RETROSPECTIVE RADIATION DOSE AUDIT FROM GHANA'S FIRST 64 MULTI-SLICE COMPUTED TOMOGRAPHY (CT) SCANNER

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Abstract

A retrospective patient dose audit from recently commissioned General Electric (Light Speed VCT) 64 multi-slice computed tomography scanner, the first in Ghana has been carried out. The dose data was extracted from the dose report of retrospective examinations of head, chest, lumbar spine, abdomen and pelvis for a minimum of 20 standard adult patients from direct read out from control console. The dosimetric parameters analysed were volume computerized tomography dose index ($CTDI_{vol}$), dose length product (DLP) and effective dose (E). Mean values of $CTDI_{vol}$ were: head (51.0 mGy), chest (13.2 mGy), abdomen (16.5 mGy), lumbar spine (34.6 mGy) and pelvis (15.0 mGy). Similarly, the mean DLP values were: head (393 mGy.cm), chest (471 mGy.cm), abdomen (598 mGy.cm), lumbar spine (805 mGy.cm) and pelvis (518 mGy.cm). The mean E values were: head (0.8 mSv), chest (6.8 mSv), abdomen (9.2 mSv), lumbar spine (12.3 mSv) and pelvis (6.7 mSv). There were variations of mean values of $CTDI_{vol}$, DLP and E when compared with European Guidelines for Multislice Computed Tomography and other recommendations referred as reference dose levels (RDLs), although that of lumbar spine slightly exceeded the RDLs. Regular patient dose audits in diagnostic imaging centres and comparison with RDLs is recommended, since it offers a practical approach towards optimisation of patient protection.

Keywords: CT dose display, multi-detector CT

Introduction

There has been a tremendous progress in the technological development of computed tomography (CT) since its introduction into clinical practice in 1972. This lead to the first introduction of multi-detector-row computed tomography (MDCT) in 1998. MDCT facilitates wide-range scanning, including up to whole body scanning leading to the acquisition of several slices in a single examination. This has made MDCT to be very versatile in the application of CT, resulting in continuing expansion of CT practice and tremendous impact on the clinical management of disease[1]. The wide applications of MDCT have also been used for the development of hybrid systems like Single Photon Emission Computed Tomography (SPECT)-CT, Positron Emission Tomography (PET)-CT, cone beam CT, cardiac CT and the use of CT simulator in radiotherapy treatment planning among others.

The rapid advances in MDCT continue to pose educational and practice challenges to the medical imaging community. In addition to these challenges, this new technology also has significant implications to the radiation dose administered to the population from medical applications. Indeed, the International Commission on Radiological Protection (ICRP) indicates that the organ absorbed dose from CT scans can often approach or exceed that observed in atomic bomb survivors[2].

The greatly increased availability of CT, together with its diagnostic value for an increasing number of conditions, has been responsible for a large rise in demand globally. The contribution of CT to the total global collective dose according to the 2008 UNSCEAR Survey of Medical Radiation Usage and Exposures report is about 43% of the total collective dose due to diagnostic medical radiology[3].

This increasing contribution of CT to the global collective dose requires periodic dose monitoring, management of patient dose in CT and implementation of optimisation strategies when needed. The aim of this study was to carry out a retrospective patient dose audit from recently commissioned General Electric (GE) Light Speed VCT 64 multi-slice computed tomography scanner, the first of its kind in Ghana.

Materials and Methods

CT facility

At the examined hospital, a 64-row-MDCT unit, GE Light Speed VCT (model 5124065-5, China), which is currently used for standard CT studies and some specialised examinations (such as cardiac, perfusion, lung analysis, CT colonography, dental scan and CT angiography) was used for this study. This was a 3 phase, 6 pulse CT scanner which uses the SmartmA as its automatic exposure control feature. This allows the user to set diagnostic image quality by entering "Noise Index" and a range of acceptable tube current settings (minimum and maximum milliamperage)[4]. Our CT scanner was installed in the last quarter of 2010 and was duly granted authorization by the Radiation Protection Board (RPB) of Ghana[5] after fulfilling all necessary national and regulatory requirements[6, 7] needed for issuance of a license to be use for medical diagnosis practices purposes. RPB is the Regulatory Authority in Ghana.

All clinical images of our patients are assessed by senior Consultant Radiologists for the requisite image quality to ensure that the quality criteria of the European Guidelines for Multislice Computed Tomography[1] were met. This was to ensure that the as low as reasonably achievable (ALARA) principle is implemented as outlined by the ICRP[8]. Institutional Review Board's approval was obtained for this study.

