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Scientific Paper

Effective and organ doses from common CT examinations in one general hospital in Tehran, Iran

Daryoush KHORAMIAN[1], Bijan HASHEMI[1,a]

[1]*Department of Medical Physics, Tarbiat Modares University, Tehran, Iran*

[a]*E-mail address: bhashemi@modares.ac.ir*

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Abstract

Purpose: It is well known that the main portion of artificial sources of ionizing radiation to human results from X-ray imaging techniques. However, reports carried out in various countries have indicated that most of their cumulative doses from artificial sources are due to CT examinations. Hence assessing doses resulted from CT examinations is highly recommended by national and international radiation protection agencies. The aim of this research has been to estimate the effective and organ doses in an average human according to 103 and 60 ICRP tissue weighting factor for six common protocols of Multi-Detector CT (MDCT) machine in a comprehensive training general hospital in Tehran/Iran.

Methods: To calculate the patients' effective dose, the CT-Expo2.2 software was used. Organs/tissues and effective doses were determined for about 20 patients (totally 122 patients) for every one of six typical CT protocols of the head, neck, chest, abdomen-pelvis, pelvis and spine exams. In addition, the CT dosimetry index (CTDI) was measured in the standard 16 and 32 cm phantoms by using a calibrated pencil ionization chamber for the six protocols and by taking the average value of CT scan parameters used in the hospital compared with the CTDI values displayed on the console device of the machine.

Results: The values of the effective dose based on the ICRP 103 tissue weighting factor were: 0.6, 2.0, 3.2, 4.2, 2.8, and 3.9 mSv and based on the ICRP 60 tissue weighting factor were: 0.9, 1.4, 3, 7.9, 4.8 and 5.1 mSv for the head, neck, chest, abdomen-pelvis, pelvis, spine CT exams respectively. Relative differences between those values were -22, 21, 23, -6, -31 and 16 percent for the head, neck, chest, abdomen-pelvis, pelvis, spine CT exams, respectively. The average value of $CTDI_v$ calculated for each protocol was: 27.32 ± 0.9, 18.08 ± 2.0, 7.36 ± 2.6, 8.84 ± 1.7, 9.13 ± 1.5, 10.42 ± 0.8 mGy for the head, neck, chest, abdomen-pelvis and spine CT exams, respectively.

Conclusions: The highest organ doses delivered by various CT exams were received by brain (15.5 mSv), thyroid (19.00 mSv), lungs (9.3 mSv) and bladder (9.9 mSv), bladder (10.4 mSv), stomach (10.9 mSv) in the head, neck, chest, and the abdomen-pelvis, pelvis, and spine respectively. Except the neck and spine CT exams showing a higher effective dose compared to that reported in Netherlands, other exams indicated lower values compared to those reported by any other country.

Key words: effective dose; organ dose; computed tomography dose index (CTDI); MDCT; CT protocols.

Introduction

Based on various reports from developing/developed countries [1-5], it is well known and established that the main portion of artificial sources of ionizing radiation to human results from X-ray imaging techniques. Therefore, radiation protection legislatures are highly concerned about the long-term effects, such as cancer and genetic effects, resulted from the use of such techniques in medicine. Consequently, more attention has been paid to estimate patient doses from these radiological diagnostic procedures, especially the computed tomography (CT), recognized to be responsible for the greater contribution of population cumulative dose from such diagnostic techniques [1-5].

In 2003, a national study was conducted in England on a variety of imaging techniques based on X-ray [6]. This study found that 47% of the population dose from X-ray imaging techniques comes from CT practices while only 5% of all the X-ray exams are done by this modality. This rate has been increased to 68% of the cumulative dose by 2010 [7]. In 2013, a comprehensive research was also performed in the Netherlands to achieve the national's dose reference level and the level of doses resulted from 21 normal CT protocols [8]. The results indicated that although only 11% of various X-ray examinations are perform by CT, more than 47.5% of the national cumulative dose of this country is attributed to CT exams. In this study, the DLP and effective doses were

calculated for different protocols based on the latest tissue weighting factor proposed ion ICRP report no.103 [9]. The ratio of CT doses in the national cumulative doses reported in Norway[10], Switzerland [11] and the US [3] have been 60, 50 and 67% respectively.

