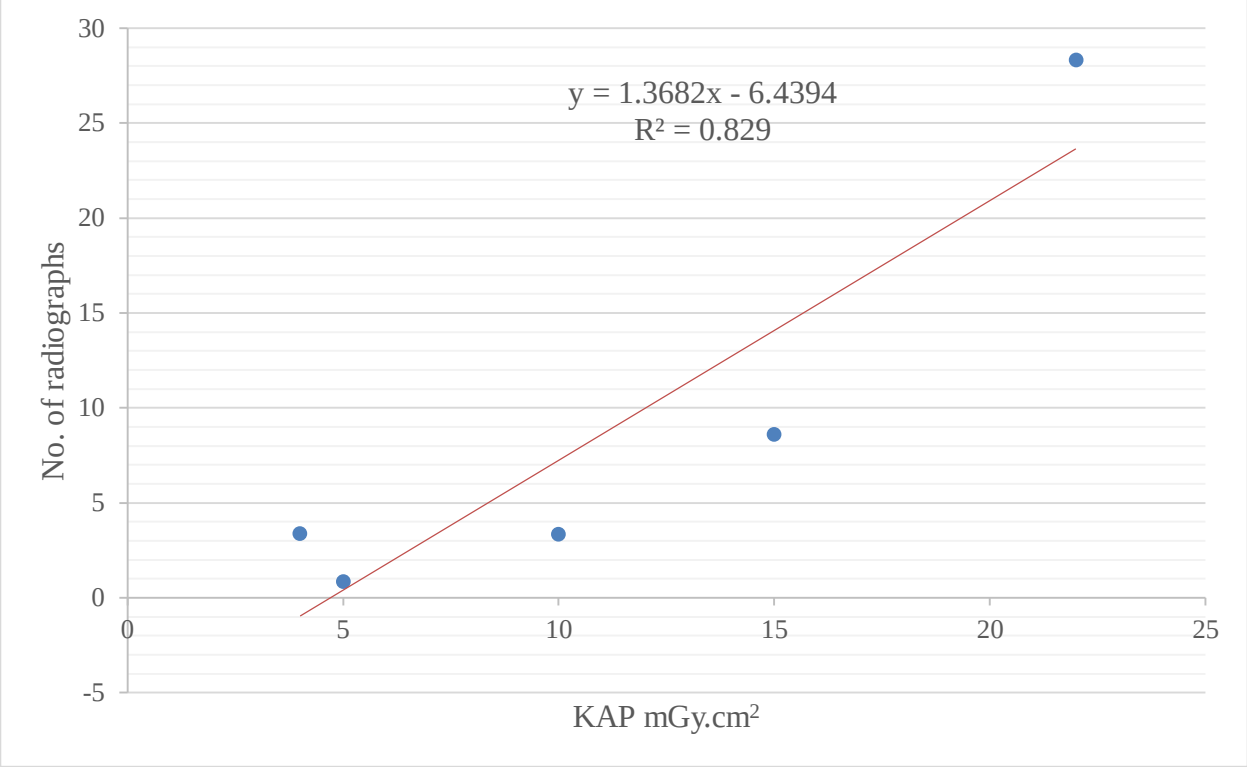


FIGURE 4.15: A graph of KAP mGy.cm^2 against number of radiographs taken per examination

Figure 4.15 illustrates the relationship between KAP mGy.cm^2 and number of radiographs taken per barium swallow examination. It can be seen that there is a positive correlation between KAP mGy.cm^2 and number of radiographs per examination for barium swallow examinations at the Greater Accra Regional Hospital. With this established relationship, the radiographer can estimate the KAP mGy.cm^2 entrance dose of patients before or during barium swallow examinations for dose optimization. Since the comparison of the KAP mGy.cm^2 of this study for all the procedures with other studies suggests that barium swallow needs to be optimised, this quick optimisation procedure can be employed taking into consideration achievement of the aim of the procedure.