CT dose descriptors

The CT dose descriptors chosen for this study were volume computed tomography dose index ($CTDI_{vol}$), dose length product (DLP) and effective dose (E). The $CTDI_{vol}$ and DLP were extracted from the dose report of retrospective CT examinations of head, chest, lumbar spine, abdomen and pelvis for a minimum of 20 standard adult patients database retrieved from our picture archiving and communication system (PACS). The methods for the dosimetry of these CT dose descriptors have appeared widely in the literature[9-15].

Computed tomography dose index

The computed tomography dose index (CTDI), which is the fundamental CT dose descriptor is defined as defined as the integral along a line parallel to the axis of rotation (*z*) of the dose profile (D (z)) for a single rotation and a fixed table position, divided by the nominal thickness of the X-ray beam. The CTDI can be assessed by using a pencil dosimeter chamber of active length 100 mm and standard-dose CT phantoms, so as to provide a measurement of $CTDI_{100}$, which is expressed in terms of absorbed dose to air [9, 16] as:

$$CTDI_{100} = \frac{1}{N\,x\,T}\int_{-50\,mm}^{+50\,mm} D(z)\,dz \quad (mGy) \qquad (1)$$

where ±50mm is length of dosimeter chamber, *N* is the number of tomographic sections, each of nominal thickness *T* (mm), from a single rotation and D (z) = measured dose (mGy). In multi-slice CT scanners, where N>1, NxT (mm) represents the total detector acquisition width, which is equivalent to the nominal beam collimation. The measurements within the standard CT dosimetry phantoms are made at the centre and peripheral positions within homogeneous cylindrical polymethylmethacrylate (PMMA) phantoms of 16 and 32 cm in diameter (CT head and body phantoms). These phantoms have the same radiation absorption and scattering properties of the standard human head and body. The weighted computed tomography dose index ($CTDI_w$) in the standard adult head or body CT dosimetry phantom for a single rotation corresponding to the technique parameters used in clinical practice is defined as:

$$CTDI_w = {}^1/_3\,x\,CTDI_{100centre} + {}^2/_3\,x\,CTDI_{100peripheral} \quad (mGy) \qquad (2)$$

where $CTDI_{100,perpheral}$ represents an average of measurements at four different locations around the periphery of the phantom. This is on the assumption that the dose in a particular phantom radiation decreases linearly with position from the surface to the centre. A standard exposure measurement can then be used to provide normalized values of dose ($_nCTDI_w$ mGy $(mAs)^{-1}$) that allow the derivation of $CTDI_w$ for other settings of current–time product. These parameters are the kVp, mA, collimation, number of slices, slice thickness in cm, pitch, start and end position, total mAs used for the measurement. The $CTDI_{vol}$ can then be derived from the $CTDI_w$ and takes into account the scan pitch.

$$CTDI_{vol} = \frac{CTDI_w}{pitch} \quad (mGy) \qquad (3)$$

where the pitch is defined as:

$$Pitch = \frac{table\ feed}{NxT} \qquad (4)$$

The table feed is the distance (mm) moved by the patient support in the z-direction between consecutive serial scans or per rotation in helical scanning; NxT (mm) is the nominal beam collimation (equation 1). The ratio of the table feed to NxT is defined as the pitch (*p*) and is dimensionless.

However in this study, we used the $CTDI_{vol}$ from the console display as defined and recommended by the International Electrotechnical Commission (IEC) of newer scanners being equipped with a dose display[16]. $CTDI_{vol}$ represents the average value of the weighted CTDI throughout the volume scanned in a particular sequence from one tube rotation and estimates from scanner modalities are based on standard-sized PMMA phantoms.

Dose–length product

Our scanner also displays the DLP per scan series and the total DLP for the complete examination. The DLP for a complete examination is defined as:

$$DLP = CTDI_{vol} \, x \, L \; (mGy.cm) \qquad (5)$$

where L is the scan length (in cm). The scan length is limited by the outer margins of the exposed scan range, irrespective of pitch which is accounted for in $CTDI_{vol}$. In a helical scan sequence, this is the total scan length that is exposed during original data acquisition, including any additional rotation(s) at either end of the programmed scan length necessary for data interpolation. In serial scanning, L is the distance between the outer margins of the first and last slices in a sequence. The DLP takes into account the scan length and number of sequences for the examination.

