Risk Analyses of Computed Tomography (CT) Digital Imaging Modality at the 37 Military Hospital, Accra.

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Abstract- Digital radiology is one of the diagnostic and therapeutic modalities which has been adopted in Ghana for health needs and research. Radiations come in two forms, either ionizing radiations or non-ionizing radiations, which may cause some form(s) of adverse effects. The main objective of the study was to determine and analyze the Weighted Computed Tomography Dose Index ($CTDI_w$) of CT scanner (which produces ionized radiation) for potential adverse effects at the 37 Military Hospital Radiology Department for both diagnostic and therapeutic radiology. To calculate the $CTDI_w$ values for of CT scanner. The study will ascertain the level of risk in the $CTDI_w$ values by comparing to the accepted standards for radiologic imaging; identify possible factors that may account for defective $CTDI_w$ values (if any). CT phantoms were used for the radiation exposure (scanning) in CT scanner. A clinical trial (therapeutic study) was adopted for the study. Results were analyzed and numerical calculations were used for the determination of the $CTDI_w$ values for the CT. The CT scanner produced radiation doses of 540.91mGy and 134.91mGy for the Head and Body phantoms respectively representing a percentage discrepancy of 901.52% and 385.45%. Higher doses from the scanner would lead to high patient or organ doses hence could expose individuals undergoing the scan to high doses and possible adverse events/effects could be recorded.

Index Terms- Computed Tomography Dose Index, Phantom, Radiology, Radiation

I. Introduction

Radiology uses medical imaging technology to diagnose and treat medical conditions. Radiology has been used for medical purposes for over a century and remains a cornerstone of the medical field. Radiology is divided into two fields: diagnostic and therapeutic radiology [1]. Diagnostic radiology is used to diagnose conditions (like necrosis, cataract, sterility, cancer, gene mutation etc.) and utilizes many different forms of imaging. Radiations come in two forms, either ionizing radiations or non-ionizing radiations, which may cause a lot of complications including necrosis, cataract, sterility, cancer, gene mutation etc. Computed Tomography produces ionized radiations and patients are being exposed to doses of radiations. These ionized radiations can cause adverse effects.

2 LITERATURE REVIEW

Usage of CT has increased dramatically over the last two decades in many countries [2].An estimated 72 million scans were performed in the United States in 2007 [3]. One study estimated that as many as 0.4% of current cancers in the United States are due to CTs performed in the past and that this may increase to as high as 1.5% - 2% with 2007 rates of CT usage [4]. However, this estimate is disputed [5]. Kidney problems following intravenous contrast agents may also be a concern in some types of studies. The computed tomography dose index (CTDI) is a commonly used radiation exposure index in X-ray computed tomography and is reported by the CT manufacturers to scan personnel for each exam. The CTDI can be used in conjunction with patient size to determine the absorbed dose. The CTDI and absorbed dose may differ by more than a factor of two for small patients such as children [6].

A Monte Carlo based method to estimate radiation dose from multi-detector CT (MDCT): DeMarco et al (2005), [7], conducted cylindrical and anthropomorphic phantoms. The purpose of their investigation was to extend the verification of Monte Carlo based methods for estimating radiation dose in computed tomography (CT) examinations beyond a single CT scanner to a multi-detector CT (MDCT) scanner, and from cylindrical CTDI phantom measurements to both cylindrical and physical anthropomorphic phantoms. Both cylindrical and physical anthropomorphic phantoms were scanned on an MDCT under the specified conditions. A pencil ionization chamber was used to record exposure for the cylindrical phantom, while MOSFET (metal oxide semiconductor field effect transistor) detectors were used to record exposure at the surface of the anthropomorphic phantom. Reference measurements were made in air at isocentre using the pencil ionization chamber under the specified conditions. Detailed Monte Carlo models were developed for the MDCT scanner to describe the x-ray source (spectra, bowtie filter, etc.) and geometry factors (distance from focal spot to isocentre, source movement due to axial or helical scanning, etc.). Models for the cylindrical (CTDI) phantoms were available. For the anthropomorphic phantom, CT image data were used to create a detailed voxelized model of the phantom's geometry. The manufacturer provided anthropomorphic phantom material compositions. A simulation of the physical scan was performed using the mathematical models of the scanner, phantom and specified scan parameters. Tallies were recorded at specific voxel locations corresponding to the MOSFET physical measurements. Simulations of air scans were performed to obtain normalization factors to convert results to absolute dose values. For the CTDI body (32 cm) phantom, measurements and simulation results agreed to within 3.5% across all conditions. For the anthropomorphic phantom, measured surface dose values from a contiguous axial scan showed significant variation and ranged from 8 mGy/100 mAs to 16 mGy/100 mAs. Results from helical scans of overlapping pitch (0.9375) and extended pitch (1.375) were also obtained. Comparisons between the MOSFET measurements and the absolute dose value derived from the Monte Carlo simulations demonstrate agreement in terms of absolute dose values as well as the spatially varying characteristics. This work demonstrates the ability to extend models from a single detector scanner using cylindrical phantoms to an MDCT scanner using both cylindrical and anthropomorphic phantoms.

