COMPUTED TOMOGRAPHY (CT) RADIATION DOSE IN CHILDREN: A SURVEY TO PROPOSE REGIONAL DIAGNOSTIC REFERENCE LEVELS IN GREATER ACCRA-GHANA

BY

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DECLARATION

I do declare that I, **PATIENCE ADDO** have under taken this research work in the Department of Nuclear Safety and Security, School of Nuclear and Allied Sciences, University of Ghana, Atomic campus under the supervision of Dr. Mary Boadu and Prof. Cyril Schandorf.

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ABSTRACT

The aim of this work was to assess the doses delivered to paediatric patients during computed tomography (CT) examinations of the head, chest and abdomen, and establishing regional diagnostic reference levels (RDRLs) for four age groups. The patient data, technique parameters and dose descriptors collected include: age, sex, tube voltage, tube current, rotation time, slice thickness, scan length, volume CT dose index ($CTDI_{vol}$) and dose length product (DLP). Currently, paediatric CT examinations account for 11% of radiation exposure.

For the paediatric age groups; < 1 year, (1-5 years), (6-10 years) and (11-15 years), the proposed RDRLs for head in terms of $CTDI_{vol}$ are (28, 38, 48 and 86 mGy) and in terms of DLP; (395, 487, 601, 1614 mGy cm) respectively. For Chest examinations, proposed RDRLs in terms of $CTDI_{vol}$ are (1 and 5 mGy) and in terms of DLP; (18 and 110 mGy cm) for age groups; < 1 year and (1-5 years) respectively. For Abdomino-pelvic examinations, proposed RDRLs in terms of $CTDI_{vol}$ are (3, 3 and 10 mGy) and in terms of DLP; (71, 120 and 494 mGy cm) for age groups; < 1 year, (1-5 years) and (6-10 years) respectively. For abdomen examinations, proposed RDRLs in terms of $CTDI_{vol}$ are (3, 5 and 5 mGy) and in terms of DLP; (83, 124 and 233 mGy cm) for age groups; < 1 year, (1-5 years) and (11-15 years) respectively.

RDRLs have been proposed for $CTDI_{vol}$ and DLP for head, chest, abdomen and Abdomino-pelvic paediatric CT examinations in this study. An optimisation is required for 11-15 years age group for the DLP values which was higher than their corresponding international DRLs. For an effective optimization of patient protection a trade-off between image quality and patients doses studies should be investigated.

DEDICATION

This work is dedicated to the most significant people in my life………..

God Almighty, The Elohim

Dr Brainerd Eric Anani, *my supportive husband*

Mr Samuel Addo, *my loving father*

Mrs Regina Addo, *my lovely mother*

Your support has been incalculable!

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LIST OF ABBREVIATIONS

AAPM……………………………………..American Association of Physicists in Medicine

ACR.. American College of Radiology

ALARA.. As Low As Reasonably Achievable

BSS…………………………………………………………..Basic Safety Standards

CT.. Computed Tomography

$CTDI_{vol}$ ……………………………………Computed Tomography Dose Index (Volumetric)

DLP…………………………………………………………………Dose-Length Product

DRLs...Diagnostic Reference Levels

EC.. European Commission

IAEA... International Atomic Energy Agency

ICRP... International Commission on Radiological Protection

IPEM... Institute of Physics and Engineering Medicine

kV...Kilo Voltage

LEKMA..Ledzorkuku Krowor Municipal Assembly

mAs……………………………………………………………Milliampere per second

mSv.. Milli-Sievert

NCRP... National Council on Radiation Protection and Measurements

ORP.. Optimization of Radiation Protection

RDRLs..Regional Diagnostic Reference Levels

RP………………………………………………………………….. Radiation Protection

RPB... Radiation Protection Board

SPSS... Statistical Package for Social Sciences

Sv... Sievert

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Computed Tomography (CT), a modality that produces non-superimposed, cross-sectional images of the body, was ushered into clinical practice in 1972. Newer and improved technological advancements of this imaging modality (such as fast acquisition and reconstruction times, spiral acquisition mode and multi-slice CT) has ensued in an incessant growth and multiplicity of CT examinations after its introduction (Jessen et al., 2000). CT is a dominant clinical instrument for the management and diagnosis of patients. Its ability to offer excellent three-dimensional clinical images has resulted in significant benefits in medical management, thus facilitating more precise and quicker diagnosis in addition to the evasion of interventional surgical procedures (National Research Council, 2006). According to the United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR (2000), in the preceding decades the practise of CT has grown extensively. Consequently, the numbers of examinations have increased to the extent that CT has had a considerable impact on patient care along with patient and population exposure from medical X-rays.

Children are progressively being referred for CT examinations. The introduction of rapid helical scanning, which advertently decreases the need for sedation, hence giving way to the evaluation of younger, weaker and disobliging children has resulted in this increased frequency. While such examinations account for a comparatively lesser proportion of imaging studies, they however add a large percentage to the total radiation dose from imaging (Mettler et al., 2000). Considerably, children are more susceptible to the detrimental effects of radiation than the adult population. At ages up to 10 years children are in general more vulnerable to radiation by a factor of three and the predicted lifetime cancer mortality risks attributable to radiation exposure from a single CT in a 1-year-old child is estimated to be 0.18% (abdominal) and 0.07% (head) (Brenner et al., 2001).

Radiation dose associated with CT has developed into a communal health concern, and appropriate reduction of radiation dose has thus become a fundamental goal in paediatric CT. There is therefore a need to rally the optimization of this high-dose imaging modality for this particularly susceptible section of the population (ICRP, 2007). This feat can be achieved by certifying that the principles of justification and optimisation (and/or as low as reasonably achievable, ALARA), the basics of radiation protection, are employed in CT. There is also the need to institute programs geared towards dose management in CT examinations—to guarantee that the risk to patients does not offset the benefit gained from the technique (ICRP, 2007).

At the heart of optimisation is the establishment of diagnostic reference levels (DRLs), initially recommended by the International Commission on Radiation Protection (ICRP) in 1996 and successively introduced into European and Irish legislation (Foley et al., 2012). DRLs permit the identification of uncharacteristically high dose levels by formulating an upper threshold, which standard dose levels should not go beyond when good practice is applied. Excessive doses in CT are not as easily recognized through image quality effects, as in standard film-based radiography. Hence, an awareness of representative dose levels permits CT users to rapidly recognize and appraise any protocols which do not meet the ALARA principle, thus refining radiographic practice. In recent years, a fundamental issue in the managing of radiation dose to patient in interventional and diagnostic radiology is the definition, establishment and application of DRLs (Aroua et al., 2004).

One such approach towards this venture is the assessment of exposure (scanning) parameters and accompanying doses for the purpose of comparison with DRLs. This approach has shown to be useful in many studies and also provides the baseline information for successive dose reduction or optimization (Muhogora et al., 2009).

1.2 STATEMENT OF THE PROBLEM

In the internationally approved system of radiation protection, a medical procedure which encompasses the exposure of a patient to ionising radiation must be both justified and optimized (ICRP, 2007). The International Basic Safety Standards (BSS) for Protection against Ionizing Radiation and for the Safety of Radiation Sources published by the International Atomic Energy Agency (IAEA) in 2014 (BSS, 2014) recommended the establishment of Dose Guidance Levels (DGLs/DRLs) for medical exposures to guarantee protection of patients and uphold appropriate level of good practice.

Studies of this nature have been documented for quite a number of developed countries on a national level (Shrimpton et al., 2006; Origgi et al., 2006; Conway et al., 1992; CRCPD, 2007; Hidajat et al., 2001; Moss & McLean, 2006 & Tsapaki et al., 2006). However, for developing countries, there is not enough information and an even greater lack of multi-national studies in this respect. Although there is information on CT usage from UNSCEAR, there is a paucity of information on doses in developing countries (UNSCEAR, 2000).

A study by Muhogora et al. (2009), a multi-national study and Gedel & Gablah (2014) showed an upsurge in the frequency of paediatric examinations. Both studies also showed that adult CT exposure parameters were being used in paediatric CT examinations in some countries, particularly Ghana thus imparting higher radiation doses to children. There is likewise a lack of evidence in corresponding follow up of dose distribution, taking into consideration the increase in CT scanners installation across the country as well as the absence of a dedicated paediatric CT machine.

1.3 OBJECTIVES

The aim of this study is to;

- Investigate the dose distribution levels ($CTDI_{vol}$ and DLP) from the CT machine control console for the selected CT facilities to identify if there is the need for optimization.
- Propose Regional Diagnostic Reference Levels (RDRLs) for paediatric CT examinations for the selected CT facilities
- Make appropriate recommendation based upon the findings.

1.4 RELEVANCE AND JUSTIFICATIONS

Risks of detrimental radiation effects for paediatrics are higher than for adults (NRPB, 1993). Therefore, it is particularly important to certify that radiation dose exposure during paediatric radiologic procedures are kept to a minimum. The establishment of reference dose levels for radiological examinations of adults, against which individual departments can liken their dose performance, has enabled hospitals where doses were higher to be recognized so that changes could be made to radiographic practices. A 30% decrease in mean doses for common types of radiographic examination was reported in a preceding survey prior to the setting of reference levels in a study carried out by the National Radiological Protection Board, NRPB (1996) over the period 1992-1995. Thus, the application of paediatric reference dose levels would promote dose optimization in paediatric examinations.

This study hopes to fill in the knowledge gap of the current frequency of paediatric examination and provide means of developing optimization of protection for paediatrics. In view of the paucity of information from developing countries, this study hopes to also establish a baseline data on the frequency and dose levels in paediatric CT examinations. This will form a foundation for future studies on dose management in CT.

1.5 SCOPE AND DEFINITION

The research work covered paediatric patients undergoing CT examinations at the Korle-Bu Teaching Hospital, Akai House Clinic, Ledzokuku Krowor Municipal Assembly (LEKMA) Hospital and Paradise Diagnostic Centre for the period January 2015- April 2016. All the aforementioned imaging facilities are located within the Greater Accra Region of Ghana.

CHAPTER TWO

LITERATURE REVIEW

This section provides a summary of the relevant literature with respect to what is known about the topic of study and the breaches in knowledge that must be addressed and closed. To adequately address this review, the following subsections are discussed:

- Introduction
- Radiation detriments
- Sensitivity of children
- Radiation protection
- Computed tomography & its evolution
- Diagnostic reference levels

2.1 INTRODUCTION

Radiation is the emission of energy as electromagnetic waves or as moving subatomic particles, especially high-energy particles which cause ionization. These particles, radiated from their sources travel in all directions rectilinearly (Dowd & Tilson, 1999). There are different types of radiation, classified according to their physical properties. Electromagnetic (EM) radiation is a type of radiation phenomenon which takes on the form of self-propagating waves in matter. EM radiation consists of electric and magnetic field components which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation and are produced by the motion of electrically charged particles. Generally, the quantum theory of physics recognizes the dual wave-particle nature of EM radiation and states that EM radiation can be treated either as waves or particles. The particle-like properties appearing as discrete packets are called quanta or photons.

Radiation at the short-wavelength end of the electromagnetic spectrum (high frequency ultraviolet, X-rays, and Gamma Rays) is ionizing, due to its composition of high energy photons. Lower-energy radiation, such as visible light, infra-red, microwaves, and radio waves, are not ionizing (United States Nuclear Regulatory Commission (USNRC), 2004). EM radiation therefore carries energy and momentum that may be imparted to matter through various interaction mechanisms. In particular, radiation is classified or described as ionizing if the energetic particles have enough energy to cause or induce ionization via removal of electrons from atoms or molecules of materials resulting in energy deposition in the materials upon interaction; otherwise, the radiation is classified as non-ionizing (William, 2001).

2.1.1 BENEFITS OF IONIZING RADIATION

X-rays are energetic, penetrating ionizing radiation and interact with matter via the Compton Effect. Because x-rays are highly penetrating and can see "through" the internal structures such as tissues, organs, etc., of living body matter, they are employed effectively in diagnostic medical and industrial imaging or radiography to facilitate investigation of diseases (Martin and Corbett, 2003). Since 1960, invasive medical procedures conducted by roentgen rays have been developed extensively, especially in the field of catheterization of the heart and blood vessels and the urinary and digestive systems (Valentin, 2000). Other researchers also, have identified many benefits such as visualizing body systems, organs, and soft tissues. It also introduces helpful diagnostic images for different pathology (Brent, 1984; Montgomery, 1997). Presently, about 30%-50% of critical decisions in medical approaches are estimated by x-ray imaging procedures or methods.

Tavakoli *et al.*, (2003) have confirmed as a matter of importance that diagnostic imaging has increased dramatically in the last 10-15 years and has now become a routine part of clinical investigations of many patients and for that matter a crucial determinant in their disease management. It has also been indicated that 70%-80% of all clinically relevant questions are solved by using x-rays in most advanced imaging departments in the economically privileged part of the world (Staffan, 2003). Such benefits as identified by Martin and Shand (2003) include, detection of previously unsuspected diagnosis, monitoring of a patient's progress in a specific disease like healing of a long bone fracture and screening for a treatable condition.

2.2 BIOLOGICAL EFFECTS AND RISK ESTIMATE OF RADIATION

The use of x-rays for diagnostic medical imaging has shown to be an exceptional assistance to good health care and diagnosis of diseases. However, by reason of the physical properties of x-rays combined with the physics of its interaction with matter, x-rays can cause biological effects (cell damage) in humans or living organisms either directly (action on cells) or indirectly (result of chemical changes near cells) if doses in excess of internationally accepted limits are administered. As an example, the genes in the reproductive cells can undergo alterations which can further lead to hereditary genetic disorders in future generations. In general, biological effect is produced by absorbed doses of EM radiation.

Biological effects of radiation are typically divided into two categories. The first category comes from exposure to high doses of radiation over short periods of time producing acute or short term effects. The second category represents exposure to low doses of radiation over an extended period of time producing chronic or long term effects (USNRC Technical Training Centre, 2004). Sherer *et al.* (2002) further categorizes the effects of radiation on living organisms into stochastic and non-stochastic.

Deterministic effects are dose related, the severity of the effects increasing with radiation dose, and are seen above a baseline threshold dose determined by factors such as type of effect and the developmental stage of the organism. They are observed only if relatively large doses are applied and multiple cells are involved (American Council of Radiology (ACR), 2008). Thus severity of deterministic effects increases with increased radiation dose above the threshold.

Stochastic effects can result from induced changes in single cells and can potentially result in neoplasia or in changes to reproductive genes. In contrast to deterministic effects, the severity of a stochastic effect does not increase as the radiation dose increases. Stochastic effects are believed to be possible at any level of radiation exposure, with the likelihood increasing as dose increases (ACR, 2008).

In the dose range relevant for radiation protection purposes, inheritable damage, cancer and leukemia belong to stochastic radiation damages. The probability that stochastic radiation damage will occur differs widely for the irradiated individual organs or tissues. The International Commission on Radiological Protection, ICRP (2007) indicates a value of 5.5 % per Sievert for cancer and 0.2 % per Sievert for heritable effects after exposure to radiation at low dose rate.

The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed. The hematopoietic cells are one of the most sensitive cells to radiation due to their rapid regeneration rate. However, muscle and nerve cells are relatively insensitive to radiation (USNRC Technical Training Centre, 2004). Special protection should be provided to certain organs of the body, namely the thyroid and the reproductive organs (gonads) because they were found to be more radiosensitive than other organs of the body (Sherer *et al.*, 2002). The possible biological effects to whole body and the associated risk factors of some important human organs arising from detrimental effects of radiation are shown in Tables 2.1 and 2.2 respectively.

