DOSE-IMAGE QUALITY ASSESSMENT FOR OPTIMIZATION OF ADULT CHEST COMPUTED TOMOGRAPHY EXAMINATIONS: A PHANTOM STUDY

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ABSTRACT

The growing number of chest-related pathologies and complications today has led to increased use of Computed Tomography (CT) for diagnostic imaging. Unfortunately, the high dose associated with CT examinations remains a radiation protection concern in a bid to reduce the likelihood of radiation-induced cancers. The purpose of this study was to suggest clinical protocols for optimization of patient dose for adult chest CT examinations with acceptable image quality. The dose and image quality of 170 CT scans of a 64-slice CT scanner were collected and analyzed. The dose parameters employed were volumetric computed tomographic dose index ($CTDI_{vol}$), dose length product (DLP) and effective dose. The signal to noise ratio (SNR) value was used to quantitatively assess the image quality. Alteration in the pitch from 1.3 to 1.5 and tube potential of 110 kV resulted in a reduction of 14.38% in the effective dose with an acceptable SNR of 9.23.

INTRODUCTION

Since the introduction of Computed Tomography (CT) in the 1970s as a diagnostic tool, CT examinations have increased significantly [1]. It has become the more preferred imaging modality for medical diagnosis due to its numerous advantages over other modalities including its fast scan time coupled with good image quality [2, 3]. In Ghana, about 17,874 chest CT examinations are conducted yearly, with recent development suggesting an upward trend [4]. The increase in use of CT worldwide, to help solve many medical problems has made CT the largest contributor to the collective effective dose received from medical exposure [5, 6]. The high dose from CT examinations has become a major concern in the use of ionizing radiation in medicine [2, 5-8]. This is because radiation-induced cancer has been associated with CT examinations [7]. This further justifies the need to optimize the dose utilized in medical imaging to As Low As Reasonably Achievable (ALARA) in order to decrease unnecessary radiation exposure to patients [9]. A recent study shows the possibility of CT dose reduction to as low as 50% with no effect on the image quality [10]. A study [6] also claimed that with optimization in CT, 70% dose reduction is achievable with diagnostic value being maintained. While various techniques to reduce the dose from CT examinations exist, there are limited studies on dose optimization using technique factors such as the pitch and kVp factor combination. This study was therefore, undertaken to obtain optimized clinical adult chest CT protocols to lower the patient dose received from adult chest CT examinations.

MATERIALS AND METHODS

Ethical clearance was obtained for the study from the Ethics Committee for Basic and Applied Sciences (ECBAS), University of Ghana (Ref no ECBAS 051/19-20) study. The study sample were collected from 170 patients and included all adults (above 18 years old) who had undergone chest CT examinations. These were collected to obtain the average routine protocol for adult chest CT at the facility. Pediatric and contrast aided examinations were not included. The routine adult chest CT examination protocols at the facility is indicated in Table 1. A Somatom Perspective 64-slice CT scanner of Siemens make (Erlangen, Germany) was used in the study.

Quality Control Tests

CT dose Profiler was used to perform quality control (QC) measurement of CT dose descriptors. It has a solid-state sensor 30-mm away from the probe end, which picks the dose profile and sends it to the software in one single spiral scan measurement regardless of the beam width. The dose delivery accuracy, geometric efficiency, tube voltage accuracy and half value layer (HVL) tests were conducted on the CT scanner. The pencil-like ionization chamber of the CT dose profiler was positioned in the central hole (Figure 1) of the properly aligned Polymethylmethacrylate (PMMA) standard CT dosimetry phantom (11). The PMMA phantom is 14 cm length and consists of a head phantom of 16 cm diameter and a body phantom of 32 cm diameter, both commonly known as the CT head and body phantom (12). The Barracuda electrometer connected the dose profiler and the Ocean software from which a template for the tests was obtained. The routine protocol for adult chest CT examinations was entered into both the operator's CT computer and the Ocean software template together with the phantom type (body) and scanner manufacturer (to obtain the correct k-factor). A scanogram of the chest region was performed and after a delay of about 3 seconds, both the operator and the software exposure were started and ended at the same time. Real time display measurements of the dose delivery accuracy were obtained and saved which were to be compared with the values displayed by the operator's console as documented by a study (13). With the dose profiler held free in air at the isocenter by the body phantom, the same procedure was used to obtain real time measurements of the geometric efficiency of the CT scanner.