Although the use of computed tomography (CT) in medical diagnosis delivers relatively higher radiation doses to patients than other radiological procedures, lack of optimized protocols could be an additional source of increased dose in developing countries [8]. The aim of this study was to determine the magnitude of radiation doses received by selected radiosensitive organs of patients from CT examinations. The study was further carried out in order to assess the influence of existing CT scanning protocols on patient organ doses. In order to achieve these objectives, patient organ doses from five common CT examinations were obtained from eight hospitals in Tanzania. The patient organ doses were estimated using measurements of CTDI, exposure-related parameters and the NRPB conversion factors. Large variation of mean organ doses among hospitals was observed for similar CT examinations. These variations were largely originated from different CT scanning protocols employed in different hospitals and scanner type. The mean organ doses in this study for the lens of the eyes (for head), thyroid (for chest), breast (for chest), stomach (for abdomen), and ovary (for pelvis), were 63.9 mGy, 12.3 mGy, 26.1 mGy, 35.6 mGy, and 24.0 mGy, respectively. These values were mostly comparable and slightly higher than the values of organ doses reported from literature for the UK, Japan, Germany, Norway and the Netherlands. It was concluded that patient organ doses could substantially minimized through careful selection of scanning parameters based on clinical indications of study, patient size, and body region being examined. Additional dose reduction to superficial organs would require the use of shielding materials.

3. METHODOLOGY

The research design for the study was a clinical experiment one (Therapeutic study). This is a study which involves the study of human subjects or any living species to answer questions about how safe a medical intervention is. The head CT phantom was scanned first. The head phantom was placed on the head rest of the CT scanner and the ionization chamber was connected to the center hole (hole 1) with other holes (Peripheral holes;2, 3, 4 and 5) well plugged with glass rods. The Electrometer of the dosimeter was put on for the readings of the CTDIs for the determination of the $CTDI_c$ and $CTDI_p$. On the console, the region of examination was selected as Head Routine. Again the name of patient and sex was selected as PHANTOM. It was ensured that nobody remained in the CT scanner room while scanning was in process. After the scan was done, a reading was recorded from the electrometer. The scan was repeated for this hole and the readings taken accordingly. Other parameter readings like the kVp (peak kilovoltage), mAs (milliamperes), slice thickness etc. were recorded at the head region of examination. After the phantom was scanned with the ionization chamber at the center, the ionization chamber was moved to the peripheral holes starting from hole 2 up to hole 5. The phantom was scanned twice with the ionization chamber in each of the holes to ensure accurate readings. These procedures used for collecting data for the head phantom were repeated for other region of examinations by changing the region of examination to Body (Topography) Adult. CT scanner, CT-16cm head and 32cm body phantoms, electrometer, ionization chamber and dosimeter were used for data collection.