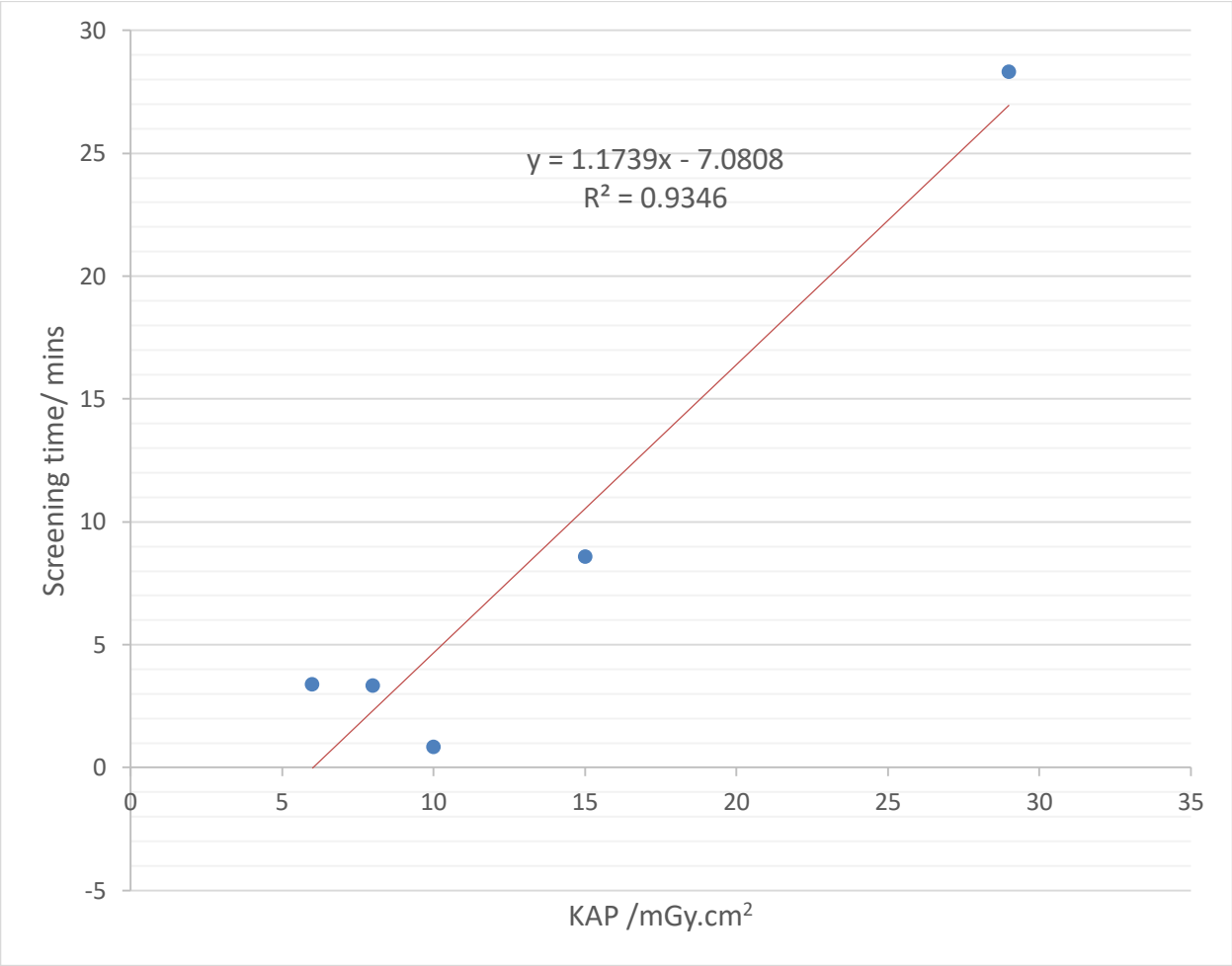


FIGURE 4.16: A graph of KAP (mGy.cm^2) against fluoroscopy screening time

Figure 4.16 illustrates the relationship between KAP /mGy.cm^2 and fluoroscopy screening time for barium swallow examinations. It can be seen that there is a positive correlation between KAP /mGy.cm^2 and fluoroscopy screening time for barium swallow examination at the Greater Accra Regional Hospital. Therefore, with the known fluoroscopy screening time of barium swallow examination, the KAP/mGy.cm^2 can be estimated from the relationship found in figure 4.16.

Optimisation by easy determination of the patient KAP value (mGy.cm^2) without physically installing a KAP meter will enhance the protection of the patients at the Hospital.

