Comparison of Measured Values of CTDI and DPL with Standard Reference values of Different CT Scanners for dose Management

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ABSTRACT

The study is based on estimate of CTDI and DLP values for patients' dose optimization procedures. Technical parameters were obtained for three groups of randomly selected patients undergoing abdominal CT examinations of 1320 patients of age 20-80 years. The measured values were obtained on image data and the standard reference values of various machines were obtained from service manual as part of QC/QA and the recommended values from ICRP publication 103. The mean CTDI and DLP parameters were; 6.33mGy and 936.25mGy respectively. Furthermore, the mean recorded values of $CTDI_{VOL}$ values were well within ICRP recommendation when the protocol was completed in one scan. On the other hand, in the case of multiscan the total $CTDI_{VOL}$ was higher than the ICRP recommendations. While the mean DLP values were higher than the recommended value of 780 mGy-cm by ICRP publication 103. Finally, approximately 37% of the total varied CTDI and DLP values were higher than the recommended dose by ICRP publication 103.
Keywords: CTDIVOL, DLP, ICRP, Dose Optimisation, Air Karma Index

I. INTRODUCTION

It is important to note that photons are high energetic EM waves with enough force to overcome the binding energy of an orbiting electrons in the shells of an atoms surrounding the nucleus. Ions are created when this energetic photon knock off electron from its orbital shell. When human body are exposed to photons free hydroxyl radicals are created [1, 2]. These are due to the interactions of x-ray with the water molecules in human body cells which consist of approximately 70% water molecules. These interactions leads to alternation of genetic information carrier, deoxyribonucleic acid (DNA), which is a self-replicating material which is present in cells of all living organisms. Both the direct interacting DNA and the nearby DNA will cause a base damage or strand breaks and the hydroxyl may even ionize DNA directly.

It should be noted that, immediately after this photons interactions various cells in human body systems may or may not rapidly repair most of these radiation-induced damage, this are based on a number of factors. However, in cases where the damage is a double-strand breaks the repairs may not easy repaired which may lead to induction of solid cancers [2].

Measurements of these damage cause by photons are described in two main folds. Those damage cause by high dose rate during therapy and those cause by low dose rate during imaging. In the case of the low dose rate during medical imaging as in the case of CT, two fundamental quantities, Computed Tomography Dose Index (CTDI) and Dose Length Product (DLP) parameters are measured and used to estimate these biological damage due to the exposure of photon energy. In most of these medical imaging where low-dose radiation exposure is use, the risk-related quantities can be obtained from the practical dosimetric quantities. These quantities are express from $CTDI_{VOL}$ and DLP, using the dose-conversion coefficients for specific organ dose and regional effective dose respectively.

II. METHODS AND MATERIAL

A. Objectives

The objective of this study is to determine standard reference CTDI and DLP values of an average adult Ghanaian undergoing abdominal CT examinations and compare with international recommended values for clinical application. In addition, to estimate CTDI and DLP for four different CT scanners types and compare with manufacturers recommendations.

B. Basic Theories

The two basic quantities that are used to estimate risk to patients undergoing radiation dose during CT examination is the Computed Tomography Dose Index and Dose Length Product. These two quantities are explain as:

C. CT Dose Index

CTDI is an acceptable radiation dose descriptor at a point in the tissues and estimate as weighted-CTDI (CTDI$_W$) or in the entire volume described as volume-CTDI (CTDI$_{VOL}$). That is, the CTDI is either an integral of all radiation dose delivered both within and beyond the scan volume. It is also express as the average dose descriptor across the field of view to take into account variations in absorbed dose across a body or an object results in a dose descriptor known as the weighted CTDI air karma index (CTDI$_w$). The CTDIw represents the average dose in the scan volume for contiguous CT scans. In the case when there is either a gap or an overlap between sequential scans, the dose descriptor volume CTDI (CTDIvol) is used. CTDIvol represents the average dose within a scan and this is displayed on the user interface of the CT scanner. In addition, CTDIvol is an index that quantifies the intensity of the CT radiation x-ray beam.