With the detector facing upwards and perpendicular to the scanning direction, the multi-purpose detector (MPD) was set up in the inner gantry and a cable used to connect it to the cabinet which was then connected to the hand held computer. With the type of measurement, tube voltage and 'Quick HVL' selected, a scanogram was performed for the position check and another to obtain the measurement for the tube voltage accuracy and HVL values was done.

Dose assessment

Dose descriptors were collected from a sample size of 170 patients from March to November, 2020. The sample size was calculated using the equation (1) below [14].

$$\frac{Z_{1-\frac{\alpha}{2}}^{2}.p(1-p)}{d^{2}} \quad (1)$$

Where $Z_{1-\alpha/2}^{2}$- the normal variate of type 1 error of 5% considering P value < 0.05;

p – expected proportion of chest CT examinations compared to other CT examinations based on previous studies;

d- precision error

The sex, age, kilovoltage, effective tube current-time product, reference tube current-time product and rotation time, mean $CTDI_{vol}$ and DLP were obtained from the Picture Archiving and Communication System (PACS) CT computer. The effective dose for each patient was empirically projected from the mean console displayed DLP by multiplication with a conversion coefficient for a specific body region [15-20]. The conversion factors were obtained by a combination of Monte Carlo simulation together with computational human phantoms. Equation 2 below was used to calculate the effective dose for each patient.

$$\text{Effective dose} = k \times DLP \quad (2)$$

Where k is the conversion coefficient for the chest, k=0.014 mSv/mGy.cm [5, 16, 18, 21].

Microsoft Excel (2016) was utilized to obtain the maximum, minimum, mean, median, range and standard deviation of the existing dose protocols.

Image quality assessment

Retrospectively acquired images for the patient protocols obtained in Digital Imaging and Communications in Medicine (DICOM) format were analyzed quantitatively using ImageJ software [22]. ImageJ is a free software that is downloadable from the public domain. The software which is able to work on any computer with Java version of 1.5 and above does not only save but prints, processes, edits, analyzes and displays images of DICOM, FITS, TIFF, JPEG, BMP, GIF and ‘raw’ image formats of 8, 16 and 32 bit images [23]. The images had been independently assessed and approved by radiologists at the facility and deemed fit for diagnostic analysis for routine chest CT examinations. The signal (mean pixel value) and noise (standard deviation of pixel value) was used to analyze the images [3, 6, 24]. Four oval regions of interest (ROIs) of the same dimensions were drawn on the lung tissue at the same slice for each image [3, 17] which was about midway the total number of slices for each image. The ratio between the mean and standard deviation of the pixel value of the four ROIs [17, 25-27] was calculated as shown in equation 3 below.

$$SNR = \frac{Mean\ signal\ in\ ROI}{Standard\ deviation} \quad (3)$$

Optimization of clinical protocols

To explore optimization measures, the Alderson RANDO anthropomorphic phantom with characteristics of the anatomy of a reference man and tissue-equivalent material surrounding an actual human skeleton were used [2, 19, 28]. The adult phantom weighs 70 kg with a height of 170 cm [19]. The phantom was aligned on the patient table using the CT laser lights as shown in figure 2 and a scanogram was performed to determine the chest area to be scanned. The study involved exposure of the phantom using the mean values of the facility's existing routine adult chest CT protocols (Table 1) and exploration of the pitch and tube potential in order to obtain protocols that would result in diagnostically fit images at a lower dose. To obtain optimized protocols that would result in an acceptable image quality yet with a lower patient dose, different exposures were taken at various pitch values of the scanner (1.5 and 1.3) and tube voltage value of 130 while maintaining all the other scan parameters as in the routine adult chest CT protocols. DICOM images of the phantom exposures were obtained and analyzed using ImageJ software following the same procedure earlier described. The results were compared with those of the existing protocols to suggest optimized protocols for adult chest CT examinations.