Effective dose

The effective dose was calculated to give a broad estimate of stochastic radiation risk of a non-uniform exposure in terms of a whole body exposure, which is common to all modalities that utilize ionising radiation. In this study, the effective dose was calculated by multiplying specific normalized effective dose per DLP conversion factors (k)[17] which were recently published based on ICRP publication 103[8] as:

$$E \approx k \, x \, DLP \; (mSv) \qquad (6)$$

where k is the anatomy-specific dose coefficient expressing effective dose normalized to DLP in a standard CT dosimetry phantom (in mSv $mGy^{-1}cm^{-1}$). These k values have been determined using Monte Carlo simulations on the Oak Ridge National Laboratory mathematical phantoms that mimic newborns, 1-, 5-, and 10-year-old children and adults[18]. Since our study focused on adults, we used the adult k values for head, chest, abdomen and pelvis CT examinations as listed in Table 1. It must be noted that for lumbar spine examination, we used the k value for abdomen since lumbar spine examination is regarded as trunk examination.

Table 1: The Adult Effective Dose Per Dose Length Product Conversion Factors Used in This Study[17] which are based on ICRP Publication 103[8].

Examination	Head	Chest	Lumbar spine	Abdomen	Pelvis
k (mSvmGy-1cm-1) *	0.0019	0.0145	0.0153	0.0153	0.0129

*The adult conversion factors that we used were those for the tube voltage of 120 since that is what we used for all our examinations as recommended by the vendor (GE Light Speed VCT model 5124065-5, China) from the original values tabulated in Table 5 of reference 29.

Results

Volume computed tomography dose index

The results of the $CTDI_{vol}$ values for adults from the examinations considered are shown in Table 2.

Table 2: $CTDI_{vol}$ values for adults from the examinations considered.

CT Examination	$CTDI_{vol}$ (mGy)		
	Minimum	Mean	Maximum
Routine head [64]	25.1	51.0	73.2
Chest [7.8]	7.6	13.2	21.0
Lumbar spine [-]	14.3	34.6	48.9
Abdomen [14.5]	3.8	16.5	27.3
Pelvis [14.5]	8.4	15.0	16.8

Note: Dash (-) means no data was available. The diagnostic reference levels (DRL) are indicated in square brackets. The DRL were obtained from the European Guidelines for Multislice Computed Tomography, Bongartz et al., 2004[1].

Table 3 shows a comparison of the mean $CTDI_{vol}$ values from this study with the European MDCT DRL-Bongartz et al., 2004[1] and other recommendations; Brix et al., 2003[19], UK MDCT DRL-Shrimpton et al., 2003[20], IAEA study-Tsapaki et al., 2006[21] and ACR 2008[22]. For purposes of consistency, we refereed to the DRL and other recommendations as Reference Dose Levels (RDLs).

Table 3: Comparison of mean $CTDI_{vol}$ values from this study with DRLs and other recommendations.

Examination	$CTDI_{vol}$ (mGy)					
	This study	European MDCT DRL-Bongartz et al., 2004[1]	Brix et al., 2003[19]	UK MDCT DRL-(Shrimpton et al., 2003[20]	IAEA study-Tsapaki et al., 2006[21]a	ACR 2008[22]
Routine head	51.0	64	60.6	100	47	75
Chest	13.2	7.8	10.9	13	9.5	-
Abdomen	16.5	14.5	12.8	14	10.9	25
Lumbar spine	34.6	-	32.4	-	-	25
Pelvis	15.0	14.5	14.8	14	-	25

Note: Dash (-) means no data was available.

[a]Data from ten representative centres in six countries, including both single slice detector computed tomography (SDCT) and MDCT scanners.

For examinations of the adult head, calculated values of $CTDI_{vol}$ refers to the 16 cm diameter CT dosimetry phantom, for examinations of the trunk, calculated values of $CTDI_{vol}$ relate to the 32 cm diameter CT dosimetry phantom.

ACR = American College of Radiology, UK = United Kingdom and IAEA = International Atomic Energy Agency

Dose length product

The results of the DLP values for adults from the examinations considered are also shown in Table 4.

Table 4: DLP values for adults from the examinations considered,

CT Examination	DLP (mGy.cm)		
	Minimum	Mean	Maximum
Routine head [337]	185	393	956
Chest [267]	228	471	672
Lumbar spine [-]	322	805	1291
Abdomen [724]	106	598	1097
Pelvis [724]	241	518	673

Dash (-) means no data was available.

Note: The diagnostic reference levels (DRL) are indicated in square brackets. The DRL were obtained from the European Guidelines for Multislice Computed Tomography of 2004[1].

