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Optimization of Radiation Dose in Cranial Computed Tomography among Adults: Assessment of Radiation Dose against Image Quality

Nnamdi O. E. Okoro [1*], Vahid Changizi [2], Elahe Jazayeri Ghareh Bagh [2], Farideh Pak [2]

1. Department of Radiology and Radiotherapy Technology, International Campus, Tehran University of Medical Sciences, Tehran, Iran.
2. Department of Radiology and Radiotherapy Technology, School of Allied Medical Sciences, Tehran University of Medical Sciences, Tehran, Iran.

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ABSTRACT

Introduction: The rapid use of computed tomography (CT) scan is of great concern, due to increase in patients' dose. Optimization of CT protocol is a vital issue in dose reduction. This study aimed to optimize radiation dose in cranial CT and assess modifications in image quality under radiation dose reduction.

Material and Methods: A poly(methyl methacrylate) phantom was used for quality control test on CT scanners. Data of 214 scan parameters, dose indicators; volume CT dose index (CTDIvol) and dose-length product (DLP) of patients who underwent cranial CT scans were collected. The data were grouped into three, with respect to the slice numbers of 24, 28, and 32. Tube voltage (kVp) and slice thickness were constant; (110 kVp and 4.8 mm, respectively), at variable tube currents (mAs). A one-sample t-test was used to compare the dose indicator values of the hospital protocol with a recommended protocol. Scan parameters were optimized for radiation dose against image quality.

Results: Increased mAs resulted in increased CTDIvol and DLP at constant kVp and slice thickness. Moreover, dose indicators recorded the lowest and highest values at the slice numbers of 24 and 32, respectively. An increase in slice numbers affected dose indicators. Dose indicators recorded significant reduction ($P<0.001$) in comparison to the recommended protocol.

Conclusion: Optimization of CT protocol considers radiation dose and image quality. Radiologists adopted protocols acquired with lower scan parameters and dose indicators lower than the recommended achievable dose limit of 58 mGy.

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Introduction

Advancements in computed tomography (CT) technology have resulted in image quality improvement and faster CT examinations in a relatively short time. However, in case of improper management of these developments, the average radiation dose delivered per examination could increase the risk to health rather than having a beneficial role.

Cranial CT scan uses a series of tomographic beams to diagnose pathologies, by providing the images of the head, including the skull, brain, eye sockets, and sinuses. Cranial CT imaging requires adequate precision in terms of radiation protection of patients. This is because the radiosensitive organs, such as the eye lens could be exposed to high radiation dose, which may lead to deterministic effects (e.g., cataracts) [1]. Several studies have shown that cranial CT scan in long period could cause cancer [2]. Furthermore, this modality may increase the risk of glioma in adult patients with a family history of cancer [3].

The received radiation doses in patients depend on certain factors, such as scanner type, tube current, voltage, and other protocols [4]. Procedures and techniques which can contribute to dose reduction in the eye lens include gantry tilting, iterative reconstruction, and bismuth shielding [5, 6]. Alterations of different CT scan parameters, such as kilovoltage peak (kVp), or modulation of the tube current (mAs), depending on the body size when the mA is manipulated, concurrent with the optimization/improvement of the image quality can lead to reduction in radiation exposure [7-13].

However, some changes in parameters or techniques could cause other problems. For example, lowering the kVp may lead to an increase in image noise, as well as absorbed radiation dose in the radiosensitive organs. Optimization of tube current and tube modulation are commonly used for dose

*Corresponding Author: Tel: +2347038630641; E-mail: e.nnamdi@yahoo.com, nas4life2002@gmail.com

reduction. The lowest possible mAs (tube current time and the rotation time) is correlative to the degree of intrinsic tissue contrast and acceptable level of image noise [14]. A 50% reduction of the tube current can cause the patient radiation dose to be reduced to half. Consequently, such reduction should be performed with precision because an increase in image noise compromises image quality [15]. A lower tube voltage results in an increase in image noise; therefore, the adjustment of other CT scan parameters, especially the tube current, has to be made to sustain the image quality [16].