Table 2.1.: Possible Biological effects to Whole Body

Dose equivalent (Sv)	Biological Effect
<0.10	No effect
0.10 - 0.25	No clinical effect is observed
0.25 0.50	No serious danger, however blood change could occur
0.50 – 1.00	Some change in blood and some damage, however no tiredness
1.00 – 2.00	Damage; possible whole body tiredness
2.00 – 4.00	Damage; Whole body tiredness, the weak may die
4.50	50% of the exposed die within 30 days, other 50% can recover, however some permanent damage may remain
> 6.00	Death rate may reach 100%

Source: United States Nuclear Regulatory Commission Technical Training Centre, (2004)

Table 2.2: Radiation Detriment to Human Tissue and Risk Factors

Tissue or organ	W_T	$\sum W_T$
Bone marrow (red), colon, lung, stomach, breast, remainder tissues [a]	0.12	0.72
Gonads	0.08	0.08
Bladder, oesophagus, liver, thyroid	0.04	0.16
Bone surface, brain, salivary glands, skin	0.01	0.04
	TOTAL	1.00

[a] The W_T for remainder tissues (0.12) applies to the arithmetic mean dose to these 13 tissues and organs for each sex: adrenals, extra-thoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (male), small intestine, spleen, thymus, uterus/cervix (female).

Source: BSS, 2014.

2.3 POPULATION SENSITIVE TO RADIATION

A number of epidemiological studies have demonstrated that the risks of radiation-induced harm in the foetus are greater than in the adult (Martin *et al.*, 2003). Sadly, unborn babies are the most vulnerable members of the population sensitive to radiation. They are sensitive particularly during their early development between weeks 2 and 15 of pregnancy. The health consequences can include stunted growth, deformities, and abnormal brain function (Centres of Disease Control and Prevention, 2005).

For a given dose, there is a difference in cancer risk from radiation exposure to children paralleled with adults. There are several reasons for this difference. First, for the most part, tissues and organs that are growing and developing are more sensitive to radiation effects than those that are fully mature (Pierce et al., 1996 & Hall, 2002).

Subsequently, the oncogenic effect of radiation may have a long (for instance, decades) latent period. This latent period varies with the type of malignancy. Leukaemia has a shorter period (approximately ≤10 years) than solid malignancies. An infant or child, therefore, has a longer life expectancy which to manifest the potential oncogenic effects of radiation compared with older adults. For example, solid radiation-induced malignancy with a 30-year latent period will more likely occur in a 10-year-old than in a 50-year-old, on the basis of life expectancy. Pierce et al (1996) summarized the radiation cancer risk at different ages and stated that those exposed at 50 years of age have approximately one third of the risk of a 30-year-old and that "projection of lifetime risks for those exposed at age 10 is more uncertain. Under a reasonable set assumptions, estimates for this group range from about 1.0 –1.8 times the estimates for those exposed at age 30."

This augmented sensitivity varies with age, with the younger ages being more at risk. Because the risk varies with age, the increased paediatric risk compared with adults will also vary depending on exactly which age groups are compared (Pierce et al., 1996).

Third, in the case of CT scanning, the radiation exposure from a fixed set of CT parameters results in a dose that is relatively higher for a child's smaller cross-sectional area compared with an adult (Huda et al., 1997).

2.4 COMPUTED TOMOGRAPHY & ITS EVOLUTION

Computed tomography (CT) introduced in the early 1970s has transformed the whole field of medicine and not only diagnostic radiology. The introduction of spiral CT in the early 1990s constituted a fundamental evolutionary step in the development and ongoing refinement of CT imaging techniques (Kalender *et al*., 1990 and Crawford & King, 1990).

Computed tomography is a powerful non-invasive and non-destructive medical imaging examination that uses highly specialized x-ray equipment to produce cross-sectional images of the body from either transmission or reflection data obtained by illumination of the specific organ or tissue from many different directions. Each cross-sectional image typifies a "tomos" or "slice" of the person's anatomy being imaged, and is used for a variety of diagnostic and therapeutic purposes (National Cancer Institute, 2013). The derived information from the transmitted or reflected x-ray photon energies is called projection and is the integral of the image in the direction specified at a given angle (Morin, Geber & McCollough, 2003).

In general, CT scans can be performed on every anatomical region of the human body for radio diagnostic, treatment planning, interventional, or screening reasons and are mostly carried out as outpatient procedures. CT scans provide greater clarity and reveal more anatomical details than conventional x-ray radiography examinations (Goldman, 2007).

2.4.1 Evolution of CT

CT has undergone substantial makeovers since the dawn of spiral CT in the 1990s and the evolution from single-detector row to multi-detector row technology. CT, since its inception, has experienced a lot of technological advancements, which has improved its speed and image acquisition (Hatziaanuou et al., 2003). A summary of such advancements is illustrated in Table 2.3.

Table 2.3: Evolution (Generation) of CT scanners

Generation	Source	Source Collimation	Detector
1st	Single X-ray Tube	Pencil Beam	Single
2nd	Single X-ray Tube	Fan Beam (not enough to cover FOV)	Multiple
3rd	Single X-ray Tube	Fan Beam (enough to cover FOV)	Many
4th	Single X-ray Tube	Fan Beam covers FOV	Stationary Ring of Detectors
5th	Many tungsten anodes in single large tube	Fan Beam	Stationary Ring of Detectors
6th	3G/4G	3G/4G	3G/4G
7th	Single X-ray Tube	Cone Beam	Multiple array of detectors

Source: http://www.kau.edu.sa

2.4.2 CT Imaging Process

The CT imaging process requires the use of specialized x-ray imaging equipment. The instrumentation includes a high thermal capacity x-ray tube and generator mounted on rigid circular support called gantry, and an assembly of detectors which rotate around the patient with the axis of rotation running from the patient's head to toe and measure the average linear attenuation coefficient between the tube and detectors. The schematic flowchart of the CT imaging process is illustrated in Figure 1. The attenuation coefficients reflect the degree to which the x-ray intensity is reduced by the tissue it traverses. The radiation detection system is composed of detection elements, such as scintillating crystals and photodiodes.

A data acquisition system (DAS) is provided in the instrumentation to measure the transmitted radiation data through the tissue, and digitizes it to allow reading by the computer system (Cunningham & Judy, 2000).

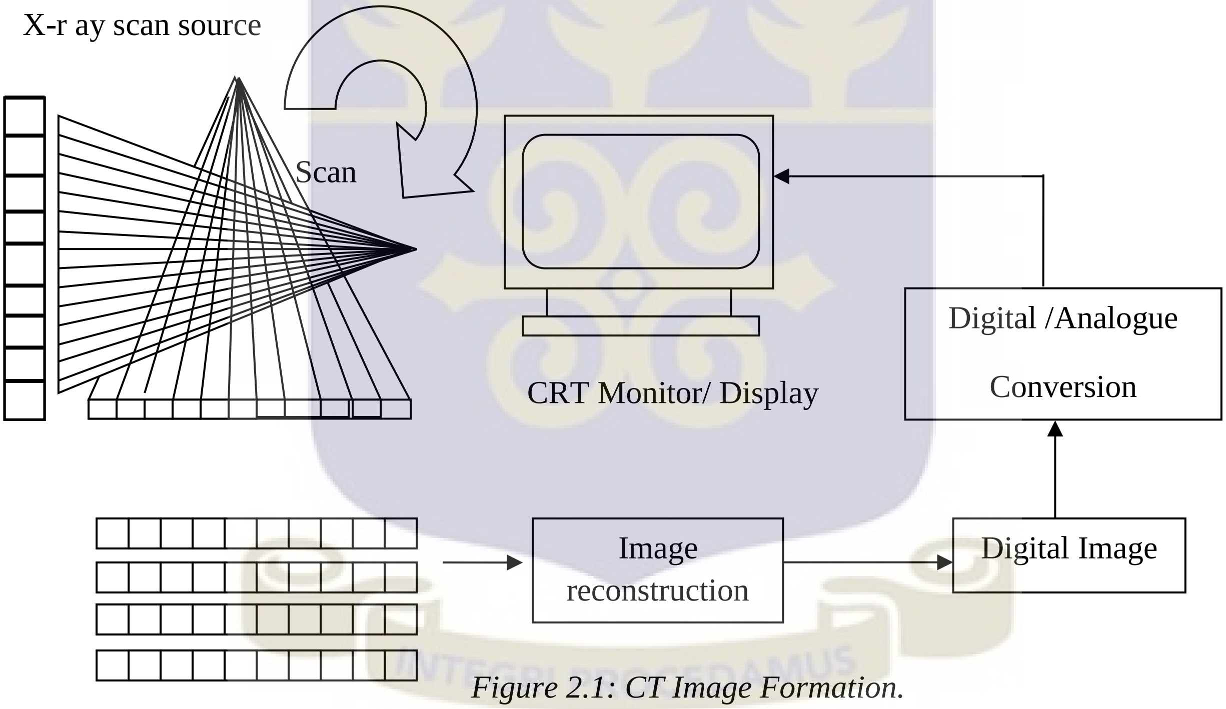

Figure 2.1: CT Image Formation.

2.5 COMPUTED TOMOGRAPHY DOSE DESCRIPTORS

Dose quantities utilized in CT include weighted CT dose index ($CTDI_w$), volume-weighted CT dose index ($CTDI_{vol}$) and dose-length product (DLP) as commonly displayed by CT scanners (Bongartz *et al*, 2004). Normalized (e.g., per100 mAs) CTDI values for different scanners can also be used with typical technique factors such as tube current-time, product, and pitch. The

CTDI values can be directly measured at typical technique factors to determine a site's typical scanner output (McCollough *et. al*, 2011). These quantities are dose indicators that characterize radiation exposure in CT for the purposes of comparing practice.

In particular, the established mean doses of a specific CT facility should be reviewed annually and revised as necessary following periodic local dose audit to monitor trends and can also be utilized for subsequent comparison with practice at other CT centres for purposes of pursuing improved patient protection (Institute of Physics and Engineering in Medicine, 2005). The CTDI and DLP are the appropriately accepted dose parameters to assess DRLs for radiation dose optimization (Hatziioannou *et al*, 2003).

Recent CT scanners' dosimetric software calculates DLP using CTDI values selected on the basis of the examination protocol and not the main body part being examined (Tsalafoutas, Thalassinou & Efstathopoulos, 2012). Thus, if the chest protocol is used for a CT head procedure then $CTDI_{vol}$ and DLP values displayed will be calculated according to the body part selected which is head CTDI values, and not the body part examined. Thus, if the CT imaging protocol for head is selected instead of the part of the body being examined, the DLP and effective dose values will increase because of its high CTDI values (Tsalafoutas, Thalassinou & Efstathopoulos, 2012).

2.5.1 CT Dose Index

According to Morin, Geber & McCollough (2003), the CTDI value represents the integral under the radiation dose profile in the z-axis of a single scan that would produce a tomographic image.

Mathematically, CTDI is referred to as the integral along a line parallel to the axis of rotation (z) of the dose profile ($D(z)$) for a single slice divided by a nominal slice thickness (T), and expressed as

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \tag{2.1}$$

where T is the nominal slice thickness pitch (Hatziioannou *et al*, 2003). The weighted $CTDI_w$ which does not account for effects of pitch or gaps in the helical CT scan is calculated via the equation, normalized to 100 mAs as

$$CTDI_w = \frac{1}{3}\left(CTDI_{100,center} + 2CTDI_{100,edge}\right) \tag{2.2}$$

The pitch is defined as the ratio of table travel distance per rotation to the nominal beam width (American College of Radiology, 2008) and quantifies the table increment per consecutive rotation. The $CTDI_{vol}$ in particular, quantifies CT scanner output for a specific scan protocol and accounts for the pitch. It represents the average radiation dose in 3-D (x-, y-, and z-directions). In Gerber's work (2002), the $CTDI_{vol}$ for a multislice system is expressed as:

$$CTDI_{vol} = \frac{1}{p}CTDI_w = \frac{1}{3p}\left(CTDI_{100,center} + 2CTDI_{100,edge}\right) \tag{2.3}$$

In respect of the travel distance per gantry rotation and nominal beam width, the $CTDI_{vol}$ is written as

$$CTDI_{vol} = \frac{1}{p}CTDI_w = \left(\frac{d}{1/w}\right)CTDI_w = \left(\frac{d}{1/nT}\right)CTDI_w \tag{2.4}$$

Where n is the number of sections per scan, d is the travel distance per gantry rotation and w is the nominal beam width. The value of $CTDI_{vol}$ can be displayed on the operator's console by most CT scanners which make it easier for comparing with radiation doses received by patients from different imaging protocols (Morin, Geber & McCollough, 2003).

2.5.2 Dose-Length Product

The DLP is another DRL parameter and represents the phantom volume irradiated during the complete examination (Hatziioannou *et al*, 2003). Mathematically, the DLP is related to the $CTDI_{vol}$ as

$$DLP = CTDI_{vol} xL = \frac{CTDI_{w} xL}{p} = \left(\frac{nT}{I}\right) CTDI_{w} \tag{2.5}$$

where L and I are scan length interval and interval of scan length respectively (Stanley, 2001). Alternatively, per the work of Hatziioannou *et al* (2003), Equation (2.5) can be expressed in terms of other parameters such as the serial scan sequence (i), number of slices (N), radiographic exposure (C), total acquisition time (t), and tube current (A) as:

$$DLP = \sum_{i} (nCTDI_{w}) TNC \tag{2.6}$$

$$DLP = \sum_{i} (nCTDI_{w}) TAt \tag{2.7}$$

To better represent the overall energy delivered by a given scan protocol, the $CTDI_{vol}$ can be integrated along the scan length to compute the DLP. According to Bongartz *et al* (2004), the DLP reflects the integrated radiation output (and thus the potential biological effect) attributable to the complete scan acquisition.

2.5.3 Factors Affecting Dose Descriptors

The choice of CT scanning protocols inadvertently influence the dose delivered to the patients hence the selection of scanning protocols and exposure parameters is of utmost importance. Examples of such scanning protocols include the choice of radiographic baseline to which the scan plane is parallel, the choice of slice thickness and spacing, the choice of peak kilo voltage (kV), mAs, gantry tilt, pitch factor etc. (Smith and Shah, 1997).

Other scanning parameters which also have some significant effect on patient dose are the scanning length and pitch factor. The nominal slice thickness which is generally in the range of 1mm-10mm is usually selected by the technologist based on the clinical requirement.

Larger slice thickness results in lower spatial resolution with lower patient dose and conversely, smaller slice thickness increases spatial resolution and increases patient dose (European Commission (EC), 1999).

Automatic tube current modulation (ATCM) allows for automatic reduction of tube current when scanning areas of relatively reduced attenuation while increasing for areas of higher attenuation without compromising on image quality (Russell et al., 2008). Prior to the introduction of ATCM, a single mAs value was selected based on experience or manufacturer's recommendation for the whole scan length though attenuation or patient size may vary for a given scan length (Goldman, 2007).

Huda (2007) observed increase in *DLP* (dose length product) which he attributed to the use of longer scan length. The effect of this, according to the author, is unnecessarily high mAs for some slices and possibly low mAs for others. Livingstone et al. (2009) realized a dose reduction of about16-28% with the use of tube current modulation while maintaining diagnostic image quality. Koller et al. (2003) observed significant variations in CT dose and attributed the variations to differences in user-selectable exposure factors. Table 2.4 shows a summary of the effect of some scan parameters on the CT dose descriptors.

Table 2.4: Effect of Scan Parameters on Dose Descriptors.

Parameter	**Effect on Dose**
mAs	Reducing mAs reduces dose (mAs proportional to $CTDI_{vol}$)
Pitch	Increasing pitch reduces dose
kVp	Lowering kVp will reduce $CTDI_{vol}$ (Relationship is not linear)
Collimation	Use widest possible collimation
Scan range	Restrict the scan range to the region of interest. Reduces DLP, no effect on $CTDI_{vol}$.

	Particularly important for repeat scans.
Dose modulation	Aims to maintain same noise level In combination scans (Chest/Abdomen)

Source: Yu et al. (2009)

2.6 PAEDIATRIC COMPUTED TOMOGRAPHY

Computed Tomography, since its inception, has undergone a lot of technological advancements, which have improved its speed and image acquisition. (Hatziaanuou et al., 2003). The resultant effect of this is the increase in the practice of CT scan worldwide and a corresponding increase in paediatric CT examinations. The advent of fast scanning has reduced the need for sedation in paediatrics scheduled for CT and has also enhanced the evaluation of younger and less cooperative children (Hatziaanuou et al, 2003; Pages et al., 2003). Regardless of the immense benefits that children and their families derive from the diagnostic information provided by CT scan, the radiation dose delivered to these patients cannot be overlooked because the radiobiological consequences are not trivial (Boone et al., 2003). Children are relatively more radiosensitive to ionizing radiation because:

- of increased sensitivity to cell damage due to cell division being more active in children
- some radio-sensitive organs such as the bone marrow represent a higher proportion of their body mass making them more susceptible to radiation-induced cancer (Ledenius, 2011).