Evaluation of the weighted $CTDI_w$ from measurements of the head and body phantoms was calculated using equation (1).

$$CTDI_w = \frac{1}{3} \cdot CTDI_1 + \frac{2}{3}\left(\frac{1}{4}\sum_{i=2}^{5} CTDI_i\right) \quad \text{(1)}$$

Source: [9]

4. RESULTS AND DISCUSSION

4.1 CT HEAD PHANTOM

The data below were the set parameters before the scan was performed for the head CT phantom

Parameters	**Values**
mAs	270
kV	130

Scan Time	1.5s
Delay	5s
$CDTI_{vol}$	63.16 mGy (16cm)
DLP	995.33 mGycm
Acq.	16 x 1.2mm
Slice Thickness	4.8mm
Scan Length	152.7mm
No. of Scans	10
No. of Images	32
Table Height	160.0cm
Tilt	14.0 ^{o}

Figure 1; demonstrate the numerically calculated (NC) $CTDI_w$ of the head phantom of 540.91mGy as against 60mGy European Commission Radiological Protection (EC) $CTDI_w$ accepted levels. This indicates a high discrepancy of 901.52% as compared to the EC $CTDI_{w\ standard}$ for the head. The high radiation dose of 540.91mGy for the head is unacceptable according to the European Commission radiation threshold. This would lead to high patient/tissue dose, which could lead to adverse health events. High radiation doses signify a high absorption of dose that is detrimental to the health of cells and tissues. Patients receiving these doses would therefore stand a very high risk of an adverse event from the scanner with high doses as calculated. The calculated CTDI is nine times the European Commission standard and that's an unacceptable radiation dose exposure (risk).

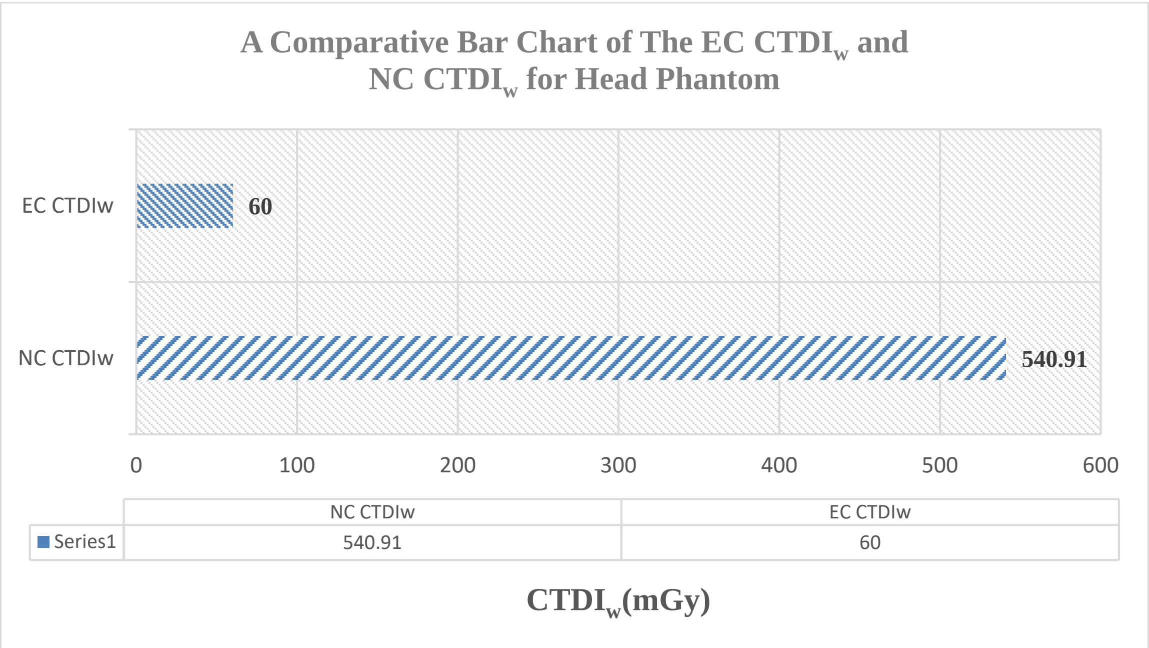

Figure 1: A Comparative Bar Graph of Numerically Calculated $CTDI_w$ and the EC $CTDI_w$ Head Phantom

4.2 CT BODY PHANTOM

Also these subsequent parameters were the planned and selected factors for the body CT phantom scan.

