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Optimization of Head CT Protocol to Reduce the Absorbed Dose in Eye Lenses and Thyroid: A Phantom Study

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ABSTRACT

Introduction: Utilization of computed tomography (CT) scans is increasing annually. This study aimed to reduce the absorbed dose of sensitive organs in the head (eye lenses and thyroid) and to assess changes in resultant images quality in head scans when the radiation dose is decreased.

Material and Methods: An anthropomorphic phantom was examined with head protocols in both helical and sectional modes using two 16-slice CT scanners. The entrance surface dose of eye lenses and thyroid was measured with standard protocols and after reducing the mAS and kilo-voltage using thermo-luminescence dosimeters (TLDs).

Results: In sectional mode with standard protocol, the highest surface dose was 2.3 mSv[1] for eye lens and 0.021 mSv for thyroid in hospital A. Moreover, in helical mode with standard protocol, the highest surface dose was 0.964 and 0.02 mSv for eye lens and thyroid in hospital B, respectively. Reducing tube current and kilovoltage decreased the dose up to 35% for eye lens and 45% for thyroid in hospital A. By the mentioned reductions a dose decrease of up to 40% was achieved for both eye lens and thyroid in hospital B. There were no considerable differences in image quality between scans with standard protocol and the protocols of reduced parameters.

Conclusion: Head CT scans with standard factors conduce to images with the best quality. It may be possible to diminish the absorbed dose up to 40% without losing information, especially in follow up head scans.

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Introduction

Probably computed tomography (CT) is the most preferred technology to obtain anatomical images of patients with high resolution and more diagnostic details. CT images are taken by rotation of an X-ray tube around the interested part of the patient's body in the gantry and they are actually composed of many transverse slices [1]. CT scan has innumerable uses in the medical procedures. However, the main problem with this technology is the very high radiation doses received by the patients whom undergo CT examinations, in comparison to other radiological examinations. The level of exposure in CT can also lead in cancers [1].

In the recent decades much attention has been given to CT dosimetry. Concerns about this phenomenon have increased with the rise in various usages of CT scan. Exposure in CT is much higher than radiography and fluoroscopy [1]. Probability of radiation effects, such as erythema and alopecia, in addition to stochastic effects, including induced cancer and hereditary effects can be estimated by calculating the absorbed doses in organs.

The number of CT examinations is increasing every year. In United States of America for example, it has increased to 4-6% [1]. The CT scans comprised only 10-15% of all the radiological exams, but comprise 67-75% of the total radiation dose of the patient population [1]. The absorbed dose in patients during the conventional radiography is 20-100 times lower than the dose received by patients during CT examinations [1].

Nowadays, assessing the radiation absorbed dose during medical procedures using ionizing radiations, in addition to the related hazards for the population are important issues discussed in radiation protection. On the other hand, Development of the helical CT scanners with shorter scan times and increased application of CT in various diagnostic fields (e.g., CT angiography) lead in higher needs for CT scans and more CT requests by physicians Thereupon rising in CT requests leads to a major increase in increment of CT examinations [2].

The radiation doses delivered to some critical organs during CT scans are considerable enough to be

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a matter of concern [3]. For instance, in the head area during head scans, thyroid and eye lenses are the most radiosensitive organs which are usually in the scan field, whereas most of the times they are not the intended organs. Therefore, any executable methods for decreasing the radiation dose will be invaluable.

As mentioned, CT scan is increasingly utilized in clinical situations with rapid technological progressions and the radiation doses associated with CT are of critical importance. Therefore, it seems necessary to teach, understand, and apply the information related to radiation protection [2, 4, 5].

Eye lenses are very radiosensitive organs. The latency period of radiation-related cataracts has an inverse relationship with the absorbed dose and may last for decades. In case the radio-opacity of eye lens is not cured, it will progress and ultimately results in blindness unless surgeon replaces the injured lens. The ICRP[1] (ICRP07) estimates the threshold doses needed to cause detectable opacities and eyesight effects in a single-track exposure in a range of 0.5-2 and 5 Sv, respectively. In addition, the ICRP estimates the threshold dose for prolonged exposures as 5-6 Sv to induce recognizable cataract and 8 Sv for impairing eyesight [6,7].

In recent decades Most scientists believed that radiation-induced cataract in human just occurs due to the exposures with high doses. However, recent studies show that this type of cataract can occur in very lower doses even below 1 Sv as the result of environmental or diagnostic radiations [7, 8]. Exposure to ionizing radiation is considered as an oncogenic risk factor, especially in young ages. It may take four decades or a lifetime for malignancies to appear.

Medical ionizing procedures take place every day all around the world and have become a worldwide issue, especially in the pediatric population who are more radiosensitive than adult. In the past, radiotherapy for curing benign or malignant conditions was the major source of irradiation for sensitive organs, such as thyroid gland. Nowadays diagnostic medical exposures are one of the largest man-made radiation sources [9]. Utilizing the CT scan examinations are increasing exponentially causing the related radiation dose to rise, especially in the pediatrics.