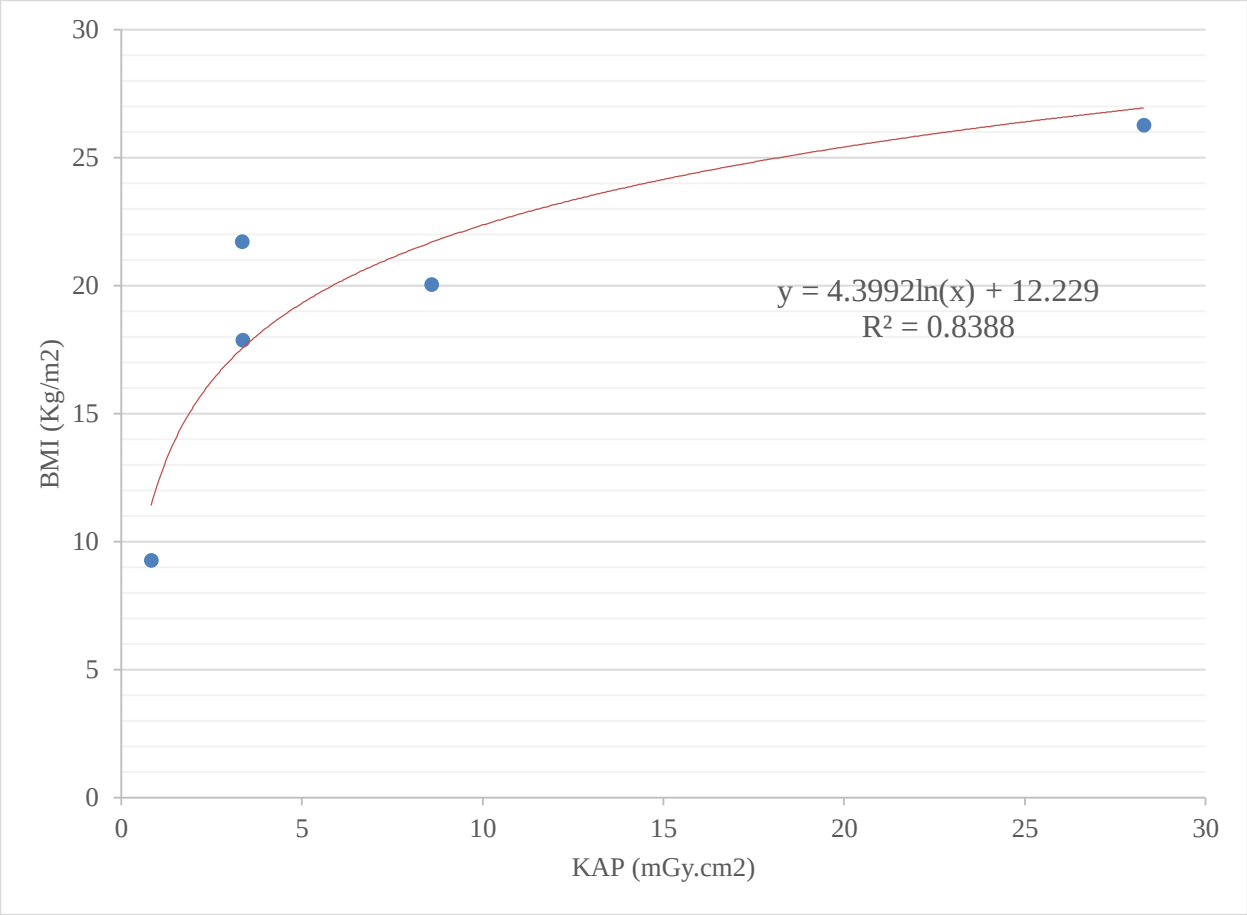


FIGURE 4.17: A graph of KAP/mGy.cm^2 against patient body mass index (BMI)

Figure 4.17 illustrates the relationship between KAP/mGy.cm^2 and body mass index of patients undergoing barium swallow examinations. It can be seen that a logarithmic correlation between KAP/mGy.cm^2 and body mass index have been proposed for the fluoroscopy machine at the Greater Accra Regional Hospital. This can also be used to augment the already proposed dose

