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# Assessment of Radiation doses to Paediatric Patients in Computed Tomography Procedures

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## Summary

**Background:** The use of pediatric CT that had recently emerged as a valuable imaging tool has increased rapidly with an annual growth estimated at about 10% per year. Worldwide, there is a remarkable increase in the number of CT examinations performed. The purposes of this study are to: (i) to measure the radiation dose and estimate the effective doses to pediatric patients during CT for chest, abdomen and brain.

**Material/Methods:** A total of 182 patients were investigated. CT scanners that participated in this study are helical CT scanners (64 slices, 16 slices and dual slices). Organ and surface dose to specific radiosensitive organs were estimated by using software from National Radiological Protection Board (NRPB).

**Results:** For all patients, the age was ranged between 1.12 month–10.0 years while the weight was ranged between 5.0 kg to 29.0 kg. The DLP was 320.58 mGy·cm, 79.93 mGy·cm, 66.63 mGy·cm for brain, abdomen and chest respectively. The effective dose was, 2.05, 1.8, 1.08 mSv for brain, abdomen and chest respectively.

**Conclusions:** The patient dose is independent of CT modality and depends on operator experience and CT protocol. The study has shown a great need for referring criteria, continuous training of staff in radiation protection concepts. Further studies are required in order to establish a reference level in Sudan.

**MeSH Keywords:** **Dose-Response Relationship, Radiation • Relative Biological Effectiveness • Tomography Scanners, X-Ray Computed**

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## Background

Nowadays, computed tomography (CT) is becoming the major source of patient exposure. It has been estimated that CT examinations make up approximately 11% of all radiological procedures and that radiation from CT delivers approximately 70% of the medically-related radiation dose [1]. Approximately 6% of CT examinations were performed on children under the age of 15 years [1–3].

The individual risk from radiation associated with a CT scan is quite small compared to the benefits that accurate diagnosis and treatment can provide. Nevertheless, unnecessary radiation exposure during medical procedures should be avoided. Unnecessary radiation may be delivered when CT scanner parameters are not appropriately adjusted for patient size [4]. In conventional x-ray procedures, medical personnel can notify if the patient was overexposed because the resulting film is overexposed, producing a dark image [2]. However, with CT as well as in other digital imaging modality, there is no obvious evidence that the patient was overexposed because the quality of the image may not be compromised. Pediatric CTs attract particular interest because of greater cell proliferation rate and increased opportunity for expression of delayed cancer effects [5]. The International Commission on Radiological

**Table 1.** CT scanners.

| Hospital | Manufacture | Model | Installation date | Detector type (slice) |
|---|---|---|---|---|
| Hospital A | Siemens | Somatom Emotion Duo | 2006 | 2 |
| Hospital B | Siemens | Sensation 16 | 2004 | 16 |
| Hospital C | Toshiba | Toshiba Aquilion | 2011 | 64 |

Protection (ICRP) estimated that risk coefficients for an average population are 5% $Sv^{-1}$, whereas for children they are 13% $Sv^{-1}$ for stochastic effects [5]. Radiation doses from CT procedures can often approach or exceed levels known with certainty to increase the probability of cancer and some deterministic effects were reported on [5]. It was estimated that one individual in 1,000 develops cancer from exposure to a 10-mSv dose of radiation [6] and 2% of current cancers in the United States are due to CTs performed in the past [7]. Therefore, it is important to evaluate radiation exposure in children in order to ensure that pediatric doses are kept to a minimum whilst maintaining the quality of radiographic images. The ICRP [5] recommended the use of a diagnostic reference level (DRL) for patients in order to determine whether protection was adequately optimized. The use of DRL has been shown to reduce the overall dose and the range of doses observed in clinical practice. For decades, CT technology has advanced significantly, therefore it is important to evaluate the radiation dose delivered to the patients from different CT modalities based on scan parameters and machine characteristics. In recent years, concerns have been raised about radiation exposure to pediatric patients during CT procedures and some studies have been published on patient radiation [7–16]. Although the task is important, still few studies have been performed in the field of measurement of radiation dose and the related risk during pediatric CT procedures compared to the frequency of the procedures. These studies have shown that there is a wide range of dose values and protocols. In addition to that, the data available on clinical doses in CT procedures are generally outdated because of the continuous development of CT X-ray generators. The objectives of this study were to: (i) evaluate the radiation dose and estimate the effective doses to pediatric patients during CT of the chest, abdomen and brain with different CT units.