There exist a great potential for the biological effects of radiation to manifest in children due to long life expectancy in children (Daros et al., n.d.). Smith et al. (2007) points out that the estimated lifetime cancer risk of a one-year old child is about 0.07%. A study by Siegel et al. (2004) showed that paediatric CT accounted for about 4% of all CT examinations in 1989 and increased to 6% in 1993. A different study conducted by Donnelly (2005) also showed that on the basis of the 2000 data, approximately 2.7 million CT scan examinations are performed on children less than 15 years annually. However, a study conducted by Muhogora et al. (2010)

revealed that in Africa, paediatric CT accounts for about 20% of all CT examinations. The above statistics raises a lot of concern considering the fact that these figures are likely to shoot up in a few years. Paterson et al., (2001) reported that paediatric CT parameters were not adjusted based on age or examination type indicating that children may be exposed to unnecessarily high radiation during CT scan. This view was supported by Galanski and Nagel (2006) who suggested that for paediatric head CT, adjustments be made based on age since the size of the head is overly large in infants and children.

Similarly, Muhogora et al. (2010) observed that 11 CT facilities that participated in their study used adult exposure parameters for children thus indicating the need to improve optimization. Therefore it is of utmost importance that when CT is chosen as the diagnostic imaging modality for children radiation dose be minimized (Sun et al., 2010). In particular, reduction in paediatric CT dose can be achieved via justification of paediatric CT use to ensure reduction of unnecessary examinations; adjustment of scanning protocols for children according to age and weight; development of automatic exposure device (AED) by manufacturers and finally user education especially for radiologic CT technologists.

2.7 RADIATION PROTECTION

The damaging biological effects of radiation to living organisms are principally due to radiation overexposures in work places including hospitals. This became apparent a few years after its discovery as noted by Grainger and Allison (2001). Because of the potential hazard of radiation, the use thereof needs to be regulated through the provision of adequate protection for occupational staff and also for patients undergoing diagnostic imaging procedures at hospitals against the harmful effects of radiation. This is achieved via a programme called radiation or radiological protection.

Radiation protection has been defined by Statkiewicz *et al.* (2002) as effective measures employed by radiation workers to safeguard patients, personnel and the general public from unnecessary exposures to ionizing radiation. Given the vast amount of data on the health risks associated with the peaceful uses of radiation including applications in medical imaging, the ICRP clearly defined the overall objective of radiation protection and stated that it is "to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure" and further suggested that current standards of protection are meant "to prevent the occurrence of deterministic effects, by keeping doses below relevant thresholds, and to ensure that all reasonable steps are taken to reduce the induction of stochastic effects" (ICRP, 1991).

A similar statement on the need for limiting exposures to ionizing radiation protection was issued by the United States National Commission on Radiological Protection (NCRP) and stated that ”the goal of radiation protection is to prevent the occurrence of serious radiation-induced conditions (acute and chronic deterministic effects) in exposed persons and to reduce stochastic effects in exposed persons to a degree that is acceptable in relation to the benefits to the individual and to society from the activities that generate such exposure" (NCRP, 1993).

A couple of decades ago, the ICRP advocated standards for radiation protection standards based on three general principles. These principles have in particular gained worldwide utilization or applications by notable radiation protection institutions or bodies including the International Atomic Energy Agency (IAEA), the NCRP, the Radiation Protection Board of Canada (RPB) and the Radiation Protection Board (RPB) in Ghana, etc. to provide guidelines for safe uses of radiation in health care. The three general principles are Justification (of a practice), Optimization (of protection), and Dose and risk limits and have been referred to as one of the two triads of radiation safety by Wolbarst (1993). Whereas *justification* refers to a positive net benefit of the activity involved in the radiation exposure of an individual, *optimization* refers to the ability to achieve that benefit by administering a dose that is *as low as reasonably achievable* (ALARA). The ALARA methods also include restriction of radiation to only the organ that is to be examined and being careful that sensitive tissues are not exposed (Statkiewicz-Sherer, 1998).

In particular, the ALARA principle refers to receiving the maximum benefits of radiation such as x-rays by using the minimum of radiation dose to avoid its risks (Bushong, 1997). The ICRP (1991) has chosen to use the term *optimization of radiation protection* (ORP) and has indicated that the recommendations for ALARA and ORP are synonymous. The NCRP approach is also to recognize optimization as being synonymous with ALARA (NCRP 1990).

2.7.1 Justification of procedures

Diagnostic investigations using ionising radiations offer potential benefits to the health care of patients and are an accepted part of medical practice. However it is recognised that exposure to such radiation is associated with an increased risk in the long term of malignant disease in those persons irradiated (Berrington de González and Darby, 2004; Engel-Hills, 2006). For example, studies conducted have indicated that in the UK about 0.6% of the cumulative risk of cancer to age 75 years could be attributed to diagnostic X-rays, which is equivalent to about 700 cases of cancer per year. In 13 other developed countries, estimates of the attributable risk ranged from 0.6% to 1.8%, whereas in Japan, which had the highest estimated annual exposure frequency in the world, it was more than 3% (Berrington de González and Darby, 2004; Manning, 2004).

Furthermore, it is assumed that the probability of occurrence of these adverse effects is directly proportional to the level of exposure, without any dose threshold (Engel-Hills, 2006). On this basis, it is necessary to consider the potential harm, albeit relatively small, arising from even the lowest levels of absorbed radiation dose and to avoid those exposures that have influence on patient management. Accordingly, it is necessary to weigh the likely benefits to patient management from diagnostic medical exposures against the potential radiological harm in order to justify such practices.

Internationally, in countries with regulatory bodies, it is recommended that all diagnostic practices should be justified (Engel-Hills, 2006). Justification is the first step in radiation protection. It is accepted that diagnostic exposure is justifiable only when there is a valid clinical indication, no matter how good the imaging performance may be. According to the International Atomic Energy Agency (IAEA), every examination must result in a net benefit to the patient (IAEA-TECDOC-1423, 2004). Justification of X-ray examination is said to have the most significant impact on radiation dose (Manning, 2004) and is possibly the most vital measure in radiation protection in diagnostic imaging procedures (Cook et al, 2001). For these reasons, in Ghana's regulations it is stated that:

"*no patient is exposed to radiation for diagnostic purposes unless the procedure is prescribed by a medical practitioner who fulfils the requirements of the Ghana Medical and Dental Council and the Ghana Health Service on training and experience for prescribing procedures involving medical exposure. The prescriber shall consider the efficacy, benefits and risks of alternative technology, for example ultrasound, magnetic resonance imaging and endoscopy*". (Radiation Protection and Safety Guide, GRPB-G9 p. 11, 2003)

Justification therefore takes into consideration the benefits and harm that an X-ray procedure can provide for the management of the patient as well as the degree to which workers and the general public are endangered with the cost of the procedure also in mind (Brennan, 2003).

2.7.2 Optimization- a balance between image quality and dose

Given the harmful effects associated with exposure to ionising radiation, it is important both to be able to measure patient doses, and to reduce them where possible. Over the years, reductions in patient doses have been achieved through advances in technology and changes in clinical practice and in the UK in particular, repeated national dose surveys by the National

Radiological Protection Board have shown a significant lowering of patient dose for individual procedure types (Hart et al, 2002; Hart et al, 2007). However, whilst some dose reduction measures have a positive effect on image quality, others degrade contrast or increase noise. Thus it is important not just to reduce doses but to optimise each imaging technique, maximising its efficiency and determining the right balance between patient dose and image quality. Once an X-ray examination is definitely justified, the principle of optimisation implies that during the examination, the margin of good over harm is maximised by given attention to all aspects of radiographic technique (ICRP, Publication 73, 2007). As with all medical investigations, including medical imaging, ethical considerations need to be addressed before ionising radiation can be administered (IR (ME) R, 2000) and one such ethical consideration relating to ionising radiation is the ‘Cost-Benefit Relationship’. Will the benefits of this radiographic examination outweigh the detrimental effects of ionising radiation?

A principle commonly used within imaging departments when administering ionising radiation is the optimisation. The concept of optimisation, was originally advocated by the ICRP in 1959, and articulated as “keeping doses as low as practicable” (ICRP Publication 101, 2006) thus laying down the precept that the maximum margin of good over harm should be achieved from any exposure. In 1996, the ICRP explained optimisation in a context that “...for any source (of medical irradiation), doses or the likelihood of being exposed should be as low as reasonably achievable (“ALARA”) and constrained by doses to individuals and risks to individuals from potential exposures” (ICRP Publication 60, 1991). In the United Kingdom, for reasons of legal precedent “ALARA” has been amended to read “ALARP”- As Low as Reasonably Practicable (Engel-Hills, 2006).

2.7.3 Dose limitation

The third principle of the radiation protection structure recommended by the ICRP is that of application of dose constraints. This principle requires that the combined effect of all relevant exposures to any individual should be constrained either by a dose limit, or to some control of risks (ICRP Publication 73, 2007). These concepts of dose limits and control of risk were introduced because of substantial biological and epidemiological evidence for radiation-induced effects in man (ICRP, 1998). The principle of limitation affects those who are occupationally exposed and the general public and suggests that employees must not be exposed to radiation dose beyond a certain limit (Ionising Radiation Regulations (IRR, 1999)**.** Dose limits do not apply to patients undergoing medical exposure, since the exposure must be justified by a net benefit to the patient, and hence clinical necessity supersedes dose limitation (Goldstone, 2003b). However, exposures must be optimised by maximising radiation protection to achieve the best balance between necessary radiation dose and diagnostic outcome (ICRP Publication 73, 2007). When justification and optimisation are effectively applied the principle of limitation may not be necessary (Goldstone, 2003b).

The second triad of radiation safety is generally referred to as the *time-distance-shielding* approaches or principles of radiation protection. These are principles are primary actions which when put into good practice provide radiological protection of personnel (occupation radiation protection), patients (medical radiation protection), and members of the public (public radiation protection) from potential risks of radiation. Bushong (1993) referred to this same triad as the "*cardinal principles of radiation protection.*"

The intensity or exposure rate (*H*) of imaging equipment such as an x-ray tube applied in imaging procedures in a hospital is dependent and proportional to the square of the applied tube voltage (V^2), the tube current (*I*), the atomic number (*Z)* of the target material. Combining these parametric quantities, we have;

$$H \propto V^2 IZ \qquad (2.8)$$

Another factor which influences radiation exposure is distance. This dependence is governed by the inverse square law of radiation exposure which states *that the intensity (exposure rate)* *of the radiation from a point source varies inversely as the square of the distance from the source provided there are no physical processes such as absorption or scattering by the medium of travel.* Mathematically, the inverse square law is expressed via

$$H \propto \frac{1}{d^2} \qquad (2.9)$$

where d is the distance between the radiation source and the exposed individual. From Eqn. (1) and invoking the inverse square law (Eqn. (2)), the total exposure can be re-formulated as

$$H \propto \frac{V^2 IZ}{d^2} \qquad (2.10)$$

For a time interval t, during which an individual undergoing a diagnostic imaging procedure is exposed to radiation, the amount of x-rays or exposure received is expressed as

$$Ht = G = \frac{V^2 IZt}{d^2} \qquad (2.11)$$

where Ht is the exposure.

From the physics, it is obvious that time is a major principle of radiation protection and is a key factor in reducing the risk of radiation exposures. In particular, the physics of radiation exposure indicates time as an essential variable or parameter. From Equation (4), the radiation exposure is directly proportional to the exposure time. Hence decreasing the exposure time during an imaging procedure will result in a decrease in exposure to radiation. The exposure time, radiation exposure and exposure rate (exposure per unit time) are thus related according to the expression:

$$Exposure = exposure \quad rate \quad X \quad exposure \quad time$$
$$\Rightarrow G = Ht \qquad (2.12)$$

These algebraic expressions simply imply that if the exposure time is kept short, then the resulting dose to the individual is small. As an example the NCRP (1989b) suggested that the dose rate in chest examination is high. However, due to the very short exposure time utilized

(≤0.05 sec), the total dose equivalent is small [~0.2 mSv (20 mrem) which is within the ALARA principle.

The second radiation protection principle or primary action relates to the distance between the source of radiation and the exposed individual. The physics indicates that the radiation exposure decreases with increasing distance from the radiation source. Thus when the distance is doubled, the exposure is reduced by a factor of 4. For example, in mobile radiography, where there is no fixed protective control booth; the personnel should remain at least 2 m from the patient, the x-ray tube and the primary beam during the exposure. In this respect, the ICRP (1982), as well as the NCRP (1989a), recommended that the length of the exposure cord on mobile radiographic units be at least 2m long. Baker, Bromilow & Costigan (1992) measured ionizing radiation exposure to nursing staff adjacent to mobile chest x-ray examinations and concluded that there were no radiation safety hazards to staff that were about 2 m away from the patients.

Shielding is the third major factor in reducing the risk of radiation exposure. Shielding implies or involves the use of certain radiation attenuating materials of high absorption across section such as concrete and lead which will attenuate or reduce the radiation intensity or exposure rate when located or placed between a patient or occupational worker and the direction of radiation beam travel. In medical diagnostic radiography, there are at least four shielding approaches including gonadal shielding, personnel shielding, room shielding, and x-ray tube shielding. These approaches are intended to protect personnel, patients and members of the public from unnecessary radiation exposures. Shielding is often achieved in diagnostic imaging radiography via wearing leaded aprons, leaded thyroid shields, and leaded eyeglasses (Bushong, 2001; Sherer *et al.*, 2002).

Additional to the radiation shielding materials, occupational workers in radiology and imaging departments wear radiation measuring and monitoring devices such as the film badge, thermoluminescent dosimeter, and optically stimulated luminescence dosimeter. These devices are worn outside the lead apron at the collar level to monitor radiation exposures to the lenses of the eyes and the thyroid (Sherer *et al.*, 2002). The 10-day rule is also an important principle used in radiology departments to avoid unnecessary radiation exposures to the human body. The 10-day rule in particular, recommends that non-urgent x-ray examinations that entail pelvic irradiation should be restricted to the first 10 days of the menstrual cycle in women of childbearing age. By professional code of practice, it is required of female staff (radiologist, radiographer, and radiology nurse) to be knowledgeable and aware of this rule and also inform female patients accordingly in respect of protecting themselves and their unborn babies radiologically from unnecessary exposures to radiation (Bury *et al.*, 1995).

2.8 DIAGNOSTIC REFERENCE LEVELS

DRLs have been defined as investigational levels applied in the identification of unusually high radiation doses for common diagnostic medical x-ray imaging procedures (Gray *et al*, 2005; Hart, Miller & Wall, 2007; National Council on Radiation Protection, 2012; American College of Radiology, 2013). They are suggested action levels above which a facility should review its methods and determine if acceptable image quality can be achieved at lower doses. DRLs are therefore important radiation estimating reference levels and a practical dose optimization tool for promotion of good practices, assessment of existing protocols, and appropriate development of new and improved protocols at each CT imaging centre. These are achieved by facilitating the comparison of doses from present practice (McCollough *et al*, 2011). The importance of DRLs in diagnostic imaging have been affirmed and approved by several renowned international, professional and regulatory organizations (Gray *et al*, 2005; Shrimpton *et al*, 2006; International Commission on Radiological Protection, 1991; International Commission on Radiological Protection, 1996; American College of Radiology, 2002;

American College of Radiology, 2008; Dosimetry Working Group, 1992). Others such as the International Atomic Energy Agency (2013); Muhogora *et al.* (2009); Tsapaki *et al.* (2006); European Commission (1999) and European Commission (2000) have indicated similar approvals of DRLs as an important dose optimization tool. According to the International Commission on Radiological Protection, DRLs are generally set at the upper third or quartile of doses sampled from actual practice data and offer an optimum range of values for a particular imaging procedure (International Commission on Radiological Protection, 2001).