Parameters	Values
mAs	130
kV	130
Scan Time	7.79s

Delay	23s
$CDTI_{vol}$	14.58 mGy (32cm)
DLP	291.71 mGycm
Acq.	16 x 1.2mm
Slice Thickness	5.0mm
Scan Length	159.1mm
No. of Scans	10
No. of Images	34
Table Height	160.0cm
Range Begin	440.5mm
Range End	271.0mm
Tilt	0.0 º

Figure 2 illustrates the numerically calculated $CTDI_w$ value of 134.91mGy as compared to the 35mGy $ECCTDI_w$ accepted standard. This is indicating a high discrepancy of 385.45% more as compared to the EC $CTDI_w$ standard for the body. This is indicative that the radiation dose churn out of the scanner is very high. High patient dose exposure could carry small to but nonzero risk and also high risks like tissues damage, cancer, gene mutation etc. the numerically calculated CTDI value for the body phantom is quite low compared to the head phantom which recorded over 900% of the European Commission standard. The 385.45% of the dose signifies over three times exposure to the dose. The rate of an adverse event by the scanner to a patient is 300% and more to be recorded. Again this (134.91mGy) dose did not conform to the European Commission radiologic imaging standard but outweighs it by 385.45%. This patient dose would produce a risk of one form or another.

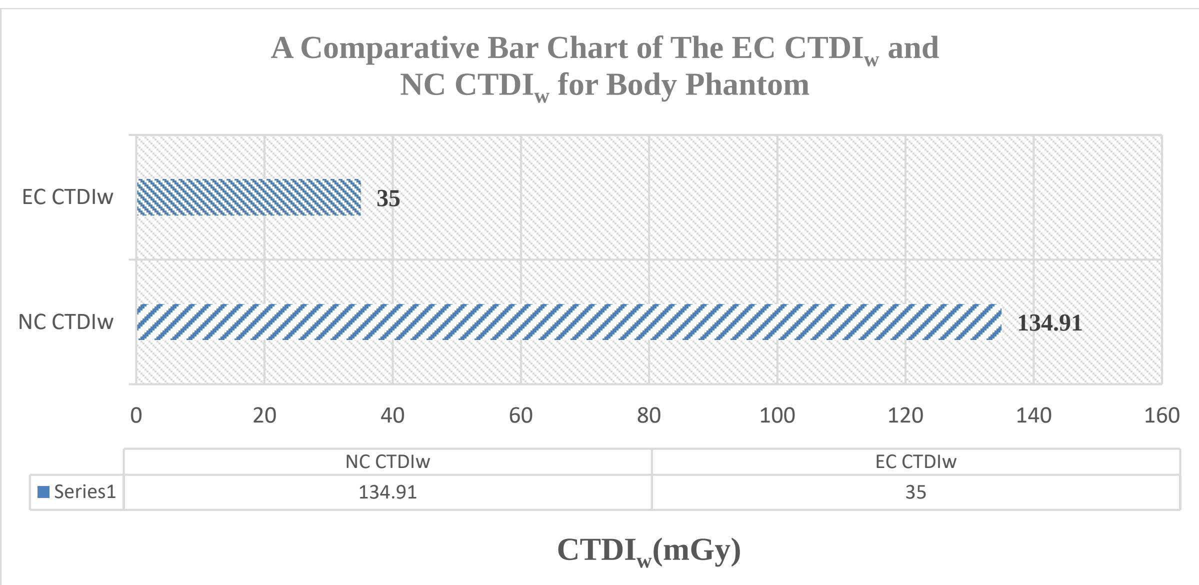

Figure 2: A Comparative Bar Graph of Numerically Calculated $CTDI_w$ and the EC $CTDI_w$ for Body Phantom

The question therefore arises, asking what is accounting for the high values. The overall comparative analysis of the head and body phantoms were analyzed on a bar graph in Figure 3. The Figure presents numerically calculated $CTDI_w$ values compared to the

European Union standards of the $CTDI_w$ values. The head phantom recorded a numerically calculated $CTDI_w$ value of 540.91mGy, which indicated a percentage discrepancy of 901.52% compared to the European Union's standard of 60mGy. Also, the body phantom showed a discrepancy of 385.45% of the numerically calculated $CTDI_w$ value of 134.91mGy to the accepted standard of 35mGy for the body.