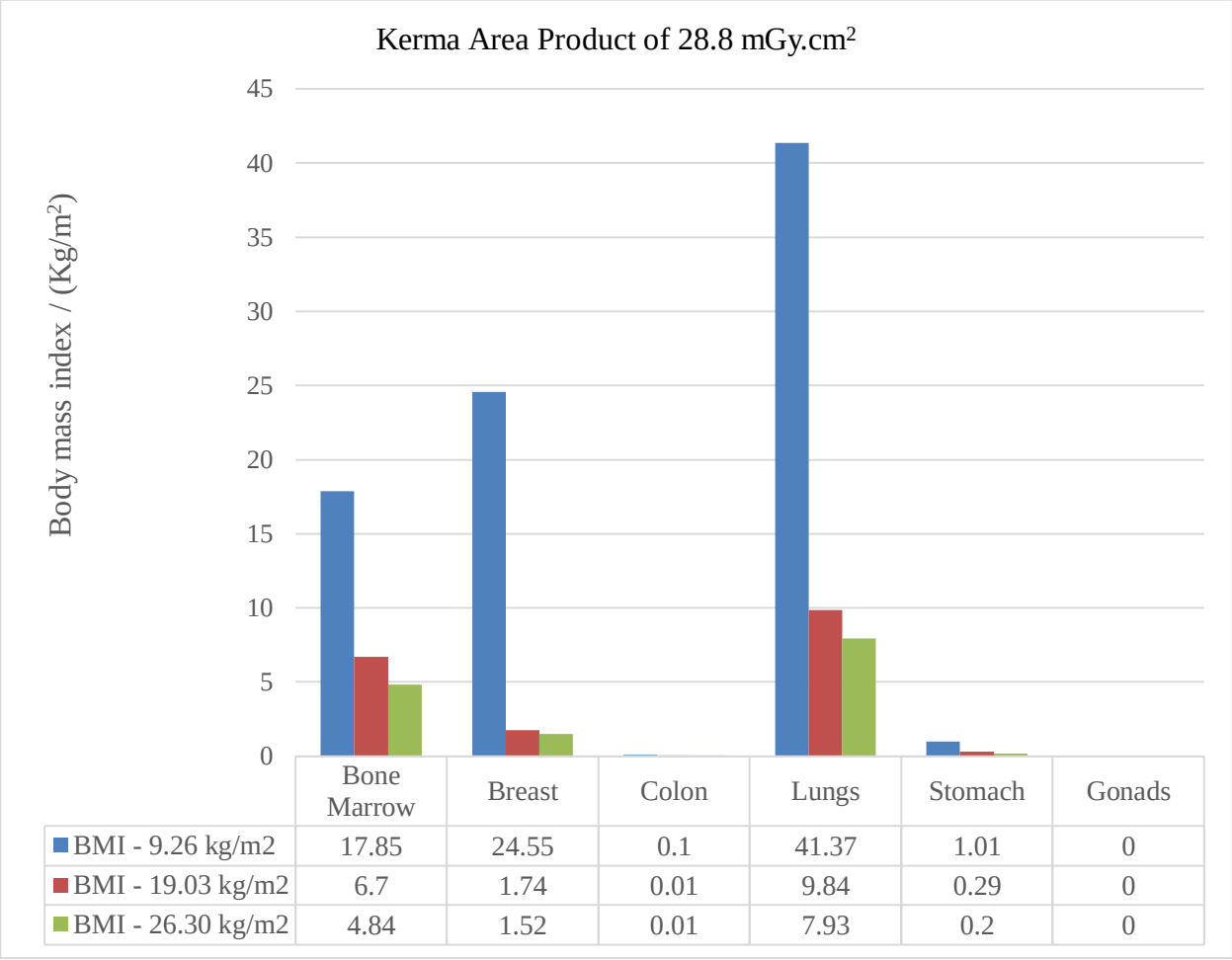
optimisation relationships. This means that before the examination starts the radiographer can estimate the KAP/mGy.cm^2 to be received by the patient by computing the body mass index of the patient.

Generally, based on which parameters (i.e. number of radiographs taken, screening time, body mass index) are readily available to the radiographer, the KAP/mGy.cm^2 for barium swallow examinations can be estimated at the Hospital. This is to serve as a guide for the radiographer in achieving optimisation without compromising the aim of the examination.

	Bone Marrow	Breast	Colon	Lungs	Stomach	Gonads
KAP – 0.83 (mGy.m2)	0.14	0.04	0	0.23	0.01	0
KAP – 8.84 (mGy.m2)	1.51	0.47	0	2.48	0.06	0
KAP – 28.80 (mGy.m2)	4.84	1.52	0.01	7.93	0.2	0

FIGURE 4.18: A bar chart of organ doses for varying KAP/mGy.cm^2

Figure 4.18 illustrates the behavior of organ doses of a patient with a body mass index of 26.0 kg/m^2 when the entrance dose KAP/mGy.cm^2 is varied. It can be seen that for a patient (i.e. constant body mass index), when the KAP value/mGy.cm^2 is increased, it increases the patient's internal organ doses. This is because there more high-energy radiation for the body to absorb. This suggests that exposing a patient to their appropriate KAP/mGy.cm^2 base on their body mass index will aid with internal dose optimization. It can also be seen that of the sensitive organs, the lungs recorded the highest dose with the gonads recording the lowest for barium swallow examinations.



	Bone Marrow	Breast	Colon	Lungs	Stomach	Gonads
BMI - 9.26 kg/m2	17.85	24.55	0.1	41.37	1.01	0
BMI - 19.03 kg/m2	6.7	1.74	0.01	9.84	0.29	0
BMI - 26.30 kg/m2	4.84	1.52	0.01	7.93	0.2	0

FIGURE 4.19: A bar chart of organ doses for varying body mass index (BMI)

Figure 4.19 illustrates the behavior of organ doses of patients with varying body mass index when KAP/mGy.cm^2 is kept constant. It can be seen that when a constant KAP /mGy.cm^2 is used for patients of varying body mass index, the organ doses decrease with increasing body mass index. This is because there is more body fat to attenuate the radiation the organs. This may have an effect on the clinical diagnostic image and increase the patient doses if there is too much body attenuation and not penetrating for image formation. It is therefore, appropriate to the right body mass index of patient corresponding with its KAP/mGy.cm^2 for patient dose optimization.

