

A survey of paediatric CT radiation doses in two selected hospitals in Kampala, Uganda: a radiation safety concern

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Abstract

Purpose: We describe radiation doses imparted to pediatric patients during Computed Tomography (CT) scan examinations by estimation weighted CT dose index (CTDI_w) and dose length product (DLP) and compare these doses with the International dose reference values. **Methods:** Demographic data and acquisition parameters of 257 pediatric CT scans done using multi-slice CT (MSCT) and dual slice CT (DSCT) were collected from request forms and CT scan consoles. The values of CTDI_w, CTDI_{vol} and DLP were calculated using ImPACT (imaging performance and assessment of computed tomography) dosimetry software for Philips MX-1800 scanner and GE Hispeed Dual scanner. Data was analyzed using mean, range, 3rd quartile, as well as chi square. **Results:** The commonest indication was head injury with the majority patient aged 0-4 years and 10-14 years for MSCT and DSCT, respectively. There were significantly higher doses imparted by MSCT compared to DSCT on both the head CTDI_w (mGy) (40 vs 22, $p = 0.000$), CTDI_{vol} (mGy) (60 vs 7, $p = 0.000$), DLP mGy.cm (1022 vs 114, $p = 0.000$) and body CTDI_w (mGy) (41 vs 18, $p = 0.000$), CTDI_{vol} (mGy) (27 vs 6 $p = 0.000$) and DLP (782 vs 73 $p = 0.001$) respectively. Pediatric 3rd quartile values for CTDI_{vol} (mGy) (57.7 vs 31) 0-1 year, (74.5 vs 47) 4-7 years and DLP mGy.cm (1068 vs 333) 0-1 year and (1168 vs 374) 4-6 years respectively for MSCT were higher than the recommended international values. The calculated CTDI_{vol} for the head were significantly higher than the values displayed on the console ($p = 0.000$, 95% Confidence Interval) for MSCT. **Conclusion:** The radiation dose values for CTDI_w, CTDI_{vol} and DLP for MSCT were significantly higher than those for DSCT and other countries which raise a radiation safety concern. Studies to establish the factors responsible for these high doses are recommended.

Keywords: Pediatric; CT; Radiation Doses; Safety

Introduction

Optimization of radiation doses during Computed Tomography (CT) examinations in paediatrics is a major radiation protection concern. There is increased use of CT examinations in clinical practice due to its short examination times, user friendliness and superior contrast resolution. A study conducted in developing countries estimated an increase in pediatric CT scan examination in Africa when compared to Asia and Eastern Europe.¹

CT scan examinations have a higher effective dose² and yet children have increased sensitivity to radiation^{3,4}. This group of patients have more life years remaining to develop cancer and as well have proportionally more growing and developing tissue and organ systems than adults which calls for a special radiation protection concern.⁵ Children are 10 times more sensitive to the effects of radiation than middle-aged adults and girls are more radiosensitive than

boys.^{6,7} The 2010-2011 annual report of one of the study sites showed that 8% of all diagnostic imaging procedures were CT scans, out of which 15% are pediatric CT scan examinations.

There are several strategies to limit CT radiation doses, which include performing necessary examinations, limiting the region of coverage and adjusting individual CT settings based on indication, region imaged and size of the child.⁸ Contrary to this, studies showed a lack of awareness and malpractice leading to higher radiation doses to children.⁹ Hollingsworth *et al.* noted 20-25% of the CT scan operators did not know the scan parameters that they use for scanning children.¹⁰ Similar findings were noted in several African countries as noted by Muhogora *et al.*⁹

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All the mentioned discrepancies call for the establishment of standard operating parameters during CT scan procedure which is a major concern in pediatric patient's radiation protection. This begins by assessing the magnitude of radiation doses imparted on pediatric patients during CT scan examinations in the form of CT dosimetry. The assessment of CT radiation doses imparted during CT scan examinations entails the knowledge of essential radiation dose descriptors as described below:¹¹

Computed tomography dose index (CTDI)

CTDI is the average absorbed dose, along the z axis, from a series of continuous irradiations.¹²

Weighted computed tomography dose index (CTDI_w)

CTDI_w is the average CTDI across the field of view.

