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Appraisal of Radiation Dose Received in Abdominal Computed Tomography Patients

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Abstract: ***While the benefits of CT exceed the potential effects of radiation exposure to patients, increasing radiation doses to the population have raised a compelling case for reduction of radiation exposure from CT. In Sudan, there was a remarkable increase of CT examinations performed. Therefore, radiation dose optimization is mandatory because of the risks associated with exposure to radiation. In this study, we have investigated the possibility of reduction patient dose in CT scan for abdomen at a constant level of image quality by adjustment of the tube current to the patient size. A total of 37 patients referred to CT centers in the period of the study with abdominal disturbances. Organ and surface dose to specific radiosensitive organs was estimated by using National Radiological Protection Board (NRPB) guidelines. The mean ED values calculated were [2.43 ± 0.85] for CT scan abdomen examinations, from the Hospital "A" and [6.57 ± 2.38] from the Hospital "B". As comparison the results with NRPB and UNSCEAR, the effective dose from CT examinations were in general relatively high, typically 1- 30 mSv. These doses can often approach or exceed levels known to increase the probability of cancer. More than a 50 percent reduction in patient dose is possible by appropriate choice of scan parameters.***

Keywords: Computed Tomography, Patients dose, Abdominal, Radiation.

1. Introduction

The absorbed doses in the patient in CT examinations constitute a large portion (about 20%) of the total dose from medical diagnostic X-ray examinations [1]. The radiation dose delivered during a CT scan is somewhat greater than that administered for an equivalent radiographic image. A CT image of the head requires a dose of about 1 to 2 rad, for example, whereas an abdominal CT image usually requires a dose of 3 to 5 rad. These doses would have to be increased significantly to improve the contrast and spatial resolution of CT images. The relationship between resolution and dose can be approximated as:

$$D = \alpha \left(\frac{S^2}{e^3\, b}\right) \quad (1)$$

Where D is the patient dose, "S" is the signal/noise ratio, "e" is the spatial resolution, "b" is the slice thickness, and "α" is a constant. From Eq. (3), the following are apparent:

1) A twofold improvement in the signal-to-noise ratio (contrast resolution) requires a fourfold increase in patient dose.
2) A twofold improvement in spatial resolution requires an eightfold increase in patient dose.
3) A twofold reduction in slice thickness requires a twofold increase in patient dose.

In multi slice computed tomography, patient dose is described as the CT dose index (CTDI). When the distance that the patient moves between slices (the couch increment CI) equals the slice thickness ST, the CTDI equals the dose averaged over all slices (multi slice average dose MSAD) [2].

Volume Computed Tomography Dose Index (CTDIvol) is a standardized parameter to measure scanner radiation output. CTDIvol is not patient dose, CTDIvol is reported in units of mGy for either a 16-cm (for head exams) or 32-cm (for body exams) diameter acrylic phantom. In these slides, the term "patient dose" is used to describe the absorbed dose to a patient, while the generic term "dose" refers to CTDIvol. For the same CTDIvol, a smaller patient will tend to have a higher patient dose than a larger patient [3]. The CTDI is the primary dose measurement concept in CT,

$$\text{CTDI} = \frac{1}{NT}\oint_{-\infty}^{\infty} D(z)\,dz \quad (2)$$

Where:
D (z) = the radiation dose profile along the z-axis, N= the number of tomographic sections imaged in a single axial scan. The value of N may be less than or equal to the maximum number of data channels available on the system, and T= the width of the tomographic section along the z-axis imaged by one data channel. In multiple-detector-row (multi-slice) CT scanners, several detector elements may be grouped together to form one data channel [4-6].

CTDI represents the average absorbed dose, along the z-axis, from a series of contiguous irradiations. It is measured from one axial CT scan (one rotation of the x-ray tube), and is calculated by dividing the integrated absorbed dose by the nominal total beam collimation. The CTDI is always measured in the axial scan mode for a single rotation of the x-ray source, and theoretically estimates the average dose within the central region of a scan volume consisting of multiple, contiguous CT scans [Multiple Scan Average Dose (MSAD)] for the case where the scan length is sufficient for the central dose to approach its asymptotic upper limit. The

CTDI offered a more convenient yet nominally equivalent method of estimating this value, and required only a single-scan acquisition, which in the early days of CT, saved a considerable amount of time [7-8].