In addition, to the high-doses reported from CT exams in many countries, the frequency of the use of this imaging technique is also on the rise. For example, based on a report published in 2007 [12] approximately 62 million CT examinations have been done in the USA per year. The number of CT examinations made annually in the Netherlands is reported by Van der Molen and colleagues [8]. According to this study, more than 1.16 million CT scans have just been performed in 2010 in the Netherlands. The amount of this examination reported for Ireland in 2012 has been 200,000 [13].

There are lots of similar reports [14, 15] indicating relatively a high level of doses contributed from CT exams in commutative doses, an increasing rate of the use of this modality, and finally the lack of a comprehensive study including various CT protocols used nowadays in multi detector machines. However it lasts about 10 years since the installation of a MDCT scanner in our hospital, so far, there is no dosimetry information on this scanner. Therefore, the purpose of this study was to evaluate the effective doses as well as organ doses resulted from six common CT protocols made by a modern multi detector machine in a comprehensive hospital in Tehran/Iran based the ICRP report 103 [9] and 60 and comparing our resulting effective doses, CTDI and DLP values with other reports from other countries. It's necessary to know the magnitude of such data and compare them to other studies to know where we stand in terms of radiation protection issues. Such data, as a part of an optimisation process, will help to manage radiation doses from CT examinations which routinely performed in the hospital.

Materials and methods

CT Scanner

The scanner investigated in this study has 16 Ultra-Fast Ceramic (UFC) detectors composed of 8 detectors having a width of 0.5 mm at the centre, 2 detectors with a width of 1 mm, 2 detectors with a width of 2 mm, and 2 detectors with a width of 3 mm located around central detectors as shown in **Figure 1**. This combination of detectors allows the scanner to collect data in 4 different modes of: 0.5×6, 1×6, 2×6 and 3×6 mm [16].

CT examination protocols

Six common CT protocols including the head, neck, chest, abdomen-pelvis, pelvis and spine were studied. The CT scan parameters for every protocol were acquired from ~20 patients over a period of one month. For this purpose, an appropriate questionnaire was completed by the investigator for each patient during his/her examination. To reach an estimation of the effective dose for an average normal six Iranian patient, the selected female and male patients had a weight of 45-65 and 60-80 kg respectively with an average height size leading to a normal BMI ranged from 20-25.

Dosimetry procedure

For CTDI measurement we used Barracuda multi meter and an ionization chamber model DCT-10 RS both manufactured by RTI Electronics (Sweden) with an active length of 10 cm, air volume of 4.9 cm^3, an external electrode (the wall) having an internal diameter 8 mm and a wall thickness of 0.5 mm, and a central electrode with 1 mm diameter suitable for a range of 80-150 kV which could be connected to the Barracuda multi meter providing an accurate measurement within ±5%. The Barracuda multi meter can be used to connect many ionizing probe types, including CT probes for a kV ranged from 80 to 150 kV that had a calibration factor close to 1.0.

Two head and body phantoms with a diameter of 16 and 32 cm respectively and a length of 15 cm made of polymethyl methacrylate (PMMA) with an effective atomic number of 6.6 and a density of 1.8 g/cm^3 were used for required dosimetric measurements. These phantoms have a hole in the centre and 4 holes at their peripheries (located at 1 cm from the surface) having a diameter of approximately 13 mm that could be used for placing various dosimeter types including the pencil ionization chamber, TLD rods, etc. (**Figure 2**). First, the ionization chamber was put in the central hole of the phantom during the CT exposure for every protocol with other holes filled with suitable Perspex rods and the relevant value displayed on the reader was recorded. Then the dosimeter was put in other the peripheral holes while again the rest of the holes were filled with Perspex rods.

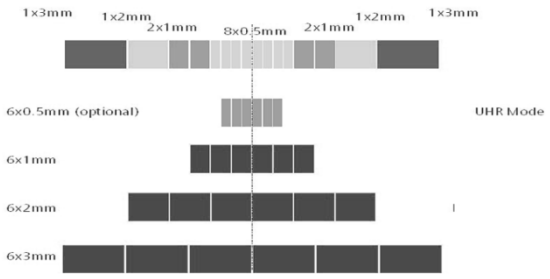

Figure 1. Detector configuration of Siemens Emotion 6 [17].