CTDI$_{Vol}$ is derived directly with volumetric multidetector row system. It is estimated by dividing $CTDI_W$ with the pitch factor (P), in order to obtain the total CTDI volume, express as $\frac{CTDI_W}{p}$ [3]. This is express from the pitch factor (P), define as a product of the number of slice (N) and the slice thickness (T) divided by the slice separation (Δd), express mathematically as:

$$pitch\ factor = \frac{\Delta d}{N.T} \tag{1}$$

Hence,

$$CTDI_{VOL} = CTDI_W.\frac{N.T}{\Delta d} = \frac{CTDI_W}{p}.$$
$$CTDI_{VOL} = \frac{1}{P}CTDI_W \tag{2}$$

Many modern CT systems calculate the Computed Tomography Air Kerma Index, C_a instead of the CTDI. Ca is a useful indicator of scanner radiation output for a specific kVp and mAs. Values of Ca can vary with nominal slice thickness, especially for the narrowest settings [3].

This was introduced to account for variations in radiation exposure in the z direction when the pitch is not equal to 1. So, $CTDI_{vol}$ takes into account the helical pitch or axial scan spacing [3]. It is of interest to note that recent publications and IAEA soon to be published Code of Practice point out the experimental difficulty in determining the dose to air, especially in the vicinity of an interface, and that, in reality, the quantity measured by instruments is air kerma. For these reasons these publications recommend the use of air kerma rather than absorbed dose to air, and consequently, the name CTDI is to be replaced in future by the Computed Tomography Air Kerma Index (C_a). [4]. Furthermore, doses to organs (e.g., kidney) are determine using the Ca and conversion factor for organ tissues as recommended by ICRP publication 103 *Table 1* [3].

Table 1. Conversion factors for ICRP publication 103.

CT examinations	Effective Dose mSv	DLP mGy cm	$CTDI_W$ mGy	CTDI$_{VOL}$ mGy	E$_{DLP}$ mSv mGy^{1}cm^{-1}
Head CT	1 – 2	1050	60	73.80	0.0023
Chest CT	5 – 7	650	30	36.90	0.017
Pelvis CT	3 – 4	570	35	43.05	0.019
Abdomen CT	5 – 7	780	35	43.05	0.0153
Abdomen-Pelvis CT	8-14				0.015
Kidney	1-3 (renal dose)				0.0086(normalized renal dose factor)

The CTDI$_{VOL}$ parameter is part of the image data recorded with the MVL application software.

The CTDI$_{VOL}$ is also defined mathematically as:

$$CTDI_{VOL} = \frac{1}{N.T} \int_{-\infty}^{\infty} D(Z) \, dz \qquad (3)$$

Where;
D (z) = the radiation dose profile along the z-axis,
N = the number of slice in a single axial scan.
T = the width/slice thickness of the tomographic section along the z-axis.

The standard S.I unit for CTDI is the mGy.
In addition CTDIvol, which represents the average absorbed radiation dose over the *x*, *y*, and *z* directions. It is conceptually similar to the MSAD. The MSAD has been recommended for specification and acceptance testing of CT scanners by AAPM and has been accepted by most practitioners as an important dose parameters in the USA [5, 6, 7].

MSAD is define as the product of CTDI and the ratio of the increment between successive slices and the slice thickness. Mathematically express as;

$$MSAD = \frac{T}{I} \, CTDI \qquad (4)$$

where T is the slice thickness and *I* the increment between successive slices.

The standard unit for the MSAD is the mGy

D. Dose Length Product in Slice Scan

Another important dose parameter of interest is the dose length product (DLP) which is associated with the $CTDI_{VOL}$. DLP, which includes the irradiated volume and represents the overall exposure for an examination and is calculated as:

$$DLP = CTDI_{VOL} * L \qquad (5)$$

where L is the scan length of an examination.

To better represent the overall energy delivered by a given scan protocol, the absorbed dose can be integrated along the scan length to compute the DLP [8]. Hence, the DLP is a dose quantity that describes the dose to the patient for a complete examination, therefore the potential biological effect can be estimated. Hence, it is used to estimate the effective to a body region. This parameter is captured and display on the image data. The international standard SI unit is the mGy cm.