According to the ICRP and ACR, a DRL is an investigational level used to identify unusually high radiation doses for common diagnostic medical imaging procedures (International Commission on Radiological Protection, 1996; American College of Radiology, 2008). Similar definitions have been established by the National Council on Radiation Protection (2012). DRLs are based on standard phantom or patient measurements under specific conditions and are considered as suggested action levels above which imaging facilities must review its methods and determine if acceptable image quality can be achieved at lower doses (Olarinoye & Sharifat, 2010).

According to the International Atomic Energy Agency (2002), DRLs are also utilized in the management of medical radiation exposures which must be controlled to evade preventable or inadvertent radiation which are insignificant to the overall clinical intention of the procedure. Wambani *et al*, (2010) has also pointed out that this is usually helpful in radiation dose optimization. In particular, radiation doses significantly higher than the DRLs could induce biological damage and may indicate non-achievement of desired or adequate image quality. DRLs are therefore integral of the optimization process and essential for assuring achievement of image quality appropriate for the diagnostic purpose. In view of the fact that optimization must balance image quality and patient, it is imperative that image quality must be maintained at appropriate levels (McCollough *et al*, 2011). According to the American College of

Radiology (2013), the precise rationale of the established DRLs in medical imaging is to provide a benchmark for comparison, and not to define a maximum or minimum dose limit. DRLs are therefore important especially in CT imaging where large radiation doses are used. As part of the optimization process, DRLs have been observed to assist in the reduction of unnecessary patient doses and the consequent radiation risks. They can also be used to improve local, regional, or national distributions of observed doses for a general medical imaging task by reducing the frequency of unjustified high or low dose values, promote a narrower range of doses that represent good practice for a more specific medical imaging task, promote an optimum range of doses for a specified medical imaging protocol. Additionally, DRLs provide a common dose metric for the comparison of DRLs between facilities, protocols and modalities, assess dose impacts of newly introduced protocols, and provide compliance with the relevant state and territory regulatory requirements (Australian Radiation Protection and Nuclear Safety, 2008).

Radiation dose or exposure surveys show the existence of appreciable variations in practice between CT imaging facilities for similar examination types and similar patient demographic groups (Morin, Geber & McCollough, 2003). Such observations point to the need for improved practices via implementation of measures to keep all doses within acceptable ranges for the clinical purpose of each examination (Olarinoye & Sharifat, 2010). Examination-specific DRLs for various patient groups are therefore needed to be set for each CT facility at the local as well as national levels for purposes of providing the motivation for checking or monitoring practice to promote improvements in patient protection (Olarinoye & Sharifat, 2010).

According to Institute of Physics and Engineering in Medicine, National Diagnostic Reference Levels (NDRLs) are set on the basis of wide scale surveys of the mean doses representing typical practice for a patient group (e.g. adults or children of different sizes) at a range of representative CT centres for a specific type of CT examination. As non-optimum doses helpful in identification of potentially unusual practice, NDRLs are therefore purposed to provide an initial check in the optimization process, and further intended to promote awareness, dose audit and comparison as the basis for improving patient radiation protection, with an implied maintenance of diagnostic quality (Institute of Physics and Engineering in Medicine, 2004).

DRLs are not dose limits, and have no relationship with numerical dose limits or dose constraints (ICRP Publication 73, 1996). In explaining their first recommendations on DRLs, the ICRP (ICRP Publication 73, 1996) indicated that they are:

- an easily measured dose quantity, such as absorbed dose in air, or entrance surface dose for a tissue- equivalent phantom or representative patient;
- an investigation level, which , if exceeded, should lead to a review of procedures and equipment in order to evaluate whether the approaches to optimisation are adequate, and to indicate when consideration of dose reducing measures should be made;
- intended for use as a simple test for identifying situations where the levels of patient dose are unusually high;
- supplementary to professional judgement;
- not intended to be used in a precise manner, but related only to broadly defined types of diagnostic examination and to broadly defined types of equipment.

Following the ICRP recommendations, the Commission of European Union issued a legislation (Medical Exposures Directive (Council Directive 97/43) which required member states to promote the establishment and use of DRLs (CEU, Council Directive 97/43, Article 4.2.a) and define DRL as "dose *levels in medical radio-diagnostic practices.... for typical examinations for groups of standard sized patients or standard phantoms for broadly defined types of equipment. These levels are not expected to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied*" (page 2).

The ICRP had proposed that DRLs be initially drawn from a percentile point in the patient dose distribution for a particular examination, and be reviewed at intervals as more optimised techniques are developed (ICRP Publication 73, 1996).

Following this guidance the EC, expressed the DRL as the dose quantity found at the 75th percentile of the mean dose distribution for each type of radiograph. Whilst, the establishment of a DRL at the 75th percentile provides a benchmark for objective assessment of application of the ALARA principle, achievement of the DRL does not guarantee good practice (European Commission, 1999). Launders et al. (2001) were of the view that the DRLs were not originally proposed as a guide to optimisation, but rather as a mechanism for identifying outdated and /or poor techniques. Table 2.5 shows a summary of some dosimetric quantities used in the establishment of DRLs in medical imaging.

Table 2.5. Dosimetric quantities used to establish the diagnostic reference levels.

Modality	Dosimetric quantity	Abbreviation	Unit
Radiography	Entrance surface dose, per view	ESD	mGy
	Dose-area product, per examination	DAP	Gy cm^2
Mammography	Air Kerma at the breast surface, per view	ESAK	mGy
Fluoroscopy	Dose-area product, per examination	DAP	Gy cm^2
Angiography and interventional radiology	Dose-area product, per examination	DAP	Gy cm^2
	Number of images, per examination	-	-
	Fluoroscopy time, per examination	-	min
Computed tomography	Weighted CT dose index, per slice or rotation	$CTDI_w$	mGy
	Dose-length product, per examination	DLP	mGy cm
Dental radiology	Entrance surface dose, per view for intra-oral examinations (apical, bitewing)	ESD	mGy

	Dose-width product for OPG	DWP	mGy mm

Since DRLs are intended to promote improvements in patient protection by allowing comparison of current practice, DRLs at all levels should be set for each examination and each patient group i.e., adults and children of different sizes (International Commission on Radiological Protection Publication 87, 2001). It is therefore important for each CT imaging facility to determine or establish its facility-specific $CTDI_{vol}$ and DLP values for each type of examination and associated clinical indication (Morin, Geber & McCollough, 2003). These values are classified as mean dose values observed for representative samples for each patient group which should be compared with relevant NDRLs (if any). DRL values higher than the NDRLs should be investigated and either justified as being clinically necessary or reduced through appropriate modifications in practice to improve patient protection (Institute of Physics and Engineering in Medicine, 2004).

2.7.1 Paediatric DRLs

Particular attention needs to be given to establish separate DRLs for pediatrics for different ages. Below as illustrated by Table 2.6 are recommended DRLs for pediatric CT based on the 2009 survey (Medical Exposure Radiation Unit, 2009). There are a number of published research articles on pediatric DRLs available in Ireland ((McCollough *et al.* 2011) or internationally (National Council on Radiation Protection, 2012; American College of Radiology, 2013) which should be taken into account when setting a benchmark from which to compare local DRLs. As new radiation dose surveys are produced, these national DRLs will be reviewed.

Table 2.6. Recommended DRLs for pediatrics CT based on the 2009 survey by Medical Exposure Radiation Unit (MERU), HSE.

Examination	Age	NDRL DLP mGycm
Head	New-born	340
	1-4 years	470
	5-9 years	620
	10-15 years	850
Abdomen/Pelvis	New-born	130
	1-4 years	160
	5-9 years	230
	10-15 years	400

The DRLs and achievable doses (AD) for adult and paediatric CT ($CTDI_{vol}$) obtained using the 16 cm diameter phantom for all head and paediatric abdomen CT examinations, and the 32 cm diameter phantom for all adult body CT examinations are shown in Table 2.7 (McCollough *et al*. 2011; National Council on Radiation Protection, 2012; American College of Radiology, 2013).

Table 2.7: DRLs and Achievable Doses for Adult and Paediatric CT ($CTDI_{vol}$)

	Patient lateral dimension	CTDI phantom diameter (cm)	DRL (mGy)	AD (mGy)
Adult head	16	16	75	57
Adult abdomen-pelvis	38	32	25	17
Adult chest	35	32	21	14
Pediatric 5 year old head	15	16	40	31
Pediatric 5 year old AP	20	16	20	14

A listing of published ICRP, ACR, EC, UK, Sweden, and Switzerland DRLs for paediatric and adult CT examinations of the head, chest and abdomen are presented in Table 2.8 (Bongartz *et al*, 2004; McCollough, 2011)

Table 2.8: ICRP, EC, ACR, UK, Sweden, Switzerland DRLs

Body regions	**Head**		**Chest**		**Abdomen**	
	$CTDI_{vol}$ mGy	DLP (mGy.cm)	$CTDI_{vol}$ mGy	DLP (mGy.cm)	$CTDI_{vol}$ mGy	DLP (mGy.cm)
Age	**ICRP PUBLICATIONS 87**					
< 1	40	300	20	200	20	170
5	60	600	30	400	35	250
10	70	750	30	600	35	500
≥ 18	60	1050	30	650	35	780
Others: ACR, EC, NCRP, Netherlands, Sweden, Switzerland						
ACR 2008	75	-	-	-	25	-
EC 2004	60	-	-	-	15-25	-
Sweden 2002	75	1200	-	-	25	-
Switzerland 2010	65	1000			15	400
UK 2003	65-100	930			14	470

Radiation dose from a slice at a particular CTDI and DLP characterizes the exposure from a complete examination and DLP increases in proportion as the number of cuts in the examinations (Ogbole, 2010). Although DLP is usually used to evaluate the radiation dose for a particular CT procedure, its value is affected by variances in the anatomy of the patient: hence the DLP values for taller patients are higher because of their greater height (Morin, Geber & McCollough, 2003). $CTDI_{vol}$ is therefore more essential in CT imaging protocols and compares radiation doses among imaging protocols (Morin, Geber & McCollough, 2003).

Other recommended Local Diagnostic Reference Levels (LDRLs) by age group for typical paediatric CT examinations as described by Murphy et al. (2013) and Brady et al. (2012) in terms of both $CTDI_{vol}$ and DLP based on rounded mean values are given in Tables 2.9 and 2.10 respectively. These have been provided relative to both phantom sizes for the body examinations. The LDRLs in terms of $CTDI_{vol}$ are much higher for the brain examinations than for the body examinations, reflecting the higher X-ray beam intensity used for the brain examinations.

Table 2.9: Irish CT DRLs for Paediatric patients

Pediatric DLP (75th Percentiles)						
Age Group	Ireland	Ireland, 2013	Europe, 2000	UK, 2003	Belgium, 2003	Swiss, 2008
	Head					
<1 year	54	333	300	270	165	270
1-5years	115	491	600	470	217	420
6-10years	80	608	750	620	228	560
11-15years	17	719	-	-	-	1000
Chest						
Age Group						
<1 year	22	73	200	200	79	110
1-5years	50	106	400	230	94	200
6-10years	20	153	600	370	147	220
11-15years	24	237	-	580	-	460

Table 2.10: Recommended local diagnostic reference levels (LDRLs) by age group for typical paediatric CT examinations

Examination	Age Range	$CTDI_{vol,32}$ (mGy)	DLP_{32} (mGy cm)	$CTDI_{vol,16}$ (mGy)	DLP_{16} (mGy cm)
Head	0–6 months	–	–	18	250
	6 months to 3 years	–	–	20	300
	3–6 years	–	–	30	450
	6–10 years	–	–	40	650
	>10 years	–	–	45	700
Chest	<5 years	2	50	3	100
	5–10 years	5	150	11	300
	>10 years	12	400	23	800
Abdomen/pelvis	<5 years	2	100	4	150
	5–10 years	5	200	10	400
	>10 years	8	350	15	750

$CTDI_{vol,16}$, volumetric CT dose index relative to the 16-cm dosimetry phantom; $CTDI_{vol,32}$, volumetric CT dose index relative to the 32-cm dosimetry phantom; DLP_{16}, dose–length product relative to the 16-cm phantom; DLP_{32}, dose–length product relative to the 32-cm phantom.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter outlines the research design, data collection procedure, the study site, the study population, sampling size, inclusion and exclusion criteria, data collection instrument and sampling method used in the study. The methods of statistical analysis and ethical issues are also presented.

3.2 RESEARCH DESIGN

A retrospective and prospective audit of patient records at the various imaging facilities for paediatric computed tomography examinations was carried out. A descriptive cross-sectional survey was considered to be appropriate for the study and thus employed in the attainment of the aim and objectives. Largely, descriptive surveys provide better means of probing and assessing the attitude and practices of people involved in a particular situation (Gray, 2004). On the other hand, surveys create platforms for the development and implementation of policies resulting from analysis of research or studies (Carter, 2000). In this study therefore, information was obtained from the sample selected from the population of interest and then, on the basis of this information, the whole study population was described. This is a major feature of a survey as asserted by Atkinson (2000).

Considering the nature of the study population, a cross-sectional study was deemed more appropriate. In this type of research study, either the entire population or a subset thereof is selected, and from these individuals, data are collected to help answer research questions of interest. Usually, information gathered represents what is going on at only one point in time (Olsen and St. George, 2004).

Data was collected for routine CT scan examinations of the head, neck, sinuses, chest (thorax), abdomen, pelvis, spine, upper limbs (hand, wrist, elbow, humerus and shoulder) and lower limbs (hips, femur, tibia and fibula, ankle), etc. In addition, serialized scans (combination scans) of head-neck, face-neck, thorax-abdomen, thorax-abdomen-pelvis, abdomen-pelvis, bones and joints were also recorded. Data on specialized examinations such as CT angiography, cardiac angiography and intravenous urography (IVU) were also collected.

The gender, age, parameters used (tube potential, time per rotation, effective mAs, scan length, slice thickness) and dose indicators ($CTDI_{vol}$ and DLP) were recorded for each patient. Data collection span the length of January 2015- April 2016.

3.3 STUDY SITES

Prior to the start of the study, a letter was sent to the Radiation Protection Institute (RPI) of the Ghana Atomic Energy Commission (GAEC) to obtain the registered number of CT facilities in the region. It was established that there were seventeen (17) CT centres/facilities within the Greater Accra Region. Telephone interviews were conducted to investigate which of these centres carried out paediatric CT imaging procedures.

Out of the seventeen (17) registered facilities, nine (9) confirmed undertaking paediatric CT examination procedures. Subsequently, introductory letters from the School of Nuclear and Allied Sciences (SNAS) were sent to the centres requesting their participation in the study (APPENDIX I). At the time of data collection however, three (3) out of the centres had equipment malfunction whereas two (2) declined interest in participating in the study.

Thus, the research work covered Korle-Bu Teaching Hospital, Akai House Clinic, Ledzokuku Krowor Municipal Assembly (LEKMA) Hospital and Paradise Diagnostic Centre for paediatric patients undergoing CT examinations for the period January 2015- April 2016. All these imaging facilities are located within the Greater Accra Region of Ghana and each hospital had one CT scanner. Data collected from these facilities were treated in an anonymous way, with the four centres being coded by alphabetical letters from A to D.

3.4 STUDY POPULATION

The target population comprised of paediatric patients with ages ranging between zero to fifteen years (0-15 years) undergoing CT examination in the selected facilities. In this survey, the paediatric population were separated into four age groups (<1 year; 1-5 years; 5-10 years; 10-15 years).

3.5 INCLUSION AND EXCLUSION CRITERIA

3.5.1 Inclusion Criteria

The target group employed in this project included;

- Paediatric patients between 0-15 years undergoing CT examinations

3.5.2 Exclusion Criteria

The non-target group and materials excluded from this study included;

- Patients other than those within the age limit
- Adults

3.6 SAMPLE SIZE

A total sample size of 306 patients was used for this study. The patient sample distribution for the various study sites is shown in Table 3.1.