Volume computed tomography dose index (CTDI_{vol})

CTDI_{vol} is the average absorbed radiation dose over the x, y and z directions as shown in **Figure 1**.

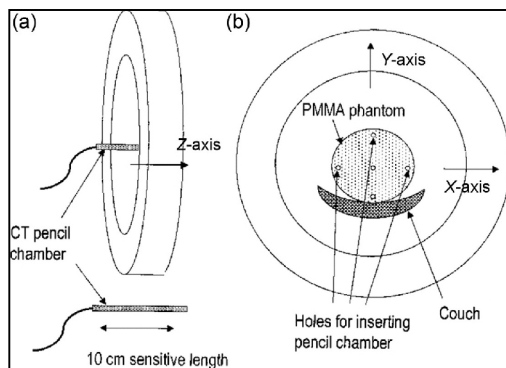


FIG.1: Diagrammatic representation of computed tomography dose index volume (CTDI_{vol}). Adopted from Lung (2009).

Dose length product (DLP)

DLP is the total energy absorbed (and thus the potential biological effect) attributable to the complete scan acquisition.

The aim of this survey was to determine radiation doses imparted on pediatric patients during CT examination in two selected hospitals and compare these doses with the International Dose Reference values.

Methods and Materials

Study design and setting

This was a retrospective cross-sectional survey carried out in two hospitals. One was a 1,500 bed capacity National Referral and Teaching Hospital, with 16 slice Philips MX1800 CT scan, i.e., MSCT. The second one was private for profit hospital with 100 beds, with GE Hispeed Dual slice CT scanner, i.e., DSCT. Review of records at the two centers showed approximately 3722 CT scan and 1200 CT

examinations were performed annually at the MSCT and DSCT, out of which approximately 400 and 150 were performed on pediatric patients, respectively (**Figure 2**).

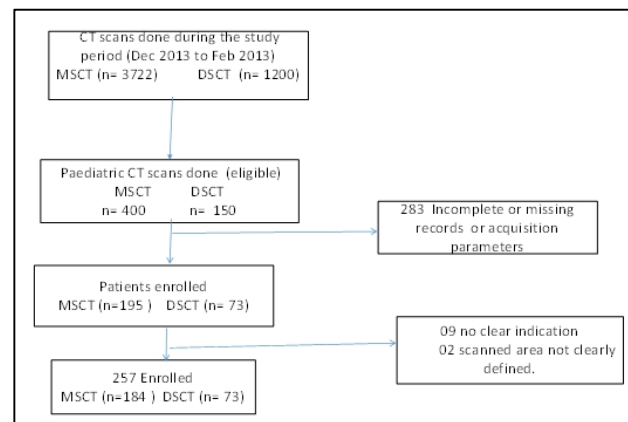


FIG. 2: Flow diagram of recruited paediatric patients who underwent CT examination.

Data collection

All CT scan examinations performed on paediatric patients at the two study centres between 1st December 2012 and 29th February 2013 were reviewed and those that met the inclusion criteria were recruited in the study. The following information was collected from the request forms and recorded in standardized data collecting sheets: age, sex, clinical indication, anatomical site scanned, scanner models and acquisition parameters from the CT scan console.

The MSCT scan machine calculates and stores automatically the CTDI_{vol} and DLP doses of each CT examination carried out in the CT console. This data can be retrieved from the console retrospectively. In contrast the DSCT scan machine calculates but does not archive the values of the CTDI_{vol} and DLP on the CT console. Hence the comparison of the calculated CTDI_{vol} and DLP with that of the displayed values was not possible for DSCT. Those examinations which lacked information on age, sex, anatomical sites and clinical indications were excluded from this study. CTDI_w, CTDI_{vol} as well as the DLP were calculated by using internet based software developed by the imaging performance assessment of CT scanners (ImPACT) group. The acquisitions parameters were used to generate CTDI_w and DLP by employing Imaging Performance and Assessment of Computed Tomography (ImPACT) patient dosimetry calculator (Version 1.0.4 27/05/201) work sheet software and entered into the data collection form. All CT dosimetry values were computed separately for the two hospitals.

