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Estimation of Organ and Effective Dose in Multislice CT Examination

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Abstract

The rapid acquisition of multislice CT scanners for diagnostic imaging in Tanzania had created the need to estimate the organ and effective doses committed to patients undergoing multislice CT examinations. The organ and effective doses were estimated using the CT-expo software by entering patients' data (age and sex), scan parameters, scanner types and models, obtained from the examination forms of 106 patients that underwent various routine examinations. The multiclice CT examinations were observed to deliver comparable or less organ and effective doses than those obtained from single slice CT examinations.

Keywords: Computed tomography; Automatic exposure control; Radiation; CT scanners

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Introduction

Computed Tomography (CT) has in recent years experienced tremendous technological advances ever since it was introduced in the early 1970s. Recently, CT scanners are considered the most superior because of providing significant clinical advantages over most medical imaging modalities [1-3]. Despite their superiority, CT examinations are the leading sources of radiation exposure from medical imaging. According to the worldwide survey conducted between 1991 and 1996, CT examinations that accounted for only 5% of all X-ray examinations performed annually, contributed to 34% of the collective doses from all X-ray examinations [4].

It is evident from the findings of this survey that Single Slice Computed Tomography (SSCT) scanners, which were introduced in the early 1990s, were associated with the increase of collective dose as shown elsewhere [5-9]. Like in other countries, SSCT examinations had been found to be the leading sources of collective dose in radiology in Tanzania [10].

To overcome the problem of high radiation dose associated with SSCT scanners, CT manufacturers considered to reduce the exposure time by further reducing the gantry rotation time [11]. According to this author, however, rotation time is inversely proportional to the square root of the X-ray tube power; based on this relationship therefore, reduction of rotation time requires an exponential increase of the X-ray tube power to maintain photon fluence rate for production of images of comparable quality. The increase of the X-ray tube power would result into the increase of tube current and thus radiation dose. Therefore, to reduce the exposure time, the CT scanner manufacturers had to modify the detector configuration designs by replacing the single detector row of SSCT scanners shown in **Figure 1(a)** with the multiple detector rows such as shown in **Figure 1(b)**.

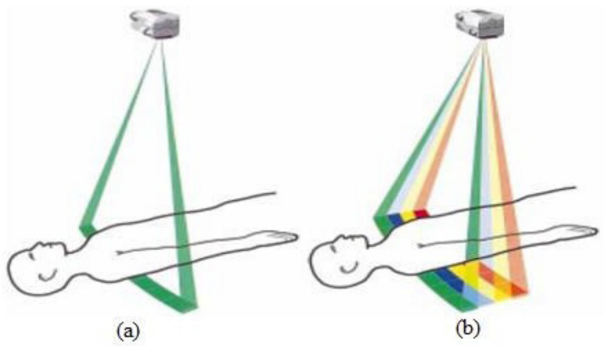

Figure 1: a) Single detector row of SSCT scanners and (b) multiple detector rows of MSCT scanners.

The version of CT scanners formed after this modification are known as Multi Slice CT (MSCT) scanners, which were first introduced in the early 2000s [12]. The MSCT scanners are designed in such a way they could minimize the examination time by increasing the z-axis coverage of the detector rows that makes it possible for the gantry to perform fewer rotations in one examination, thus reducing the exposure time.

In addition to the detector configuration modification, the Automatic Exposure Control (AEC) systems, that reduce radiation dose based on patient size, have also been incorporated in these CT scanners. The AEC systems perform radiation dose reduction automatically by modulating tube currents in real time based on the X-ray attenuations of different sections of the body, to produce attenuation profiles such as shown in **Figure 2**.

Table 1 summarizes technological development of CT scanners from conventional scanners (in 1970s) through SSCT (in 1990s) to MSCT scanners (in 2000s). It is evident from this table that despite the inherent limitations to reduce the rotation time, significant reduction of rotation time from 1.0 s in SSCT scanners to 0.33 s in MSCT scanners was achieved. It is also evident from the table that the observed reduction of the rotation time was attributed to the increase of the X-ray tube power from 10 kW in SSCT scanners to 100 kW in MSCT scanners.

The increase of the X-ray tube power is the evidence that the X-ray tube current and the radiation dose increased; thus making the dose reduction potential of MSCT scanners uncertain. This work therefore, estimated the organ and effective doses committed to patients undergoing MSCT examinations in Tanzania.