Generally, body mass index and KAP/mGy.cm^2 have influences on the internal organ doses received by patients. The organ doses increases when the KAP/mGy.cm^2 increases for a fixed body mass index. Also, the organ doses decrease when the body mass index increases for a fixed KAP/mGy.cm^2 reading. This suggests that appropriate selection or usage of body mass index and KAP/mGy.cm^2 will go a long way on enhancing patient dose optimization during barium swallow examinations at the Hospital. The proposed dose reduction techniques i.e. optimization should be included in the diagnostic procedures of the hospital for implementation.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 INTRODUCTION

This chapter provides the conclusions on the observations of this study and recommendations for radiation dose reduction to patients during barium series procedures at the Greater Accra Regional Hospital in Ghana.

5.1 CONCLUSIONS

The current patient reference dose and dose reduction techniques during barium series examinations (i.e. barium swallow, barium enema and barium meal) at the Greater Accra Regional Hospital has been assessed. A review of some proposed patient dose indicators in literature during fluoroscopy examinations have indicated the examinations protocol used, fluoroscopy screening time, number of radiographs taken per examination and radiation field size used for the examination contribute to the patient dose (external and internal) if not optimized.

The patient current reference doses during barium series at the Greater Accra Regional Hospital indicates that barium swallow has the highest KAP/mGy.cm^2 value followed by barium enema and barium meal accordingly. The varying KAP/mGy.cm^2 values for the examinations under study was attributed to be the difference in examination protocols, screening time and number of radiographs taken per examination since the radiation beam size was constant throughout the examinations. Comparisons of the KAP values/mGy.cm^2 for all the examinations of this study with that of Otoo, Gyekye et al and Gyasi et al were all below that of other studies except for barium swallow. Barium meal examinations recorded the highest effective dose to patients, followed by barium swallow recorded second the highest and barium enema accordingly. The

breast, stomach and gonads received the highest dose for barium swallow, barium meal and barium enema respectively. It was seen that the variation in the organ doses was the proximity of the organs in the beam of the radiation, part of the body being exposed to radiation, and patient demographics. Barium meal recorded the highest fluoroscopy screening time, followed by barium swallow recorded second highest and barium enema recorded lowest. It was seen that fluoroscopy screening time was not the only contributing factors to patient entrance doses. Barium meal and barium enema have the same highest number of mean radiographs taken per examination followed by barium swallow. Other factors in addition to number of radiographs taken per examination contributed to entrance patient doses.

The assessed dose reduction techniques for barium swallow examinations revealed a strong correlation between KAP/mGy.cm^2) and number of radiographs taken, screening time and patient body mass index. Therefore, based on which parameters (i.e. number of radiographs taken, screening time, body mass index) are readily available to the radiographer, the KAP/mGy.cm^2 for barium swallow examinations could be estimated at the Hospital for optimisation. It was seen that body mass index and KAP/mGy.cm^2 have influences on the internal organ doses received by patients. The organ doses increased when the KAP/mGy.cm^2 increased for a fixed body mass index and the organ doses decreased when the body mass index increased for a fixed KAP /mGy.cm^2 . Ensuring appropriate KAP/mGy.cm^2 was used for a patient (with known body mass index) was key to patient dose optimisation during barium swallow examinations at the Hospital.

5.2 RECOMMENDATIONS

Recommendations to the hospital management, the regulatory body and research community in the field of this study have been provided below.

5.2.1 Hospital Management

It is recommended that the proposed dose reduction techniques for barium swallow examinations should be tried and implemented for dose reduction. It is incumbent on management to ensure that the Hospitals diagnostic procedures are amended to factor the proposed dose reduction techniques. Training of the vital people (i.e. radiologist and radiographers) on the amended protocols would reduce errors for effective implementation. It is recommended to the radiographers and radiologist to practically familiarize themselves with the proposed dose reduction techniques for effective implementation. It is essential to note that the recommended dose reduction techniques should not be a substitute to obtaining the aim of the procedure.

5.2.2 Regulatory Authority

It is recommended to the regulatory authority to establish diagnostic reference levels with the involvement of all relevant stakeholders for implementation at diagnostic centers. In order to enhance patient dose optimization, the authority should enforce the regulatory requirement of written examination protocols. The regulatory authority should inspect this during their routine inspections. It is also recommended the authority to enforce patient dosimetry at regular intervals at all facilities. The data is to be collected would to aid in the review of established DRLs.