The as low as reasonably achievable (ALARA) principle was introduced to limit the side effects in patients after radiation exposure while ensuring that the diagnostic quality is not compromised [17]. To protect the patients from radiation-related detrimental effects, it is important to optimize CT protocols according to the ALARA principle [18]. It is imperative to optimize CT investigations with more emphasis on radiation dose reduction to a level that does not affect or compromise diagnostic image quality [19-21].

Emphasis must be put on the adoption of appropriate strategies for the optimization of CT procedures and radiation dose reduction as a result of the extensive use of CT and growing concerns about increased radiation exposure [22]. Optimization of exposure parameters and protocols in CT scanning has attracted interests in various studies. It has also urged the identification of CT radiation dose administered in practice through the guidelines provided by the diagnostic reference levels (DRL), both at the local and national levels [19-21, 23-25].

Due to the radiosensitivity of the head organs (e.g., eye lenses), it is essential to optimize cranial CT scans. Optimization implies that the radiation dose to the patient is suitable for medical purposes, as well as ensuring adequate radiation protection with acceptable diagnostic image quality. A recommended protocol of the American Association of Physicists in Medicine (AAPM) [26] served as a guide in the course of our study for comparitive purposes and dose optimization. Regarding this, the aim of this study was to optimize radiation dose in cranial CT in adults and assess the subsequent modifications in resultant image quality at the reduced radiation dose state.

Materials and Methods

Data collection

Data containing 214 images of adult patients, undergoing axial cranial CT scans from July to September 2018, were retrospectively collected from our radiology department. The patients were imaged using the Siemens Somatom Emotion 16-slice and Philips Brilliance 16-slice CT scanners. Volume CT dose index (CTDIvol) and dose-length product (DLP) were the data of particular interest.

The obtained data from the applied protocols were categorized in three groups with respect to different slice numbers of 24, 28 and 32, while the kVp and slice thickness were constant at 110 kVp and slice thickness of 4.8 mm. Furthermore, to ensure that these data were acquired under proper function and good performance of the CT equipment, a quality control (QC) test was performed using the CTDI phantom [poly(methyl methacrylate) (PMMA); PTW, Freiburg, Germany] as shown in Figure 1.

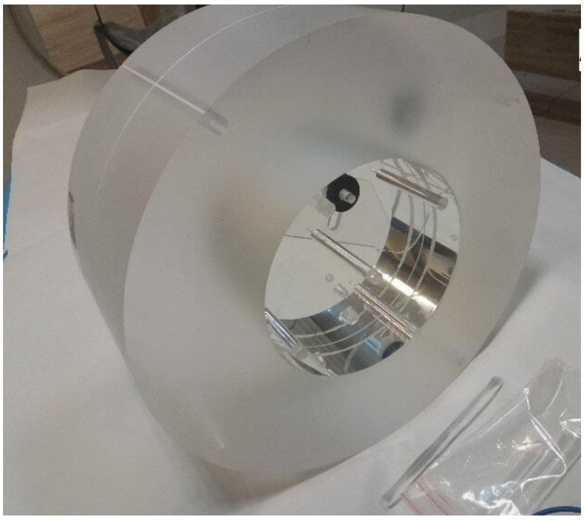

Figure 1. CTDI phantom with five inserts made of poly (methyl methacrylate)

Quality control test

The CTDI phantom (PMMA, PTW, Freiburg, Germany) as shown in Figure 1 was used for the QC test in the present study. The phantom was 16 mm in diameter to represent a human head. It was 150 mm in length containing five cylindrical holes along the z-axis, one at the center and four at the periphery (10 mm from each edge of the phantom). The phantom was made of PMMA with inserts made of the same materials.