Evidences show a direct epidemiological relationship between the small but noticeable increased risk of inducing thyroid cancer and the radiation doses equivalent to that used in computed tomography. Consequently, augmented medical exposures might result in higher incidence of papillary thyroid cancer [9,10].

CT technology is progressing rapidly and advanced CT scanners with more detector rows, such as 16, 64, and even 256 slice systems have developed (as well as the models with 2, 6, 8, 10, 32, and 40 slices). Therefore, the number of data channels acquired per axial rotation has increased. It is believed that in near future even larger axial coverage per rotation (>4 cm) will be accessible commercially [11, 12]. These great developments caused many changes in clinical utilization of CT and warned us to revise the aspects of risks versus benefits in radiation doses [5].

Regarding radiation protection and the “As Low as Reasonably Achievable (ALARA)[2]” principle, evaluation of doses in CT seems quite necessary [13]. It should be noted that in examinations performed as high contrast levels (e.g., scans of bones or lungs) with decreased dose up to 50% or more, image quality and information are not missed [2].

With this background in mind, the present study measured the absorbed dose in radiosensitive organs of the head area, including eye lenses and thyroid gland in sectional and helical head CT scans using a RANDO phantom [14, 15, 16]. Furthermore, a protocol to reduce the absorbed dose in these organs while the diagnostic quality of the resultant images is maintained was assessed. We aimed to achieve the mentioned goals by creating reasonable changes in the tube current and kilovoltage [17,18].

In high contrast imaging, such as imaging the lung or bones, a relevant loss of information does not occur even if the dose is reduced by 50% or more [2]. Therefore, this study was conducted to evaluate the possibility of decrease in the radiation dose delivered during head CT in the sectional and helical modes. Quality of the resultant images was analyzed concerning the systemic changes in the scanning parameters [19, 20, 21]. In this study, the major purpose was to optimize the standard head CT protocol in order to reduce the absorbed dose in eye lenses and thyroid gland while the quality of images is acceptable.

Materials and Methods

Phantom

RANDO phantom (IMAGING Solutions, Australia) is an anthropomorphic heterogeneous phantom with real bones of real human skeleton. The head and neck phantom utilized in this study was made of ten transverse sections and the thickness of each section was 2.5 cm (Fig. 1). This phantom is made of equivalent soft tissue with the density of 1.25±0.985 g/cm^3 and atomic number equal to 25±7.3 [14, 16].

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[1] International Commission on Radiation Protection

[2] As Low As Reasonably Achievable

Figure 1. RANDO phantom of head and neck examined as the target

CT Scanners

Two CT scanners were used to perform the CT examinations in sectional and helical modes. Both of them were SOMATOM AR.SP made by Siemens, Germany. The scanners were the 16-slice type, which are utilized in the emergency wards of hospitals A and B.

Dosimeters

For this study, 39 thermoluminescent dosimeters (TLD-100) of the PTW type (Harshaw, ThermoFisher Scientific, USA) were used to record and measure the entrance surface dose (ESD) at the eye lenses and thyroid gland (Fig. 2) [22]. The PTW type manual TLD reader system (Fimel, UK, France) was applied for reading the TLDs (Fig. 3). The RANDO phantom of head and neck was set in head CT protocol position on the table just like the position of real patients (Fig. 4).

In order to measure the surface effective dose of eye lenses during CT exams, a capsule containing one TLD was placed on each eye and was fixed with tape. Moreover, for measuring the surface effective dose of thyroid gland a capsule containing one TLD was placed on each lobe of thyroid and was fixed by tape (Fig. 4). Within 24 hours after executing the protocols, TLDs were readout using the LTM manual detector reader system (Fimel, UK, France) (Fig. 3). The average effective doses of eye lenses and thyroid gland were calculated based on the recorded doses of right and left eye lenses and thyroid lobes.

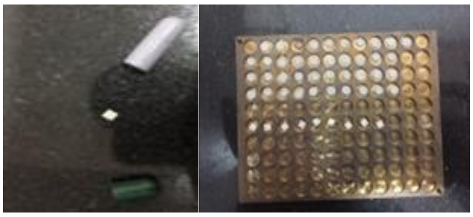


Figure 2. Thermo luminescent dosimeters put in empty capsules and used to record the organs absorbed dose

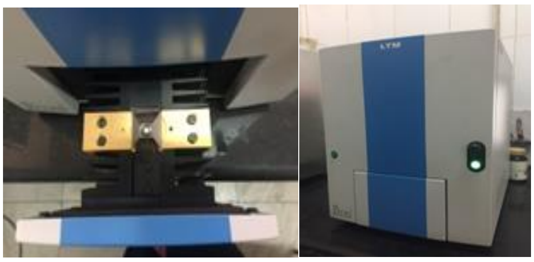


Figure 3. Automatic detector TLD reader system

Figure 4. Locating the phantom in the gantry fixed in head CT protocol position and locating the dosimeters on the phantom as one TLD in an empty capsule on each eye and each thyroid lobe, followed by fixing by tape

Protocols

First, a digital projection image containing the whole length and volume of phantom was obtained (topogram, scout). Afterwards, volume and length of the scan were defined by the operator through gantry angulation according to the supraorbitomeatal line. In the first step, a standard head CT scan was performed to measure the routine effective dose of eyes and thyroid in both sectional and helical modes in both hospitals A and B.