## Material and Methods

### Patient demographic data

This is a retrospective analysis of radiation doses recorded for routine CT examinations for a total of 182 patients (102 for brain, 30 for abdomen and 50 for chest). The age of all children who were included in this study ranged between 0–10 years. For each patient, the following data were recorded (age, gender, weight and height) as well as the following scan parameters (start position, end position, kVp, mAs [total mAs, reference mAs and effective mAs], pitch, slice thickness, number of slices, field of view [FOV], total scan time, rotation time, table feed per rotation, displayed $CTDI_{vol}$ and displayed DLP). Ethics and research committees at all hospitals approved the study and informed consent was obtained from all patients prior to the procedure.

### CT machines

CT scanners that participated in this study are helical CT scanners in three hospitals. All scanners displayed volume Computed Tomography Dose Index ($CTDI_{vol}$) and Dose Length Product (DLP). The data were collected from each CT scanner (manufacture, model, year of installation, focal axial distance [FAD] and detector type). The CT machine characteristics are presented in Table 1. The data was collected from the following radiological departments: (i) El Nilein Medical Diagnostic Centre (hospital A), (ii) The National Ribat University Hospital (hospital B) (iii) Alamal National Hospital (hospital C). All quality control tests were performed to the machines prior to any data collection. The tests were carried out by experts from Sudan Atomic Energy Commission (SAEC). All the data were within an acceptable range.

### CT protocol

For brain CT, two techniques were used in all hospitals as routine protocols: sequential and routine helical, while in hospital C only the helical technique was used. In sequential technique, the operator can use high mAs (good image quality), angulate the gantry to avoid tilt of the head, and these angulations reduce the radiation dose to the lenses. However, the disadvantages of this technique are: long scan time, high mAs (meaning high radiation dose to the patient). When the patient lies in a correct position, spiral technique is preferred due to short scan time and low dose to the patient. CTs of the abdomen and chest in all patients were carried out with a helical technique. All patients were screened for allergy and renal function in order to avoid contrast-induced nephropathy. Contrast medium was used in some cases such as trauma and aneurysm. The scan phase for contrast medium in all investigations was based on the clinical indication.

### Effective dose estimation

Radiation dose estimates were determined using the volume CT dose index ($CTDI_{vol}$) in Gy and the dose-length product (DLP) in mGy·cm as provided on the scanner console. The organ dose conversion factor f (organ, z) was obtained from the NRPB datasets (NRPB-SR250) based on the Monte Carlo simulations [17]. The CTDOSE software supplied by the ImPACT group (ImPACT CT Patient Dosimetry Calculator, version 0.99x; ImPACT, London, England) [18] was used and scanning parameters such as kV, mA, exposure time, pitch, slice thickness, gender, and start and

**Table 2.** The mean values and standard deviation of the scan parameters.

| Exam | Hospital A | | Hospital B | | Hospital C | |
|---|---|---|---|---|---|---|
| | kVp | mAs | kVp | mAs | kVp | mAs |
| Brain | 119.3±10 | 147.9±40 | 118.9±6.6 | 126.2±85 | 122.4±3.0 | 140.3±60 |
| Abdomen | 115.4±8.8 | 33.3±27 | 120.0±0 | 43.0±12 | 120.0±0 | 50.0±18 |
| Chest | NA | NA | 120.0±0 | 35.2±30 | 120.0±0 | 43.6±45 |

NA – not available.

**Table 3.** Patient radiation doses (mGy·cm) in different hospitals.

| Body part | Hospital | Min | Median | Mean | 3rd quartile | Max |
|---|---|---|---|---|---|---|
| Brain | A | 113.0 | 280.0 | 300±117.9 | 397.5 | 492.0 |
| | B | 72.0 | 290.0 | 328.8±225 | 323.0 | 995.0 |
| | C | 118.0 | 310.0 | 350±117.9 | 419.5 | 502.0 |
| Abdomen | A | 72.0 | 290.0 | 328.8±225 | 323.0 | 995.0 |
| | B | 54.0 | 92.8 | 94.5±31 | 122.7 | 138.0 |
| | C | 60.0 | 280.5 | 295.1±230 | 350.5 | 1020.0 |
| Chest | A | 33.6 | 49.2 | 62.5±71 | 69.3 | 140.1 |
| | B | 30.0 | 36.0 | 73.1±78 | 76.1 | 190.5 |
| | C | 42.6 | 55.7 | 80.4±80 | 86.5 | 160.6 |

end positions of each scan were used as input data to the CTDOSE spreadsheet in organ dose estimations [18].