5.2.3 Research Community

The scientific community should explore detailed investigation into other factors of patient dose reduction techniques not considered in this study. The community is also encouraged to translate the findings of this study into easy and applicable suggestions for clinical use. Similar studies in different facilities and on the other fluoroscopy examinations are encouraged to aid in the strengthening of patient dose optimization.

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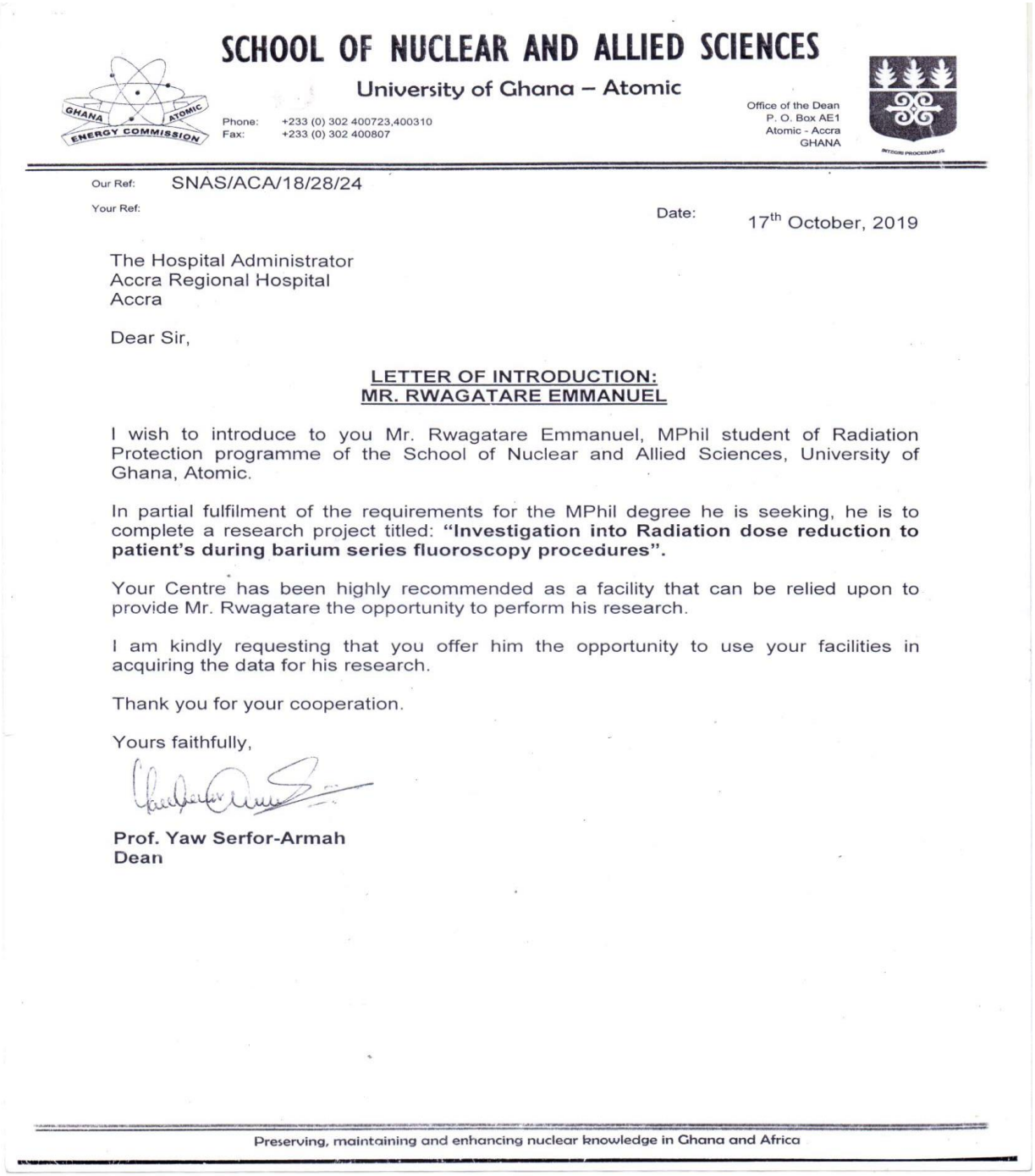
APPENDIX I: ETHICAL CLEARANCE ARRANGEMENTS



SCHOOL OF NUCLEAR AND ALLIED SCIENCES

University of Ghana – Atomic

GHANA ATOMIC ENERGY COMMISSION

Phone: +233 (0) 302 400723,400310
Fax: +233 (0) 302 400807

Office of the Dean
P. O. Box AE1
Atomic - Accra
GHANA

INTEGRITY PROFESSIONALISM

Our Ref: SNAS/ACA/18/28/24

Your Ref:

Date: 17th October, 2019

The Hospital Administrator
Accra Regional Hospital
Accra

Dear Sir,

LETTER OF INTRODUCTION:
MR. RWAGATARE EMMANUEL

I wish to introduce to you Mr. Rwagatare Emmanuel, MPhil student of Radiation Protection programme of the School of Nuclear and Allied Sciences, University of Ghana, Atomic.

