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DOSE REDUCTION IN CHEST CT EXAMINATION

A. Sulieman[1,2,*], N. Tammam[2], K. Alzimami[3], A. M. Elnour[2], E. Babikir[3] and A. Alfuraih[1]
[1]Radiology and Medical Imaging Department, College of Applied Medical Sciences, Prince Sattam bin Abdulaziz University, Alkharj, Kingdom of Saudi Arabia
[2]College of Medical Radiologic Science, Sudan University of Science and Technology, Khartoum, Sudan
[3]Radiological Sciences Department, College of Applied Sciences, King Saud University, Riyadh, Saudi Arabia

*Corresponding author: abdelmoneim_a@yahoo.com

Computed tomography (CT) examinations involve relatively high doses to patients. The objectives of this study were to optimise the radiation dose for patient during CT chest scan and to estimate the lifetime cancer risk. A total of 50 patients were studied: control group (A) (38 patients) and optimisation group (B) (12 patients). The optimisation protocol was based on CT pitch increment and lowering tube current. The mean volume CT dose index ($CTDI_{vol}$) was 21.17 mGy and dose length product (DLP) was 839.0 mGy cm for Group A, and $CTDI_{vol}$ was 8.3 mGy and DLP was 339.7 for Group B. The overall cancer risk was estimated to be 8.0 and 3.0 cancer incidence per million for Groups A and B, respectively. The patient dose optimisation during CT chest was investigated. Lowering tube current and pitch increment achieved a radiation dose reduction of up to 60 % without compromising the diagnostic findings.

INTRODUCTION

Man-made sources of radiation account for ~14 % of the annual radiation dose from all sources of radiation[1, 2]. The average level of radiation exposure due to the medical applications in developed countries is equivalent to 50 % of the global average level of natural exposure, although obviously there will be marked variations in the doses received by individuals worldwide depending on health-care level[1]. Medical exposure is the largest source of man-made exposure to ionising radiation that accounts for nearly 96 % of all man-made radiation exposure to human and continues to grow substantially[1, 2]. CT scanning is recognised as a high radiation dose modality and estimated to be 17 % of the radiological procedure and responsible for 70 % medical radiation exposure[3, 4]. Advances in CT technology have made possible new CT applications and have expanded the role of CT into new types of clinical diagnoses[4, 5]. The doses can often approach or exceed levels known with certainty to increase the probability of cancer, and some deterministic effects were reported in some angiography/perfusion brain studies[6, 7]. It has been estimated that 1 individual in 1000 develops cancer from exposure to a radiation dose of 10 mSv[8], and 2 % of current cancers in the United States are due to CTs performed in the past[9]. CT scan of the chest is widely used to evaluate different clinical conditions. The effective dose in chest CT is in the order of 8 mSv (around 400 times more than chest radiograph dose), and in some CT examinations like that of pelvic region, it may be around 20 mSv[6]. During CT chest procedure, breast dose in female patients may be as much as 30–50 mGy, even though breasts are not the target of imaging procedure[6]. In previous literature, CT dose reduction achieved by tube current modulation has been reported to be up to 26–50 %[10], and a dose reduction of up to 40–50 % could be achieved by means of iterative reconstruction algorithms without degrading image quality and reconstruction speed. In addition to that radiosensitive organs shielding reduced the radiation exposure to radiation-sensitive organs, such as the breast, thyroid and eye lens by 20–50 %[11]. Shields are, however, associated with greater image noise and streak artefacts[11]. Furthermore, a reduction of patient dose by 10–50 % was documented when automatic exposure control (AEC) is used without loss of image quality[6].

In recent years, concerns have been raised about the radiation exposures to patients during CT procedures and some studies have been published in patient radiation protection[12–17]; yet, still few studies have been performed in dose optimisation during CT chest procedures[2, 13–17]. These studies have shown that there is a wide range of dose values and acquisition protocols. In addition to that the data available on patient doses in CT procedures are generally outdated because of the continuous development of CT X-ray generators and technologic innovation that have taken place over the past decade from single-slice CT in 1998[18] to 320-slice CT in 2009 and 640 slices in 2013. The objective of this study was to evaluate and optimise the radiation dose to patients undergoing CT chest exam with 64-slice CT scanner.

MATERIALS AND METHODS

CT machine

The study was performed with 64-slice CT scanner Toshiba Aquilion (Toshiba Medical Systems, Otawara, Japan). It consists of 64 × 0.5 mm detector rows and a maximum gantry rotation speed of 0.4 s. The system has quantum de-noising software resulting in 15 % less image noise than that produced by the 16-slice system. The CT machine was manufactured in 2008 and installed in 2011. All quality control tests were performed to the machine prior to the data collection. These tests were carried out by experts from the Sudan Atomic Energy Commission (SAEC). All the parameters were within the acceptable range.