The data obtained was analyzed using Microsoft Excel (2016). The mean, minimum, maximum, standard deviation, range and median was calculated for the dose protocols. The existing and suggested optimized protocols were compared using the paired T-test to obtain the p-value < 0.05 ($p = 0.03$) using the data analysis tool.

RESULTS

Quality control tests

The console displayed value of the dose delivery accuracy and the tube voltage accuracy deviated from the measured value by 5.40% and 2.38% respectively. This is within the Coefficient of Variation values of 20% (EAC, 2012 and IAEA 2012) for dose delivery accuracy and ±5 (AAPM, 2008) for the tube voltage accuracy acceptable limits. The machine Half Value layer was 7.49mm Al (Shefer et al, 2013), which is acceptable for values of a tube voltage greater than 100 kV. The geometric efficiency is the measure of the percentage of X-rays transmitted through the patient that reach the active areas of the detectors. The machine had a geometric efficiency of 82% that is higher than the acceptable value of not less than 70% (Impact, 2018 and Kobayashi et al, 2010). Table 1 shows that the results obtained for the different tests performed were within the acceptable limit of the international standards applied basing on the acceptance criteria of the International Atomic Energy Agency, American Association of Physicists in Medicine and European Commission standards. This implied that the CT scanner was in good working condition for the study.

Assessment of existing dose protocols

The average age of adults who received chest CT examinations was 51 years with the minimum and maximum ages of 22 and 90 years, respectively. Tube loading of 30 mAs and 159 mAs were the minimum and maximum values of the effective mAs with a mean value of 88.17 mAs. The average $CTDI_{vol}$, DLP and effective dose was 6.99 mGy, 233.18 mGy*cm and 3.22 mSv respectively.

Assessment of existing patient image quality

Quantitative image analysis resulted in a mean SNR of 16.01. This fits the Rose model criterion which states that an image with SNR ≥5, one is able to observe the image from a disticnt background thus it can serve for diagnostic purposes with minimal risks of artefacts. A SNR of 8.63 and 26.75 was obtained as the lowest and highest value for the images respectively.

Optimization of dose and image quality

Image A (Table 2) which was obtained using the mean existing routine adult chest CT parameters gave an effective dose of 2.07 mSv and DLP of 147.62 mGy*cm. The mean value of three different values of 130 kV tube voltage and 1.5 and 1.3 pitch values was used. An effective dose of 1.77 mSv was obtained from scanning the second image B with the same tube potential of 110 kV but using a higher pitch value of 1.5. The phantom was scanned at a higher tube potential of 130 kV with pitch values of 1.5 and 1.3 to obtain images C and D respectively. Image C had a DLP of 164.37 mGy*cm and an effective dose of 2.30 mSv while image D gave a DLP of 162.11 mGy*cm with 2.27 mSv as the effective dose.

All the phantom images at the different parameters had a SNR > 5 with the image A for the existing adult CT chest routine protocols having the highest value of 42.36. Images B, C and D had SNR of 9.23, 8.05 and 5.87 respectively and were all fit for diagnostic use. The summary of the comparison of the dose and image quality assessment of the phantom images for both the routine and suggested optimization protocols is indicated in Table 2. There was 14.38% reduction in the effective dose of image B compared to the image A with an acceptable SNR of 9.23. An increase of 11.37 and 9.83% in the effective dose was observed for images C and D that were scanned at tube potential of 130 kV together with SNR values of 8.05 and 5.87 respectively. A comparison of the SNR and effective dose for the existing and suggested optimized protocols was made using the paired T-test and a p- value of 0.03 was obtained. This value lies within the $p<0.05$ bracket indicating a significant relationship among the protocols.