In partial fulfilment of the requirements for the MPhil degree he is seeking, he is to complete a research project titled: **"Investigation into Radiation dose reduction to patient's during barium series fluoroscopy procedures".**

Your Centre has been highly recommended as a facility that can be relied upon to provide Mr. Rwagatare the opportunity to perform his research.

I am kindly requesting that you offer him the opportunity to use your facilities in acquiring the data for his research.

Thank you for your cooperation.

Yours faithfully,

Prof. Yaw Serfor-Armah
Dean

Preserving, maintaining and enhancing nuclear knowledge in Ghana and Africa

SCHOOL OF NUCLEAR AND ALLIED SCIENCES

University of Ghana – Atomic

Phone: +233 (0) 302 400723,400310
Fax: +233 (0) 302 400807

Office of the Dean
P. O. Box AE1
Atomic - Accra
GHANA

Our Ref: SNAS/ACA/18/28/26

Your Ref:

Date: 23rd October, 2019

The Chief Executive Officer
Accra Metropolitan Assembly
Accra

Dear Sir,

APPLICATION FOR ETHICAL CLEARANCE

Mr. Rwagatare Emmanuel is a second year MPhil Radiation Protection student of the School of Nuclear and Allied Sciences, University of Ghana, Atomic.

As part of the partial fulfilment of the MPhil degree, he is to do a comprehensive research and his research project titled: **"Investigation into Radiation dose reduction to patient's during Barium series fluoroscopy procedures"** at the Radiology Department, Korle-Bu Teaching Hospital and Accra Regional Hospital.

The student will need Ethical Clearance before he can execute the project.

I therefore kindly write to seek ethical clearance from your outfit to assist him for the data collection from the above Hospital facilities.

Thank you.

Yours faithfully,

Prof. Yaw Serfor-Armah
Dean

ACCRA
METROPOLITAN
ASSEMBLY

Ref. No. MH-A/0048/VOL 5/197

Date: 7TH November, 2019

METRO PUBLIC HEALTH DEPARTMENT

PROF. YAW SERFOR-ARMAH
DEAN
SCHOOL OF NUCLEAR AND ALLIED SCIENCE
UNIVERSITY OF GHANA – ATOMIC

RE: APPROVAL FOR ETHICAL CLEARANCE FOR A STUDY TITLED *'INVESTTIGATION INTO RADITION DOES REDUCTION TO PATIENT'S DURING BARIUM SERIES FLUOROSCOPY PROCEDURES'*

Reference is made to the above heading.

I am pleased to inform you that the Director of Metro Public Health Department on behalf of the Accra Metropolitan Assembly has approved the Ethical Clearance of the above mentioned study.

The validity of this ethical clearance is one year effective 7th November, 2019 to 6th November, 2020.

You will be required to apply for renewal of ethical clearance on a yearly basis if the study is not completed at the end of this clearance. You will be expected to provide six monthly progress reports and final report upon completion of your study.

FLORENCE S. KUUKYI
DIRECTOR: METRO PUBLIC HEALTH DEPARTMENT

Making Accra a Smart Sustainable City

APPENDIX II: PATIENT DATA COLLECTION SHEET

Name of Institution ……...

Patients identification No.: ……...

Equipment manufacturer…….…….

Model number……..... Serial number…….

Patient exposure Information

Patient Weight…….. Patient Height…….

Sex ……Age …….

Examination Parameters

Examination type ……..

Initial Time …….. Final Time …… Beam on Time ……

Source-Image Distance …….

Spot Radiograph:

kV	mAs	Projection	Image Size	Part of Body

Average Fluoroscopy Tube Voltage (kVp): ……...

Fluoroscopy tube current-time (mAs) …….

Console KAP Reading……..

KAP meter reading: Initial:……. Final:……..