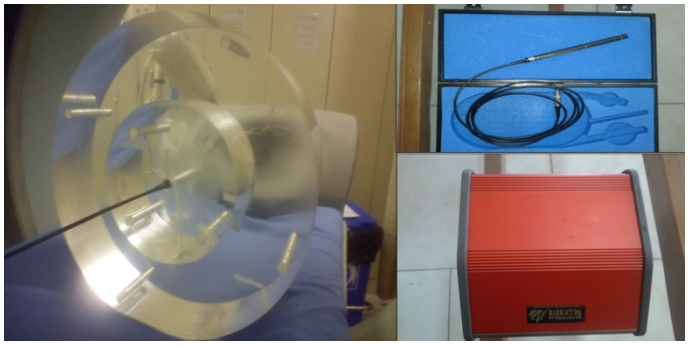

Figure 2. View of the phantom, Barracuda multi meter and ionization chamber that used in this study.

These measurements were also used to get the $CTDI_{100}$ in centre and peripheral the phantom. This procedure was repeated 3 times for every CT protocol and the average of readings was considered for it. Therefore, 15 exposures were performed for each protocol. Then the $CTDI_w$ was calculated by using the following equation:

$$CTDI_w = {}^{2}/_{3} \times CTDI_{100(periphery)} + {}^{1}/_{3} \times CTDI_{100(centre)} \quad \text{Eq. 1}$$

In which, the weighting factor of 2/3 and 1/3 are used for the peripheral and central $CTDI_{100}$ values of the head and body phantoms respectively [18]. Since CTDI is defined as the dose per unit length in *z*, its value should reduce with the increase in helical pitch. This leads to the introduction of $CTDI_{volume}$ as mentioned in **Equation 2**:

$$CTDI_{volume} = CTDI_{\mathrm{w}} \times \frac{\mathrm{n} \times \mathrm{T}}{\mathrm{L}} \quad \text{Eq. 2}$$

In which n, T and L are the number of slices, slice thickness and the amount of the CT bed movement during the imaging procedure. (n×T)/L quantity in the spiral/helical CT is known as the pitch number (p). Finally, dose created during the scan (DLP) was calculated by multiplying $CTDI_v$ by scan length (L) as shown in **Equation 3** [19,20].

$$DLP = CTDI_{volume} \times \mathrm{L} \quad \text{Eq. 3}$$

While modern CT scanners display $CTDI_v$ and DLP for each scan, but quality control tests show that the displayed values are different from the measured ones [21] as they are calculated based on only the defined CT parameters of each protocol. Therefore, we compared the displayed and measured $CTDI_v$ and DLPs for each CT exam protocol to examine whether there is a significant discrepancy between them or not.

It should to note that all the values reported in this study are in mean ± one standard deviation (1 SD) format. For $CTDI_{100}$ measurements, as we mentioned above, we repeat measurements 3 times for every CT protocol and the average of readings was considered for it (measurement standard uncertainty). To $CTDI_w$, $CTDI_v$, DLP calculation the standard deviation is one standard deviation from the mean of patient's data which presented in **Table 1**.

Effective dose calculation

Although the best way to assess organs/tissues doses are direct dosimetry by using the thermo luminescent dosimeters (TLD) and anthropomorphic physical phantoms, using this method is time consuming [22,23]. Therefore, the Monte Carlo simulation method and mathematical phantoms are used for this purpose. Hence, to calculate organs/tissues doses and also effective doses for every CT protocol the CT-Expo v2.2 Monte Carlo based program was used [24] on both of average man and woman mathematical phantoms. The weighting factors of relevant organs/tissues required to be used for calculating the effective dose based on the ICRP 60 [25] and 103 [9] reports are mentioned in **Table 2**.

Statistical analysis

To comparison of calculated and displayed values of the CTDIv and DLP we used independent samples t-test. In all cases p value of 0.05 considered as significant. Statistical analyses were performed by SPSS IBM version 21.

Table 2. Organs/tissues weighting factor based on the ICRP reports 60 and 103.

Tissue or organ	ICRP60 [1991]	ICRP103 [2007]
Gonads	0.2	0.08
Red bone marrow	0.12	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.12
Liver	0.05	0.04
Oesophagus	0.05	0.04
Thyroid	0.05	0.04
Bone surface	0.01	0.01
Skin	0.01	0.01
Brain	Remainder organ	0.01
Salivary glands	--	0.01
Remainder tissues	0.05	0.12

Table 1. The number of patients, their mean age and the average value of examination parameters undergoing six routine CT protocols.