Regarding the scanner in hospital A, the standard parameters were 110 kVp and 270 mAs for the sectional mode, in addition to 110 kVp and 120 mAs for the helical mode. In hospital B, the standard parameters of the scanner included 130 kVp and 180 mAs for the sectional mode, in addition to 110 kVp and 175 mAs for the helical mode. In the next step, the tube current of scanner was reduced in two stages as 20 mAs per stage. The level of tube current reduction was chosen considering the limitations and permissible conditions of the scanners in each stage. In the fourth step, regarding the scanner limitations, the kilovoltage was diminished in one stage.

The doses in standard protocol were recorded, followed by changing the TLDs and replacing the new TLDs in eye lenses and thyroid area. As mentioned above, the tube current was reduced in two stages, with the same unchanged kilovoltage. The tube current was reduced as 20 mAs per stage. In the fourth step, with the constant primary tube current, the kilovoltage was lessened to 80 kVp. All these changes were repeated in both helical and sectional modes with the scanners in hospitals A and B. In all the stages of changing the parameters, head CT protocol was implemented on the phantom. The standard and changed parameters applied in scanners A and B are shown in tables 1-8.

Firstly, for measuring the routine effective dose of eyes and thyroid gland, the standard head CT protocol of the ward was performed by the general routine parameters in sectional mode (as stage 1). These routine parameters are mentioned in Table 1. Following changing the TLDs and replacing them with new TLDs in eyes and thyroid area, the kilovoltage remained constant and the tube current was reduced in two stages as 20 mAs per stage. In stage four, the kilovoltage was reduced to 80 kVp while the tube current was primary constant of 270 mAs. In each stage, the TLDs were changed to record the new effective dose of eyes and thyroid. Table 2 demonstrates the used parameters on the scanner in each stage.

Table 1. Standard head CT protocol for the sectional mode (stage1) in hospital A

Tube current (mAs)	Tube voltage (Kv)	Scan time (s)	Slice thickness (mm)
270	110	1	5

Table 2. Parameters applied on the scanner in different stages of the study for sectional mode in hospital A

	Tube current (mAs)	Tube voltage (Kv)
Stage 2	250	110
Stage 3	230	110
Stage 4	270	80

Next, in order to measure the effective dose of eyes and thyroid in the standard helical mode, the routine standard helical head CT protocol of the ward was performed. The usual parameters of the standard helical head CT protocol in hospital A are summarized in Table 3. After changing the TLDs and replacing them with new TLDs in the eyes and thyroid area, similar to the sectional mode, the kilovoltage remained unchanged and the tube current was diminished in two stages as 20 mAs per stage. In the fourth stage, by the primary constant tube current of 120 mAs, the kilovoltage was reduced to 80 kVp. In every stages, the TLDs were changed to record the new doses of eyes and thyroid. The applied parameters on the scanner in every stages are mentioned in Table 4.

Table 3. Standard head CT protocol for the helical mode (stage1) in hospital A

Tube current (mAs)	Tube voltage (Kv)	Scan time (s)	Slice thickness (mm)
120	110	1.55	5

Table 4. Parameters applied on the scanner in different stages of the study for the helical mode in hospital A

	Tube current (mAs)	Tube voltage (kV)
Stage 2	100	110
Stage 3	80	110
Stage 4	120	80

All the aforementioned stages for hospital A were repeated in hospital B in the same manner as demonstrated in tables 5-8.

Table 5. Standard head CT protocol for the sectional mode (stage1) in hospital B

Tube current (mAs)	Tube voltage (Kv)	Scan time (s)	Slice thickness (mm)
180	130	0.6	3.6

Table 6. Parameters applied on the scanner in different stages of the study for the sectional mode in hospital B

	Tube current (mAs)	Tube voltage (Kv)
Stage 2	160	130
Stage 3	140	130
Stage 4	180	80

Table 7. Standard head CT protocol for the helical mode (stage1) in hospital B

Tube current (mAs)	Tube voltage (Kv)	Scan time (s)	Slice thickness (mm)
175	110	4.65	6

Table 8. Parameters applied on the scanner in different stages of the study for the helical mode in hospital B

	Tube current (mAs)	Tube voltage (Kv)
Stage 2	155	110
Stage 3	135	110
Stage 4	175	80

The resultant eight protocols per scanner (four sectional and four helical) were documented as softcopy with comparable window width (WW), window level (WL), and magnification factor.

Image Quality Assessment

The obtained images were saved using Digital Imaging and Communications in Medicine (DICOM) format (Fig. 5). First, the resultant images were labeled and numbered by random letters and digits according to the hospitals, in which the exams were completed, in addition to the changed parameters and the mode. This naming method helped us to define the images series reliably. Supposing that the best image quality belongs to the standard protocol and the quality will improve by elevating the radiation doses, image quality loss was expected in scans with decreased parameters.