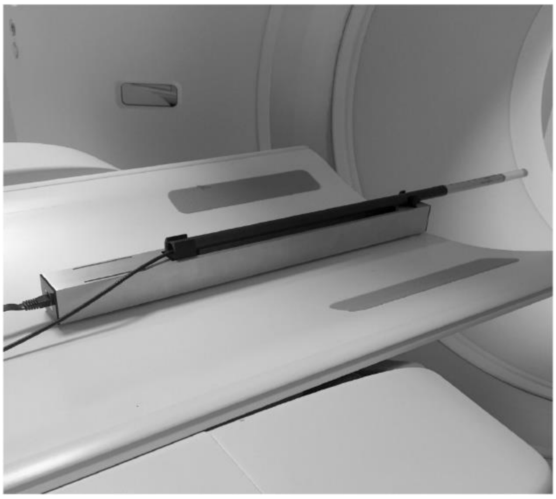

Figure 2. A 100-mm pencil ionization chamber in position for CTDI air measurement

Two CT scanners were used for the QC test, namely the 16-slice type Siemens Somatom Emotion and Philips Brilliance scanners. Examinations were performed in axial and helical modes. The CTDI air was measured using an ion chamber (100 mm; Figure 2) that was placed in the aperture of the CT gantry. In addition, the $CTDI_{100,c}$ (center) was measured through the insertion of ion chamber in the hole center of the CTDI phantom. The ion chamber was connected to an electrometer (PTW DIADOS, Freiburg, Germany; Figure 3), which was joined to a separate high-voltage supply.

Figure 3. An electrometer used for dose and dose-rate measurement

Figure 4. CTDI phantom in position with the pencil ionization chamber connected to the electrometer and positioned in the center hole of the phantom for $CTDI_{100,c}$ measurement

The $CTDI_{100,c}$ value was obtained, following an exposure to the tomographic beam. The CTDI $_{100,\ p}$ (periphery) value was measured by inserting the ion chamber inside each of the peripheral holes of the phantom. The phantom was exposed to tomographic beam (Figure 4). The CTDIvol and DLP values were calculated automatically by the electrometer in order to estimate the delivered dose to any point. Mathematically, weighted CTDI (CTDIw) was calculated using the *Equation (1)*:

$$CTDIw=1/3\ CTDI_{100,c}+2/3\ CTDI_{100,p} \quad (1)$$

where *c* represents center, and *p* signifies periphery.

In addition, CTDIvol was calculated using *Equation (2)*:

$$CTDIvol=CTDIw/P \quad (2)$$

where *p* denotes pitch (the ratio of table feed per gantry rotation and the total beam collimation)

The DLP was estimated using *Equation (3)*:

$$DLP=CTDIvol\ x\ L_{tot,} \quad (3)$$

Where L_{tot} signifies total scan length.

The effective dose was estimated based on the DLP. Furthermore, a DLP to E conversion coefficient was referred to as "*k*" that depends only on the anatomic region (head) examined as recommended by the National Radiological Protection Board [27]. Mathematically, it is represented as follows:

$$E_{DLP}=k\ x\ DLP \quad (4)$$

Where E_{DLP} displays effective DLP (estimated effective dose), *k* represents conversion coefficient for the head region (0.0021), and DLP denotes dose-length product.

Statistical analysis

The data were analyzed in Microsoft Excel 2010 and SPSS software (version 24; IBM, Chicago, Illinois, USA). Mean and standard deviation of the tube current and CT indices values were calculated. In addition, the effects of mAs on DLP were represented graphically for all the three groups with different slice numbers. The paired sample t-test was used to assess the difference between the axial and helical scans taken based on the applied protocols in terms of mean DLP values. Furthermore, a one-sample t-test was used to compare the applied protocols with those of AAPM on axial scan mode and Siemens Somatom Emotion 16-slice CT scanner. Statistical significance was set at a p-value less than 0.05.

Two radiologists with 4-6 years of experience, who were unaware of the series of images acquired, technical parameters, and one another attitudes, independently performed a quantitative assessment of the randomized cranial CT images acquired by the protocols.

Axial, non-contrast enhanced cranial CT images were acquired from two different patients (Figure 5). The image in Figure 5 (a) was acquired using the technical parameters of 110 kV, 299 mA, 0.37 s, and slice thickness of 4.8 mm. While the other image in Figure 5 (b) was acquired using the technical parameters of 120 kV, 114 mA, and slice thickness of 4.5 mm.

The reviewers assessed the images at the level of the basal ganglia for gray-white matter contrast-to-noise ratio (CNR), spatial resolution, image noise, CT number uniformity, low-contrast detectability, and image sharpness. The assessment tool used by the reviewers was a written imaging report.