## Results

Patients' age ranged between 1.12 month and 10 years, the height ranged between 30–130 cm, the weight ranged between 5.0–29.0 kg and Body mass index (BMI) ranged between 9.05–43.9. No significant difference was noticed between different age groups: (P value =0.57). The clinical indications for brain CT were as follows: 32.69% cases of hydrocephalus, 32.69% – epilepsy, 13.46 – a mass and 7.69% – a trauma. A total of 69.56% of clinical indications for abdominal CT constituted renal disorders, 17.39% – liver and bowel disorders, and 13.04% – a mass. Clinical indications for chest CT included: pneumonia in 40%, chest deformity in 20%, lymphadenopathy in 20%, and diaphragmatic hernia in 20%. Table 2 shows mean values of exposure parameters for the recorded tube current setting (not adjusted for gantry rotation cycle speed and kilovoltage). Table 3 shows the measured DLP (mGy·cm) per procedure for all CT examinations. This data shows asymmetry in distribution, the mean, median, minimum, third quartile and the maximum values. The mean $CTDI_{vol}$ per procedure was 28.6±9.4 mGy, 23.6±16.5 mGy and 26.0±12 mGy for hospital A,B and C, respectively. The patient dose was independent of CT modality and depended on operator's experience and CT protocol.

## Discussion

Pediatric radiation dose for CT of the brain, abdomen and chest was evaluated in this study. The mean and sd values of the exposure parameters were presented in Table 2. The slice thickness was 2 mm, 5 mm, and 6 mm, and the rotation time for spiral technique was 0.75s, 1.5s and for sequential technique 1.88s, 2.5s, and 8.15s. These parameters produced radiation values presented in Table 3 which shows variation in dose between the three departments. This could be attributed to the fact that technologists used different imaging protocols even at the same department. This is known to result in high mAs (high mAs, high dose) and long scan time. Moreover, sometimes pediatric patients were scanned with adult protocols (scanner design, patient age >5years or weight >20 Kg). For total values, the DLP average was 320.5±200 mGy·cm, $CTDI_{vol}$ average was 25.0 m ±14.9 Gy and effective dose average was 2.1±1.6 mSv. A large variability in DLP was due to the application of different techniques, designs of scanner and repetition of scans and those, in turn, were correlated to effective dose (0.3–8.2 mSv) and to $CTDI_{vol}$ (3.5–69.1 mGy). In these groups, 80 patients were scanned only one time and 22 patients were scanned more than one time. Although different CT modalities were used, minor variation was noticed in dose values. These values are comparable with previous studies [13–15], as shown in Table 4. Radiation dose from head CT scans may vary considerably as a result of inherent differences in the equipment and because of variations in exposure technique and scanning protocol. The variations in scan parameters (kVp and mAs) do not seem to differ enough to produce some of the differences in DLP that are noted in Table 3. For example, the imaging protocol and machine type may lead to a large difference in the mean DLP for the abdomen (94.5 mGy·cm) at hospital B, as compared to hospital A and C (328.8 and 295.1 mGy·cm, respectively).

**Table 4.** Shows the results of previous studies as well as the presented one.

| Author | Country | No of patients | DLP (mGy·cm) | $CTDI_{vol}$ (mGy) | mAs average | Effective dose (mSv) |
|---|---|---|---|---|---|---|
| Verdun et al. [13] | Switzerland | 4000 | | | | |
| Brain | | | 416.66 | 30 | NR | NR |
| Chest | | | 176.66 | 7.66 | NR | NR |
| Abdomen | | | 270 | 9.66 | NR | NR |
| Tsapaki et al. [14] | Greece | 160 | | | | |
| Brain | | | 594 | NR | NR | 1.4 |
| Chest | | | 577 | NR | NR | 10.9 |
| Abdomen | | | 430 | NR | NR | 7.1 |
| Shirmpton [15] | UK | 10 | | | | |
| Head | | | 453 | 50 | NR | 1.86 |
| Chest | | | 266 | 15 | NR | 4.6 |
| Present study | Sudan | 182 | | | | |
| Brain | | | 320.5 | 25 | 132.48 | 2.1 |
| Abdomen | | | 79.9 | 3.4 | 37.54 | 1.8 |
| Chest | | | 66.6 | 1.6 | 32.46 | 1.1 |

NR – not reported.