Table 3.1: Sample Distribution of Patients

FACILITY	FREQUENCIES
Centre A	148
Centre B	122
Centre C	27
Centre D	9

3.7 SAMPLING METHOD

A purposive non-probability sampling method is usually selected in a deliberative and non-random fashion in order to achieve a certain goal (Vin, 2014). Hence the use of a non-probability convenience sampling method, was used mainly for two reasons; because of easy accessibility to patients who presented themselves for chest, head and Abdomino-pelvic (i.e. since these form the bulk) examinations in most CT imaging centres. Bowling (2009) argued that it is expedient to use convenient sampling in such situations. Again, because the various centres do not use the appointment system for booking patients, it was necessary that this method is used in order to obtain the required number of patients in the short period that this study was undertaken.

3.8 RESEARCH TOOL AND DATA COLLECTION

A data collection sheet (APPENDIX II) adopted from a study conducted by Muhogora et al. (2010) across nineteen (19) developing countries was used to obtain radiation dose dependent data on patient –related factors such as age, gender and diagnostic purpose of examination.

Key data on exposure related parameters such as tube kilovoltage (kV), tube current time exposure product (mAs), slice thickness, scan length, number of slices, $CTDI_{vol}$ and *DLP* were also collected by means of the data sheet. The technical specifications of the scanners used in each hospital are listed in Table 3.2.

Table 3.2: Equipment Specifications

STUDY SITE	MANUFACTURER	MODEL NO.	SERIAL NO.	YEAR OF MAKE	MAX. mAs	MAX. kV
Centre A	Toshiba	TSX-301A	4CA1292037	September 2012	550	135
Centre B	General Electric (GE)	5124069-5	408936CN3	November 2008	Auto Ma	150
Centre C	Neusoft Medical System	454110161281	NDLR100004	April 2010	300	140
Centre D	Hitachi	KA-13364403	W 0450	February 2015	400	140

3.9 CT DOSIMETRY

On most modern CT scanners, the $CTDI_{vol}$ and DLP values are displayed as estimated values following the CT the scout images (also known as topogram/scanogram). The resultant itemised values from each individual part of the examination and total values are also displayed at the conclusion of an examination based on the scan parameters used (Tsalafoutas, Thalassinou & Efstathopoulos, 2012). At most of the selected facilities, this final dose screen is captured for each patient so that these values could readily be collected for use in the survey. According to Brady et al. (2012), the $CTDI_{vol}$ values represent standardised dose measurements made in two different polymethylmethacrylate, homogeneous, cylindrical phantoms. The measurements are made at the periphery and centre of the cylindrical phantoms and weighted accordingly to take into account the varying dose distributions with depth in the phantom resulting from the beam-shaping filters in the CT scanner. Typically, a 16-cm-diameter phantom is used to represent the head of an adult or child (or child's body) and a 32-cm-diameter phantom is used to represent an adult's body.

To better represent the overall energy delivered by a given scan protocol, the $CTDI_{vol}$ can be integrated along the scan length to compute the DLP. According to Bongartz *et al* (2004), the DLP reflects the integrated radiation output (and thus the potential biological effect) attributable to the complete scan acquisition.

Recent CT scanners' dosimetric software calculates DLP using CTDI values selected on the basis of the examination protocol and not the main body part being examined (Tsalafoutas, Thalassinou & Efstathopoulos, 2012). Thus, if the chest protocol is used for a CT head procedure then $CTDI_{vol}$ and DLP values displayed will be calculated according to the body part selected which is head CTDI values, and not the body part examined. Thus, if the CT imaging protocol for head is selected instead of any part of the body being examined, the DLP and effective dose values will increase because of its high CTDI values (Tsalafoutas, Thalassinou & Efstathopoulos, 2012).

3.9.1 Regional Diagnostic Reference Levels (RDRLs) and International Benchmarking

The Regional diagnostic reference levels were derived in terms of $CTDI_{vol}$ and DLP distributions for the facilities based on third (3^{rd}) quartile dose values from the survey in all age groups for each type of CT examination. Appropriate inter-comparison were made with International values to verify whether Ghana was meeting National and international standards.

3.10 DATA ANALYSIS

The data obtained was statistically analysed using the Statistical Package for Social Sciences (SPSS) version 22.0 software programme and Excel (Microsoft). The results were presented using descriptive statistics in the form of graphs, tables, and charts.

The mean values of $CTDI_{vol}$ and DLP were compared with international paediatric CT DRLs. Inferential statistics such as means were utilized to summarize data to provide statistical meanings to the study.

3.11 ETHICAL ISSUES

According to Polgar and Thomas (1999), the primary consideration of scientific ethics is the protection of the rights and welfare of participants. Consequently and in accordance with established protocols on research of the University of Ghana, permission was sought from the heads of the various facilities/Centres prior to the collection of the patient dose data. Facilities were also coded with letters for anonymity.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this Chapter, the results of the study conducted at the facilities mentioned in chapter three are presented in the form of charts and tables. These include the frequency of paediatric examinations and dose audits as well as the discussions on the findings compared with relevant literature.

4.2 RESPONSE RATE

As per information obtained from the RPI of GAEC, there are seventeen (17) CT centres/facilities within the Greater Accra region. Out of the seventeen (17) registered facilities, nine (9) confirmed they performed paediatric imaging. At the time of data collection however, three (3) out of the centres had equipment malfunction whereas two (2) declined interest in participating in the study. Also, one (1) of the four (4) facilities had lost some of the stored data from the information storage system, thus leaving a deficit in the expected stored data. Thus, the research work covered four (4) out of the nine (9) facilities representing a response rate of 44.44%.

Statistically, higher sample sizes reduce the likelihood of encountering Type-I and Type-II errors and allow for prospects of increasing the significance level of the findings, since the confidence level of the results are likely to increase with a higher sample size. Hence a small sample size may dent the reliability of results unlike a larger sample size which may provide a more accurate reflection of the behaviour of the whole study group. The sample size of this study may have some statistical effect on the overall outcome.

4.3 DEMOGRAPHIC DATA

4.3.1 Gender Demographics

A total of three hundred and six (306) patient dose data were collected for this study. Out of this, 181 (59.2%) were males and 125 (40.8%) were females. According to the 2015 Revision of World Population Prospects, the current male to female population ratio in Ghana is 50.9% to 49.1% respectively (United Nations Department of Economic and Social Affairs: Population Division, 2015). Hence the ratio of male to female as gathered from the study is consistent with this assertion.

4.3.2 Age Distribution

Table 4.1: Age distribution of participants.

Age Range	Frequency	Percentage
Less than 1year	52	17.0
1-5 years	100	32.7
6-10 years	74	24.2
11-15 years	80	26.1
Total	306	100.0

The term paediatric as used in this study referred to persons with age range from zero to fifteen years (0-15 years). As presented in Table 4.2, 32.7% (*n=100*) of the patients were between the ages of 1-5 years while the minority (17%, *n=52*) were less than a year old. Thus majority of the target population for the study fell within the age of 1-5 years. According to an article by the Arlington Medical Resources (n.d.), it was estimated that about 33% of all paediatric CT examinations were performed on children in their first decade of life, with 17% in children at or under the age of 5. These numbers are important because organs and tissues in younger children are more vulnerable to radiation induced cancer. These findings are in agreement with the results of the current study.

4.3.3 Distribution of Examination Type Recorded During the Study

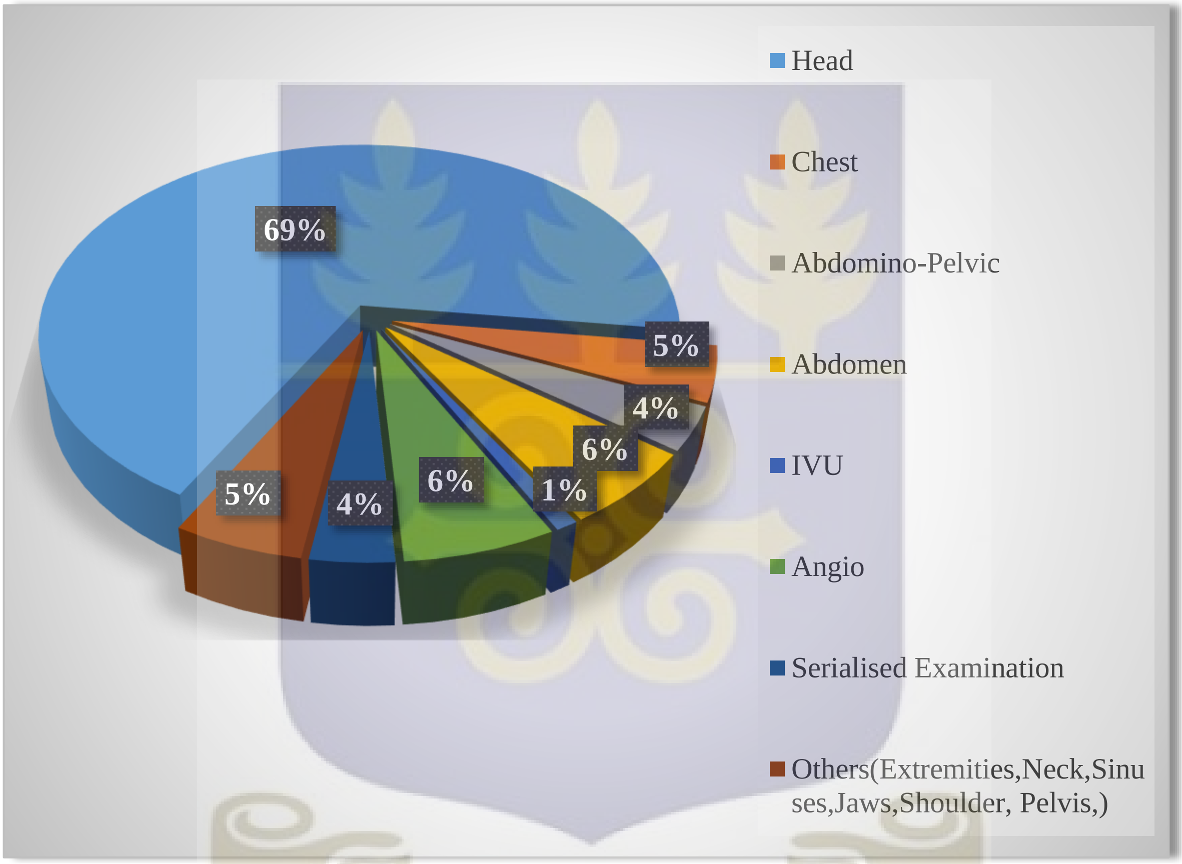

Figure 4.1: Frequency of examination type (anatomical area) conducted for paediatric examinations.

The introduction of fast scanning has heightened the evaluation of younger and less cooperative children (Hatziaanuou et al, 2003; Pages et al., 2003) and has provided new applications such as assessment of common renal disorders as well as vascular evaluations with applications in CT angiography. This is evident as shown in Figure 4.1, with angiography and IVU constituting a total of 6% (n=20) and 1% (n=3) respectively of the total examinations performed.

Taking into account the two routine CT examinations—abdominal and head—the prevailing projected induced malignancies are of the digestive organs and of the brain respectively. Although the brain was once considered a relatively radioresistant organ, more recent data submit that it is significantly radiosensitive, predominantly at very low doses, and that the risk of effect increases as the age decreases (Karlsson et al., 1998). Ron et al. (1995) assumed based on research findings that the estimated cancer risks from paediatric CT procedures would, by definition, be larger, predominantly for CT examinations of the head, because of the greater contribution of radiation-induced cancer of the thyroid. This in relation to the findings from the current study (69% head examinations, n= 211) raises a lot of concern while bearing in mind the sensitivity of the lens of the eyes (which are most likely to be exposed during CT scan of the head).

On the basis of these assumptions, Brenner et al. (2001) predicted the overall number of deaths attributable to the first year of CT examinations in the United States as approximately 700 from head examinations and 1800 from abdominal examinations, of which approximately 170 and 310, respectively, would be attributable to head and abdominal CT examinations in individuals who were less than 15 years at the time of examination.

In both cases, childhood CT examinations contribute significantly to the overall estimated CT-related potential cancer mortality. The vice versa (more cancers from head examinations) may be true in the case of Ghana based on the results of this study since head CT scans recorded the highest frequency.

4.4 FREQUENCY OF PAEDIATRIC EXAMINATIONS

A study by Siegel et al. (2004) showed that paediatric CT accounted for about 4% of all CT examinations in 1989 and increased to 6% in 1993. Donnelly (2005) conducted a similar study which showed that on the basis of the 2000 data, approximately 2.7 million CT scan examinations are performed on children less than 15 years annually.

Nonetheless, a study conducted by Muhogora et al. (2010) revealed that the frequency of paediatric CT was numerically highest in participating centres in Africa (20%) followed by centres in Asia (16%) and Eastern Europe (5%). Japan had a reasonably low paediatric CT frequency in comparison with most other participating countries, which tends to indicate a better level of justification and availability of alternative imaging modalities. The paediatric CT frequency ranges indicate substantial variations within most countries.

The current study involved collection of data expected to be representative of Greater Accra Region, which is a sub-region of Ghana. Out of a total of 6147 examinations carried out during the period of the study (January, 2015- April, 2016) in the various centres, 5473 were adult examinations whereas 674 represented paediatric examinations. The study showed that currently paediatric CT examination represents 11% of the total CT examinations performed. As compared to results from Muhogora et al. (2010), the frequency tends to exceed that of Eastern Europe (5%) which is larger (population) than the sub-region in question and also greater than half of that of Africa (20%). This finding is consistent with that of Muhogora et al. (2010) and may warrant investigation into the justification of such procedures and as well as resorting to other alternative imaging modalities. Paediatrics represent a relatively small, yet increasing fraction of the total number of CT examinations. However, the blend of higher radiation doses to children for a given CT examination and, more significantly, the much larger lifetime risks per unit dose of radiation that apply to children, result in lifetime cancer mortality attributable to the radiation exposure from CT that is significantly higher in children than in adults (Brenner et al., 2001).

4.4.1 Frequency of CT Examinations Carried Out With Respect To Age of Patients and Gender

Table 4.2: Cross-Tabulation of Examination Type With Respect To Age and Gender.

Gender	**Age Range**	**Anatomical Area Examined (Examination Type)**								**Total**
		Head	Chest	Abdomino-Pelvic	Abdomen	IVU	Angio.	Serialised Exam	Others	
Male	Less than 1 year	20	0	1	6	0	0	0	0	27
	1-5 years	34	2	3	1	2	6	4	4	56
	6-10 years	35	0	1	0	0	3	1	5	45
	11-15 years	42	1	0	2	1	3	2	2	53
Total		131	3	5	9	3	12	7	11	181
Female	Less than 1 year	19	1	0	0	-	1	0	4	25
	1-5 years	24	6	1	6	-	5	2	0	44
	6-10 years	20	2	3	2	-	1	1	0	29
	11-15 years	17	2	2	2	-	1	1	2	27
Total		80	11	6	10		8	4	6	125
Total	Less than 1 year	39	1	1	6	0	1	0	4	52

	1-5 years	58	8	4	7	2	11	6	4	100
	6-10 years	55	2	4	2	0	4	2	5	74
	11-15 years	59	3	2	4	1	4	3	4	80
Total		211	14	11	19	3	20	11	17	306

The predictable lifetime cancer mortality risks from abdominal CT examinations are to some extent greater for women than for men. This effect is caused by the significantly greater estimated risks per unit dose for digestive organ cancer in women. For head examinations however, the sex effect conversely, is smaller because estimated brain tumour risks do not differ significantly with sex. The predictable risk for abdominal CT examinations decreases much more slowly with increasing age at examination than does the risk from head examinations. This effect is also caused by the near constancy of the estimated lifetime risk (per unit dose) for digestive organ cancer from birth to approximately 25 years old (Brenner et al., 2001).

A total of ten ($n=10$) female patients of varied age groups had abdominal CT examination as compared to nine ($n=9$) male patients. The same applies to Abdomino-pelvic examinations; n=5 and n=6 for male and female respectively. The latter may involve the exposure of the reproductive organs to radiation during the procedure. Angiography is represented by 20 patients, $n=12$ and $n=8$ for male and female respectively. This comprised either brain or cardiac vasculature assessment and hence involved the exposure of the breast in females as well as the likely exposure of the thyroid in both sexes. These may in the end increase the attributable lifetime risk of organ cancer in the patients especially in females due to their predispositions.