The scans were sorted out in four groups for the two hospitals and the two scan modes separately and were reviewed according to this grouping. Images which were named by letters and digits before were then presented using softcopy form in a hidden model so that the reviewers were blinded about the radiation parameters, clinical data, and absorbed doses, as well as the comments and opinions of other reviewers.

Four reviewers with different previous experience in brain CT examination, including three radiologists and one medical physics PhD observed the resultant images to assess the images quality. They assigned number 1 to the images with the best quality in their opinion and assigned numbers 6 or 7 to the images with the worst quality. Furthermore, the reviewers were requested to note the considerable differences between the helical or sectional scans from the same scanner.

Therefore, the quality of images obtained from the three steps of highest, average, and lowest doses were recognized. The reviewers were asked to determine the acceptable and unacceptable image qualities and the ones, which are applicable for real patients in different hospitals and clinics. Totally 16 subjective classifications, (four based on modes and four based on reviewers) were compared together regarding loss of quality by decreasing the surface dose.

Figure 5. Images from scanning the phantom, assessed by four experienced examiners to evaluate the effect of radiation reduction on the image quality

Statistical Analysis

All the data were analyzed using the SPSS software version 16 (IBM, USA). For the statistical analysis, the research was divided into two parts, including inter-hospital and intra-hospital. The histogram diagrams were utilized to assess normalization of the data. The analysis was performed by Shapiro-Wilk test, independent t-test, Mann-Whitney test, one way analysis of variances, and Kruskal-Wallis test. $P < 0.05$ was considered as significant level for all tests.

Results

Dose Measurements

In hospital A, for the sectional mode with a primary constant effective tube current, the mean dose of eye lenses was reduced from 2.3±0.02 mSv in 110 kVp to 1.22± 0.03 mSv in diminished 80 kVp voltage. According to the comments of reviewers, the diagnostic quality of resultant images had few positive changes. In the helical mode, the mean dose of eye lenses had a decrease of 0.796±0.005 to 0.33±0.001 mSv in change from 110 to 80kVp. It should be noted that no noticeable change was observed in the image quality.

In the sectional mode, the mean absorbed dose of thyroid reduced from 0.021±0.002 mSv in 110 kVp to 0.008±0.0001 mSv in 80 kVp, which is significant in this scale. In the helical mode, the mean dose of thyroid changed from 0.019±0.005 to 0.009±0.0001 mSv in 110 and 80kVp, respectively. The latter alteration is a significant reduction ($P < 0.05$).

In hospital B, for the sectional mode in a primary constant tube current, the eye lenses mean dose reduced from 0.437±0.005 mSv in 130 kVp to 0.132±0.004 mSv in 80 kVp. Moreover, the thyroid mean dose showed a decrease from 0.02±0.004 mSv in the first condition to 0.01±0.002 mSv in the second one.

In the helical mode, the eye lenses mean doses declined from 0.964±0.003 to 0.609±0.001 mSv in 110 and 80 kVp, respectively. Furthermore, the thyroid mean doses in this mode reduced from 0.02±0.001 mSv in the first condition to 0.008±0.0002 mSv in the second one, which was an almost considerable change. Regarding the comments of reviewers about the diagnostic image quality, there was no considerable change in the diagnostic information.

In hospital A for the sectional mode with a primary constant voltage, the mean absorbed doses of eye lenses were measured for different tube currents in all the stages. The results of which are shown in Table 9. Considering the abilities and limitations of the scanner, the effective tube current was reduced as 20 mAs per stage.

Table 9. Mean absorbed dose of eye lenses in different tube currents for the sectional mode in hospital A

Effective tube current (mAs)	Average absorbed dose of eye (mSv)
270	2.3±0.02
250	1.97±0.04
230	1.7±0.05

As displayed in Table 9, with reducing the tube current as 40 mAs, the eye lens absorbed dose can decreased by 0.6 mSv without any detectable negative effects on the images quality. The mean absorbed doses of eye lenses in the helical mode in hospital A are mentioned in Table 10.

Table 10. Mean absorbed dose of eye lenses in different tube currents for the helical mode in hospital A

Effective tube current (mAs)	Average absorbed dose of eye (mSv)
120	0.796±0.005
100	0.809±0.004
80	0.626±0.001

In addition, the thyroid mean absorbed doses were assessed for the sectional mode in different tube currents and the results are demonstrated in Table 11.

Table 11. Mean thyroid absorbed dose in different tube currents for the sectional mode in hospital A

Effective tube current (mAs)	Average absorbed dose of thyroid (mSv)
270	0.021±0.002
250	0.017±0.001
230	0.017±0.003

The thyroid mean absorbed doses were evaluated for the helical mode in different tube currents as mentioned in Table 12.

Table 12. Mean thyroid absorbed dose in different tube currents for the helical mode in hospital A

Effective tube current (mAs)	Average absorbed dose of thyroid (mSv)
120	0.019±0.005
100	0.017±0.006
80	0.011±0.003

For the sectional mode in hospital B with a primary constant voltage, the mean absorbed doses of eye lenses were measured in different scanner tube currents and the results of these changes are summarized in Table 13.