The CT scanner recorded the following $CTDIs_w$. The Head CT phantom gave a numerically calculated $CTDI_w$ of 540.91mGy compared to the 60mGy standard of the European Commission

(EC) with a 901.52% of discrepancy. The Body CT phantom also recorded a $CTDI_w$ of134.91mGy to the 35mGy of the EU with a percentage discrepancy of 385.45%.

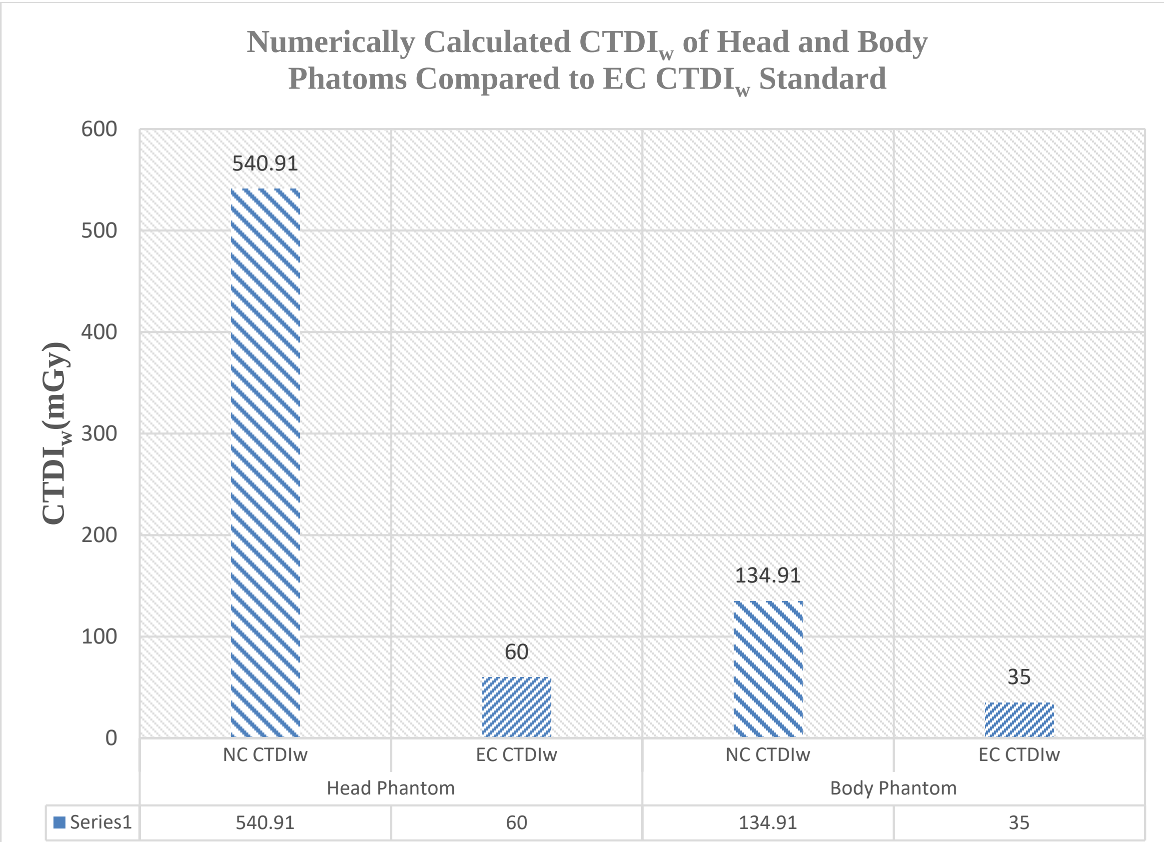

Figure 3: The Overall Analyses of the Numerically Calculated $CTDI_w$ of Head and Body Phantoms Compared to the EC $CTDI_w$ Standards.