Table 5 shows a comparison of the mean DLP values from this study with the European MDCT DRL-Bongartz et al., 2004[1] and other recommendations; Brix et al., 2003[19], UK MDCT DRL-Shrimpton et al., 2003[20] and IAEA study-Tsapaki et al., 2006[21] .

Table 5: Comparison of mean DLP values from this study with previous recommendations.

Examination	DLP (mGy cm)				
	This study	European MDCT DRL-Bongartz et al., 2004[1]	Brix et al., 2003[19]	UK MDCT DRL-Shrimpton et al., 2003[20]	IAEA study-Tsapaki et al., 2006[21]a
Routine head	393	337	1016	930	527
Chest	471	267	350	940	447
Abdomen	598	724	552	560	696
Lumbar spine	805	-	445	-	-
Pelvis	519	724	398	560	-

Note: Dash (-) means no data was available.

[a] Data from ten representative centres in six countries, including both SDCT and MDCT scanners

For examinations of the adult head, calculated values of DLP refers to the 16 cm diameter CT dosimetry phantom, for examinations of the trunk, calculated values of DLP relate to the 32 cm diameter CT dosimetry phantom.

UK = United Kingdom and IAEA = International Atomic Energy Agency

Effective dose

Our effective dose values for adults from the examinations considered are shown in Table 6.
Table 6: Effective dose values for adults from the examinations considered.

CT Examination	E (mSv)		
	Minimum	Mean	Maximum
Routine head	0.4	0.8	1.8
Chest	3.3	6.8	9.7
Lumbar spine	4.9	12.3	19.6
Abdomen	1.6	9.2	16.8
Pelvis	3.1	6.7	8.7

Table 7 shows a comparison of the E values from this study with other E values from the European MDCT DRL-Bongartz et al., 2004[1] , Brix et al., 2003[19], UK MDCT DRL-Shrimpton et al., 2003[20] , Olerud M 2003[23], IAEA study-Tsapaki et al., 2006[21] and UNSCEAR 2008 Report[3].

Table 7: Mean values of effective dose E compared with those of European MDCT DRL-Bongartz et al., 2004[1] , Brix et al., 2003[19], UK MDCT DRL-Shrimpton et al., 2003[20] , Olerud M 2003[25], IAEA study-Tsapaki et al., 2006[21] and UNSCEAR 2008 Report[3].

Examination	E (mSv)						
	This study	European MDCT DRL-Bongartz et al., 2004[1]	Brix et al., 2003[19]	UK MDCT DRL-Shrimpton et al., 2003[20]	Olerud M 2003[23]	IAEA study-Tsapaki et al., 2006[21]a	UNSCEAR 2008 Report[3]
Routine head	0.8	1.0	2.8	1.5	2.0	1.2	1.6
Chest	6.8	4.8	5.7	7.1	11.5	5.9	9.7
Abdomen	9.2	12.1	10.3	9.9	12.8	8.2	12.0
Lumbar spine	12.3	-	8.1	-	-	-	3.3
Pelvis	6.7	12.1	7.2	9.9	9.8	-	9.8

Note: Dash (-) means no data was available.

[a] Data from ten representative centres in six countries, including both SDCT and MDCT scanners

Discussion

CT continues to stand out as the most significant contributor to the collective effective dose from all radiographic procedures. This has been confirmed by the latest global survey of Radiation Usage and Exposure from UNSCEAR[3]. Some studies have extrapolated the risk of CT-associated cancer using data from the atomic bomb survivors[24, 25] although there have been no studies to directly attribute CT in cancer-related deaths. Then the advent of MDCT has increased CT usage trendmendously with the demand increasing from both referring clinicians and patients due to versatile applications, faster acquisition (few seconds of scanning) and superior image quality. For these reasons, there is the need for periodic monitoring and assessment of patient CT radiation exposure since CT dose and its risks have become a public health issue.

According to Shrimpton at al., 2005[20], a survey of reference dose quantities ($CTDI_{vol}$, DLP) and effective doses, when compared with diagnostic reference levels have been demonstrated to be a practical means of promoting strategies for management of patient dose This is in line with the implementation of ICRP's principle of optimisation of protection[8]. This study offered us the opportunity to assess the performance of our CT scanner from a dose index report which introduced by the IEC[16] that newer CT scanners must be equipped with a dose display. Patient dose is not saved per se with the dose display, but the user gets a feedback by comparison of the displayed dose index report with RDLs. So in routine clinical scanning of patients, changes in scan technique parameters and their implication for patient dose can be obviously be seen instantly. Thus, this confirms the assertion that the dose display can be used for purposes of patient dose optimisation.