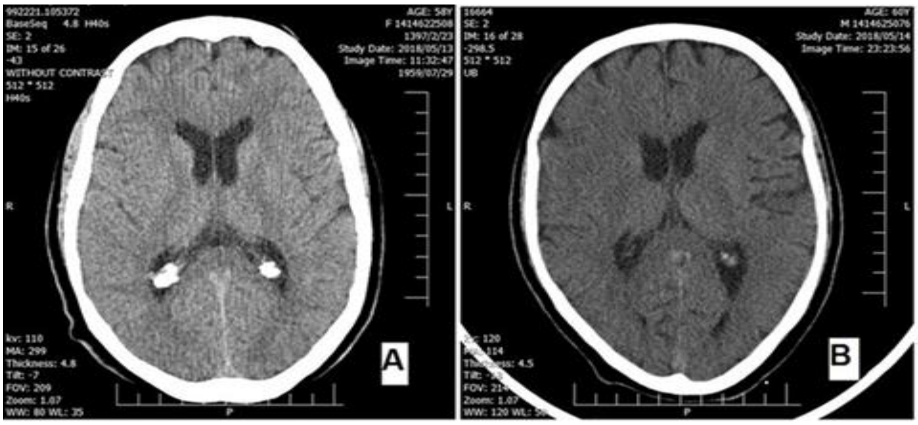

Figure 5. Cranial computed tomography (CT) images from two different patients obtained at the level of basal ganglia, assessed by consultant radiologists to evaluate radiation dose reduction effect on image quality; (a) axial brain CT image acquired at 110 kVp, 299 mAs, and 4.8 mm slice thickness, (b) axial cranial CT image acquired at 120 kVp, 115 mAs, and 4.5 mm slice thickness

Moreover, they detected a relatively decreased contrast between gray- and white-matter CNR in Figure 5 (a), as compared to that in Figure 5 (b). They also observed a significant increase in image noise levels and beam hardening artifacts, as well as less spatial resolution, in Figure 5 (a) than in Figure 5 (b).

Reviewers manually assessed the CT-number uniformity of the two CT images using image viewer program DicomWorks, version 1.3.5 (2002 Philippe PeLoic Boussel). They manually placed the region of interests within the images. They analyzed the results with the use of program QAlite (The Institute For Radiological Imaging Sciences, Inc, MD, US). The uniformity of the image in Figure 5 (a) worsened by 2.8 HU, compared to that of Figure 5 (b), which measured 1.4 HU. In other words, Figure 5 (a) had more image noise and artifacts than Figure 5 (b).

The reviewers detected low contrast in Figure 5 (a), compared to that in Figure 5 (b). This was due to an increase in the noise and artifacts recorded in Figure 5 (a). Figure 5 (b) had improved low-contrast detection performance. However, the gray-white matter differentiation was well appreciated in both figures 5 (b) and (a). The consultant radiologists concluded that the image quality as illustrated in Figure 5 (b) was of acceptable and reasonable diagnostic value with lower patient dose.

Results

The QC tests performed on the CT scanners were satisfactory. The CTDIvol and DLP values obtained from Philips Brilliance 16-slice CT scanner with constant CT parameters for slice number 24 are listed in Table 1. As it can be seen, all the parameters had constant values, and the standard deviation recorded zero. The mean values of dose indices were 23.65±0.36 mGy and 353.40±0.00 mGy.cm for CTDIvol and DLP, respectively. Table 2 shows CTDIvol and DLP values obtained from Philips Brilliance 16-slice CT scanner (helical scan) with constant CT parameters for high and variable slice numbers. All the scan parameters had constant values, and the standard deviation recorded zero. Except for the slice numbers which had variable values and standard deviation of 119.32. The mean values of dose indices were 33.81±0.01 mGy and 697.75.40±146.81 mGy.cm

The CTDIvol, DLP, and effective DLP values as a function of the tube current (mAs) for the three groups of slice numbers were obtained for the Siemens Somatom Emotion 16-slice CT scanner (Table 3). The mean values of the tube current and dose indices were analyzed. It was observed that the increase in tube current resulted in an increase in CTDIvol (mGy), DLP (mGy.cm), and effective DLP (mSv).