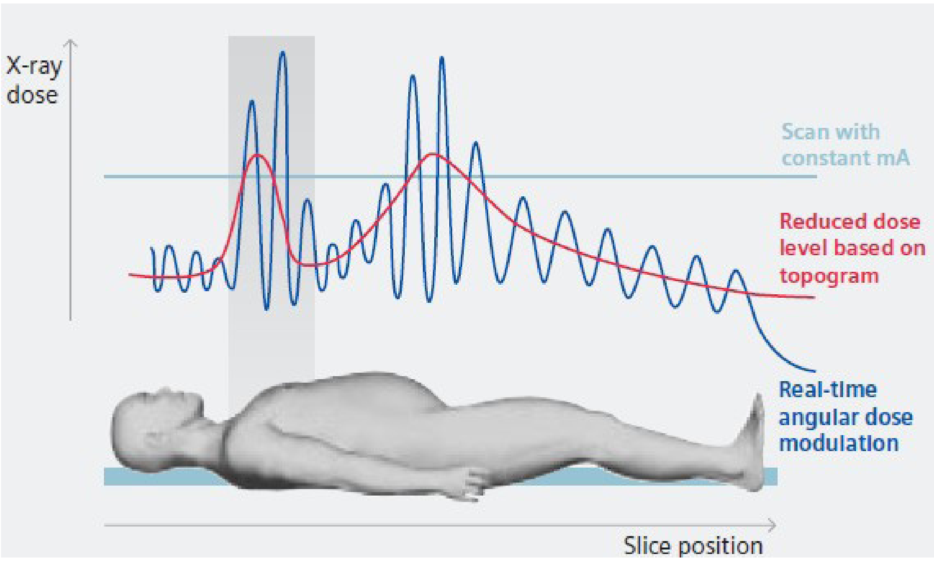

Figure 2: Typical attenuation profiles of different body sections.

	1972	1980	1990	2004	2005(DSCT)
Rotation time(s)	300	5-10	1-2	0.33-0.5	0.33
Data per 360o Scan (MB)	0.058	1	1-2	10-100	20-200
Data per spiral scan (MB)	-	-	24-48	200-4000	200-8000
Image matrixb	80 x 80	256 x 256	512 x 512	512 x 512	512 x 512
Power (KW)	2	10	40	60-100	2 x 80
Slice thickness mm	13	2-10	1-10	0.5-1	0.5-1
Spatial resolution (LPcm-1)	3	8-12	10-15	12-25	12-25
Contrast resolution	5 mm/5 HU/	3 mm/3 HU/	3 mm/3 HU/	3 mm/3 HU/	3 mm/3 HU/
	50 mGy	30 mGy	30 mGy	30 mGy	30mGy

Table 1: Summary of technological advancement of CT scanners from 1972 to 2005.

Materials and Methods

The study was conducted using six MSCT scanners acquired by five hospitals: The hospitals have been coded as MM, RM, TM, MN, and AK. Information about MSCT scanners (types and models), acquisition (installation) dates are summarized in **Table 2**. The numbers of detector rows are also indicated in this table.

Data from 106 patients that underwent various routine CT examinations in different hospitals were recorded in the patient examination forms. The data recorded were age, sex, and various scan parameters that were obtained from CT scanner consoles after performing the routine examinations of the head, chest, abdomen, pelvis, cervical spine or lumbar spine. The number of patients and types of examinations performed in different hospitals and the mean values of the scan parameters, extracted from the patient examination forms, are presented in Appendix A.2.

Results and Discussions

Patient age, sex and scan parameters, extracted from patient examination forms, were the inputs to the CT-expo spreadsheet for the estimation of organ and effective doses. Additional inputs to this software, were the scan region and range selected on a mathematical phantom corresponding to the region of the patient whose dose was being estimated. The outputs of the CT expo software were the organ and effective doses per scan and per examination based on the ICRP 103 recommendations as shown in **Figure 3**.

The organ doses for different patients were obtained from patients' CT-expo spreadsheets and averaged to obtain the mean organ dose per hospital as presented in **Table 3**. It is evident from (table 3) that RM had an overall higher dose for all organs. The highest dose observed for brain examinations at this hospital, could be attributed to the use of a fixed tube load of 350 mAs for all head examinations.

Hospital	Type and model of CT scanner	No. of detector rows	Manufacturer	Manufacture date	Acquisition date
MM	Siemens Somatom Emotion 6	6	China Siemens	Nov 2008	Jun 2009
RM	Philips Brilliance 64	64	USA Philips	Apr 2009	Aug 2010
TM	Siemens Somatom Sensation 16	16	Siemens HealthCare German	Mar 2012	Aug 2012
MN	Philips Brilliance 6	6	Ohio USA Philips	Feb 2009	Jun 2009
TK	Siemens Somatom Emotion 6	6	Siemens HealthCare German	Nov 2011	Jul 2012

Table 2: MSCT scanner types and models acquired between 2009 and 2012.