From the results of our study, the mean values of $CTDI_{vol}$ were: head (51.0 mGy), chest (13.2 mGy), abdomen (16.5 mGy), lumbar spine (34.6 mGy) and pelvis (15.0 mGy). The mean DLP values were: head (393 mGy.cm), chest (471 mGy.cm), abdomen (598 mGy.cm), lumbar spine (805 mGy.cm) and pelvis (518 mGy.cm). For E, the mean values were: head (0.8 mSv), chest (6.8 mSv), abdomen (9.2 mSv), lumbar spine (12.3 mSv) and pelvis (6.7 mSv)

A comparison of the mean values of $CTDI_{vol,}$ DLP and E was made with the European MDCT DRL-Bongartz et al., 2004[1], Brix et al., 2003[19], UK MDCT DRL-Shrimpton et al., 2003[20], Olerud M 2003[23], IAEA study-Tsapaki et al., 2006[21], ACR 2008[22] and UNSCEAR 2008 Report[3] (Tables 3, 5 & 7). As expected, there were wide variations across all the dose descriptors for all CT examinations considered when we compared our results with the RDLs. With respect to $CTDI_{vol}$, our value for head CT (51.0 mGy) was lower than all RDLs and close to that of Tsapaki et al., 2006[21] (47 mGy), although the latter's study consisted of both SDCT and MDCT across ten CT centres. The $CTDI_{vol}$ for lumbar spine was higher than that of ACR 2008[22] (25 mGy) and slightly above that of Brix et al., 2003[19] (32.4 mGy). All our DLP values were within the RDLs except that of lumbar spine (805 mGy.cm) which exceeded Brix et al. (445 mGy.cm). For lumbar spine examination, Brix et al's mean scanned volume length (15.0 cm) was generally lower than in the current study (23.3 cm), which seems to have great implication for DLP. On effective dose, all our value (12.3 mSv) were also within the values of the RDLs with the exception of lumbar spine which exceeded that of exceeded Brix et al. (8.1 mSv) and UNSCEAR 2008 Report[3] (3.3 mSv). This was to be expected because of the strong dependence of effective dose on DLP and scan length in general.

RDLs are intended to be used in a broad sense acting as parameters to help identify relatively poor or inadequate use of patient technique factors, the exposure settings and the extent of the scan should be further investigated to lower the dose without affecting image quality. In this regard, the monitoring of $CTDI_{vol}$ provides control and is useful for the assessment of differences in technique parameters such as tube current, rotation time (tube rotation) and voltage. Similarly, DLP monitoring provides control taking into account the technique parameters, volume or irradiation or length of scanned volume and the number of series for an overall patient exposure.

Estimating effective dose values allows comparisons of different regional radiation exposures and of different modalities. It also reflects the difference in biological sensitivity of exposes tissues or organs. We used the new DLP to ED conversion factors that were recently presented by Deak et al.[17] to estimate the effective dose. These factors were derived using the latest ICRP 103 recommendations and were found to be significantly higher than the corresponding factors determined using the ICRP 60 recommendations[26].

The major limitation of our study arises from the current dose index estimates from the CT modalities which are based on standard-sized PMMA phantoms. As a consequence, there may be errors in these dose index reports due to obvious variations in patient sizes from the standard" size that the phantoms assume. It must also be noted that an estimate of effective dose from the dose index gives a rough estimate and does not take into account the gonads. Nevertheless the dose index reports facilitates dosimetry clinical auditing and it is also a practical approach in optimization as these doses can be compared with reference levels to assess the performance of CT scanners. The ultimate goal is to set up a national dose registry where patient doses can be tracked and benchmarked against known international best practices. Recently, the ACR launched a CT dose index registry (DIR), which is a new component of the ACR National Radiology Data Registry (NRDR)[27]. The DIR allows medical imaging facilities to track and compare dose information for all CT exams to other facilities of similar size or geographic area and to national benchmarks.

Conclusion

In this study, the CT dose report index data appears to be useful as benchmarking tool to compare the performance of our CT facility. However, further studies are needed by way of phantom measurements to permit comparison. For the future, a mechanism must be put in place for the routine recording all patient dosimetry data. This will facilitate dosimetrical clinical auditing and doses can be compared to reference values. By far, our results demonstrate that our CT scanner was within the international dose levels. However, some technical actions are recommended to standardise the dose levels. The results from this study will also be a guide in the establishment of local and national dose reference levels in our country.

Acknowledgement

The authors wish to express their gratitude to the Radiation Protection Institute of the Ghana Atomic Energy Commission and the Akai House Clinic for their support and cooperation during the study.

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