4.5 CHARACTERISTICS OF SCANNING PARAMETERS

Table 4.3a: Characteristics of Scanning Parameters Used for CT Examinations.

Scan Parameters	No.	Minimum	Maximum	Mean	
				Statistic	Std. Error
Tube Potential (kVp)	306	80.00	140.00	111.29	0.73
Milliampere second (mAs)	306	13.30	350.00	156.80	4.95
Slice Thickness in centimetres	306	0.05	1.00	0.12	0.01
Scan Length in centimetres	306	0.20	1195.00	19.21	3.89
Number of slices for examination	306	2.00	1491.00	344.01	13.01

Table 4.3b: Average Scanning Parameters per CT Examination Type

Examination Type	**Scan Parameters per CT Examination Type Mean ± SD (Min-Max Range)**				
	Tube Potential (kVp)	**Milliampere second (mAs)**	**Slice Thickness (cm)**	**Scan Length (cm)**	**Number of Slices**
Head	109.64 ± 0.90 *(80.00-135.00)*	197.33 ± 3.85 *(32.00-350.00)*	0.13 ± 0.01 *(0.05-1.00)*	19.18 ± 5.61 *(0.20-1195.00)*	301.23 ± 12.49 *(2.00-801.00)*
Chest	107.14 ± 4.50 *(80.00-120.00)*	36.55 ± 2.84 *(14.00-55.60)*	0.09 ± 0.02 *(0.05-0.38)*	18.53 ± 2.48 *(5.63-36.00)*	388.00 ± 43.54 *(48.00-711.00)*
Abdomino-Pelvic	120.00 *(120.00)*	47.96 ± 11.23 *(19.60-150.50)*	0.63 *(0.06)*	25.84 ±2.34 *(13.13-34.45)*	528.09 ± 36.58 *(325.00-705.00)*
Abdomen	114.74 ± 2.58 *(80.00-120.00)*	32.24 ± 2.43 *(19.60-62.50)*	0.12 ±0.04 *(0.05-0.50)*	28.82 ± 2.74 *(7.50-45.44)*	675.11 ± 93.60 *(77.00-1491.00)*
IVU	120.00 *(120.00)*	57.23 ± 23.92 *(27.20-104.50)*	0.06 *(0.06)*	25.38 ± 9.24 *(13.40-43.55)*	476.67 ± 199.20 *(104.00-785.00)*

Angiography	115.00 ± 2.46 *(80.00-120.00)*	79.37 ± 19.91 *(13.30-277.00)*	0.06 *(0.06)*	9.57 ± 1.17 *(1.95-24.45)*	252.65 ± 12.43 *(121.00-361.00)*
Serialised Examinations	118.18 ± 3.25 *(100.00-140.00)*	115.02 ± 28.35 *(21.60-350.00)*	0.14 ± 0.04 *(0.06-0.50)*	14.51 ± 1.95 *(4.94-25.00)*	309.73 ± 48.22 *(48.00-465.00)*
Others	115.29 ± 2.73 (100.00-140.00)	98.15 ± 25.00 (17.00-350.00)	0.10 ± 0.03 (0.05-0.50)	18.333 ± 2.78 (0.21-33.88)	455.88 ± 76.23 (63.00-974.00)

The maximum-to-minimum value is shown in brackets against each mean (average) value.

According to Brady et al. (2012), investigating the local scan parameters provides a better indication of areas that may need further optimisation. In Table 4.3a, the characteristics of the scanning parameters was evaluated. The average values of each scanning parameter per the examination performed was also calculated. This provided a summary of the mean exposure factors used per examination protocol (Table 4.3b).

The tube voltage needed to adequately image the body of a child is lower compared to that of an adult, since a child is smaller (ICRP, 2013). Various researchers have studied the use of low-tube-voltage CT for improving the image quality or decreasing the radiation dose, particularly in paediatric patients. (Yu et al., 2011; Dougeni, Faulkner and Panayiotakis, 2012). This is consistent with results of the current study (Table 4.3a), thus it may be argued in this respect, that the mean tube voltages are within acceptable limits.

A study by Matsunaga et al. (2014), led to the assumptions that; the use of tube voltages of 120 kV was the same for both adult and paediatric head scans. A tube voltage of 120 kV was also most commonly used for paediatric chest and abdominal scans, similar to adult CT scans although the tube voltage required to penetrate the body of a child is lesser than that of an adult. It was recommended that, tube voltages of 100 kV and, sometimes, as low as 80 kV should be more frequently used to scan the chests and abdomens of children, as the mean CTDI values for paediatric examinations using voltages ranging from 80 to 100 kV were significantly lower than those for paediatric examinations using 120 kV. Hence, low-tube-voltage CT may therefore be useful for reducing radiation doses among paediatric patients.

As shown in Table 4.3b, the utilization rate for tube voltage of approximately 110 kVp was used for paediatric head. This value obtained differs from the previous studies by just a slight margin (a difference of 10 kVp) but may have significant effect on radiation dose to patient as *"no radiation is too small"*. Brady et al. (2012) recommended in particular, that the usage of 80 kV for both chest and Abdomino-pelvis imaging in children under 5 years old leads to significant dose saving. From the current study however, the average tube potential for chest and Abdomino-pelvis imaging were approximately 107 kVp and 120 kVp respectively, which were higher than the aforementioned study.

Again, Brady et al. (2012), in addition to scan length, acknowledged that the reference mAs values for imaging of the chest should be justified, particularly in relation to the abdomen/pelvis examination values for the same age groups. Due to the inherent contrast in the chest as well as the lack of attenuating tissue, it is expected that these values might be lower for chest examinations than for abdomen/pelvis examinations. These findings were consistent with the current study as demonstrated in Table 4.3b. The average tube current for chest was approximately 37 mAs while that of abdomen/pelvis was approximately 48 mAs. From the above data, it is apparent that the choice of CT scanning protocols advertently impacts the dose delivered to the patients. The selection of scanning protocols and exposure parameters thus is of utmost importance as concluded from a study by Smith et al. (1997).

4.6 CT DOSIMETRY

The CT dose descriptors chosen for this study were volume computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP). These values were extracted from the dose report of retrospective and prospective CT examinations of head, chest, Abdomino-Pelvic, abdomen and other examinations (pelvis, sinuses, extremities, etc.) database retrieved from the picture archiving and communication system (PACS) at the various facilities. For the purpose of appropriate comparison however, discussions will be limited to most common routine procedures such as head, abdomen, chest and abdomen/pelvis.

4.6.1 Mean $CTDI_{vol}$ Values

Table 4.4a: Mean $CTDI_{vol}$ Values

Examination Type	**Mean CTDIvol values (mGy) Mean (Min-Max)**			
	Less than 1 year	**1-5 years**	**6-10 years**	**11-15 years**
Head	21.94 *(9.30-86.00)*	34.39 *(3.96-240.04)*	41.21 *(10.80-86.00)*	60.70 *(4.19-86.00)*
Chest	1.00 *(1.00)*	2.90 *(1.20-5.60)*	4.14 *(1.50-6.77)*	3.23 *(2.40-3.80)*
Abdomino-Pelvic	3.02 *(3.02)*	3.05 *(2.56-3.41)*	5.58 *(2.88-12.45)*	4.98 *(4.32-5.63)*
Abdomen	1.99 *(0.70-3.26)*	3.67 *(1.70-10.00)*	3.97 *(3.63-4.30)*	4.55 *(4.10-4.70)*

IVU	-	4.38 *(3.81-4.95)*	-	8.25 (8.25)
Angio	2.72 *(2.72)*	4.71 *(1.54-13.34)*	17.28 *(2.18-57.94)*	30.17 *(1.77-58.00)*
Serialised Exam	-	8.54 *(3.35-13.34)*	11.05 *(8.12-13.97)*	31.55 *(11.78-68.98)*
Others	2.88 *(1.10-6.70)*	4.75 *(4.30-5.67)*	25.63 *(4.02-59.16)*	14.07 *(6.03-27.00)*

Table 4.4b: Comparison of mean CTDI$_{vol}$ values from this study with DRLs and other recommendations for head, chest, abdomen and abdomen-pelvic CT examinations.

AGE RANGE	**HEAD**		**CHEST**		**ABDOMEN**		**ABDOMINO-PELVIC**	
	THIS WORK	*ICRP, 2000*	*THIS WORK*	*ICRP,2000*	*THIS WORK*	*ICRP, 2000*	*THIS WORK*	*MERU, 2009*
Less than 1 year	22	40	1	20	2	20	3	-
1-5 years	34	60	3	30	4	35	3	-
6-10 years	41	70	4	30	4	35	6	-
11-15 years	61	60	3	30	6	35	6	-

The mean CTDI$_{vol}$ values were rounded off to the nearest whole number and compared with established DRLs from published literature. The mean CTDI$_{vol}$ values of the current study for examination of the head (22-60 mGy), chest (1-3.23 mGy) and abdomen (2-5 mGy) were lower than that from ICRP (2000) recommended values (40-60 mGy, 20-30 mGy and 20-35 mGy respectively) and available data from literature (Table 2.7). A study by Matsunaga et al. (2014) in Japan resulted in mean $CTDI_{vol}$ values as follows;

- Head: 31.5 mGy and 42.4 mGy for tube potential of 100 kV and 120 kV respectively
- Chest: 5.0 mGy and 10.5 mGy for tube potential of 80-100 kV and 120 kV respectively
- Abdomen: 6.4 mGy and 12.6 mGy for tube potential of 80-100 kV and 120kV respectively

These values in comparison with the average $CTDI_{vol}$ of head for age 11-15 years from the current study were however higher. The same was observed in comparison to a study by Brady et al. (2012) illustrated by Table 2.9. The $CTDI_{vol,16}$ values which represents phantom measurements for paediatric studies of the head were all lower (18-45 mGy) than the current study findings (22-60 mGy). The high tube voltage and tube current utilised at the centres in the current study could be a key factor resulting in this variation. $CTDI_{vol,32}$ is used to represent phantom measurements in paediatric body such as chest and abdomen. These ranged from 2-12 mGy while $CTDI_{vol,16}$ for chest ranged from 3-23 mGy. Results from the current study ranged from 1-3.23 mGy across all age ranges and were lower compared to results from Brady et al. (2012). Again, for abdomen/pelvis examinations, the current findings range between 3-5 mGy while results from Table 2.9 range between 2-8 mGy and 4-15 mGy for $CTDI_{vol,32}$ and $CTDI_{vol,16}$ respectively. It was observed that findings from the current study were within the limits although they were low.

4.6.2 *Mean DLP Values*

Table 4.5a: Mean DLP Values

Examination Type	**Mean DLP values (mGy cm) Mean(Min-Max)**			
	Less than 1 year	**1-5 years**	**6-10 years**	**11-15 years**
Head	324.88 *(93.10-1828.60)*	471.07 *(13.34-1785.60)*	528.68 *(146.67-1914.60)*	985.11 *(146.60-2215.70)*
Chest	18.40 *(18.40)*	60.87 *(18.80-141.66)*	104.69 *(37.60-171.77)*	141.10 *(62.30-181.70)*
Abdomino-Pelvic	70.93 *(70.93)*	97.88 *(80.37-126.03)*	251.1 *(110.73-609.90)*	227 *(200.90-253.12)*
Abdomen	51.46 *(11.30-83.84)*	90.25 *(52.64-150.48)*	183.03 *(154.06-212.00)*	223.45 *(204.10-234.40)*
IVU	-	130.97 *(112.25-149.68)*	-	457.42 *(457.42)*
Angio	44.56 *(44.56)*	86.06 *(28.16-259.80)*	120.46 *(62.01-230.58)*	156.14 *(46.93-232.55)*
Serialised Exam	-	208.96 *(106.20-320.10)*	327.99 *(165.94-490.04)*	872.02 *(311.52-1931.45)*
Others	88.28 *(12.70-207.73)*	115.32 *(81.53-142.50)*	599.67 *(117.63-1301.50)*	359.29 *(183.23-505.10)*

Table 4.5b (i): Comparison of mean DLP values from this study with DRLs and other recommendations for head CT examinations.

AGE RANGE	HEAD				
	THIS WORK	*ICRP, 2000*	*Galanski et al. DRLs in Ger., 2006/7*	*Verdun et. al DRLs in Swiss, 2008*	*Shrimpton et. al DRLs in UK, 2003*
Less than 1 year	325	300	390	270	270
1-5 years	471	600	520	420	470
6-10 years	529	750	710	560	620
11-15 years	985	1050	920	1000	930

Table 4.5b (ii): Comparison of mean DLP values from this study with DRLs and other recommendations for chest CT examinations.

AGE RANGE	CHEST				
	THIS WORK	*ICRP, 2000*	*Galanski et al. DRLs in Ger., 2006/7*	*Verdun et. al DRLs in Swiss, 2008*	*Shrimpton et. al DRLs in UK, 2003*
Less than 1 year	18	200	55	110	200
1-5 years	61	400	110	200	230
6-10 years	105	600	210	220	370
11-15 years	141	650	205	460	580

Table 4.5b (iii): Comparison of mean DLP values from this study with DRLs and other recommendations for abdomen CT examinations.

AGE RANGE	ABDOMEN				
	THIS WORK	*ICRP, 2000*	*Galanski et al. DRLs in Ger., 2006/7*	*Verdun et. al DRLs in Swiss, 2008*	*Shrimpton et. al DRLs in UK, 2003*
Less than 1 year	51	170	145	130	170
1-5 years	90	250	255	300	250
6-10 years	183	500	475	380	500
11-15 years	223	780	500	500	560

Table 4.5b (iv): Comparison of mean DLP values from this study with DRLs and other recommendations for Abdomino-pelvic CT examinations.

AGE RANGE	ABDOMINO-PELVIC				
	THIS WORK	*ICRP, 2000*	*Galanski et al. DRLs in Ger., 2006/7*	*Verdun et. al DRLs in Swiss, 2008*	*Shrimpton et. al DRLs in UK, 2003*
Less than 1 year	71	130	-	-	-
1-5 years	98	160	-	-	-
6-10 years	251	230	-	-	-
11-15 years	227	400	-	-	-

The findings of this current study for head, chest and abdomen respectively were lower than the ICRP (2000) recommendations with the exception of mean DLP for less than 1 year (325 mGy cm). The mean values were excessively low for chest and abdomen examinations with the exception of head examinations which fell within the range of DLP values for ICRP (2000) recommended levels. The DLP for abdomen from Switzerland (Verdun et al., 2008), 400 mGy cm and UK (Shrimpton et al., 2006) 470 mGy cm were also higher than findings from this study.

With reference to Table 2.8 (Murphy et al., 2013; Shrimpton & Wall, 2000; Shrimpton et al., 2006; Pages et al., 2006 and Verdun et al., 2008), mean DLP value of head examinations for current study (325 mGy cm) for less than 1 year were higher than those obtained in Europe, UK, Belgium and the Swiss for same age. Data comparison were however higher for Ireland (Murphy et al., 2013) with respect to the same examination and age. With respect to DLP values for chest examinations, mean values for this study were lower compared to the DRLs of Ireland, Europe, UK, Belgium and the Swiss across all age groups as shown in Table 2.8.

Comparison with recommended local diagnostic reference levels (LDRLs) by age group for typical paediatric CT examinations from Australia were also made (Table 2.9). Mean values from this study were lower than that from Brady et al. (2012) across all ages for chest and abdomen/pelvis examinations. It was however observed that the mean values for head (325-985 mGy cm) were higher than findings from Australia (250-700 mGy cm).

Some more comparison were made with data available from literature (Germany, Switzerland and UK) and summarised in Table 4.5 (i-iv). Some disparities were observed in the mean DLP values for head from this study and that from previous recommendations. For head, mean DLP from this work was 471 mGy cm for 1-5 years which was higher than values obtained from Switzerland (Verdun et al., 2008), 420 mGy cm and UK (Shrimpton et al., 2003), 270 mGy cm but lower than data from Germany (Galanski et al., 2007), 390 mGy cm. Mean values for chest and abdomen for this study were lower compared to previous recommendations for all ages. There was however insufficient literature regarding DLP for Abdomino-pelvis examinations from previous recommendations. Thus, appropriate comparisons were not reached.