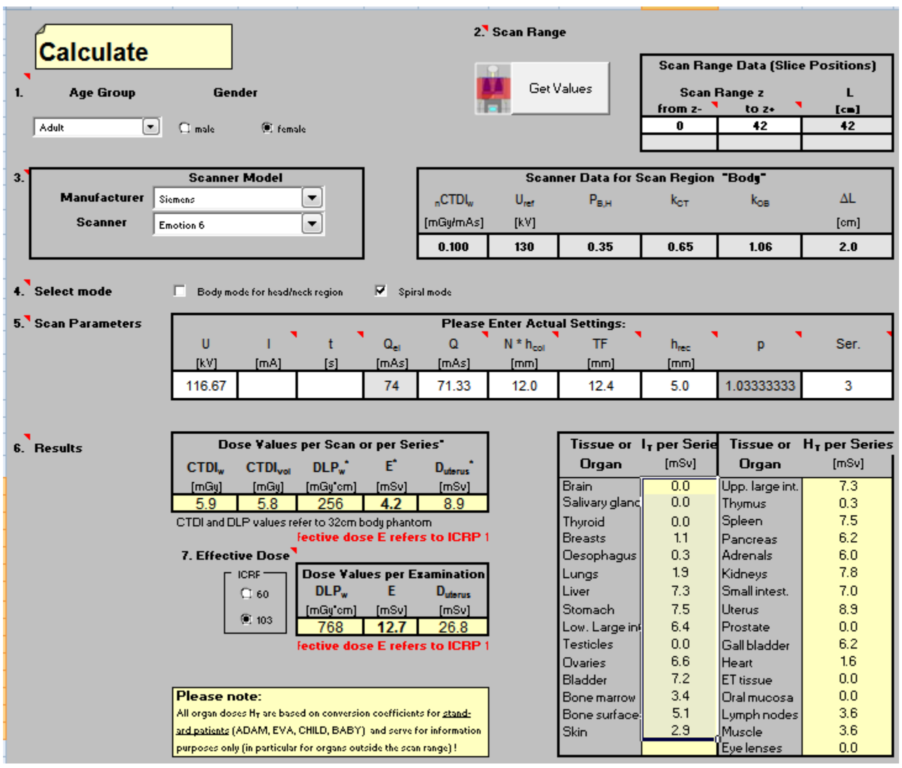

Figure 3: Typical patient's CT-expo spreadsheet for an 18 years old female that underwent routine abdomen CT at AK.

ORGAN	MM	RM	AK	MN	TM
Brain	40.0 ± 14.1	49.1 ± 1.3	42.4 ± 6.2	41.7 ± 11.4	45.9 ± 3.8
Eye lenses	58.7 ± 25.5	32.0 ± 33.2	55.6 ± 6.3	51.7 ± 13.4	60.0 ± 7.1
Salivary glands	27.8 ± 30.9	5.7 ± 1.6	16.3 ± 13.2	17.3 ± 17.3	14.9 ± 10.1
Thyroid	17.0 ± 32.0	18.5 ± 18.0	7.6 ± 14.0	5.8 ± 10.8	3.3 ± 2.0
Oesophagus	5.2 ± 3.7	14.4 ± 14.1	1.8 ± 3.0	2.3 ± 3.8	0.8 ± 1.6
Breasts	2.8 ± 2.2	25.5 ± 9.0	2.4 ± 3.0	3.4 ± 3.8	2.8 ± 2.5
Lungs	4.3 ± 3.4	18.5 ± 10.7	2.9 ± 2.8	3.8 ± 4.6	4.0 ± 2.7
Liver	7.1 ± 4.3	14.6 ± 10.7	9.7 ± 10.0	10.8 ± 9.3	15.8 ± 7.4
Stomach	7.1 ± 4.7	13.8 ± 11.4	10.5 ± 11.3	12.6 ± 9.3	14.3 ± 7.5
Lower colon	5.5 ± 2.7	23.7 ± 0.6	7.1 ± 4.0	14.0 ± 5.9	9.7 ± 7.3
Upper colon	8.1 ± 2.5	16.0 ± 12.1	10.9 ± 5.3	21.4 ± 16.1	13.9 ± 7.1
Testicles	4.8 ± 5.4	18.3 ± 0.5	6.0 ± 2.2	6.4 ± 5.2	3.0 ± 2.4
Ovaries	6.4 ± 1.1	24.6 ± 0.5	6.8 ± 4.6	14.8 ± 7.5	11.4 ± 8.8
Bladder	6.6 ± 3.1	26.8 ± 0.7	8.0 ± 5.2	18.3 ± 4.1	13.9 ± 7.2
Bone marrow	4.2 ± 2.1	8.9 ± 2.6	4.3 ± 1.8	7.1 ± 3.5	5.7 ± 3.1
Bone surfaces	10.1 ± 6.7	16.6 ± 4.0	10.1 ± 7.5	19.8 ± 17.0	11.6 ± 8.6
Skin	3.4 ± 1.7	7.4 ± 3.0	3.4 ± 1.2	5.0 ± 2.5	4.4 ± 2.5