5.1 CONCLUSION

The CT scanner produced radiation dose indexes of 540.91mGy and 134.91mGy for the Head and Body phantoms respectively. The $CTDI_w$ showed a respective percentage discrepancy of 901.52% and 385.45% for the Head and Body phantoms. Higher doses from the scanner would lead to high patient or organ doses hence could expose individuals undergoing the scan to high doses and possible adverse events/effects could be recorded if the same scan parameters are used to scan human beings. The calculated $CTDI_w$ didn't conform to the European Commissions' standards for radiologic imaging. The following parameters or factors accounted for the high percentage of discrepancy of the $CTDI_w$.

- The scan parameters set, i.e. mAs, kV, slide thickness, scan length etc.
- Image quality for the easy diagnosis: Contrast medium couldn't be administered to phantoms

- Number of slice: More slices required more doses to produce them.
- Table height: Tall tables bring objects for scanning close to the radiation dose where the dose is very strong.
- Type of the scanner: Multislice,

5.2 FACTORS ACCOUNTING FOR THE DISCREPANCIES IN THE $CTDI_w$.

- Justification: In most cases the clinician who refers a patient for a CT scan will ensure that the benefits provided by the information in the examination far outweighs the risks associated with the radiation dose.
- Radiation dose depends on the tube current (amperage), slice scan time, and tube peak kilo voltage. Increasing the mAs will increase the scan time and therefore the dose proportionally. Thus CT radiation dose is often expressed a dose per mAs (or per 100mAs),
- These are some of the scan parameters. Whereas most scanners are normalized to a 100mAs, the one used for this study normalized to270mAs and 130mAs for the head and body respectively.
- Image quality: The greater the dose, the greater the quality of the image. Quality images lead to easy diagnosis therefore clinicians require quality images for their diagnostics.
- Table height: Taller tables bring patients or phantoms closer to the gantry where the dose is denser. Radiation doses are delivered in conical shape. This is the attenuation principle. The table heights recorded 160.0cm each for the head and body phantom scans.
- A multislice CT scanner produces high mAs hence longer scan lengths and increased radiation dose while a single slice CT scanner gives low mAs and hence low dose. The scanner for this study was a16 slice (multislice) one.

Higher number of slices leads to high scan lengths and respective radiation doses. Table 1 give an illustration of mean or average number of images/slices for some countries compared to this study.

Region of Exam	This Study	Germany	UK	Netherland	Japan
Head	32	24	25	Not Available	9
Body	34	32	25-34	28-31	16

Table 1: Mean number of images/slices for some countries compared to this study, Source: [8]

The CT scanner recorded the following $CTDI_w$. The Head CT phantom gave a numerically calculated $CTDI_w$ of540.91mGy compared to the 60mGy standard of the European Commission (EC) with a 901.52% of discrepancy. The Body CT phantom also recorded a $CTDI_w$ of 134.91mGy to the 35mGy of the EU with a percentage discrepancy of 385.45%.

5.3. RECOMMENDATIONS

In the analyses of the data and findings of the study, some discrepancies were identified with the $CTDI_w$ values of the CT scanner and as a result some recommendations and suggestions were provided for radiation dose reduction As Low As Reasonably Achievable (ALARA);

- Justification: The exam must be medically indicated. Thus the exam must be beneficial to the patient

- Optimization: The exam must be performed using doses that are As Low As Reasonably Achievable (ALARA), consistent with the diagnostic task.
- Minimization of Number of slices and hence scan length without affecting the image quality
- Modulation of the exposure parameters (e.g. mAs, kV, exposure time, etc.) taking into account the age, weight, transverse diameter of the patient
- The use of protective shields (e.g. lead apron) for regions that are not a concern for examination and are highly irradiated
- Contrast media should be used to enhance image quality in patients.
- Radiologist should ensure that no more radiation is used than obtaining diagnostic information in any radiologic examination in CT.

5.4. FUTURE WORK TO BE DONE

There are other radiology imaging modalities that need to be looked at as well to determine the conformity or otherwise to accepted standards for imaging viz a viz the radiation dosages and possible adverse events that it brings to human health. Ghana is fast growing with technology and health delivery and it concerns us to find out if other health facilities using these imaging equipment conform to the standards. Other radiology equipment like the Mammography Machine, Fluoroscopy, X-Ray would be looked at.

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