E. Materials

The materials used are shown in Figure 1-4

Table 2. Specifications of CT Scanners

Manufacturer	Scanner model/scan mode
Philips Brilliance 64	Brilliance 64, multi slice, axial and helical modes
Siemens Emotion 16	Emotion 16, multi slice, axial and helical modes
GE Lightspeed VCT 64	Lightspeed VCT 64, multi slice axial and helical modes
Toshiba Aquilion ONE	Aquilion ONE, multi slice, axial and helical modes

Figure 1. Philips medical System

Figure 2. Siemens Medical Systems

Figure 3. Toshiba Medical Systems

Figure 4. GE Medical Systems

F. Methodology

Both CTDI and DLP parameters were obtained as part of the image data and recorded. In addition the DLP was obtained by multiplying the volumetric Computed Tomography dose index by the length of body section covered by the scanning procedure and is calculated as stated above. The Air Kerma Length Product, P_{KL}, will soon replace the DLP by name during the scanning procedure, which display the values on the operator's console.

Standard reference values of various machines were obtained from service manual during QA/QC and the recommended values from ICRP publication 103.

III. RESULTS AND DISCUSSION

A. Results

Table 3. GE Measured $CTDI_{VOL}$ and DLP

Scanner (Manufacturers)	AGE	$CTDI_{vol}$ (mGy)	DLP mGy-cm
GE Lightspeed VCT 64			
Mean	46	6.21	1008.88
Max	80	16.30	3496.40
Min	20	3.00	234.40

Table 4. Siemens Measured $CTDI_{VOL}$ and DLP

Scanner (Manufacturers)	AGE	$CTDI_{vol}$ (mGy)	DLP mGy-cm
Siemens Emotion 16			
Mean	48	6.22	864.16
Max	80	15.90	2568.30
Min	20	3.20	213.60

Table 5. Philips Measured $CTDI_{VOL}$ and DLP

Scanner (Manufacturers)	AGE	$CTDI_{vol}$ (mGy)	DLP mGy-cm
Philips brilliance 64			
Mean	45	6.37	1002.60
Max	80	16.30	3124.40
Min	20	3.00	281.90

Table 6. Toshiba Measured $CTDI_{VOL}$ and DLP

Scanner (Manufacturers)	AGE	$CTDI_{vol}$ (mGy)	DLP mGy-cm
Toshiba Aquilion one			
Mean	43	6.21	880.75
Max	80	15.90	2865.30
Min	20	3.20	216.60

Table 7. Average Measured $CTDI_{VOL}$ and DLP

Scanner (Manufacturers)	AGE	$CTDI_{vol}$ (mGy)	DLP mGy-cm
AVERAGE			
Mean	45	6.33	936.25
Max	80	16.20	3496.40
Min	20	3.00	213.60

B. Discussions

The analysis of the abdominal image data at the various CT centres in the study show that the mean $CTDI_{VOL}$ and DLP values were 6.33mGy and 936.25 mGy-cm. The detailed average values of the various CT scanners for $CTDI_{VOL}$ and DLP values are shown in Table 3 for general electric, Table 4 for Siemens, Table 5 Philips and Table 6 for Toshiba.. Furthermore, the mean recorded values of $CTDI_{VOL}$ values shown in Table 7 were well within ICRP recommendation when the protocol was completed in a single scan. On the other hand, in the case of multiscan, the mean $CTDI_{Vol}$ value was higher than the ICRP recommendations.

The four common CT machines used in Ghana are GE, Philip, Siemens and Toshiba. The various CTDI$_{VOL}$ and DLP measured values are shown in Table 1.
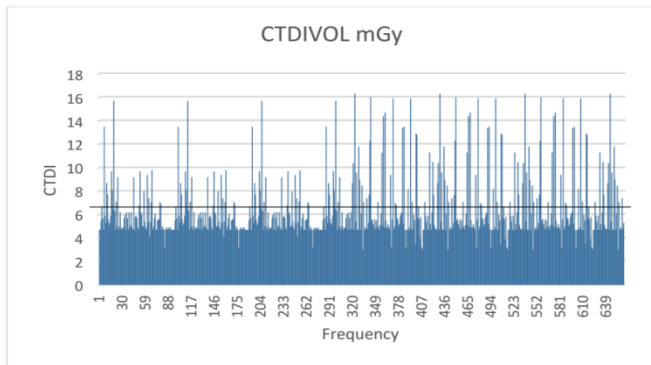