Table 3: Mean organ doses (mSv) per series per hospitals.

However, the highest organ dose of 88.5 mSv was delivered to the thyroid for the patient who underwent cervical spine examination at MM. A close look at the examination form for this patient, shows that the use of high tube load (250 mAs) for the cervical spine examination could have attributed to high radiation dose to this organ. In addition, sex could have been responsible for the high thyroid dose in this female patient. This is because a male patient that undertook the same examination based on similar scan parameters in the same hospital, received lower thyroid dose of 74.2 mSv.

In order to compare the organ doses obtained in this study with the corresponding doses obtained from other studies, the mean organ doses for different hospitals were averaged to obtain the mean organ dose for this study and compared in **Table 4**.

It is evident from this table that the organ doses obtained in this study were comparable or lower than those obtained by Ngaile and Msaki and Nishizawa, et al.from different CT procedures using different SSCT scanners [13, 5]. Moreover, the organ doses obtained in this work were lower than the corresponding doses obtained by Elnour and Sulieman, despite using Sensation 16 scanner model that was also investigated in this study [14]. In addition, the overall high organ doses obtained by Hidajat, et al. using Somatom Plus scanner were expected for this SSCT scanner [15]. This could be attributed to different scan parameters as observed elsewhere [16].

To assess the contribution of different types of examinations to the stochastic risks, the effective doses obtained from patients CT-expo spreadsheets were used to calculate the mean effective dose per examination type per hospital as presented in **Table 5**.

Organ	This study	Ngaile and Msaki	Elnour and Sulieman	Hidajat et al.	Nishizawa et al.
Eye lenses	51.6 ± 11.4	63.9 ± 32.6	-	24.8	--
Breasts	7.4 ± 10.2	26.1 ± 10.8	-	22.6	15.90
Lungs	6.7 ± 6.6	31.5 ± 10.6	-	20.5	19.60
Liver	11.6 ± 3.6	34.1 ± 10.3	18.4	15.0	8.96
Stomach	11.7 ± 3.6	35.6 ± 10.7	18.3	15.4	9.19
Testicles	7.7 ± 6.0	12.5 ± 19.9	8.1	-	-
Ovaries	12.8 ± 7.4	24.0 ± 17.1	15.4	14.9	15.14
Bladder	14.7 ± 8.2	28.8 ± 21.7	-	16.1	10.56

Table 4: Mean organ doses (mSv) to selected organs obtained in this study compared with those obtained in other studies.

Hospital	Head	C/spine	Chest	Abdomen	Pelvis	L/spine
MM	2.2 ± 1.0	6.6 ± 2.0	3.1 ± 1.2	13.2 ± 6.0	2.8	5.3
RM	3.2 ± 0.2	-	25.6 ± 2.5	46.7 ± 3.6	28.5 ± 9.5	-
AK	2.6 ± 0.8	4.2	6.2 ± 1.3	13.3 ± 8.2	3.2	7.7 ± 3.4
MN	3.6 ± 2.9	-	1.9 ± 1.1	22.5 ± 7.7	7.4	-
TM	3.6 ± 1.4	-	3.4	24.8 ± 13.8	-	3.8

Table 5: Mean effective doses (mSv) committed to individual patients undergoing various routine examinations.

It is evident from this table that the highest mean effective doses were observed for the routine abdomen examinations. This was expected because abdomen, comprising a number of high attenuating and radiosensitive organs, requires high radiation dose to produce an image of comparable noise level. In addition, abdomen examinations constitute the longest scan lengths.

Conclusion

The estimation of the organ and effective doses committed to patients undergoing multislice CT examinations in different hospitals showed that, on average, multislice CT scanners deliver comparable or lower radiation doses than those obtained in single slice CT examinations, and are within the European Commission's diagnostic reference levels.

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