Patient data

A total of 50 patients were divided into two groups: the first group (A) as control group (38 patients), and the other as optimisation group (B) (12 patients). Procedures in Group A were performed with the department's local protocol. Ethics and research committee approved the study, and informed consent was obtained from all patients prior to the procedure. All patients suffered from chest problems that required referring them to the CT department. Data were collected to study the effects of patient-related parameters [age, sex, weight, height and body mass index (BMI)] and diagnostic purpose of examination on radiation dose. The exposure-related parameters were taken into consideration: gantry tilt, potential in kilovoltage (kVp), tube current (mA), rotation time, slice thickness, number of slices, and start and end points of scans, but special consideration was paid to the effect of pitch table increment on patient dose. The collection of patient exposure parameters was done using survey forms prepared for collection of patient exposure-related parameters.

Organ dose calculation

Organ doses were estimated using normalised CT dose index (CTDI) values published by the ImPACT group[19]. For the sake of simplicity, the $CTDI_{100,air}$ will henceforth be abbreviated as $CTDI_{air}$. In this study, volume CTDI ($CTDI_{vol}$, mGy) and dose length product (DLP, mGy cm) were indicated by the scanner software, and by using these parameters and applying conversion factors for chest, effective dose (mSv) was calculated. The organ dose conversion factor f (organ, z) was obtained from the National Radiological Protection Board (NRPB) datasets (NRPB-SR250) based on the Monte Carlo simulations[18].

Estimation of effective dose

Patient doses were determined by using the $CTDI_{vol}$ expressed in mGy and the DLP in mGy cm as provided on the scanner console. The CTDOSE software supplied by the ImPACT group (ImPACT CT Patient Dosimetry Calculator, version 0.99×; ImPACT, London, UK)[19] was used, and typical scanning parameters such as kVp, mA, exposure time, pitch, slice thickness, gender, and start and end positions of each scan were used as input data to the CTDOSE spreadsheet in organ dose estimations[19].

Table 1. Image acquisition parameters for both groups during CT chest procedures.

Parameter	Control	Optimisation
kVp	130 (120–140)	130 (120–140)
mAs	175 (100–250)	132 (100–164)
Detector configuration	0.5 × 64	0.5 × 64
Rotation time	0.5	0.5
Noise[a]	28.4	48.2
SD index	8.5	19.2
Slice thickness, mm	5.0	5.0
Pitch		
PF	0.84	1.48
HP	0.53	0.95
SDOFOV, L	400.0	400.0
Reconstruction mode	Helical 3D	Helical 3D

[a]Before processing.

CT dose optimisation strategies steps

CT dose optimisation was performed for patients during CT chest. Routine image acquisition was performed using AEC settings. Using AEC dose can increase or decrease depending on reference image quality setting at the time of installation. Toshiba Aquilion 64 slice has the capability to automatically alter the tube current (mA) on the basis of each individual patient's size and shape. However, in this study, the dose reduction strategy was based on reduction in tube current (mA) and increase in pitch while maintaining diagnostic image quality based on patient characteristics. Image acquisition for both groups is illustrated in Table 1. Three consultant radiologists evaluated all the medical images.

Cancer risk estimation

The risk (RT) of developing cancer in a particular organ (T) following CT chest after irradiation was estimated by multiplying the mean organ equivalent (H_T) dose with the risk coefficients (f_T) obtained from the ICRP publication[20]. The overall lifetime mortality risk (R) per procedure resulting from cancer probability was determined by multiplying the effective dose (E) by the risk factor (f). The risk of genetic effects in future generations was obtained by multiplying the mean dose to the ovaries by the risk factor[20].

RESULTS

Patient demographic data and scan parameters are presented in Table 2. Patient demographic data were

Table 2. Demographic data of patient and scan parameters for both groups: mean and the range in the parenthesis.

Patient group	*N*	Age (y)	Weight (kg)	BMI (kg m^{-2})
A	38	50.21 (15–77)	71.6 (40.0–84.0)	26.2 (19–32.1)
B	12	54.42 (29–75)	72.33 (65.0–80.0)	25.8 (22.8–28.3)

Table 3. Dose parameters.