Table 13. Mean absorbed dose of eye lenses in different tube currents for the sectional mode in hospital B

Effective tube current (mAs)	Average absorbed dose of eye (mSv)
180	0.437±0.005
160	0.274±0.004
140	0.3±0.002

The mean absorbed doses of eye lenses were recorded for different tube currents in the helical mode as shown in Table 14.

Table 14. Mean absorbed dose of eye lenses in different tube currents for the helical mode in hospital B

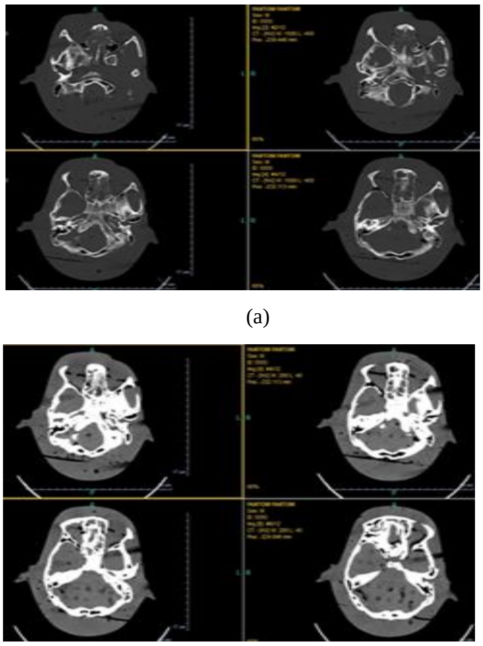
Effective tube current (mAs)	Average absorbed dose of eye (mSv)
175	0.964±0.003
155	1.243±0.004
135	0.503±0.003

In both helical and sectional modes in hospital B, with changing the tube current the thyroid mean absorbed dose remained constant and equal to 0.02±0.005 mSv.

Image Quality Assessment

In order to investigate the quality of the obtained images, four reviewers, including radiologists A, B, and C, in addition to a medical physics PhD (D) evaluated and compared the images. The reviewers were blinded about the series of the images, protocols, and each other opinions.

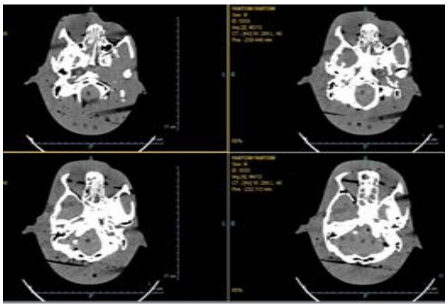
All the reviewers stated that reducing the voltage and tube current in the ranges mentioned in this study did not have a significant negative effect on the image quality and diagnostic information. The negative impact was just observed in protocol stage 2 (160mAs and 130Kv) of the sectional mode (Fig. 6) and protocol stage 3 (135mAs and 110Kv) of the helical mode (Fig. 7) in hospital B.



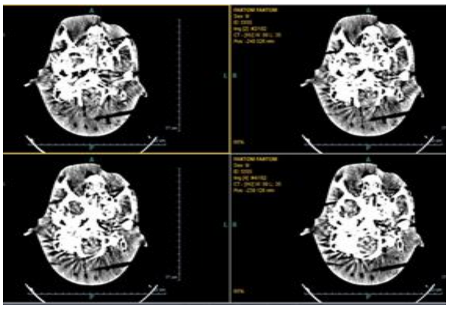
(a)

(b)

Figure 6. Standard sectional protocol stage1 (a) in comparison to the protocol stage 2 for the sectional mode (b) in hospital B, which had a significant detectable loss of quality and information according to the comments of reviewers



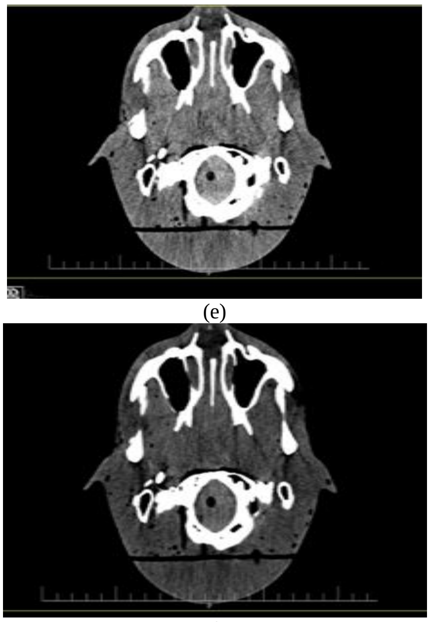
(c)



(d)

Figure 7. Standard helical protocol stage1 (c) in comparison to the protocol stage 3 for the helical mode (d) in hospital B, which had a significant detectable loss of quality and information according to the comments of reviewers

