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CT radiation dose optimization and reduction for routine head, chest and abdominal CT examination

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Abstract

The purpose of this study is to find an optimization approach to minimize the absorbed dose to adult patients undergoing CT examination, while maintain the diagnostic image quality. A single detector CT was considered, to represent typical practice in King Hamad University Hospital. We included 626 patients in this study and investigated radiation dose for three anatomical regions, head, chest and abdomen and pelvis. For each type of CT examination, two groups of patients were considered. 383 patients in Group I: were imaged according to the protocols set by the manufacturer. Group II: 243 patients were imaged according to the protocols set by our team after optimization. We were able to adjust the adjustable factors such as noise index, scan time, pitch, rotation time and slice thickness. For each examination the weighted volume CT dose index (CTDIvol) and dose length product (DLP) were recorded and noise is measured. Each study was also reviewed for image quality. Measured (CTDIvol, DLP) were compared to international reference levels. For Group I, the CTDIvol and DLP values were higher than the reference levels. After Dose optimization the CTDIvol and DLP values were significantly reduced to have lower values than the reference levels. The results of our study showed that the CTDIvol and DLP values taken from images done using the protocols set by the Ct machine developers are higher than the reference levels which indicate that manufacturers are focusing their efforts toward improving image quality rather than the minimizing the dose that can be given to the patient.

Introduction

The use of helical, multislice CT (MSCT) is rapidly growing due to technological improvements in the modern machines. Advances in CT imaging techniques have resulted in a significant increase in the frequency of CT examinations in both adult and children, replacing more and more radiographic examinations. However, CT can be responsible for the increase of carcinogenesis [1-4]. But we have to accept the fact that with the vast improvement of technology, patients benefited from a quicker and more accurate diagnosis and precise anatomic information for planning therapeutic procedures. This lead to a substantial increase in the collective dose, as reported by international organizations (ICRP 2000 and United Nations Scientific Committee 2000) [5]. In spite of this constructive contributions of CT to modern healthcare, attention must also be given to the health risk associated with the ionizing radiation received during a CT exam. Because of this potential radiation risk from this increased use of CT makes it important that CT doses be kept as low as reasonably achievable. However, modern CT scanners have a wide variety of exposure factors and involve techniques that allow dose optimization to the patient [6-9]. Guidelines to optimize the protection of patients during CT procedures have been provided by various international organizations [10-13]. All implemented guidelines include reference doses that are defined as diagnostic reference levels (DRLs) or guidance levels. These guidelines assist in the optimization and reduction of patient protection and allow comparisons between the different CT scanners and techniques. The dose parameters suggested in the guidelines are the volume CT dose index (CTDIvol) and dose length product (DLP) for the entire examination.

Although there is still adequate room for improvement, CT dose reduction requires a combination of different approaches or strategies. These include optimization of scanning protocols according to age- or weight-based adjustments, justification of CT use by referring physicians and emergency departments, decrease of unnecessary examinations, development of better exposure protocols by manufacturers, and better training and education for radiological technologists. However, to our knowledge, no reports are available in Bahrain with regard to the investigation of CT scanning protocols. There are no standardized procedures for CT imaging across hospitals in Bahrain, as each hospital has its own specific protocol, which are not necessarily optimized in terms of dose reduction.

The purpose of this study was to assess the adult CT practice, analyze CT scanning parameters used in routine head, chest and abdomen and pelvis imaging in the radiology department at King Hamad University Hospital. Moreover, our practical goal was to find an optimization approach to minimize the absorbed dose to adult patients undergoing CT examination, while maintain the diagnostic image quality.

We hope that the results of this study could be used by radiologists and medical imaging technologists to modify their existing practice and serve as one of the basis for optimization of CT imaging. Additionally, the medical community in Bahrain needs to better educate the public to the risks and benefits associated with CT, such that they can make conscience decisions based on scientific facts regarding their healthcare.