Generally, it was observed that the $CTDI_{vol}$ values increased with regards to age for all types of examination, irrespective of the examination type (body or head region) except for chest (11-15 years) which decreased. The DLP also increased with age for each type of examination irrespective of the region.

4.7 REGIONAL DIAGNOSTIC REFERENCE LEVELS

Regional diagnostic reference levels, *RDRLs* were derived in terms of $CTDI_{vol}$ and DLP distributions for the facilities based on third (3rd) quartile dose values from the survey in all age groups for each type of CT examination.

Table 4.6a: RDRLs with respect to $CTDI_{vol}$ from Current Study

Age Range	**RDRL, $CTDI_{vol}$ (mGy)**							
	Head	Chest	Abdomino -Pelvic	Abdomen	IVU	Angio	Serialised Exam	Others
Less than 1 year	28	1	3	3	3	45	-	6
1-5 years	38	5	3	5	5	95	13	5
6-10 years	48	-	10	-	45	198	-	45
11-15 years	86	-	-	5	58	231	-	24

Table 4.6b: RDRLs with respect to DLP from Current Study

Age Range	RDRL, DLP (mGy cm)							
	Head	Chest	Abdomino-Pelvic	Abdomen	IVU	Angio	Serialised Exam	Others
Less than 1 year	395	18	71	83	-	45	-	208
1-5 years	487	110	120	124	-	95	311	143
6-10 years	601	-	494	-	-	198	-	1122
11-15 years	1614	-	-	233	457	231	-	501

DRLs have been defined as investigational levels employed in the identification of unusually high radiation doses for common diagnostic medical x-ray imaging procedures (Gray et al, 2005; Hart, Miller & Wall, 2007; National Council on Radiation Protection, 2012; American College of Radiology, 2013). They are recommended action levels above which a facility should review its methods and determine if satisfactory image quality can be attained at lower doses. DRLs are therefore important radiation approximating reference levels and a practical dose optimization tool for promotion of good practices, evaluation of existing protocols, and appropriate development of new and heightened protocols at each CT imaging centre.

Additionally, DRLs provide a common dose metric for the comparison of DRLs between facilities, protocols and modalities, assess dose impacts of newly introduced protocols, and provide compliance with the relevant national and regional regulatory requirements (Australian Radiation Protection and Nuclear Safety, 2008).

The ICRP had proposed that DRLs should be initially drawn from a percentile point in the patient dose distribution for a particular examination, and be revised at intervals as more optimised methods are developed (ICRP Publication 73, 1996). Following this guidance the EC, expressed the DRL as the dose quantity found at the 75th percentile of the mean dose distribution for each type of radiograph. This was adopted in the current study to propose age-based RDRLs for Greater Accra region (Table 4.6a and 4.6b for CTDIvol & DLP respectively). These RDRLs should be considered as temporary only, to be replaced in the future by more robust data established through surveys of measured doses on a larger sample of patients leading to pragmatic dose distributions.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The frequency of paediatric CT examinations and the typical values of the related dose quantities ($CTDI_{vol}$, DLP and DRLs) were surveyed in four centres performing paediatric CT examinations in the Greater Accra of Ghana. Mean values averaged over the participating centres were calculated and the corresponding RDRLs were established in terms of $CTDI_{vol}$ and DLP distributions for the facilities based on third (3rd) quartile dose values from the survey in all age groups for each type of CT examination. Appropriate inter-comparison were made with International values to verify whether Ghana was meeting National and international standards.

This investigation revealed that out of a total of 6147 CT examinations carried out in the various participating centres, the frequency of paediatric examinations accounted for 11%, with an average of 270 per centre performing paediatric CT. Significant disparities of the radiation dose delivered to the paediatric population were found and thus the need for initiation of an optimisation process in order to reduce this variation in dose.

A major element of the optimisation process is a unanimity on the necessity of DRLs in medical imaging. This becomes a priority in the light of contributions such as described in an article by Martin and Semelka (2006) in the Lancet on the "*Health Effects of Ionising Radiation from Diagnostic CT*". A set of RDRL values for CT examinations of the head, the chest and the abdomen and for the various age groups are proposed here for temporary use in paediatrics until a more extensive survey is organised to collect dose data on a large sample of patients and to establish pragmatic dose distributions.

The frequency of paediatric CT examinations in participating CT facilities in Greater Accra is relatively higher than in countries of Eastern Europe. This highlights the need to emphasise the application of suitability criteria for CT examinations in children. Generally, the $CTDI_{vol}$ and DLP values in participating centres in this study were lower than corresponding values from ICRP, other countries in Asia and in Eastern Europe. Although a few were higher with respect to specific age ranges.

In view of the paucity of information from developing countries, this study has established a baseline data on the frequency and dose levels in paediatric CT examinations. This will form a foundation for future studies on dose management in paediatric CT.

5.2 RECOMMENDATIONS

The Medical Exposure Directive, 97/43/Euratom (1997), endorses the evaluation of patient dose either in standard phantoms or groups of standard-sized patients on every equipment in every room of every radiological facility periodically, and after every major change or service with the long-term objective of annual assessments after the establishment of DRLs. Hence, the comparison of the surveyed doses from the current study with pre-established DRLs.

It is imperative to note that meeting the DRL does not always mean that good practice is performed. Quality assurance including quality control should also be maintained even when the DRL is not exceeded and particularly so if the doses are far below the DRL as is the case from findings of this study.

Furthermore, conducting a CT dose survey within a facility is crucial for understanding and investigating local practice. The mean values from this survey are also valuable for comparison with national and/or international DRLs to expedite benchmarking and ultimately optimisation of dose.

From the findings of this study, the recommendations below are addressed to the relevant stakeholders.

5.2.1 Hospital Authorities

Hospital Authorities are advised to;

- In the short term, conduct a review of protocols to determine whether there is appropriate justification for paediatric CT examinations
- Analyse the local scan parameters to provide a better indication of areas that may need further optimisation
- Derive LDRLs specific to the facility for common protocols based on clinical indication and/or weight. This may result in tapered ranges for the scan parameters and allow more directed LDRLs.
- Institute paediatric dose management system involving the principles of justification, optimization of patient dose, quality management and quality control of equipment used for imaging

5.2.2 Scientific Community

Further work should be conducted to include all CT centres within the country to establish paediatric NDRLs to promote the habit (culture) of paediatric CT dose management.

5.2.3 Regulatory Authority

- The medical professional bodies in collaboration with the Regulatory Authority (RPI & RPB) should formulate regulations that will be binding on imaging centres (stakeholders) to periodically undertake dose assessment for both paediatric and adult examinations and also participate in research geared towards sanitizing patient radiation exposure.
- Conduct periodic monitoring of facilities to monitor dose descriptors to verify compliance with NDRLs and internationally accepted DRLs.

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APPENDIX I - INTRODUCTORY LETTER

SCHOOL OF NUCLEAR AND ALLIED SCIENCES
University of Ghana – Atomic
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Office of the Director
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GHANA

Our Ref: SNAS/ACA/15/26/8
Your Ref:

Date: 5th January, 2016

The Managing Director
Medical Imaging Ghana Ltd.
Roman Ridge
Accra

Dear Sir/Madam,

LETTER OF INTRODUCTION:
MS. PATIENCE ADDO

I wish to introduce to you Ms. Patience Addo, M.Phil 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 M.Phil degree she is seeking, she is to complete a research project titled **"Computed Tomography (CT) Radiation Dose in Children: A Survey to Establish Regional Diagnostic Reference Levels in Greater Accra, Ghana".**

Your facility has been highly recommended for some aspect of her research.

I am kindly requesting that you offer Ms. Addo the necessary assistance in acquiring data for her research.

Thank you for your cooperation.

Yours faithfully,

Prof. Yaw Serfor-Armah
Dean

Preserving, maintaining and enhancing nuclear knowledge in Ghana and Africa

APPENDIX II - PATIENT DATA SHEET

Name of Institution: ……………………………………………………………

Equipment manufacturer: ....

Model Number: ....

Serial Number: ....

Year of Make: ....

Tube Current: ....

Patient Exposure Parameters

Patient ID/Sex	Age	Wt.	kV	mAs	Slice thickness (cm)	Scan length (cm)	No. of Slices	Exam	DLP Gy.cm	CTDI vol (mGy)

APPENDIX III - PATIENT DOSE DATA FROM PARTICIPATING CENTRES

Centre	Gender	Age	kV	mAs	Slice Thickness(mm)	Scan Length(mm)	Slice No.	Exam. Type	DLP	CTDI
A	Male	11-15years	120	40.0	0.50	45.44	569	Abdomen	234.40	4.70
A	Female	Less than 1year	80	150.0	0.05	11.95	240	Head	123.40	10.30
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	Less than 1year	80	150.0	0.50	13.95	280	Head	151.80	10.80
A	Female	6-10years	120	225.0	0.50	16.50	551	Head	1570.60	86.00
A	Male	11-15years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Male	Less than 1year	80	150.0	0.05	11.95	240	Head	123.40	10.30
A	Female	Less than 1year	100	150.0	0.05	12.75	256	Head	250.80	19.60
A	Female	11-15years	120	225.0	0.05	15.00	501	Head	1441.50	86.00
A	Male	6-10years	135	225.0	0.05	15.95	320	Head	995.80	62.20
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	225.0	0.05	17.49	584	Head	1656.60	86.00
A	Male	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	Less than 1year	100	31.0	0.50	23.10	771	Abdomen	53.60	1.90

A	Female	11-15years	120	225.0	0.05	21.00	701	Head	1957.60	86.00
A	Male	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	Less than 1year	135	225.0	0.05	15.95	320	Head	995.80	62.20
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	225.0	0.05	15.48	517	Head	1484.60	86.00
A	Male	Less than 1year	80	150.0	0.05	9.95	200	Head	93.10	9.30
A	Male	6-10years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Female	11-15years	120	225.0	0.05	15.99	534	Head	1527.50	86.00
A	Male	1-5years	100	150.0	0.05	15.90	320	Head	325.70	20.40
A	Male	11-15years	120	225.0	0.05	22.98	767	Head	2129.70	86.00
A	Male	11-15years	135	225.0	0.05	15.95	320	Head	995.80	62.20
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	50.0	0.05	33.88	848	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	258.20	6.70
A	Female	11-15years	120	30.0	0.05	44.70	1491	Abdomen	204.10	4.10
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	Less than 1year	80	150.0	0.05	1195.00	240	Head	123.40	10.30

A	Male	Less than 1year	80	150.0	0.05	15.95	320	Head	177.90	11.10
A	Male	1-5years	120	150.0	0.05	21.48	717	Head	1221.00	52.50
A	Male	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	6-10years	120	225.0	0.05	20.49	684	Head	1914.60	86.00
A	Female	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Female	11-15years	120	225.0	0.05	16.50	551	Head	1570.60	86.00
A	Female	11-15years	120	40.0	0.10	36.00	451	Chest	181.70	3.50
A	Male	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	11-15years	120	225.0	0.05	13.98	467	Head	1355.50	86.00
A	Male	Less than 1year	80	150.0	0.05	11.95	240	Head	123.40	10.30
A	Male	Less than 1year	80	21.0	0.05	15.95	320	Abdomen	11.30	0.70
A	Female	6-10years	100	22.0	0.05	20.10	671	Chest	37.60	1.50
A	Male	11-15years	100	33.0	0.05	21.30	711	Chest	62.30	2.40
A	Female	1-5years	80	42.0	0.05	15.95	320	Chest	22.60	1.40
A	Female	1-5years	80	42.0	0.05	15.95	320	Chest	22.60	1.40
A	Female	1-5years	80	35.0	0.05	15.95	320	Chest	18.80	1.20
A	Male	1-5years	120	225.0	0.05	18.00	601	Head	1699.60	86.00
A	Female	6-10years	100	150.0	0.05	15.95	320	Head	315.80	19.70

A	Male	Less than 1year	80	150.0	0.05	15.95	320	Head	177.90	11.10
A	Male	1-5years	120	30.0	0.20	29.19	974	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	142.50	4.30
A	Female	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	1-5years	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Male	Less than 1year	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Female	Less than 1year	100	150.0	0.05	12.75	256	Head	250.80	19.60
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Male	Less than 1year	80	150.0	0.05	15.95	320	Head	177.90	11.10
A	Female	6-10years	120	225.0	0.05	18.00	601	Head	1699.60	86.00
A	Female	11-15years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Female	11-15years	135	225.0	0.05	15.95	320	Head	995.80	62.20
A	Male	11-15years	120	225.0	0.05	16.98	567	Head	1613.60	86.00
A	Male	11-15years	120	225.0	0.05	16.98	567	Head	1613.60	86.00

A	Female	1-5years	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Male	11-15years	120	225.0	0.05	15.90	534	Head	1527.50	86.00
A	Female	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	30.0	0.05	26.70	891	Abdomen	56.00	1.80
A	Female	Less than 1year	100	17.0	0.05	11.95	240	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	12.70	1.10
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Female	Less than 1year	100	24.0	0.05	11.95	240	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	17.70	1.50
A	Female	Less than 1year	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Male	11-15years	120	225.0	0.05	19.98	667	Head	1871.70	86.00
A	Male	1-5years	120	225.0	0.05	18.99	634	Head	1785.60	86.00
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	11-15years	120	225.0	0.05	16.98	567	Head	1613.60	86.00
A	Male	1-5years	100	150.0	0.05	13.95	280	Head	277.80	19.80

A	Female	11-15years	120	225.0	0.05	22.98	767	Head	2129.70	86.00
A	Male	Less than 1year	100	195.0	0.05	11.95	240	Head	284.80	23.70
A	Female	11-15years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Male	11-15years	120	225.0	0.05	15.95	534	Head	1527.50	86.00
A	Male	11-15years	135	225.0	0.05	15.95	320	Head	995.80	62.20
A	Male	Less than 1year	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	120	225.0	0.05	18.00	601	Head	1699.60	86.00
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	6-10years	100	150.0	0.05	15.95	320	Head	315.80	19.70
A	Male	Less than 1year	80	150.0	0.05	15.95	320	Head	177.90	11.10
A	Male	1-5years	120	30.0	0.05	29.19	974	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	142.50	4.30
A	Female	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	1-5years	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Male	Less than 1year	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Female	Less than 1year	100	150.0	0.05	12.75	256	Head	250.80	19.60

A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	225.0	0.05	18.48	617	Head	1742.60	86.00
A	Male	11-15years	120	225.0	0.05	15.48	517	Head	1484.60	86.00
A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	Less than 1year	100	14.0	0.05	13.80	461	Chest	18.40	1.00
A	Female	Less than 1year	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	Less than 1year	100	25.0	0.05	26.19	874	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	68.60	2.20
A	Female	Less than 1year	100	187.0	0.05	15.95	320	Head	394.80	24.70
A	Male	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Female	1-5years	100	30.0	0.05	28.20	941	Abdomen	56.30	1.70
A	Female	Less than 1year	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Male	11-15years	120	225.0	0.05	24.00	801	Head	2215.70	86.00

A	Male	1-5years	100	225.0	0.05	13.95	280	Head	404.10	28.90
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	80	150.0	0.05	15.95	320	Head	172.50	10.80
A	Male	1-5years	80	150.0	0.05	18.99	634	Head	387.90	18.70
A	Male	Less than 1year	100	210.0	0.05	15.95	320	Head	442.10	27.60
A	Female	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	Less than 1year	100	225.0	0.05	15.98	320	Head	473.70	29.60
A	Female	6-10years	100	150.0	0.05	15.95	320	Head	315.80	19.70
A	Female	1-5years	120	30.0	0.05	34.50	1151	Abdomen	124.20	10.00
A	Male	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	Less than 1year	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Female	Less than 1year	100	75.0	0.05	33.28	833	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	254.10	6.70
A	Male	11-15years	120	225.0	0.05	18.00	601	Head	1699.60	86.00
A	Female	Less than 1year	80	150.0	0.05	11.95	240	Head	123.40	10.30
A	Female	11-15years	120	41.0	0.10	36.00	451	Chest	179.30	3.80
A	Female	Less than 1year	80	150.0	0.05	11.95	240	Head	123.40	10.30