#### Abdomen

For the abdomen, slice thickness of 5, 6, and 10 mm, and rotation time of 0.5, and 1s were used. The exposure parameters produced radiation values presented in Table 2 which shows variation in dose between the three centers. It is important to note that in hospital A and B, all patients were scanned for abdomen and pelvis according to the department protocols while in hospital C, the technologist used different protocols for abdomen and for pelvis. Pelvis scans were performed only upon request of the referring physician. However, since the abdomen and pelvis contain sensitive organs, the radiation dose delivered to patients becomes a particular concern, especially in young patients and in those with chronic diseases who undergo repeated CT examinations. The large variability in DLP was due to repetition of scans (phase) and patients' weight, and these were correlated to the effective dose of 0.4–6.9 mSv and to $CTDI_{vol}$ of 1.2–27.3 mGy. In these groups, 17 patients were scanned only one time and 13 patients were scanned more than once. These dose values are lower than in the previous studies [13–15], as shown in Table 4.

#### Chest

A total of 50 patients had chest scans with elected exposure factors as shown in Table 2. The slice thickness was 5 mm and the rotation time was 0.5, 0.75 and 1s. The resulting radiation values are presented in Table 3. The large variability in DLP was due to the repetition of scans and patients' weight. These were correlated to the effective dose of 0.5–2.4 mSv and also to $CTDI_{vol}$ of 1.2–5.6 mGy. In this group there were 30 patients who were scanned only one time and 20 patients scanned more than once. These values are lower than in the previous studies as shown in Table 4.

#### General discussion

In this study, pediatric radiation dose was investigated for brain, abdomen and chest CT procedures. Although, CT examinations exposure the patients to relatively high radiation doses as compared to planar radiography, these procedures are justified by the ability to detect alternative and/or additional diagnoses. In this study, some technologists used the same parameters as for adults and children. This problem was addressed previously in the literature in different countries [4–11,15,16]. Training of the technologists is the best solution for patient dose optimization. It is important to note that no shielding was used (such as thyroid, gonad or eye lens shields) in the hospitals to protect radiosensitive organs from scatter radiation. The previous studies shown in Table 4 revealed wide variations in terms of screening time, number of radiographic images, DLP and effective dose. These variations suggest that pediatric patients are still exposed to a large amount of unnecessary radiation and optimization is not fulfilled yet. The study revealed that the dose for the brain and chest showed minor variations, but for the abdomen the variations were large. There may be reasonable reasons for some variability in practice, of which the most important one is the difference in clinical indications. This difference is greater if technologists, radiologists and referring doctors are insufficiently knowledgeable in the capabilities of CT machines and in radiation risk. Although in this study different CT modalities were investigated the dose values were comparable at all three hospitals. In this context, Arthurs et al. [19] and Rixe et al. [20] reported that on average, 64 CT DLPs were 9% lower than 16 CT DLPs with better image quality and lower effective dose. If there was a choice, it would be 64 CT for this patient group. CT dose optimization was not implemented in the examined hospitals. Goldman et al. [12] reported that dual slice or four slice CT scanners delivered the lowest radiation doses to patients depending on scan parameters as well as the poorest image quality but good enough for patient diagnosis. The 16- and 64-slice CT scanners or higher CT modalities produced more than adequate diagnostic image quality and delivered more than necessary dose to patients.

## Conclusions

The assessment of radiation dose to pediatric patients undergoing CT of the brain, abdomen and chest was presented in this work. Different data in request forms and department protocols were responsible for these variations. The main contributor to high dose variations was the use of different techniques and protocols for adults in some cases, which shows the importance of using only pediatric protocols for CT examinations in children. In addition, the study showed a great need for referring criteria, continuous training of staff in radiation protection concepts.

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### Conflict of interests

The author certifies that there is no conflict of interest to declare that might be relevant to the submission of this paper.

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