Materials and methods

Patient examinations

In this study, medical images taken by Optima CT660 system (GE Health Care, WI, USA) are considered. Adult head, chest, and

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abdominal and pelvis CT examinations were chosen for the evaluations because they are most common procedures performed in the radiology department. The hospital ethics committees of King Hamad University Hospital approved the study protocol.

Radiation dose

Radiation dose to the patient was monitored for each study by means of the two standard dose indicators, volume CT dose index (CTDIvol) and dose length product (DLP), that were calculated by the CT scanner for each CT study. The CTDIvol parameter is representative of the average dose delivered within the reconstructed section. The CTDIvol represents the weighted CT dose index divided by the pitch and describes the average dose throughout a 160-mm-diameter circular Plexiglas phantom, incorporating the central dose weighted by a 1/3 factor and the peripheral dose weighted by a 2/3 factor. The DLP can be related to energy imparted to organs and can thus be used to assess the overall radiation burden of a given examination. It is equal to the product of the CTDIvol and the length of the scan in centimeters (Huda and Mettler 2011 [14]).

Effective dose estimate

The effective dose estimate was determined by using a DLP-based method in which CT dose estimates are calculated by multiplying a DLP value and an appropriate conversion factor. Accordingly, conversion factors for the DLP-based method should be updated (ICRP 2007, Deak et al 2010 [15]) (Table 1).

Statistical analysis

For each type of CT study, differences between the two groups of patients in terms of radiation dose values were evaluated for statistical significance. Differences were considered significant at $P < 0.05$ and 0.01.

Data collected

The studied data included patient sex, and age; tube voltage and tube current settings; pitch; section thickness; number of sections; volume CT dose index (CTDIvol) and dose length product (DLP). Patients in Group I was imaged according to the protocols set by the GE. Group II were imaged according to the protocols set by our team after optimization.

Results

We evaluated our three most frequent types of CT studies: adult brain CT performed without contrast material (unenhanced CT), abdomen and pelvis CT, chest CT in adult patients. Data from 626 examinations for the two studied groups of patients who underwent routine head, chest, abdominal and pelvic CT were collected. Group I was for patients before optimization, while Group II for the patients after optimization. These subjects included 152 patients who underwent head CT, 422 who underwent chest CT, and 52 who underwent abdominal CT.

Prior to the introduction of dose optimization, and to evaluate the dose, patients' data were collected, analyzed and compared with the international standards [16-18]**.** The general results are shown in Table 2.

The CTDIvol and DLP values were higher than the reference levels given by of the international standards. Dose reduction through optimization of the examination protocol was then considered. We were able to adjust the adjustable factors such as noise index, scan time, pitch, rotation time and slice thickness. However, we limited the pitch to ≤ 1.37, as sampling gaps occur if higher pitch values are used that lead to image reconstruction artifacts. In planning the scan, issues that are related to quality had to be considered include image noise and image contrast. For the purpose of minimizing radiation dose exposure, noisier images, if sufficient for radiological diagnosis, should be accepted. Dose reduction efforts were matched with this critical component in order to maximize the quality/dose ratio. For chest examination we restricted our protocol for a slice thickness of 5mm, while we allowed the value to be 2.5 or 5mm for abdominal and pelvic examination. We initially tried 5 mm, but this section thickness was judged sometimes to be insufficient by our radiologists in terms of spatial resolution. Hence, for abdomen and pelvis CT the slice thickness was chosen to be either 2.5 mm for renal or 5 mm for routine evaluation. However, a thinner section thickness (1.25 or 0.625mm) was required in few cases to achieve better spatial resolution and enable assessment of fine anatomic details in these studies.

The range of the modulated tube current in milliamperes was decided subjectively by a registered radiology technologist, in a range set by the technologist, on the basis of different factors. The noise index NI was initially set at its lowest value and slowly increased until the image quality was determined to be sufficient by the radiologists. A lower NI leads to lower noise and thus into an improved image. However, a lower NI (better image quality) requires higher tube current for a given pitch and tube rotation time and therefore delivers higher patient radiation dose. The rotation time for most types of scans was lowered from 1 second to 0.5 second.