Figure 5. CTDI$_{VOL}$ of the abdomen exams

The mean DLP values were higher than the recommended value of 780 mGy-cm by ICRP publication 103 as presented by the black line in *figure 2*. In addition approximately 37% of the total varied DLP values were higher than the recommended dose by ICRP.
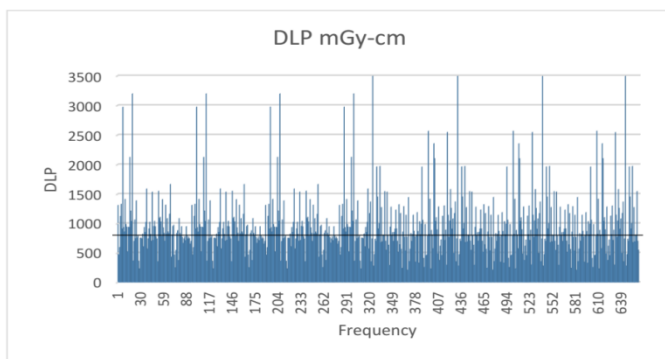

Figure 6. DLP of the abdomen exams

Table 6. Variation of CTDI and DLP values in nine countries

Parameters	Greece	Taiwan	Italy	Wales	Poland	Tanzania	Ireland	UK	Ghana
CTDI$_{VOL}$(mGy)	19.10	22.00	24.30	22.00	23.70	17.00		19.10	9.5	6.33
DLP(mGy-cm)	633	453	517	745	550	982		433	446	936.25

C. Analysis

The result of these two exposure parameters (CTDI and DLP) on the abdomen are the deposition of dose to various organs and other abdominal tissue (organ and effective dose) based on the extrapolation by the linear non-threshold (LNT) and other models may lead to cancer. Furthermore, optimization refers to the process

of keeping the exposure of patients to the minimum necessary to achieve the required diagnostic objective. Patient dosimetry and DRLs are used as important tools for optimization of patient radiation protection. Unfortunately, values of these DRLs are not available for Comparison in Ghana. BSS set requirements and recommendations for implementation of the principle of optimization of radiation protection of patients in medical facilities using ionizing radiation. Recommendations from IAEA using BSS and other related international bodies such as ICRP, EC and AAPM set out basic essential practice principles that assist clinicians in clinical practice. Hence, values of this study were compare with those from these international organizations for purposes of optimization and not exact dose values to various tissues. The recommendations set by ICRP as compared to measured values are shown with black line in fig. 5 and fig. 6 for CTDI$_{VOL}$ and DLP respectively.

The primary aim of the recommendations is to contribute to an appropriate level of protection for patients and clinicians against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure. In addition, this aim cannot be achieved solely on the basis of scientific knowledge on radiation exposure and its health effects. It requires a model for protecting humans and the environment against radiation. Evidence from the study shows that all the four centers have followed the recommended protocol of the manufacturers. Unfortunately however, an approximately 37% exceeded the recommended dose based on ICRP recommendation. The variation in individual protocol by various manufacturers lead to some amount of estimated variations. In addition it was observed that various scanners uses different scanning protocols based on variation in equipment design among manufacturers. This was also based on models which were responsible for most of these variations.

The recommended CTDI$_{VOL}$ and DLP values of this study were comparable to ICRP recommendation. An average measured values of this study were 6.33 and 936.25 for CTDI$_{VOL}$ and DLP values respectively. Whereas the ICRP recommended values for DLP was 780 mGy-cm provided all other factors remain the same. These CTDI$_{VOL}$ and DLP estimated values were also

comparable to those measured in Greece, Taiwan, Italy, Wales, Poland, Tanzania, Ireland and UK as shown in Table 2.

IV. ACKNOWLEDGEMENTS

V. CONCLUSION

Radiation dose during x-ray CT imaging is an important patient protection and safety concern. Reducing radiation dose result in a reduction of the risk to patient. Two important factors CTDI and DLP parameters are used in estimate dose to patients in terms of effective dose or specific organ dose however, reducing dose also reduces the signal and thereby reduces the signal to noise ratio in the resulting CT image, and hence, the image quality is affected. Therefore a balance should be established between these dose parameters and the quality of the images produced. It is of interest to note that with all the scanners and the various scanning protocols used were adequate enough to achieve maximum optimisation. In other word enough measures were taken to achieve the balance between patience dose and adequate images good enough to be used for diagnoses. The established values were also agreed with international recommendations by ICRP.

VI. REFERENCES

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