DISCUSSION

For the past years now, dose optimization in CT examinations has been a much-studied issue in the use of ionizing radiation in medicine (specifically in medical imaging) in order to ensure that patient doses are optimum with acceptable image quality, confident for diagnosis. This will help to reduce the potential for deterministic and stochastic effects to the exposed individual from CT examinations [29, 30]. The study assessed the $CTDI_{vol}$, DLP and effective dose (main dosimetric parameters in CT) in an anthropomorphic phantom, with a change in scanner parameters from the routine ones at the facility in a bid to optimize the patient dose received in adult chest CT examinations. With literature confirming that, the use of automatic tube current (AEC) reduces the patient dose in CT examinations while maintaining the image quality [31, 32]. AEC ensures that the patients' body parts receive non-uniform but proportionally sufficient amount of radiation to traverse through them based on their thickness and this in turn reduces the effective dose received by the patient. A dose reduction of 5.6 to 42.2% was achieved with AEC applied to an adult RANDO phantom as the one used in this study for chest CT examinations [(33)]. Studies by Sabarudin and Singh particularly recommended use of AEC for adult chest CT examinations with the possibility of dose reduction [(29, 34)]. Basing on the study's aim to optimize the patient dose, the study utilized AEC for the adult chest CT examinations in connection optimized pitch and kVp factor.

A decrease in the tube potential results in decreased number of photons reaching the detector leading to a lower dose. However, this comes at the expense of increase in the image noise as reported by Davoudi et al in a study where 35% dose reduction was achieved by 15% decrease in tube potential with increased image noise [(6)]. In order for optimization to be reached, the image quality should be maintained together with a low patient dose; therefore, it was considered a better option to increase the tube potential with an increase in the pitch. This, however still resulted into an increase in the dose output.

The inverse relationship of pitch and patient dose is highlighted in literature with high pitch values resulting into lower patient doses in CT examinations [(6, 31, 34)]. This agrees with the results of the current study as an increase in the pitch value at the same tube potential resulted in a reduction of 14.38% in the effective dose with conservation of an acceptable image quality. For one to achieve a low dose with SNR ≥5 (able to distinguish the image from the background) according to the Rose model criterion [(35, 36)], dose optimization would have been attained and in the long run, patients protected from the harmful effects of receiving unnecessary exposure during CT examinations.

CONCLUSION

Alteration of scan parameters was the method applied in this study aimed at obtaining optimization protocols for adult chest CT examinations. The dose and image quality of the adult chest protocols at the facility were assessed. Exploration of the mean dose and SNR obtained with the aid of an anthropomorphic phantom resulted into a patient dose of 1.77±0.04

mSv together with a SNR of 9.23 indicating a dose reduction of 14.38%. The obtained image was sufficient enough to ensure that the patient is protected from the harmful effect of radiation as well satisfactory diagnosis by the referring Physician. The study therefore recommends tube potential of 110 kV and pitch of 1.5 as the optimized protocols (compared to the routine pitch 1.3 and tube potential of 110 kV) for adult chest CT examinations while maintaining all the other parameters the same as the ones already being used.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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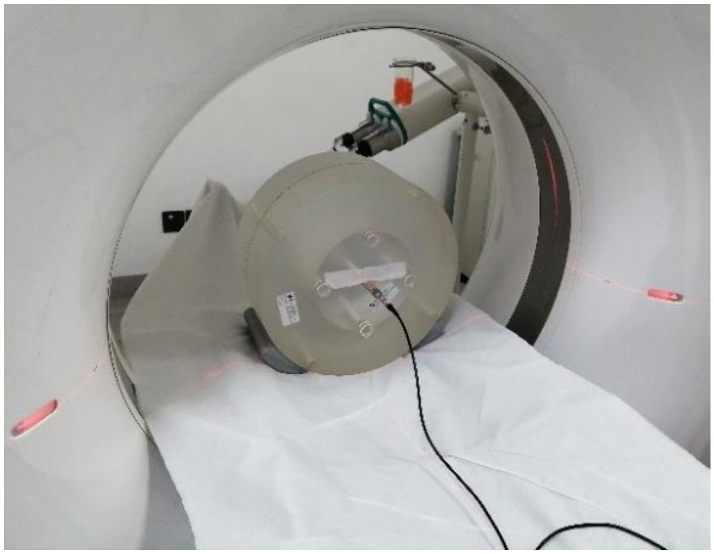