The important technical factors and radiation doses, including volumetric CT dose index and DLP values, at routine head, chest, and abdominal CT for Group I and group II are listed in Tables 3, 4, and 5, respectively.

Both CTDIvol and DLP were significantly lowered from for unenhanced female adult brain from (79 to 40 mGy) and for male adult from (79 to 46 mGy) (Table 3). Regarding adult abdomen and pelvis CT (Table 4), CTDIvol were lowered from (20.7 to 19.0) for adult females and for adult males from (37.3 to 17.8 mGy) when dose optimization was considered compared with CTDIvol and DLP when dose optimization was not used. Regarding chest CT in adult patients (Table 5), CTDIvol and DLP were lowered from (21.4 to 14.2 mGy) and from (22.3 to 14.3 mGy) for adult males.

Discussion and conclusion

In this study we investigated the DRLs for three anatomical regions, head, chest and abdomen and pelvis for both females and male patients. Two groups were considered, in Group I patients were imaged according to the protocols set by the GE and in Group II patients were imaged according to the protocols set by our team after optimization.

The results of our study demonstrate that the radiation doses for Group I were higher than the international guidelines. This indicates that manufacturers are focusing their efforts toward improving image quality regardless to the radiation limits and guidelines. After optimization (Group II) radiation doses were lower than the DRLs for the head, abdomen and chest CT examinations.

The mean weighted CT dose index CTDIvol for head after optimization (Group II) (43.8 mGy) for head CT in the entire sample (Female and Male patients) was comparable to values reported by other authors (34–56 mGy) [19,20] (58-66) [8], and in the range of the value reported by the IAEA coordinated research project (19-51 mGy) [11]. The mean DLP (760 mGy.cm) for head CT was comparable also to

Table 1. Adult Conversion Factors for Dose-Length Product-Based CT Dosimetry Based on International Commission on Radiological Protection (ICRP) Publication 103, (ICRP 2007) and summarized by [15].

Age	kVp	Male					Female				
		Head	Neck	Chest	Abdomen	Pelvis	Head	Neck	Chest	Abdomen	Pelvis
Adult	80	0.0017	0.005	0.0107	0.0132	0.01	0.0019	0.0055	0.0188	0.017	0.0157
	100	0.0018	0.0049	0.0104	0.0132	0.0099	0.002	0.0053	0.0183	0.017	0.0155
	120	0.0018	0.0049	0.0105	0.0134	0.01	0.002	0.0053	0.0185	0.0173	0.0157
	140	0.0018	0.005	0.0107	0.0134	0.0102	0.002	0.0055	0.0188	0.0173	0.016

Table 2. Comparison of Head, Chest, and Abdominal CT Dose Values with DRLs given in the international standards [16,17,18]. Group I was imaged according to the protocols set by the GE. Group II were imaged according to the protocols set by our team after optimization.

Examination	*Dose Parameter*	*Group I*	*Group II*	*EU 2004*	*UK 2003*	*IAEA 2006*
Head CT	**CTDIvol (mGy)**	79	44	60	100	47
	DLP (mGy·cm)	1218	760	1050	1050	1050
Chest CT	**CTDIvol (mGy)**	22	14	30	14	9.5
	DLP (mGy·cm)	794	401	650	580	447
Abdominal CT	**CTDIw (mGy)**	31	18	35	13	10.9
	DLP (mGy·cm)	1097	831	780	560	696

Table 3. The important technical factors and radiation doses, at routine head, for Group I and group II. Group I was imaged according to the protocols set by the GE. Group II were imaged according to the protocols set by our team after optimization.

Head	**Group I**		**Group II**	
	Adult Females	**Adult males**	**Adult Females**	**Adult males**
No of Patients	44	50	25	33
Average Age	53.4	54.4	53.2	53.9
Milliampere	224-322	202-385	157-344	202-409
$CTDI_{vol}$ (mGy)	79	79	40	46
DLP (mGy.cm)	1198	1207	655	831
Slice thickness (mm)	2.5	2.5	5	5
Rotation time (second)	1.2	1	0.5	0.5
pitch	0.78	0.76	0.98	0.98
Conversion factor	0.002	0.0018	0.002	0.0018
E (mGy)	2.4	2.2	1.3	1.5

Table 4. The important technical factors and radiation doses, at routine abdomen and pelvis, for Group I and group II. Group I was imaged according to the protocols set by the GE. Group II were imaged according to the protocols set by our team after optimization.