Patients	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	Effective dose (mSv)
Control group	832.7 (209–1860)	21.2 (8.20–120.0)	14.2 (3.6–31.6)
Optimised group	339.6 (209–374)	8.3 (8.6–8.2)	5.8 (3.5–6.3)
Reduction, %	52.0	60.8	59. 2

Table 4. Organ equivalent dose (mSv) and risk estimation.

Organ	Patient group	Organ equivalent dose (mSv)	Risk factor × $Sv^{-1} \times 10^{-4}$	Cancer probability 10^{-6}
Breast	A	13.4	116	155.4
	B	5.2		60.3
Thyroid	A	1.6	20	3.2
	B	4.1		8.2
Uterus	A	0.05	6.3	0.03
	B	0.11		0.07

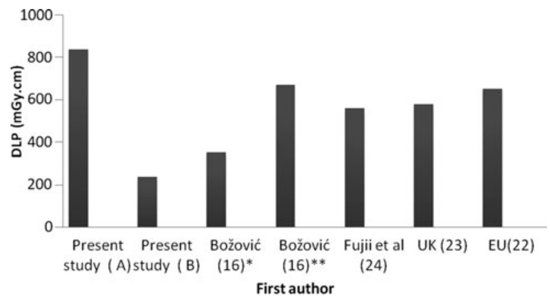

Figure 1. Comparison of DLP (mGy cm) for CT chest procedures with previous studies. *,**Different CT modality.

comparable. Although many patients were elderly, 55 % of them were below 40 years old. The tube voltage was constant for both groups, while the mAs for control group is higher by 25 % compared with optimised group (Table 1). Table 3 presents the patient's dose values in terms of $CTDI_{vol}$, DLP and effective dose. Dose reduction of 60 % was achieved by using optimisation technique. Table 4 shows the effective dose values used to estimate the cancer risks associated with the organ dose to adjacent organs. It is also reveals that the probability of radiation-induced cancer for different organs was in a magnitude of 10^{-6}. The breast has the highest dose due to its position inside the radiation field (Table 4).

DISCUSSION

The radiation dose depends on patients' parameters (weight) and scan parameters. No significant difference was noticed in terms of weight, height and BMI between the two patient groups. Hence, the comparison between the two groups will be more reliable. According to the result in Table 2, the mean $CTDI_{vol}$ was 21.2 mGy and DLP was 839.7 mGy cm for Group A and $CTDI_{vol}$ was 8.3 mGy and DLP was 239.6 mGy cm for Group B. The main reason for higher doses is different pitch value in this study. Other factors such as insufficient education of operators and practitioners in the newly emerging technology and patient-related factors were also reported in literature[2]. A reduction of radiation dose of up to 60 % of the total scan dose and effective dose was achieved (Table 2). All CT images were acceptable and easy to diagnose. After optimisation, the effective dose was 5.7 mSv per procedure showing a reduction of 59 %, while there was increase in noise, but within the acceptable range. Image quality was judged subjectively by three consultant radiologist. Average scan lengths, calculated dividing DLP and CTDI, were 39.2 cm and 40.1 for Groups A and B, respectively. Although scan length depends on patient height, the results indicate that the scan range is not optimally determined compared with a study published by Bozovic *et al.*[17]. The mean DLP per CT chest procedure for Group A was higher than previously reported studies[21–24], while DLP after optimisation was lower than those values (Figure 1).

CT chest involves direct irradiation of the breast, and the thyroid and uterus lie adjacent to the field (Table 3), which necessitates estimating the organ dose received by scattered radiation. Breast has the highest organ dose with the highest cancer probability compared with thyroid and uterus. Therefore, CT procedure of chest in young girls and young females needs to be carefully justified in view of high breast dose and probability of cancer incidence.

The overall cancer risk was estimated to be 8.0 and 3.0 cancer incidence per million for Groups A and B, respectively. The cancer risk of developing cancer following a CT scan is significantly reduced by radiation dose optimisation. Consequently, referring doctors must justify the decision to perform each CT scan weighing the undoubted benefits of CT scans against the potential risks. The study protocol of dose reduction that allows patient dose reduction without the loss of diagnostic accuracy was designed for optimisation of image quality to meet clinical requirements. With this protocol, dose reduction of up to 60 % was achieved. The disadvantage of this technique is that it needs a good level of clinical experience.

CONCLUSION

The patient dose optimisation during CT chest was investigated. By lowering tube current and pitch increment, a radiation dose reduction of up to 60 % was achieved without compromising the diagnostic findings. Optimisation requires continuous efforts and close cooperation between radiologists, radiographers and regularity authorities. Optimising protocols must be applied with care to ensure that they are tailored to clinical need and patient size.

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