Data management and analysis

Frequency tables and graphs were used to measure and summarize the relative frequency of sex and anatomic sites, and used range to measure their distribution by age. The arithmetic mean of all information was entered on the data

collection forms. The forms were cross-checked and edited for errors. The data was then entered into a computer using EPI INFO, version 7.0.8.0 (2011), software for storage and initial analysis. Further analysis was done using SPSS software version 19.0 (2011).

Ethical consideration

The University research and ethics committee, the committee on human research, the hospital institutional review board and the national council for science and technology approved the protocol and gave a waiver of consent. Informed consent was obtained for screening and for enrolment into the study.

Results

Background characteristics

A total of 268 patients met inclusion criteria. Eleven cases were excluded as nine cases did not have clear indications and two cases were difficult to clearly categorize the region scanned (**Figure 2**). The patients' age ranged from 1 week-17 years (mean of 8.1 years) and 3 weeks-17 years (mean 9.1 years), **Table 1**. The male to female ratio in both hospitals was 1:1.

The majority of CT scan examinations were done on children of 0-4 (33%) and 10-14 (29%) year age groups for

DSCT and MSCT, respectively (**Table 1**). The most common clinical indication for pediatrics CT scan examination in both hospitals was head injury (**Table1**).

TABLE 1: Demographic and clinical indications, stratified according to the Hospitals.

Characteristics	MSCT (n= 184), n (%)	DSCT (n= 73), n (%)
Female (%)	79 (43)	38 (52)
Median age (1QR)	8.1 (1week -17 years)	9.1 (3 weeks-17 years)
Clinical Indications		
Head Injury	85 (46)	29 (40)
Brain Tumour	24 (13)	2 (3)
Seizure	17 (9)	15 (21)
Congenital anomaly	18 (10)	3 (4)
Infection	9 (5)	7 (10)
Spinal injury	4 (2)	3 (4)
Others*	28 (15)	16 (22)

*Others include abdominal mass, mucocele, nasal blockage, headache, aphasia, cerebral palsy, delayed milestone, movement disorder, scalp pulsation, generalized hyper-reflexes, body weakness, pancreatic pseudo cyst, post tetralogy of Fallot repair, pelvic fracture and lower back pain.

Table 2 and **Table 3** the mean values of CTDIw and CTDIvol for the head were more than for the body and these increased with age as demonstrated in Table 2 and 3 at both hospitals.

TABLE 2: Mean CT dosimetry values according to anatomical sites and age group, MSCT.

Age groups in years	Anatomical sites and CT dosimetry					
	Head*			**Body		
	CTDIw (mGy)	CTDIvol (mGy)	DLP (mGy.cm)	CTDIw (mGy)	CTDIvol (mGy)	DLP (mGy.cm)
0-4	54	41	827	20	29	595
5-9	61	45	1013	30	45	846
10-14	43	64	1137	24	35	994
15-18	48	71	1336	21	32	1038

* Head is the region above the base of the neck. **Body is the region below the base of the neck.

Table 2 shows the mean values of CTDIvol and DLP of the head CT scan examinations increase with the age of the patients.

TABLE 3: Mean CT dosimetry values of head and body CT scan examination according to the age group, DSCT.

Age groups in years	Anatomical sites and CT dosimetry					
	Head			Body		
	CTDIw (mGy)	CTDIvol (mGy)	DLP (mGy.cm)	CTDIw (mGy)	CTDIvol (mGy)	DLP (mGy.cm)
0-4	18	5	66	2	3	81
5-9	23	8	107	4	3	97
10-14	32	12	153	5	6	212
15-18	32	10	134	5	7	105

TABLE 4: Calculated (using ImPACT*) mean CT dosimetry values of CT scan examinations of the head and body for all age groups compared to the scanner values, MSCT.