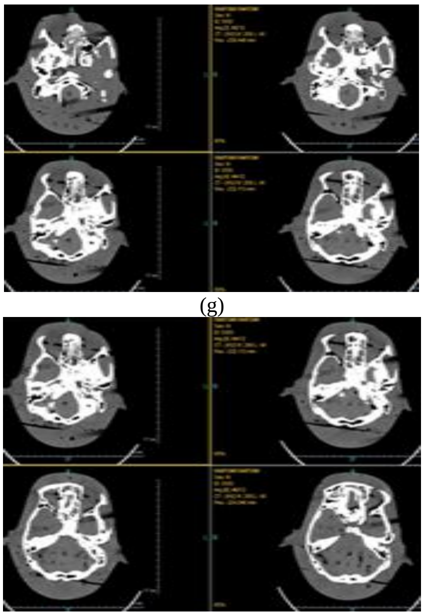
In addition, reviewers A and C notified that the best image quality in this ranking belonged to the images of the protocol stage 4 for the sectional mode in hospital A (Fig. 8), protocol stage 3 for the sectional mode (Fig. 9), and standard helical protocol (stage1) in hospital B (Fig. 10). In general, the quality of images in hospital B was revealed to be higher than the images produced in hospital A. In both hospitals, the image quality in the sectional mode was much better than the helical mode.



(e)

(f)

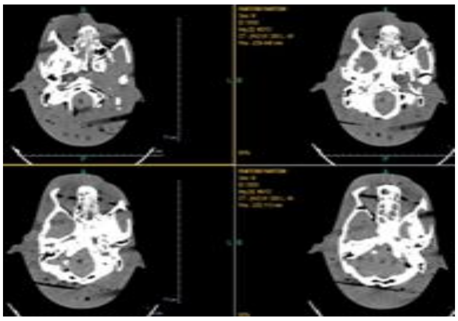
Figure 8. Standard sectional protocol stage1 (e) in hospital A in comparison to the protocol stage 4 for the sectional mode (f) in hospital A (high quality), which had the best quality in hospital A according to the comments of reviewers



(g)

(h)

Figure 9. Standard sectional protocol stage1 (g) in hospital B in comparison to the protocol stage 3 for the sectional mode (h) in hospital B, which had a high quality in comparison to other scans in the sectional series in hospital B according to the comments of reviewers



(i)

Figure 10. Standard helical protocol stage1 (i) in hospital B, which had a high quality in comparison to other scans in the helical series in hospital B according to the comments of reviewers

Discussion

Due to the developments in CT examinations over recent 25 years, the frequency of CT scans and subsequent concerns about the resultant radiation doses increased [2]. Moreover, with development of the multi-detector scanners this portion seems to become more significant [4].

The (ICRP) has published recommendations regarding minimizing the radiation dosage during CT examinations [4, 23].

In past, the major belief was that the radiation-induced cataract in human results from irradiations with high doses. However, in the recent decades, several studies revealed that radiation-induced opacities in eye lenses may occur at much lower doses as the result of medical or environmental irradiations even at doses well under 1 Sv [24].

No official recorded threshold dose has been recorded for incidence and development of thyroid malignancies and any radiation dose to thyroid gland seems to be hazardous [2, 25].

Irradiation in children raises the risk of inducing solid cancer because children are the most radiosensitive people. Furthermore, children have a long lifetime versus the adults and cancer has more time and chance to appear and develop [26].

There have been several previous studies on the radiation dose received in thyroid and eye lenses during CT scans and the absorbed dose in these organs has been measured. Considering the results of these studies, it is clear that the absorbed dose in eye lenses and thyroid is high enough to be the matter of concern and it is necessary to find an effective way to reduce this dose without missing the diagnostic information [27-31].

The current study investigates the changes in absorbed dose of eye lenses and thyroid in head CT scans with reducing the voltage from 130 to 80 kVp, as well as the tube current from 270 to 140 mAs in the sectional mode and from 175 to 80 mAs in the helical mode. Moreover, the relationship between these components was assessed. Furthermore, the effects of these changes on image quality were evaluated. These comparisons were performed for both helical and sectional modes using two 16-slice CT scanners form the same company.

Although the images obtained by CT examinations with higher dose levels have less noise, the previous studies showed no considerable improvement in image quality by increasing the radiation dose [2]. The literature state that the standard parameters applied on the scanner by manufacturer lead in the best image quality. However, reasonable changes in the parameters can reduce the radiation dose without noticeable quality alteration in the resultant images [2]. The radiation dose in CT exams can be diminished in different ways, such as reducing the tube potential, tube current, and scan time [23].

Decreasing the kVp does not change the radiation dose proportionately; for example, by reducing the tube voltage from 140 to 80 kVp, the radiation dose slakes in five models. According to the findings of the present study in hospital A, the absorbed dose of eye lenses and thyroid had a mean decline of up to 50 and 55% with reducing the tube potential, respectively. In addition, in hospital B with decreasing the tube potential, the absorbed dose reduced up to 50 and 55% in eye lenses and thyroid gland, respectively.