$CTDI_{100}$ represents the accumulated multiple scan dose at the center of a 100-mm scan and underestimates the accumulated dose for longer scan lengths. It is thus smaller than the equilibrium dose or the MSAD. In the case of $CTDI_{100}$, the integration limits are ±50 mm, which corresponds to the 100mm length of the commercially available "pencil" ionization chamber [17]. On the assumption that dose in a particular phantom decreases linearly with radial position from the surface to the centre, then the normalized average dose to the slice is approximated by the (normalized) weighted CTDI: $[mGy(mAs)^{-1}]$

$$nCDTI_W = \frac{1}{C}\left(\frac{1}{3}CDTI_{100,\,C} + \frac{2}{3}CDTI_{100,\,P}\right) \quad (3)$$

Where:
- C is the tube current x the exposure time (mAs)
- $CTDI_{100,\,p}$ represents an average of measurements at four different locations around the periphery of the phantom [9-10]

Volume $CDTI_{vol}$ represent dose for a specific scan protocol, which almost always involves a series of scans, it is essential to take into account any gaps or overlaps between the x-ray beams from consecutive rotations of the x-ray source. This is accomplished with use of a dose descriptor known as the Volume $CTDI_w$ ($CTDI_{vol}$), where

$$CDTI_{vol} = \frac{N \times T}{I} \times CDTI_w \quad (4)$$

Where I= the table increment per axial scan (mm). Since pitch is defined as the ratio of the table travel per rotation (I) to the total nominal beam width (NxT).

$$Pitch = I / (NxT) \quad (5)$$

Thus, Volume CTDI can be expressed as;

$$CTDI_{vol} = 1 / pitch \times CTDI_w \quad (6)$$

While $CTDI_{vol}$ estimates the average radiation dose within the irradiated volume for an object of similar attenuation to the CTDI phantom, it does not represent the average dose for objects of substantially different size, shape, or attenuation or when the 100-mm integration limits omit a considerable fraction of the scatter tails [3].The Dose Length Product (DLP) is also calculated by the scanner. DLP is the product of the length of the irradiated scan volume and the average $CTDI_{vol}$ over that distance. DLP has units of mGy*cm [11].

$$DLP\ (mGy\text{-}cm) = CTDI_{vol}\ (mGy) \times scan\ length\ (cm) \quad (7)$$

The DLP reflects the total energy absorbed (and thus the potential biological effect) attributable to the complete scan acquisition. Thus, an abdomen-only CT exam might have the same $CTDI_{vol}$ as an abdomen/pelvis CT exam, but the latter exam would have a greater DLP, proportional to the greater z-extent of the scan volume [12].

2. Materials and Methods

The data used in this study were collected from Department of Radiology, Department A (Elnileen Medical Diagnostic Centre- Khartoum) and Department B (Antalya Medical Center Department of Diagnostic Radiology – Khartoum). A total of 37 patients were evaluated. The age of all patients who were admitted in this study between 14–80 years. For each patient the following data were recorded patient demographic data, exposure factors, and scan parameters were recorded. For each patient, the following data were recorded (age, gender, weight and height) as well as the following scan parameters (kVp, mAs, slice thickness, number of slices, rotation time, displayed CTDIvol 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. The patient dose estimation from CT examination using the Monte Carlo technique requires measurements of CTDI and conversion coefficient data packages. Due to the fact that the software does not take into account the patient size, that is, the software was not discriminate between tall and short patients, it was necessary to adjust the scan region indicated on the human skeleton from each patient survey form in NRPB's mathematical phantom for each individual examination [14]. Modern CT systems display the $CTDI_{vol}$ and DLP information for every scan acquisition.Patient dose, particularly equivalent doses in the patients' organs, can be used for assessment of the associated carcinogenic risk of radiation. Effective dose is often used as an expression of population patient risk; however it is correctly applicable only for limited conditions. Although effective dose calculations require specific knowledge about individual scanner characteristics, a reasonable estimate of effective dose, independent of scanner type, can be achieved using the relationship:

$$Effective\ Dose = E_{DLP} \times DLP \quad (8)$$

Where E_{DLP} is a weighting factor ($mSv \times mGy^{-1} \times cm^{-1}$) which depends only upon body regions.