Values	Calculated CTDIvol(mGy)	Scanner CTDIvol(mGy)	Calculated DLP(mGy.cm)	Scanner DLP(mGy.cm)
Head	62.7	46.5	1114	1056
Body	24.65	19.707	745	829.005

[The calculated CTDIvol for the head were significantly higher than the values displayed on the console (p-value = 0.000, 95%CI)]

TABLE 5: Comparison of mean CT dosimetry values of scanners in relation to the head (95% CI).

Hospital and Region scanned	CTDI _w (mGy)	CTDI _{vol} (mGy)	DLP (mGy.cm)
Head			
MSCT	40	60	1022
DSCT	22	7	114
<i>P</i> -value	0.000	0.000	0.000
Body			
MSCT	41	27	782
DSCT	18	6	73
<i>P</i> -value	0.000	0.001	0.001

[There were significantly higher CTDI_w (mGy), CTDI_{vol} and DLP values for MSCT compared to DSCT for both the head and body]

The calculated CTDI_{vol} for the head using a MSCT were significantly higher than the values displayed on the console (62.7 mGy vs 46.5 mGy, $p = 0.000$, 95% Confidence Interval (CI). However, DLP, the calculated CTDI_{vol} and the displayed values were not significantly different for the body and DLP values (**Table 4**). There were significantly higher doses imparted by MSCT compared to DSCT on both the head and body respectively (**Table 5**).

TABLE 6: Comparison of the 3rd quartile values of CTDI_{vol} and DLP for head CT scan examination for MSCT with Quality criteria (2004) at www.msct.info.¹⁹

Age group	Institutes	CTDI _{vol} (mGy)	DLP (mGy.cm)
0-1 year	MSCT	57.7	1068
	Quality criteria	31	333
4-6 years	MSCT	74.5	1168
	Quality criteria	47	374
Adults		72	945

TABLE 7: Obtained 3rd quartile CTDI_{vol} (mGy) data as function of age group (years) compared with data reported from other countries.

Age Group	B	F	GR	D	CH	UK	MSCT
<1	35	30	-	33	20	30	57.7
1-4	43	40	50	40	30	45	78.5
5-9	49	50	65	50	40	50	72.5
10-14	59	-	-	65	60	65	76.1

Dash (-) indicates data not available.

B: Belgium; **F:** France; **GR:** Greece; **D:** Germany; **CH:** Switzerland; **UK:** United Kingdom.

Table 7 shows that 3rd quartile values of CTDI_{vol} for MSCT were higher than those of the other countries.

The 3rd quartile values of CTDI_{vol} (mGy) and DLP mGy.cm for age group of 0-1 year and 4-6 years for MSCT were higher than the values of quality criteria 2004 survey (**Table 6**). When the MSCT 3rd quartile CTDI_{vol} (mGy) values were compared to other countries, they were higher doses (**Table 7**). The CTDI_w, CTDI_{vol} and DLP of the DSCT scanner were less than those from UK 2003 survey (**Table 8**).

Table 8: Comparison of mean CT dosimetry values with DSCT scanners.

Age Group	Shrimpton <i>et al.</i> (UK 2003)	DSCT
0-1 Year		
CTDI _w (mGy)	35	13
CTDI _{vol} (mGy)	35	4.5
DLP (mGy.cm)	270	60
5 years		
CTDI _w (mGy)	50	20
CTDI _{vol} (mGy)	50	8
DLP (mGy.cm)	470	103

The mean CT dosimetry values of CTDI_w, CTDI_{vol} and DLP of the dual CT scanners are less than that of values from UK 2003 (Shrimpton *et al.* 2003) survey.