Table 1. Computed tomography dosimetry indices at constant scan parameters (axial scan: Philips Brilliance 16-Slice CT scanner)

	kVp (kV)	mA (mAs)	Slice thickness (mm)	Number of Slices	CTDIvol (mGy)	DLP (mGy.cm)
	120	200	4.5	24	23.20	353.40
	120	200	4.5	24	23.40	353.40
	120	200	4.5	24	23.70	353.40
	120	200	4.5	24	23.87	353.40
	120	200	4.5	24	24.10	353.40
Mean values	120	200	4.5	24	23.65	353.40
Std (X)	0.00	0.00	0.00	0.00	0.36	0.00

kVp: kilovoltage peak, mA: Milliamperage, mAs: milliampere-second, Std (X): standard deviation, CTDIvol: volume CT dose index, DLP: dose length product, mGy.cm: milligray.centimeter, mGy: milligray

Table 2. Computed tomography dosimetry indices at constant scan parameters (helical scan: Philips Brilliance 16-Slice CT scanner)

	kVp (kV)	mA (mAs)	Slice thickness (mm)	Number of Slices	CTDIvol (mGy)	DLP (mGy.cm)
	120	250	1.0	168	33.80	629.20
	120	250	1.0	286	33.80	557.90
	120	250	1.0	352	33.83	663.20
	120	250	1.0	376	33.80	574.40
	120	250	1.0	476	33.80	878.80
	120	250	1.0	483	33.80	883.00
Mean values	120	250	1.0	356.83	33.81	697.75
Std (X)	0.00	0.00	0.00	119.32	0.01	146.81

kVp: kilovoltage peak, mA: Milliamperage, mAs: milliampere-second, Std (X): standard deviation, CTDIvol: volume CT dose index, DLP: dose length product, mGy.cm: milligray.centimeter, mGy: milligray

Table 3. Computed tomography dosimetry indices at different tube currents (mAs) for the three groups of slice numbers (n) at constant scan parameters (axial scan: Siemens Somatom Emotion 16-Slice CT scanner)

	Slice number (n)=24				Slice number (n)=28				Slice number (n)=32			
	mAs	CTDIvol (mGy)	DLP (mGy.cm)	$E_{DLP}=K$ *(0.0021)* x *DLP* (mSv)	mAs	CTDIvol (mGy)	DLP (mGy.cm)	$E_{DLP}=K$ *(0.0021)* x *DLP* (mSv)	mAs	CTDIvol (mGy)	DLP (mGy.cm)	$E_{DLP}=K$ *(0.0021)* x *DLP* (mSv)
	145	24.13	386.08	0.81	146	24.23	387.68	0.81	154	25.52	408.32	0.86
	153	25.06	400.96	0.84	154	25.36	405.76	0.85	161	27.71	443.36	0.93
	162	25.20	403.20	0.85	159	25.97	415.52	0.87	165	28.03	448.48	0.94
	165	27.03	432.48	0.91	164	26.31	420.96	0.88	169	28.57	457.12	0.96
	168	27.12	433.92	0.91	169	27.40	438.40	0.92	171	28.89	462.24	0.97
	169	27.26	436.16	0.92	172	27.71	443.36	0.93	172	29.54	472.64	0.99
	171	27.68	442.88	0.93	174	27.86	445.76	0.94	175	33.17	530.72	1.11
	176	28.99	463.84	0.97	176	29.10	465.60	0.98	200	39.61	633.76	1.33
	177	29.09	465.44	0.98	178	29.49	471.84	0.99	-	-	-	-
	183	29.19	467.04	0.98	180	29.89	478.24	1.00	-	-	-	-
	185	29.26	471.36	0.99	190	30.07	481.12	1.01	-	-	-	-
	-	-	-	-	198	30.93	494.88	1.04	-	-	-	-
Mean	168.55	27.29	436.67	0.92	171.67	27.86	445.76	0.94	170.88	30.13	483.08	1.01
Std (X)	12.10	1.84	29.51	0.06	14.65	2.09	33.51	0.07	13.56	4.39	70.25	0.15

mAs: milliampere-second, CTDIvol: volume CT dose index, DLP: dose length product, E_{DLP}: Effective dose-length product, mGy: milligray, mGy.cm : milligray.centimeter