Protocol	Gender	Patient nos.	Age ± SD	kV	mAs ± SD	Collimation	Slice thickness (mm)	Scan Length (mm) ± SD
Head	Male	11	47 ± 23	110	144 ± 30	6×3	1, 3, 6	131 ± 39
	Female	9	52 ± 17	110	154 ± 16	6×3	1, 3, 6	140 ± 12
Neck	Male	16	45 ± 17	110	146 ± 45	6×2, 6×1	1.25, 2.5, 4	305 ± 25
	Female	4	52 ± 10	110	94 ± 44	6×2, 6×1	1.25, 2.5, 4	176 ± 45
Chest	Male	11	54 ± 23	110	1296 ± 38	6×2	2.5, 5	141 ± 74
	Female	10	57 ± 14	110	107 ± 45	6×2	2.5, 5	288 ± 39
Spine	Male	10	43 ± 15	110	136 ± 11	6×2	2.5, 4	277 ± 107
	Female	10	53 ± 12	110	139 ± 18	6×2	2.5, 4	285 ± 86
Abdomen-Pelvis	Male	8	57 ± 19	110	101 ± 22	6×2	2.5, 4, 5, 8	464 ± 86
	Female	13	55 ± 9	110	141 ± 36	6×2	2.5, 4, 5, 8	474 ± 72
Pelvis	Male	9	50 ± 19	110	140 ± 43	6×2	2.5, 5	301 ± 47
	Female	11	62 ± 14	110	126 ± 29	6×2	2.5, 5	298 ± 53

Results

The average value of the $CTDI_v$ calculated was: 27.32 ± 0.9, 18.08 ± 2.0, 7.36 ± 2.6, 8.84 ± 1.7, 9.13 ± 1.5, 10.42 ± 0.8 mGy for the head, neck, chest, abdomen & pelvis, pelvis and spine CT exams respectively based on the radiological parameters used for the CT protocol performed on the patients. The dose length product (DLP) was also obtained by multiplying the relevant $CTDI_v$ by the scan length for every CT protocol. These values were compared with the relevant $CTDI_v$ and DLP average values displayed on the scanner console (**Figure 3**).

From the recorded radiation parameters used for various CT examination of every patient, the required data was obtained and put in the CT-expo 2.2 calculation software to calculate the patient effective and organs/tissues doses. Effective (based on both of the ICRP 60 and 103 reports) and organ/tissue (based on the ICRP 103 report) doses calculated are shown in **Figures 4** and **5** respectively.

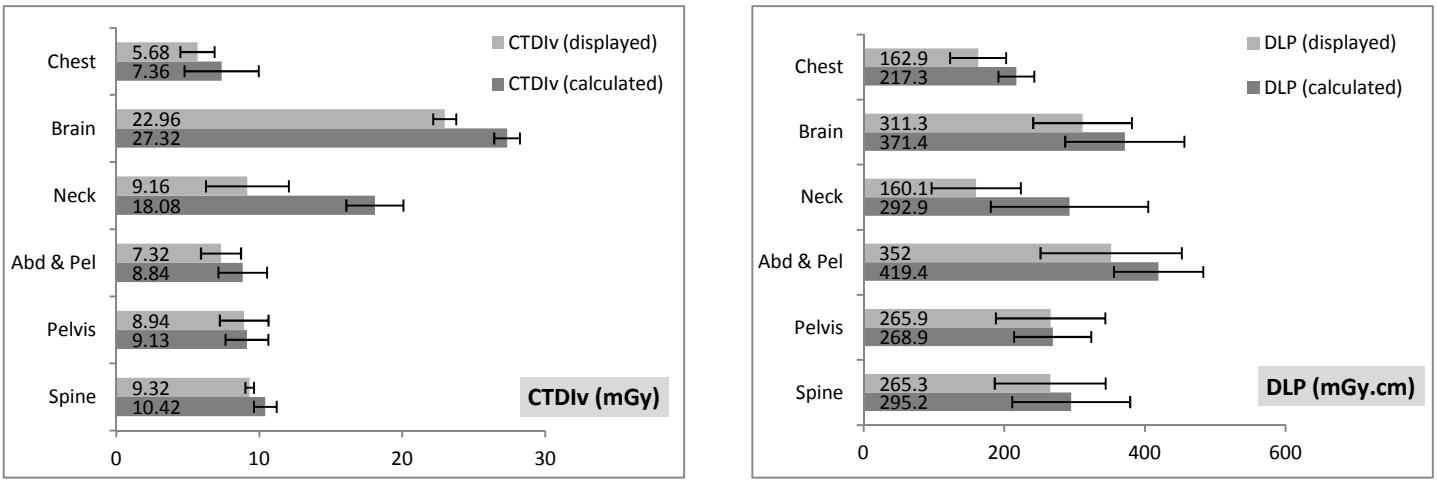

Figure 3. Comparing the calculated and displayed CTDIv and DLPs values (mean ± 1SD) for every CT examination based on the radiological parameters of various CT protocols performed on the patients.