Abdomen and pelvis	**Group I**		**Group II**	
	Adult Females	**Adult males**	**Adult Females**	**Adult males**
No of Patients	95	167	70	90
Average Age	44.5	44.1	39	42.2
Milliampere	308-429	303-410	304-403	299-408
$CTDI_{vol}$ (mGy)	20.7	37.3	19.0	17.8
DLP (mGy.cm)	1090	1100	814	838
Slice thickness (mm)	2.5	2.5	2.5-5	2.5-5
Rotation time (second)	0.85	0.85	0.5	0.5
pitch	1.35	1.35	1.37	1.37
Conversion factor	0.0173	0.0134	0.0173	0.0134
E (mGy)	18.9	14.7	14.1	11.2

Table 5. The important technical factors and radiation doses, at routine chest, for Group I and group II. Group I was imaged according to the protocols set by the GE. Group II were imaged according to the protocols set by our team after optimization.

Chest	**Group I**		**Group II**	
	Adult Females	**Adult males**	**Adult Females**	**Adult males**
No of Patients	14	13	12	13
Average Age	60.7	57.2	59.1	46.5
Milliampere	342-426	218-376	330-425	250-380
$CTDI_{vol}$ (mGy)	21.4	22.3	15.2	14.29
DLP (mGy.cm)	770	819	480	401
Slice thickness (mm)	2.2	2.1	5	5
Rotation time (second)	1.25	1.13	0.5	0.5
pitch	0.85	0.88	1.37	1.37
Conversion factor	0.0185	0.0105	0.0185	0.0105
E (mGy)	14.2	8.6	8.9	4.2

the results reported by other authors such as [21] (740 mGy .cm) and [22] (587 mGy. cm) (31), and [17] (787 mGy.cm). It should be noted, however, that all of these authors reported values that were much lower than the European and IAEA DRL (1050 mGy.cm).

The mean weighted CT dose index for abdominal CT after optimization was 18.2 mGy, which is in the range of values (16–29 mGy) reported by a number of other authors [17,19,23]. On the other hand, the mean DLP for abdominal CT (830 mGy. cm) is higher than the values reported by [23] (493–551 mGy.cm). It should be noted, however, that the above values were taken in the upper part of the abdomen and not in the entire abdominal region, so the scanned region in the patient was substantially decreased. On the other hand, all of the abdominal CT examinations performed in the KHUH were in fact abdominal-pelvic examinations, and this partially explains why the mean DLP for abdominal CT (696 mGy.cm) at our hospital was higher than the mean DLP for our entire sample (549 mGy.cm).

Moreover, the mean weighted CT dose index (14.3 mGy) for chest CT was lower than the value reported in the previous IAEA-coordinated research project (16.2 mGy) (IAEA 2004) [10]. The mean DLP (401 mGy. cm) for chest CT was lower than the IAEA-reported value (455 mGy.cm) [11].

Our study was limited by the decision to examine only adult patients from our hospital, so the results did not include smaller health centers or private hospitals in the country.

We found that dose optimization resulted in significant reductions in radiation dose to adults ($P \leq 0.001$). As our study was performed in one center only and with one type of CT scanner, hence these obtained data and results should be confirmed in studies that evaluate CT scanners from other manufacturers. In conclusion, we recommend routine use of dose optimization for all CT examinations, because this approach affords a significant dose reduction while preserving image quality. Implementation of dose optimization requires a fine-tuning process to identify optimal signal-to-noise level for each type of CT study performed. Although, we investigated the effect of dose optimization on all our CT protocols, but this study is limited to our radiology department and further investigation should be done in other hospitals in the country.

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