Table 4. Mean values of the applied protocols compared to the AAPM protocols (axial scan: Siemens Somatom 16-slice & Philips Brilliance 16-slice CT scanners)

Protocol	Siemens Somatom Emotion 16-slice CT scanner			Philips Brilliance 16-slice CT scanner		
	AAPM	Applied	*Std (X)*	AAPM	Applied	*Std (X)*
kVp	130	110	14.14	120	120	0.00
mAs	250	170	56.57	400	200	141.42
Slice thickness (mm)	4.0	4.8	0.57	6.0	4.5	1.06
CTDIvol (mGy)	58.7	28.43	21.40	53.4	23.65	21.04
DLP (mGy.cm)	939.2	444.15	350.05	854.40	353.40	354.26

Std (X): standard deviation, AAPM: American Association of Physicists in Medicine, kVp: kilovoltage peak, mAs: milliampere second, CTDIvol: volume CT dose index, DLP: dose length product, mGy: milligray, mm: millimeter, mGy.cm: milligray.centimeter

Table 5. Mean values of the applied protocols compared to the AAPM protocols (helical scan mode: Philips Brilliance 16-slice CT scanner)

Protocols	AAPM Protocol	Applied Protocol	Standard Deviation *Std (X)*
kVp	120	120	0.00
mAs	350	250	70.71
Slice thickness (mm)	0.9	1.0	0.07
Pitch	0.500	0.542	0.03
CTDIvol (mGy)	53.3	33.81	13.78
DLP (mGy.cm)	852.8	697.73	109.65

Std (X): standard deviation, AAPM: American Association of Physicists in Medicine, kVp: kilovoltage peak, mAs: milliampere second, CTDIvol: volume CT dose index, DLP: dose length product, mGy: milligray, mm: millimeter, mGy.cm: milligray.centimeter

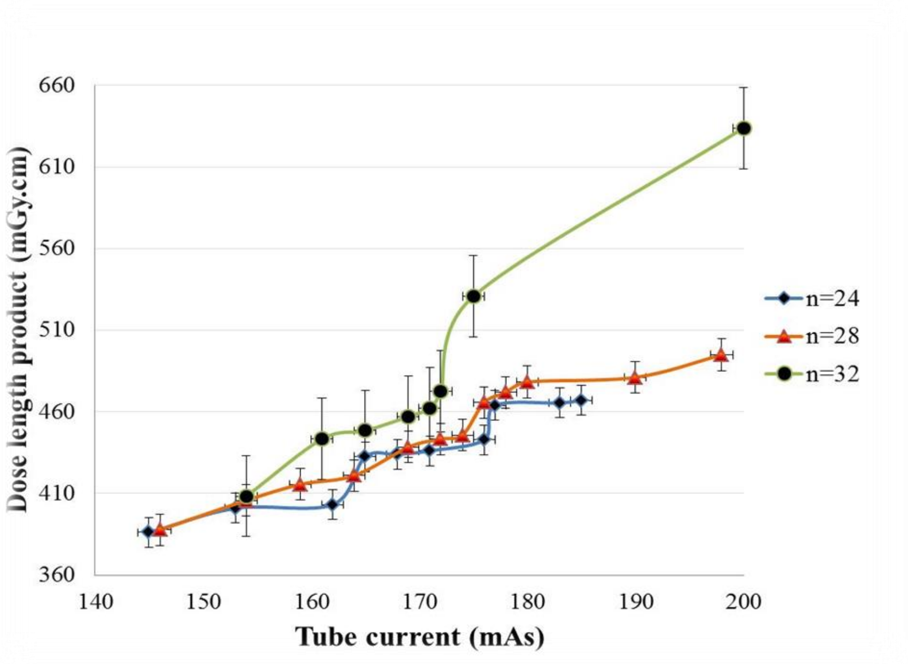

Figure 6. Effect of tube current (mAs) on dose-length product (mGy.cm), obtained from axial scans for n=24, 28 and 32 respectively. Dose-length product values increase the most for n= 32 in comparison with n=24 and 28 respectively.