A	Male	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	1-5years	100	150.0	0.05	15.95	320	Head	325.70	20.40
A	Female	Less than 1year	120	225.0	0.05	19.50	651	Head	1828.60	86.00
A	Female	6-10years	120	30.0	0.05	44.70	1491	Abdomen	212.00	4.30
A	Female	6-10years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Female	Less than 1year	100	150.0	0.05	13.95	280	Head	277.80	19.80
A	Female	1-5years	120	225.0	0.05	18.99	634	Head	1785.60	86.00
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	6-10years	100	150.0	0.05	15.95	320	Head	315.80	19.70
A	Male	11-15years	120	225.0	0.05	24.00	801	Head	2215.70	86.00
A	Female	1-5years	120	30.0	0.05	33.30	1111	Abdomen	120.40	3.20
A	Female	Less than 1year	80	150.0	0.05	15.95	320	Head	177.90	11.10
A	Male	11-15years	120	40.0	0.10	43.40	544	Abdomen	225.00	4.70
A	Female	1-5years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	100	225.0	0.05	15.95	320	Head	473.70	29.60
A	Male	11-15years	120	225.0	0.05	16.98	567	Head	1613.60	86.00
B	Male	6-10years	120	276.0	0.25	10.40	56	Head	609.76	60.98

B	Male	6-10years	120	276.0	0.06	0.75	288	Head	240.40	30.05
B	Male	6-10years	120	196.0	0.25	9.42	72	Head	657.04	51.77
B	Male	6-10years	120	196.0	0.06	12.16	384	Head	379.46	29.90
B	Female	11-15years	120	287.0	0.06	0.56	256	Head	236.89	58.64
B	Female	11-15years	120	287.0	0.25	11.61	40	Head	360.18	29.72
B	Male	6-10years	120	330.0	0.06	0.42	256	Head	268.00	64.71
B	Male	6-10years	120	350.0	0.25	29.71	120	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	941.75	31.39
B	Female	1-5years	120	40.0	0.38	25.20	48	Chest	90.07	4.32
B	Female	1-5years	120	70.0	0.06	20.38	327	Serialised Examination	308.07	12.32
B	Female	1-5years	120	36.8	0.38	7.50	77	Abdomen	71.75	2.26
B	Female	1-5years	100	119.5	0.50	6.94	32	Head	213.41	12.97
B	Male	1-5years	100	119.5	0.50	7.60	48	Serialised Examination	320.10	13.34
B	Male	1-5years	120	207.0	0.25	2.05	52	Head	324.76	40.59
B	Female	6-10years	100	109.5	0.06	11.70	192	Head	146.67	12.02
B	Female	6-10years	120	111.0	0.25	4.94	122	Serialised Examination	490.04	13.97
B	Male	1-5years	120	27.2	0.06	13.40	104	IVU	112.25	3.81
B	Male	Less than 1year	120	23.6	0.06	36.10	221	Abdomen	83.84	3.26
B	Male	6-10years	120	237.0	0.06	2.59	256	Head	250.63	41.46

B	Female	1-5years	120	19.6	0.06	13.13	403	Abdomino-Pelvic	85.09	3.00
B	Male	11-15years	120	100.0	0.06	12.55	441	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	490.61	16.56
B	Female	6-10years	120	118.0	0.06	3.19	520	Head	600.96	16.21
B	Male	11-15years	120	260.0	0.06	0.36	224	Head	176.91	42.91
B	Male	6-10years	120	260.0	0.06	2.09	288	Head	176.91	42.06
B	Male	11-15years	120	119.5	0.06	15.26	256	Head	213.41	12.75
B	Male	11-15years	120	350.0	0.06	11.70	448	Serialised Examination	1931.45	68.98
B	Female	11-15years	120	336.0	0.06	3.77	256	Head	270.36	67.28
B	Male	1-5years	120	232.0	0.06	5.00	256	Head	255.80	42.63
B	Female	6-10years	120	270.0	0.06	3.52	224	Head	224.27	55.81
B	Female	1-5years	120	26.8	0.06	7.25	217	Angio	49.15	2.93
B	Male	11-15years	120	334.0	0.06	3.75	224	Head	269.57	67.33
B	Female	6-10years	120	260.0	0.06	3.75	224	Head	176.84	44.21
B	Male	11-15years	120	60.5	0.06	26.60	673	Head	202.85	4.19
B	Male	11-15years	120	234.0	0.06	5.75	288	Head	256.41	42.74
B	Female	6-10years	120	273.0	0.06	3.75	224	Angio	230.58	57.94

B	Female	11-15years	120	304.0	0.06	2.50	224	Head	257.74	64.44
B	Male	11-15years	120	277.0	0.06	3.76	224	Angio	232.55	58.00
B	Male	6-10years	100	150.0	0.06	0.61	158	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	257.27	17.86
B	Female	1-5years	120	29.6	0.06	9.48	271	Angio	68.61	3.41
B	Female	11-15years	120	62.5	0.06	37.95	681	Abdomen	230.31	4.70
B	Female	6-10years	120	258.0	0.06	3.75	224	Head	176.16	44.04
B	Male	1-5years	120	22.4	0.06	6.58	121	Angio	42.45	2.72
B	Female	1-5years	100	119.5	0.06	13.50	224	Head	186.71	13.34
B	Male	1-5years	120	37.2	0.06	14.88	439	Abdomen	150.48	4.91
B	Female	6-10years	120	55.6	0.06	13.68	355	Chest	171.77	6.77
B	Male	11-15years	120	300.0	0.06	0.87	224	Head	250.69	61.52
B	Male	Less than 1year	100	109.5	0.06	5.90	320	Head	225.59	11.28
B	Male	6-10years	120	32.4	0.06	24.45	295	Angio	86.99	4.02
B	Male	11-15years	100	60.5	0.06	10.75	321	Angio	46.93	1.77
B	Male	1-5years	120	49.5	0.06	6.90	241	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	81.53	4.72
B	Male	11-15years	120	74.5	0.06	17.95	361	Angio	117.66	4.06

B	Male	1-5years	120	40.0	0.06	19.20	541	IVU	149.68	4.95
B	Male	1-5years	120	24.8	0.06	8.93	235	Angio	52.36	2.93
B	Male	1-5years	100	119.5	0.06	17.50	288	Head	13.34	240.04
B	Male	1-5years	120	46.0	0.06	8.70	277	Angio	94.84	4.63
B	Male	6-10years	120	200.0	0.06	13.89	465	Serialised Examination	165.94	8.12
B	Male	6-10years	140	145.6	0.06	21.24	352	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	380.22	15.71
B	Male	1-5years	120	257.0	0.06	1.95	256	Head	175.82	43.95
B	Male	6-10years	120	310.0	0.06	3.75	224	Head	250.61	62.65
B	Male	11-15years	120	289.0	0.06	3.57	256	Head	239.57	59.61
B	Male	1-5years	100	119.5	0.06	10.75	223	Angio	186.71	13.34
B	Male	1-5years	120	32.0	0.06	16.13	224	Head	76.70	3.96
B	Female	11-15years	120	58.0	0.06	32.55	617	Abdomino-Pelvic	253.12	5.63
B	Male	11-15years	120	295.0	0.06	5.21	288	Head	375.20	62.45
B	Male	1-5years	100	109.5	0.06	15.50	256	Head	195.58	12.22
B	Male	6-10years	120	350.0	0.06	2.30	352	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	1301.50	59.16
B	Female	11-15years	120	62.5	0.06	34.20	641	Abdomino-Pelvic	200.90	4.32
B	Male	1-5years	120	13.3	0.06	12.13	295	Angio	259.80	11.30
B	Female	1-5years	100	49.5	0.06	5.80	201	Angio	34.88	1.84

B	Female	1-5years	120	37.6	0.06	7.83	283	Chest	116.51	5.58
B	Male	1-5years	120	230.0	0.06	4.70	288	Head	251.65	41.14
B	Female	6-10years	120	26.0	0.06	20.83	487	Abdomino-Pelvic	138.60	4.12
B	Female	1-5years	120	32.4	0.06	8.33	235	Angio	68.46	3.83
B	Female	11-15years	120	318.0	0.06	3.76	224	Head	257.74	64.28
B	Male	1-5years	120	49.5	0.06	23.00	369	Chest	141.66	5.60
B	Male	Less than 1year	120	22.8	0.06	17.88	331	Abdomen	37.62	1.58
B	Female	6-10years	120	260.0	0.06	2.83	224	Head	176.91	40.71
B	Female	1-5years	120	32.0	0.06	9.10	337	Chest	49.65	2.05
B	Male	6-10years	120	260.0	0.06	3.75	256	Head	176.84	44.21
B	Male	1-5years	120	28.0	0.06	5.63	335	Chest	25.03	1.40
B	Female	Less than 1year	100	109.5	0.06	10.75	224	Head	171.09	12.22
B	Female	1-5years	100	119.5	0.06	15.50	256	Head	213.36	13.34
B	Female	1-5years	120	29.6	0.06	1.95	241	Angio	28.16	1.54
B	Male	Less than 1year	120	23.6	0.06	19.45	361	Abdomen	82.57	3.21
B	Male	6-10years	120	37.2	0.06	12.05	277	Angio	102.25	4.99
B	Female	1-5years	100	119.5	0.06	16.10	288	Serialised Examination	240.07	13.34
B	Male	1-5years	120	49.5	0.06	0.21	232	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	94.73	5.67

B	Male	Less than 1year	120	24.4	0.06	16.75	325	Abdomino-Pelvic	70.93	3.02
B	Female	6-10years	120	260.0	0.06	0.90	224	Head	176.91	44.23
B	Male	6-10years	120	260.0	0.06	1.00	224	Head	176.84	44.21
B	Female	11-15years	120	276.0	0.06	3.75	224	Angio	227.42	56.86
B	Female	Less than 1year	120	24.4	0.06	9.73	211	Angio	44.56	2.72
B	Male	1-5years	120	28.8	0.06	18.00	445	Serialised Examination	131.15	4.23
B	Female	6-10years	120	150.5	0.06	34.45	681	Abdomino-Pelvic	609.90	12.45
B	Male	6-10years	120	314.0	0.06	2.16	224	Head	396.53	66.03
B	Female	Less than 1year	100	109.5	0.06	19.56	320	Head	244.42	12.18
B	Male	1-5years	100	119.5	0.06	14.94	256	Head	213.41	13.26
B	Male	6-10years	120	274.0	0.06	3.91	256	Head	362.62	60.36
B	Male	1-5years	120	350.0	0.06	3.65	320	Head	1357.48	67.87
B	Male	Less than 1year	100	109.5	0.06	13.73	224	Head	171.09	12.02
B	Female	6-10years	120	50.0	0.06	35.70	577	Abdomen	154.06	3.63
B	Male	6-10years	120	49.5	0.06	16.23	395	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	117.63	4.02
B	Male	1-5years	120	28.0	0.06	26.53	451	Abdomino-Pelvic	80.37	2.56
B	Female	1-5years	100	119.5	0.06	7.80	320	Head	266.76	13.34

B	Male	11-15years	140	104.3	0.06	5.44	246	Serialised Examination	311.52	11.78
B	Female	11-15years	120	61.0	0.06	21.30	413	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	183.23	6.03
B	Male	1-5years	120	21.2	0.06	17.90	445	Abdomino-Pelvic	100.01	3.23
B	Male	Less than 1year	100	109.5	0.06	13.20	224	Head	171.16	12.23
B	Male	1-5years	120	26.0	0.06	11.68	247	Angio	61.19	3.29
B	Male	1-5years	120	38.4	0.06	24.00	541	Abdomino-Pelvic	126.03	3.41
B	Male	11-15years	120	104.5	0.06	43.55	785	IVU	457.42	8.25
B	Female	1-5years	100	119.5	0.06	6.55	320	Head	266.76	13.24
B	Male	6-10years	120	49.5	0.06	31.90	705	Abdomino-Pelvic	145.27	2.88
B	Female	6-10years	120	49.5	0.06	32.00	513	Abdomino-Pelvic	110.73	2.88
B	Female	1-5years	100	119.5	0.06	11.60	320	Head	266.73	13.34
B	Female	11-15years	120	265.0	0.06	5.42	288	Head	478.90	59.64
B	Male	6-10years	120	260.0	0.06	3.28	256	Head	176.84	43.83
B	Male	Less than 1year	120	19.6	0.06	12.25	445	Abdomen	39.84	1.29
B	Female	1-5years	120	24.4	0.06	25.88	415	Abdomen	52.64	1.81
B	Male	1-5years	120	21.6	0.06	18.35	457	Serialised Examination	106.20	3.35
B	Male	1-5years	120	28.0	0.06	18.20	457	Serialised Examination	148.15	4.67
B	Male	6-10years	80	112.5	0.06	13.65	353	Angio	62.01	2.18

C	Male	1-5years	120	150.0	0.60	20.00	41	Head	772.80	35.10
C	Male	Less than 1year	120	150.0	0.60	16.00	33	Head	667.40	35.10
C	Male	6-10years	120	150.0	0.60	19.00	39	Head	737.70	35.10
C	Male	6-10years	120	150.0	0.60	2.00	7	Head	175.60	35.10
C	Male	1-5years	120	150.0	0.60	20.00	8	Head	807.90	35.10
C	Male	Less than 1year	120	150.0	0.60	12.00	25	Head	491.80	35.10
C	Male	11-15years	120	150.0	0.60	15.00	31	Head	632.30	35.10
C	Male	11-15years	120	150.0	0.60	7.00	18	Head	351.30	35.10
C	Male	11-15years	120	150.0	1.00	3.60	4	Head	146.60	20.40
C	Male	11-15years	120	150.0	0.50	15.00	32	Head	562.00	35.10
C	Male	1-5years	120	150.0	0.60	13.00	27	Head	526.90	35.10
C	Male	6-10years	120	150.0	0.65	14.00	29	Head	562.00	35.10
C	Male	11-15years	120	150.0	0.60	14.00	29	Head	562.00	35.10
C	Male	6-10years	120	150.0	0.60	17.00	35	Head	667.40	35.10
C	Female	1-5years	120	150.0	0.60	14.00	29	Head	562.00	35.10
C	Female	6-10years	120	150.0	0.30	12.00	49	Head	650.20	48.20
C	Female	1-5years	120	150.0	0.33	11.50	47	Head	626.10	48.20
C	Female	1-5years	120	150.0	0.65	2.00	6	Head	140.50	35.10

C	Female	1-5years	120	150.0	0.30	14.00	57	Head	559.90	36.10
C	Male	1-5years	120	150.0	0.30	12.50	51	Head	674.30	48.20
C	Male	1-5years	120	150.0	1.00	0.20	2	Head	73.30	36.60
C	Male	11-15years	120	150.0	0.30	14.00	57	Head	559.90	36.10
C	Female	Less than 1year	120	150.0	0.30	12.00	49	Head	650.20	48.20
C	Female	Less than 1year	120	150.0	0.30	1.00	8	Head	120.40	48.20
C	Male	11-15years	120	150.0	0.25	13.80	48	Head	577.90	40.10
C	Male	6-10years	120	150.0	0.25	14.40	50	Head	602.00	40.10
C	Female	11-15years	120	150.0	0.25	18.00	62	Head	373.30	20.10
D	Female	11-15years	120	112.5	0.25	25.00	104	Serialised Examination	373.10	13.90
D	Male	11-15years	120	262.5	0.25	25.00	56	Head	580.30	41.40
D	Male	11-15years	120	262.5	0.25	25.00	72	Head	663.20	41.40
D	Male	6-10years	120	262.5	0.25	25.00	64	Head	663.20	41.40
D	Female	11-15years	120	112.5	0.50	25.00	63	Others(Extremities,Neck,Sinuses,Jaws,Shoulder, Pelvis,)	505.10	27.00
D	Female	1-5years	120	125.0	0.25	23.75	56	Head	341.60	24.40
D	Male	1-5years	120	262.5	0.25	23.75	56	Head	580.30	41.40
D	Female	1-5years	120	262.5	0.25	23.75	63	Head	663.20	41.40

D	Male	6-10years	120	262.5	0.25	23.75	56	Head	580.30	41.40