APPENDIX III: GENDER PERCENTAGE DISTRIBUTION

Examination	This Study		Total No. Patients
	No. of Males (%)	No. of Females (%)	
Barium Swallow	24 = 53.33 %	21 = 46.67 %	45
Barium Meal	15 = 51.72 %	14 = 48.28 %	29
Barium Follow Through	2 = 28.57 %	5 =71.43 %	7
Barium Enema	20 =51.28 %	19 = 48.72 %	39

APPENDIX IV: ESTIMATED MEASURED KAP ($Gy.Cm^2$) VALUES FOR EACH EXAMINATION

Examination	**Kerma Area Product ($mGy.cm^2$)**
Barium Swallow	42.01 ± 6.54
Barium Meal	4.56 ± 0.70
Barium Follow Through	29.2 ± 8.15
Barium Enema	9.53 ± 1.76

APPENDIX V: ESTIMATED MEAN EFFECTIVE DOSE

Examinations	**Effective Dose (mSv)**
Barium Swallow	1.55 ± 2.85E-03
Barium Meal	1.94 ± 5.48E-03
Barium Follow through	0.94 ± 3.39E-03
Barium Enema	0.43 ± 3.10E-03

APPENDIX VI: MEAN ORGAN DOSES

III.1: Estimated mean organ doses during barium swallow examinations compared with other studies

Barium swallow	This Study	Gyasi et al., 2016	Gyekye et al., 2009
Bone marrow	0.77 ± 0.19	0.64 ± 0.06	0.34 ± 0.05
Breasts	4.71 ± 1.26	6.79 ± 0.58	9.23 ± 1.38
Colon(Large intestine)	8.05E-02 ± 5.03E-0	16E-03 ± 3.7E-04	2.3E-02 ± 0.67E-02
Lungs	2.69 ± 0.69	3.07 ± 0.27	1.16 ± 0.17
Stomach	0.813 ± 0.20	0.21 ± 0.03	1.09 ± 0.16
Gonads	2.29E-03 ± 1.97E-03	0.00 ± 0.00	6.7E-04 ± 2.9E-04

III.2: Estimated mean organ doses during barium meal examinations compared with other studies

Barium meal	This Study	Gyasi et al., 2016	Gyekye et al., 2009
Bone marrow	0.90 ± 0.11	2.48 ± 0.16	0.99 ± 0.14
Breasts	1.26 ± 0.72	24.11 ± 1.87	9.23 ± 1.38
Colon(Large intestine)	3.24 ± 0.72	0.63 ± 0.09	0.65 ± 0.13
Lungs	1.22 ± 0.48	12.07 ± 0.86	3.23 ± 0.46
Stomach	3.54 ± 1.17	19.97 ± 1.35	10.69 ± 1.5
Gonads	2.91 ± 0.27	0.01 ± 1.9E-03	1.2E-02 ± 0.54E-02

III.3: Estimated mean organ doses during barium enema examinations compared with other studies

Barium enema	This Study	Gyasi et al., 2016	Gyekye et al., 2009
Bone marrow	0.25 ± 7.47E-02	2.14 ± 0.09	1.42 ± 0.17
Breasts	0.12 ± 7.71E-02	0.26 ± 0.02	0.12 ± 1.5E-02
Colon(Large intestine)	0.72 ± 0.24	12.02 ± 0.55	9.52 ± 1.10
Lungs	0.19 ± 7.25E-02	0.75 ± 0.06	0.23 ± 0.04
Stomach	0.78 ± 0.29	21.26 ± 1.10	10.90 ± 1.30

Gonads	0.95 ± 0.33	1.37 ± 0.17	8.53 ± 2.09

III.4: Mean organ doses for the examinations considered for this study.

Organs	**Barium swallow**	**Barium Meal**	**Barium Follow Through**	**Barium Enema**
Bone marrow	0.77 ± 0.19	0.91 ± 0.11	4.95 ± 0.11	0.25 ± 7.47E-02
Breasts	4.71 ± 1.26	1.27 ± 0.72	0.29 ± 0.17	0.12 ± 7.71E-02
Colon(Large intestine)	8.05E02 ± 5.03E-0	3.24 ± 0.72	2.13 ± 0.67	0.72 ± 0.24
Lungs	2.69 ± 0.69	1.22 ± 0.48	0.74 ± 0.57	0.19 ± 7.25E-02
Stomach	0.81 ± 0.20	3.54 ± 1.17	1.312 ± 0.42	0.78 ± 0.29
Gonads	2.29E-03 ± 1.97E-03	2.91 ± 2.27	2.70 ± 2.12	0.95 ± 0.33

APPENDIX VII: FLUOROSCOPY SCREENING TIME FOR EACH EXAMINATION

Examination	Fluoroscopy screen time (min)
Barium Swallow	11.70 ± 2.10
Barium Meal	28.00 ± 6.77
Barium follow through	49.00 ± 5.71
Barium Enema	7.90 ± 0.99

APPENDIX VIII: NUMBER OF RADIOGRAPHS TAKEN PER EACH EXAMINATION

Examination	**No. of Radiographs**
Barium Swallow	10.00 ± 1.70
Barium Meal	15.00 ± 2.48
Barium follow through	15.00 ± 1.63
Barium Enema	15.00 ± 2.99