Discussion

The use of CT scan as an imaging modality for examining children is on the increase due to short examination times, user friendliness, superior spatial resolution and high-quality contrast. The need for adjustments in parameters in this population has been of great importance lately due to the serious radiation risk involved.

The majority of paediatric CT scan examinations were performed on children of 10-14 and 0-4 years at MSCT and DSCT respectively. In contrast, Mark *et al.* noted the highest frequency of CT scan examinations to be in the age group 15-19 years.¹³ These differences in the frequencies could be due to the difference in the incidence of diseases according to geographic sites and race. The availability and affordability of non-ionizing radiations imaging modalities like ultrasound and magnetic resonance imaging (MRI) as an alternative for the very young children in the developed countries can be additional factor for these variations. The lack of awareness about the role of ultrasound as an imaging tool in the young patients with open fontanels and the hazards of CT radiations can also be the reason for the high number of CT scan examinations performed on the very young children as noted in this study. This agrees with Shrimpton *et al.* findings¹⁴. Brenner *et al.*⁵ noted that the estimated life time cancer risk for abdominal paediatrics CT scan examination are significantly greater than those for head examinations.

There were slightly more girls than boys (52% vs. 48%) for DSCT. Similar findings were noted in a study by Nasoor *et al.*¹⁵ In contrast, more boys were scanned by the MSCT. Boys tend to be more physically active than girls hence prone to head injuries.

Head CT scans were more common than body CT scan in both hospitals. Similar findings were noted by Mark *et al.*¹³ and Buls *et al.*¹⁶ This is because of the frequency of head injury which warrants CT scans. In developing countries,

most abdominal imaging and cranial imaging in the very young is done by ultrasound scans.

The findings from our study and other studies showed CT dose values increase as the age of the patient increases (**Table 2 and 3**).¹⁷ This finding agrees with the principles of radiation protection in paediatrics patient which entails the use of less radiation doses in the very young children. The mean values of CTDI_w, CTDI_{vol} and DLP were higher for males when compared to females in both hospitals. Brenner *et al*⁵ noted the estimated lifetime cancer risk from CT radiation is greater for girls than for boys. Thus, the findings of lesser radiation dose given to girls in our setup may be an encouraging finding.

The calculated CTDI_{vol} and the Scanner CTDI_{vol} values for head using the MSCT were significantly higher than those from the DSCT ($p = 0.000$, 95% CI), **Table 4**. Shrimpton *et al*¹⁸ using the ImPACT dosimetry calculator noted similar findings. The differences between the calculated and displayed values of CTDI_{vol} could be due to low accuracy of the displayed CTDI_{vol} value or the machine is calibrated for an adult phantom head size (16 cm) instead of a child's head size (12 cm).

The CTDI_{vol} and DLP values (mean, range and 3rd quartile) for the MSCT were significantly higher as compared to the DSCT ($p = 0.00$), **Table 5** and other countries (**Table 7**). Radiation doses increase as the number of slices acquired per tube rotation increases. Children that were scanned by the MSCT were exposed to higher doses as compared to adults in the western world while those scanned using the DSCT doses received radiation doses that were within acceptable range (**Table 6**). This study didn't explore the likely causes for these differences, which will be the next stage of the research. However, inappropriate technical parameters, lack of appropriately calibrated parameters in the existing protocols according to the age, weight and size of the children led to the use of adult protocols. This is a radiation safety concern during the use of medical exposures which should be appropriately addressed. This highlights the concern by previous studies of children being more sensitive to radiation than adults.^{5, 18}

There were limitations to this study. First, the values of CTDI_w were not displayed on the MSCT console. Therefore comparison of the calculated values with the displayed scanner values was not possible. Second, CTDI_w, CTDI_{vol} and DLP values were not displayed on the DSCT console. Therefore comparison of the calculated values with the displayed scanner values was not possible. Third, the majority of the CT scan examinations were performed on the head. Thus it was difficult to draw statistically significant conclusion from the values obtained for body CT scan examinations.