Reduction in the absorbed dose in both hospitals with similar changes in scan parameters was almost equal. Based on the comments of reviewers about the image quality, there was no detectable change in the diagnostic information. The previous studies demonstrated that decreasing the voltage from 120 to 80 KVp results in radiation dose decline and improved contrast between the organs with different contrasts [23].

Our results are similar to Imai et al., who indicated that reducing the scanner voltage from 120 to 100 and 80 kVp caused the dose to lessen up to 40% in eye lenses [32]. The mentioned study was about reducing the dose in brain CT angiography (CTA) and was different with our study in that they used 64-slice raw detector scanner and only one scanner was utilized. Their results suggested that the suitable tube potentials for axial CTA and 3D CTA images were 100 and 80 kVp, respectively. Furthermore, they concluded that the appropriate tube current was the one recommended by the manufacturer [32].

In addition, in similar tube potential, the level of dose reduction in our study was more than the study performed by Imai et al., which was because of other scan parameters and different scanners. The major belief was that by increasing the radiation dose in CT examinations, the quality of obtained images will improve and there is a direct linear relationship between the radiation absorbed dose and effective tube current (mAs) [32]. Recent studies demonstrated that images with acceptable quality and reduced absorbed doses of up to 63% can be obtained by decreasing the radiation dose in CT protocols [33].

Images taken by the standard protocol have much better quality, compared to those obtained by a low-dose protocol. However, the quality of low-dose images seems acceptable and in some special clinical cases it is sufficient [33]. As displayed in Table 9, with diminishing the tube current as 40 mAs in hospital A, the eye lens absorbed dose had a reduction of 0.6 mSv. Despite the considerable reduction in the absorbed dose, no significant detectable change was observed in the image quality.

According to the results shown in tables 9 and 10, changing tube current in the helical mode had less effect on reduction of eye lens dose, in comparison to the sectional mode. The latter result might be due to the lower levels of the general parameters of scanner in the helical mode. The mean absorbed dose of eye lens in the helical mode declined 0.17 mSv when the tube current was reduced as 40mAs without any important change in the image quality.

Regarding the results shown in tables 11 and 12, reducing the tube current in hospital A did not result in important differences in thyroid absorbed dose in the sectional mode protocols. This may be attributed to the position of thyroid, which is more exposed to the scattered radiations. In the helical mode, the reduction of thyroid dose was more detectable. According to Table 13, in hospital B in the sectional mode, with 40 mAs decrease in tube current, the mean absorbed dose of eye lenses could reduce as 35% without any negative effect on the image diagnostic quality.

As indicated in Table 14, in hospital B in the second stage of the helical mode protocols, a sudden unexpected increment was found in the recorded dose, which is probably because of the environmental effects on the specific series of TLDs. It is known that the recorded dose in TLDs might get affected and change as a result of environmental factors (e.g., temperature, light, and humidity) [22].

As shown, decreasing tube current of the scanner leads in a reduction of up to 40% in the absorbed dose. In both sectional and helical modes, the thyroid absorbed dose was 0.02 mSv in all the three protocols. According to the results in hospital B, in both sectional and helical modes, thyroid absorbed dose did not change by decreasing the tube current.

In total, the absorbed dose of thyroid gland is much lower than the eye lenses. This difference can be attributed to the position of thyroid exposing it to the scattered radiations, in comparison to the eye lenses, which are exposed to the primary radiations.

Our results are consistent with the findings of Udayasankar et al. However, one of the differences between these two studies is the exam target. In the present study, a RANDO phantom was used as the target while Udayasankar et al. performed their study on real patients. Therefore, it was easier and more reliable in the latter study to judge the diagnostic quality of scans.

The other difference was in the number of scanners; as in the study completed by Udayasankar et al. the protocols were applied only on one 4-slice CT scanner. Moreover, the results were not compared with another scanner performance and it can be one of the limitations of the study. According to the results of Udayasankar et al., decreasing the tube current from 220 to 80 mAs causes the absorbed dose to decrease about 63%, compared to the standard protocol [33].

Although the dose reduction leaded in a considerable fall in the image quality, the quality of resultant images was acceptable [33]. Udayasankar et al. revealed that the dose reduction was more significant, compared to the current study. This was because of the higher decline in tube current, in comparison to this study protocols, in addition to the difference between the used scanners. However, in general scale, the level of dose reduction was similar in both studies.

In the present research, the scanners used in both hospitals belonged to the same factory and because of the primary settings applied on the scanners; changes in tube current and potential were chosen regarding the capacity and limitations of the CT scanners. Due to the limited heat capacity of X-ray tubes in gantry, mostly in the helical CT scan, the radiation factors are chosen in lower levels. Therefore, generally a pitch[1] factor of 1 in the helical CT does not reduce the dose significantly [2]. However, in the current study, in hospital A the doses recorded in the helical protocols are considerably lower than the sectional protocols.

It should be noted that the scan parameters in this hospital in the helical mode are set in much lower levels, compared to the sectional mode. The doses obtained from the different protocols between hospitals A and B were assessed and compared. It was revealed that the absorbed doses of eye lenses and thyroid gland in hospital B in the standard protocol and also in optimized protocols were much lower than the absorbed dose of these organs in the exams performed in hospital A.