3. The Results

This study involved 37 CT patients undergoing abdomen examinations in Department of Radiology, Department A (Elnileen Medical Diagnostic Centre, Khartoum) and Department B (Antalya Medical Center Department of Diagnostic Radiology, Khartoum). The results were tabulated in the Tables (mean ± standard deviation (SD)) and the range of the readings in parenthesis. The dose values in diagnostic radiology are small, therefore the dose were presented in (mSv). The mean and the standard deviation were calculated using the excel software. For dose calculation, patient individual exposure parameters were recorded (tube voltage (kV), tube current and exposure time product (mAs) and Focus to skin distance (FSD), CTDI volume, DLP dose (mGy.cm). Patient demographic data (age, height, weight, BMI) were presented per department. Patients' ESD were measured in two CT departments equipped with two different

CT imaging machines. Figures (1-9) showed the results of the measured.

Department A:

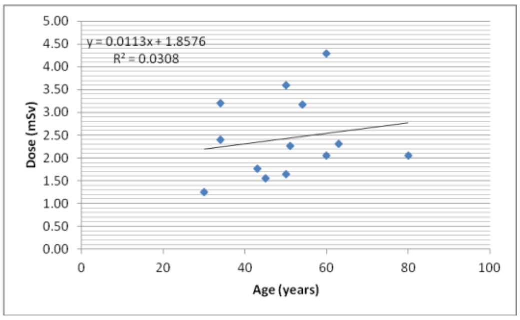

Figure 1: Correlation between Age and dose

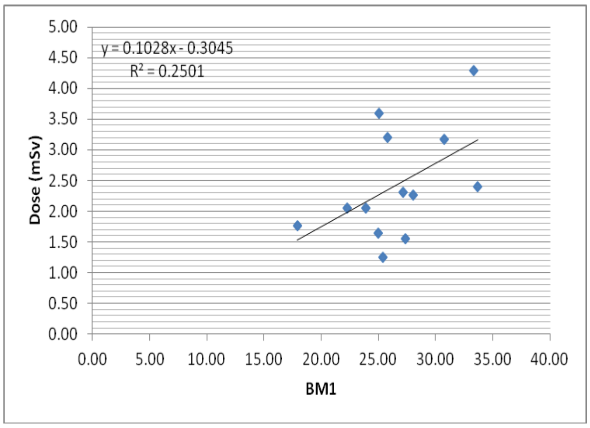

Figure 2: Correlation between Body Mass Index(BMI) and dose

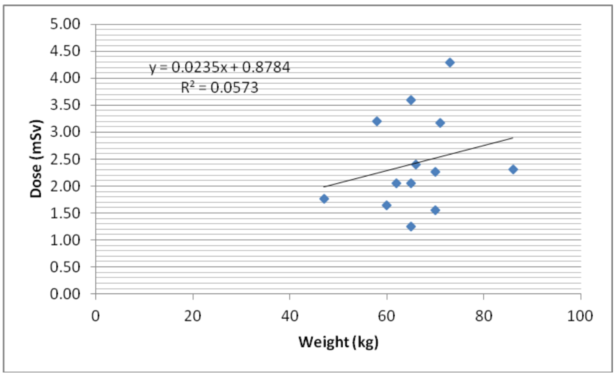

Figure 3: Correlation between body weight and dose

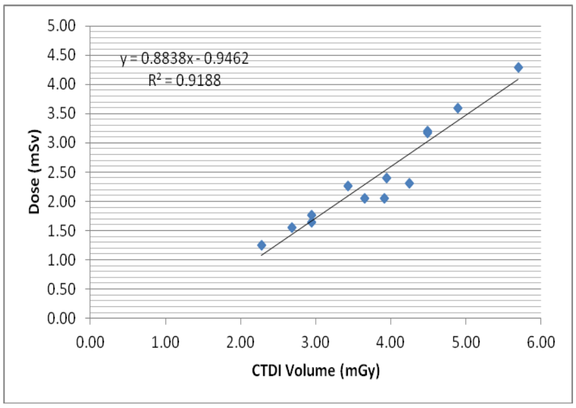

Figure 4: Correlation between CTDI volume and dose

Department B:

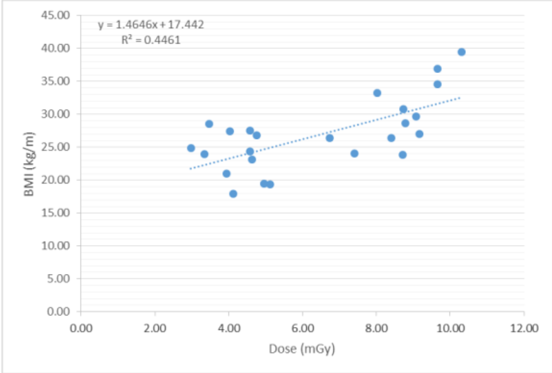

Figure 5: Correlation between Body Mass Index and dose

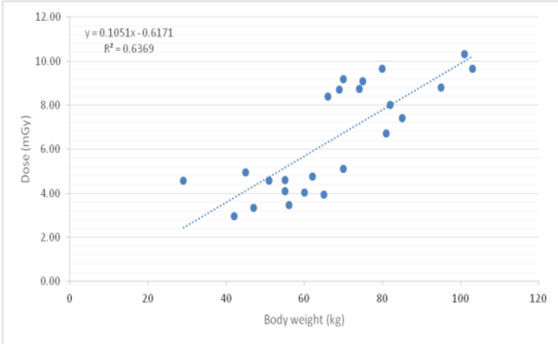

Figure 6: Correlation between body weight and dose

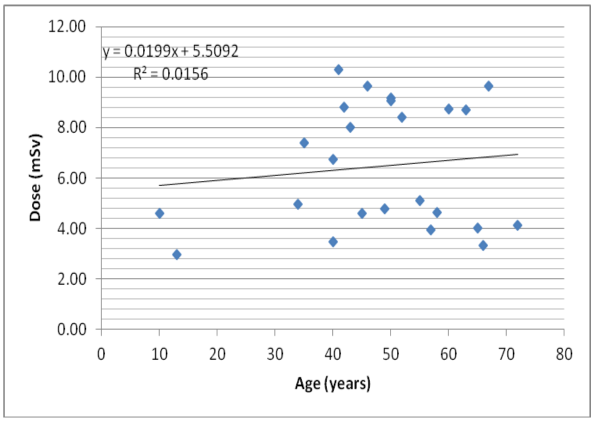

Figure 7: Correlation between Age (years) and dose

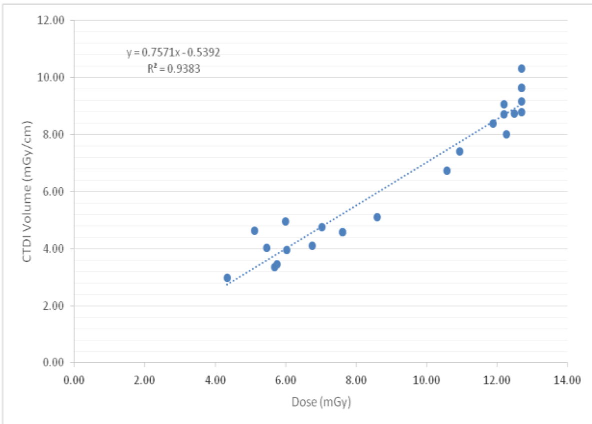

Figure 8: Correlation between CTDI volume and dose

Table 1. shows the mean and standard deviation of effective dose is used for CT abdomen examination in the study sample from Hospital (A) and Hospital (B)

Deparment	Hospital “A”	Hospital “B”
Effective Dose (mSv)	2.43 $\pm$ 0.85	6.57 $\pm$ 2.38

4. Conclusion

In this paper, we have described a common sense approach to more efficient radiation dose management for body CT. It is not possible to provide recipes or “one size fits all” protocols for body CT because of differences in patient body habitus, clinical indications, and CT scanner capabilities. Understanding the interrelationships between CT technical factors, image quality, and radiation dose is essential. Doses for standard-sized patients are within national DRLs. Doses for all patient sizes on GE scanner are ~25% higher than on Siemens Doses for large patients are up to 3x higher on GE scanner compared to Siemens scanner. Noise values on Siemens scanner increase with patient size but on GE scanner there was no correlation between noise and patient size. In current literature, numerous differing recommendations can be found on how to reduce (mAs) settings with patient weight or diameter.

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