Figure 1: CT dose profiler inserted into central hole of PMMA head and body CT phantom

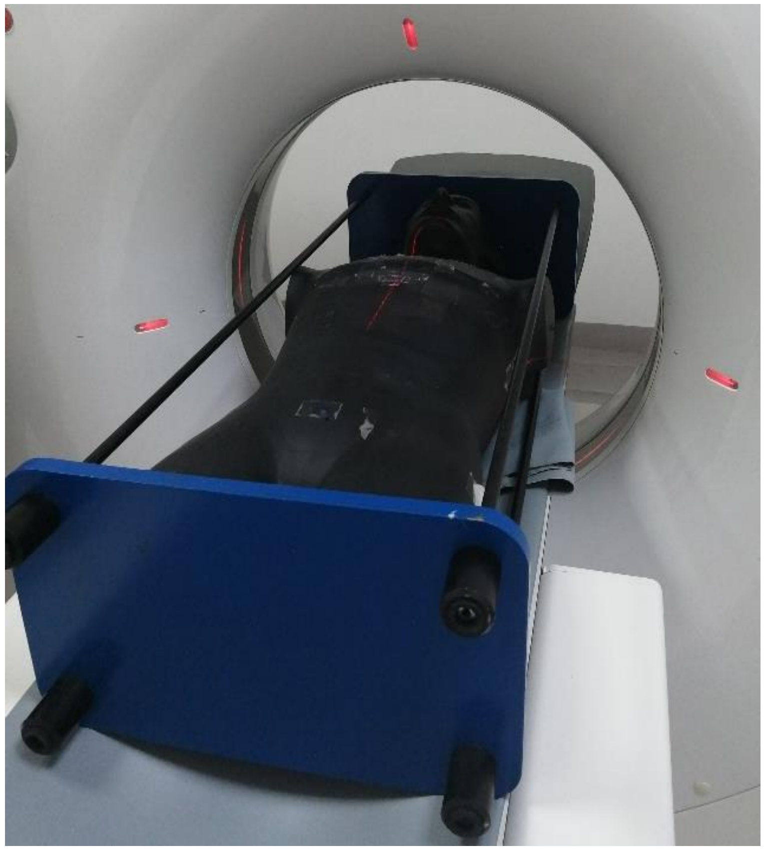

Figure 2: RANDO anthropomorphic phantom aligned on patient couch for optimization measurements

Table 1: Facility routine protocols for adult chest CT examinations

Parameter	**Value**
Quality reference mAs	70
Effective mAs	122
Tube potential, kV	110
Scan time, seconds	8.09
Rotation time, seconds	0.6
Delay, seconds	3
Slice thickness, mm	5
Acquisition, mm^2	32 x 0.6
Pitch	1.3

Table 2: Dose and image quality assessment for routine and suggested optimization protocols

Image ID	Tube Potential (kV)	Pitch	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)	Effective dose (mSv)	SNR	% change in dose
A	110	1.3	4.52±0.26	147.62±8.49	2.07±0.12	42.36	-
B	110	1.5	3.86±0.09	126.41±2.95	1.77±0.04	9.23	-14.38
C	130	1.5	5.02±0.23	164.37±7.53	2.30±0.11	8.05	+11.37
D	130	1.3	4.96±0.14	162.11±4.58	2.27±0.06	5.87	+9.83