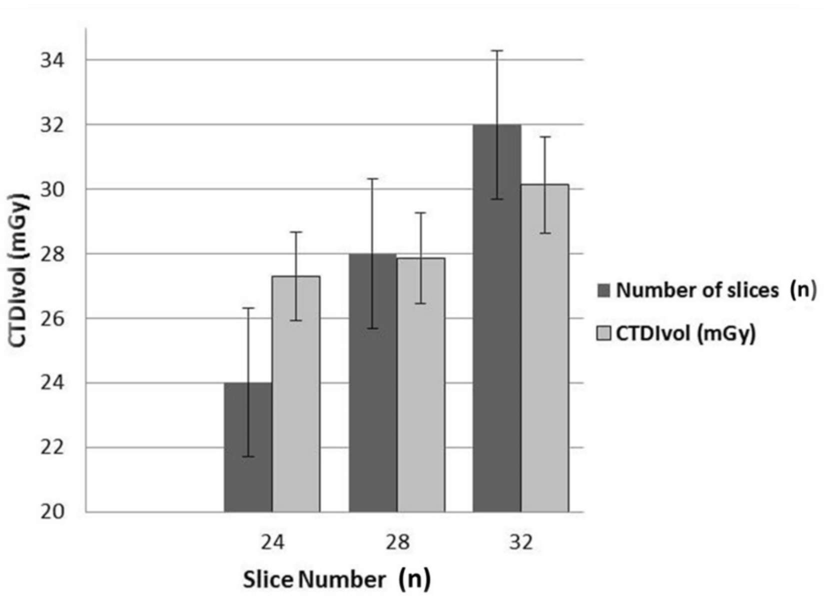

Figure 7. Bar chart showing a significant increase in volume CT dose index with respect to the slice number

The graphical analysis showed that DLP elevated as tube current (mAs) selection increased for all the three groups of slice numbers (Figure 6). DLP values increase the most for n= 32, in comparison with n= 24 and 28 respectively at constant tube voltage of 110 kVp and slice thickness of 4.8 mm. The graphs were represented with error (positive and negative) bars. Bar chart analysis showed a significant increase in CTDIvol with respect to the 3 different slice numbers (Figure 7).

The values of the applied protocols, compared to the recommended protocols, which were obtained at axial scan mode for the Siemens Somatom Emotion and Philips Brilliance 16-slice CT scanners are indicated in Table 4. The values were expressed as mean±standard deviation of the dosimetry indices. The results showed that applied protocol recorded low values of CT dosimetry indices at lower scan parameters, compared to that of the recommended protocol.

One-sample t-test results showed that the applied protocols (e.g., kVp, mAs, slice thickness, and CTDIvol) for axial scans were significant (P<0.001). This signifies that AAPM protocols were higher and could lead to an increase in radiation dose to patients. For the Philips Brilliance 16-slice CT scanner, there was no significance between the applied parameter (kVp) and AAPM parameter (kVp) on axial scan mode (P=0.363). This implies that kVp of the applied and AAPM protocols were valuable for cranial CT scans. However, the other scan parameters (e.g., mAs, slice thickness and CTDIvol) of the applied unit were significant (P<0.001), compared to those of AAPM. In addition, for helical scan mode, the applied parameters of mAs and CTDIvol were significant (P<0.001), compared to those of AAPM. The other protocols (e.g., kVp, slice thickness, and pitch) were not significant.

Table 5 presents the applied protocol values for the Philips Brilliance 16-slice CT scanner using helical/spiral scan mode, compared with the recommended protocol. The results were presented as the mean±standard deviation of the independent variables.

A paired sample t-test analysis showed a significant difference between the mean DLP values for axial and helical scans of the applied protocols (t_5=-6.032, P=0.002). A significant difference was observed for CTDIvol for axial and helical scans (t_5=-63.343, P<0.001). The DLP in the axial scan scored a mean difference of -337.13 lower than the DLP in the helical scan (95% CI: -480.79, -193.47). The CTDIvol in axial scan scored a mean difference of -10.24 less than CTDIvol in helical scan (95% CI: -10.66, -9.83). In addition, the slice numbers in axial scan scored a mean difference of -332.83 less than the slice numbers in helical scan (95% CI: -458.05, -207.62).