On the other hand, the reviewers who assessed the image quality notified that the image quality of scans was better in hospital B than hospital A. In both hospitals, the recorded doses for right and left side organs were evaluated and a minor increase was found in doses of left organs, which might be related to the starting point of tube rotation. The X-ray tube starts rotation from the left side of gantry and terminates in the same side and this factor leads in a minor rise in the absorbed dose of left side organs.

Assessment of the protocols demonstrated that in general in hospital B, the tube current is much lower (90 mAs) and the tube potential is a little higher (20 KVp) than the same parameters in hospital A. It shows that reduction in the tube current and a little increase in the voltage might result in lessened absorbed dose in significant amounts. In addition, the images quality remains unchanged and even improves in some cases. This improvement in the image quality is related to the slight increase in radiation beam energy which causes less photons to stop in the patient body. Consequently, much photons containing visual information will pass the patient body and will be absorbed by the detectors.

Quality of the resultant images was assessed and compared by the reviewers (i.e., radiologists A, B, and C, as well as the medical physics PhD), who were blinded regarding the series of scans, protocols. and each other comments. All the reviewers noted that in general changing the scan parameters had negligible effects on image quality. The exceptions in which the reduction in the image quality was significant included the protocols stage 2 for the sectional and stage 3 for the helical modes in hospital B. However, these changes in the quality were not of high importance in some special cases, such as fractures, hemorrhages, and locating cerebral VP shunts. On the other hand, in cases which need more resolution, namely tumoral conditions, Intraventricular Hemorrhages (IVHs), and Intraparenchymal Hemorrhages (IPHs), the alterations in the quality seem inappropriate.

In addition, reviewers A and C ranked the images of protocol stage 4 for the sectional mode in hospital A, stage 3 for the sectional mode, and the standard helical protocol (stage1) in hospital B as the best image qualities. In general, the quality of scans performed in hospital B was better than the scans in hospital A. In both hospitals, images in the sectional mode had a better quality than images in the helical mode.

One of the limitations of this research was using a RANDO phantom instead of real patients as the target. Because X-ray attenuation and morphologic structures in an anatomic phantom have many differences with the natural tissues in real cases. Obviously assessing the images obtained from a real diagnostic clinical scan is much more reliable, compared to the images obtained from a phantom scanning. This problem was evident in all the comments of viewers.

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[1] Pitch: The ratio of tale progress per every 360 degree rotation of tube on slice thickness

However, in an experimental study with repetitive scans it was compulsory to use an anthropomorphic phantom instead of real cases. Regarding the aim of study to assess the image quality in relation to the radiation dose, using the described method seemed to be suitable. Nonetheless, further studies to investigate the maximum possible limits of reducing the radiation doses and to find out the applicable methods of using these new parameters in clinical real cases are recommended.

According to the results of recorded doses and the comments of reviewers, reduction in the image quality was considerable but still appropriate for some special cases and such a dose reduction will possibly be practicable in assessing some special conditions, including bone fractures, air related evaluations (e.g., pneumocephalus and pneumoventricle), and severe hemorrhages in traumas. An optimized CT protocol is an admissible method to replace the standard protocol where multiple control scans are required. This is especially important in pediatric patients with a Ventriculoperitoneal shunt (VP shunt) for hydrocephalus in their brain and those who have to undergo repetitive follow up scans. However, in cases which need more attention and resolution (e.g., tumoral conditions) this dose reduction and the resultant images seem to be inappropriate.

In addition, considering the acceptable quality of resultant images and noticeable reduction in the absorbed radiation dose, we recommend this dose reduction in clinical conditions with real patient cases, especially in patients with caducity, Intraventricular Hemorrhages (IVHs), Intraparenchymal Hemorrhages (IPHs), and almost every ICHs[1]. Moreover, regarding the high radiosensitivity of children, we suggest evaluating low dose protocols in pediatric patients undergoing CT scans and trying to decrease the absorbed dose in such researches. Furthermore, for future studies we recommend to assess the effect of other scan parameters, such as pith, scan time, and slice thickness, as well as the impact of changes in these factors on radiation doses and image quality.

Conclusion

Generally, the manufacturers set the scan parameters of standard protocol on the scanners in order to obtain images with the best quality and achieve the highest diagnostic information. Moreover, scan parameters are advisedly chosen concerning the radiation protection aspects and physical characteristics and limitations of X-ray tube. However, the radiation dose can be significantly reduced without loss of quality or information, especially in some particular conditions with high contrast enhancing, such as ICHs, IVHs, ventricular shunts, and bone fractures.

This purpose can be reached by applying reasonable changes in some scan parameters in the standard head CT protocol. In the present study, it was suggested that altering the tube potential and current can diminish the ESD up to 50%. Furthermore, radiological knowledge of the operator, who executes the CT examinations and his awareness about radiation dose in scans, can help to reduce the absorbed dose significantly and realize the ALARA principle.

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[1] Intracerebral Hemorrhage

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