In conclusion, the calculated CTDI_{vol} value for CT of the head performed by the MSCT was significantly higher than the displayed value /on the console. This could be due to lack of appropriately calibrated acquisition parameters in the existing protocols.

Furthermore, the radiation dose values for CTDI_w, CTDI_{vol} and DLP for MSCT were significantly higher than that of the DSCT and relatively higher when compared to values of other countries as well the National Radiation Protection Board UK.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Appendix I:ImPACT patient dosimetry calculator

Version 1.0.4 27/05/2011

Access at <http://www.impactscan.org/ctdosimetry.htm>

Using CTDosimetry.xls

To calculate doses using CTDosimetry.xls, the user must enter a number of parameters relating to the scanner and the scan series. The following four selections, made in the top left box on the Scan Calculations worksheet define the Monte Carlo data set that is used:

Manufacturer

Select the scanner manufacturer from the drop down list.

Scanner

Select the scanner model or scanner model group for the drop down list.

kV

Choose the appropriate scan kV.

Scan Region

Choose head or body

Scan and patient data is entered in the box on the top right of the Scan Calculations worksheet.

Tube current

The x-ray tube current. Note that this should be the actual scanner mA, and not the 'effective mAs' displayed on some multi-slice scanners.

Rotation time

The scanner tube rotation time

Spiral pitch

The scanning pitch (table travel per rotation/total collimated slice width). For axial scanning, (couch increment)/(collimated slice width) should be used

mAs/rotation

The total mAs per gantry rotation. Do not enter data in this box - it is calculated automatically.

Effective mAs

The mAs/per rotation divided by the spiral pitch. This is a calculated value that provides a basis for comparison of spiral protocols with different pitches

Collimation

The total nominal x-ray beam width along the z-axis, selected from a range of possible values in the drop down box. This determines the relative CTDI compared to the reference (usually 10 mm) collimation.

Rel. CTDI

The CTDI at the selected collimated x-ray beam thickness, relative to the CTDI at the reference collimation (usually 10 mm)

CTDI (air)

The free in air CTDI₁₀₀ value (in mGy/100mAs), as defined in EUR 16262: European Guidelines on Quality Criteria for Computed Tomography, pub. European Commission (link to this document at bottom of page). CTDI values for most of the scanners are listed on the Scanner Worksheet. Pressing the 'Look up' button will enter the value in this cell. The value in this cell is corrected for the relative CTDI value in the cell above.

CTDI (soft tissue)

The CTDI to ICRU muscle, used as an approximation to the dose to soft tissue within the body. This is the CTDI(air) x 1.07 for CT scanner energies

nCTDI_w

Weighted CTDI measured in a standard CTDI phantom (normalised for 100 mAs). $CTDI_w = (CTDI_{centre} + 2 * CTDI_{periphery})/3$

CTDI_w

Weighted CTDI measured in a standard CTDI phantom. $CTDI_w = (CTDI_{centre} + 2 * CTDI_{periphery})/3$.

CTDI_{vol}

Volume weighted CTDI, given by $CTDI_{vol} = CTDI_w / \text{Spiral Pitch}$

DLP

Dose Length Product, given by $CTDI_{vol} \times \text{Scan length}$

Start Position

The start position of the scan series. The diagram on the Phantom worksheet shows the position of the phantom's organs relative to the number scale, which is 0 at the base of the trunk. This value can be entered manually in the worksheet, or can be taken from the shaded area on the Phantom worksheet diagram. This can be adjusted using the up and down arrows. Pressing the 'Get From Phantom

Diagram' button enters these values into the start and end position boxes in Scan Calculation.

End Position

The end position of the scan series - Note that this should include the slice thickness, so, for example, a single 5mm slice 20cm from the base of the trunk would have a start position of 20, and an end position of 20.5cm. Start and End position values are interchangeable. The weighted CTDI (CTDI_w), volume (CTDI_{vol}) and dose length product (DLP) are also displayed.

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