Discussion

After performing a periodical QC test, the CT scanners were certified to be in a good condition. This was with respect to image quality and radiation dose for the optimization of our protocols, as advised [28].

The present study showed that in contrast to the Philips Brilliance 16-slice CT scanner, different mAs with constant kVp were applied by the Siemens Somatom 16-slice CT scanner in cranial imaging. This can be considered for DRL using this modality. As it was expected, CTDIvol and DLP increased linearly with mAs at constant kVp for slice numbers of 24, 28, and 32.

CTDIvol and DLP values for slice number 24 recorded the lowest values in comparison with the dose indicator values for slice numbers of 28 and 32 respectively. This is in line with the study done by

Aliasgharzadeh et al. [29]; which reported that minimized number of slices resulted to reduction in patients' dose.

The mean CTDIvol for slice number 24 was 27.29 mGy for the Siemens, with 110 kVp and 185 mAs. This was against 23.65 mGy for the Philips, with 120 kVp and 200 mAs. The lower kVp and mAs for the Philips resulted in a higher CTDIvol (i.e., kVp has the most significant effect on radiation dose 0). This is in agreement with the study carried out by McNitt-Gray and Tang et al. [30, 31] which reported that altering the kVp had the highest influence on patient dose and image quality.

In one hospital, two different CT scanners (Philips Brilliance and Siemens Somatom Emotion 16-slice) were used for a routine brain scan. The results of this study showed that different CTDIvol and DLP values were obtained using these two different scanners. This is in line with the results reported by Jaffe et al. [32], in which their phantom data showed that patients were subjected to different organ doses in the lenses and brain, depending on the CT scanner that was used.

There were linear variations among the dots in the graph of figure 6, signifying that the difference in patients' head sizes affects DLP and CTDIvol values for the 3 different slice numbers. Patients with small head sizes were likely to receive a higher radiation dose than those with big heads if the same protocols were applied. This was in line with the results obtained by Huda et al. [33]. Consistent with the results reported by Toori et al., Figure 7 indicated that CTDIvol increased linearly with respect to slice number [34].

Moreover, in line with the results presented by Tsalafoutas, paired sample t-test analysis for axial and helical scans implied that in cranial CT examinations, patients received more radiation dose during helical scans [35]. In helical scans, higher slice numbers, kVp, and mAs with less slice thickness resulted in an increase in patient dose with the best image quality.

The mean and standard deviation values of the applied protocols were compared with those of the AAPM protocols for axial and helical scan modes. It was observed that the different parameters of the AAPM were higher than those of the applied protocols. Patients were more likely to receive a higher dose of radiation if the AAPM protocols were used for cranial CT examinations. As it can be seen in tables 4 and 5, the CTDIvol and DLP using the AAPM protocols, from the two CT vendors were higher, compared to our applied protocols. This difference may be attributed to the nonclarification of DRL in the AAPM protocol.

The radiologists were satisfied with the CT images produced by the lower scan parameters because they are of reasonable diagnostic value and result in decreased patient dose. This is in line with the study done by Zarb et al [36], which demonstrated that changes in scan parameters reduce the dose with little or no effect in image quality. Recommended protocols produce the best image quality but with high radiation dose. The results of a couple of studies performed by Park et al. and Ben-David et al. [37, 38] demonstrated that lower kVp gave better gray-white matter contrast for a non-enhanced brain CT scan. This is in line with our results, in which lower mAs with a moderate tube voltage value of 120 kVp contributed to improved gray-white CNR for non-contrast enhanced cranial CT scans. The contrast was improved at moderate mAs and slice thickness as demonstrated in this study. Consistent with the results obtained by Park et al., image noise and artifacts were notable at a lower constant tube voltage of 110 kVp [37].

Conclusion

Efforts to optimize CT scan protocol should consider both dose and clinical image quality. This practice was achieved by investigating the scan parameters of our protocol. In this regard, lower scan parameters resulted in lower CTDIvol and DLP values than the achievable dose levels proposed by the American College of Radiology (57 mGy) and AAPM (58 mGy), while providing CT images of diagnostic quality. This became possible after radiologists at our institution accepted scan protocols acquired with lower scan parameters.

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