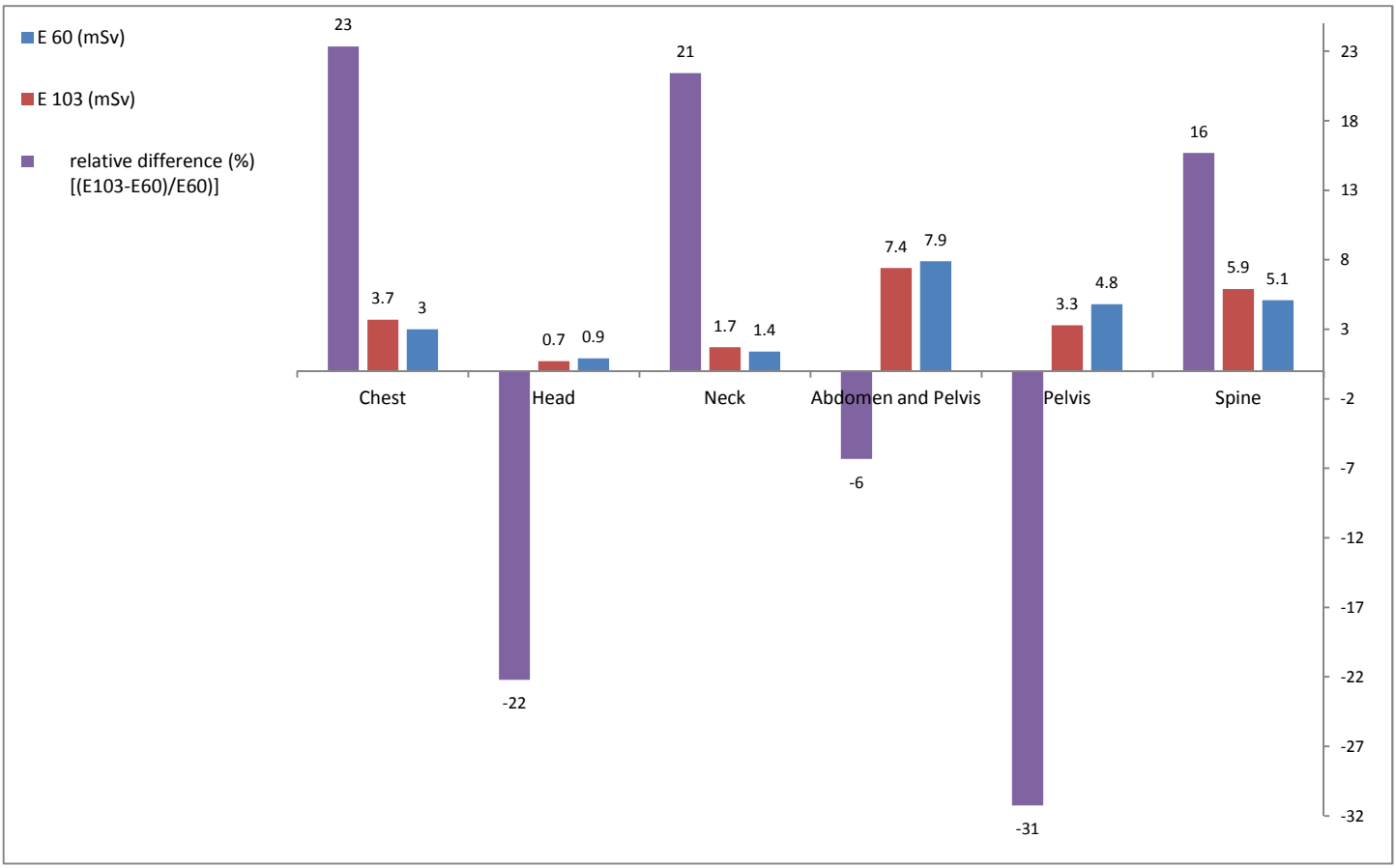

Figure 4. Estimated effective dose based on patients' radiological CT examinations and the ICRP reports 60 and 103 recommended organs/tissues weighting factors and the relative values [(E103-E60)/E60)]. E: the effective dose

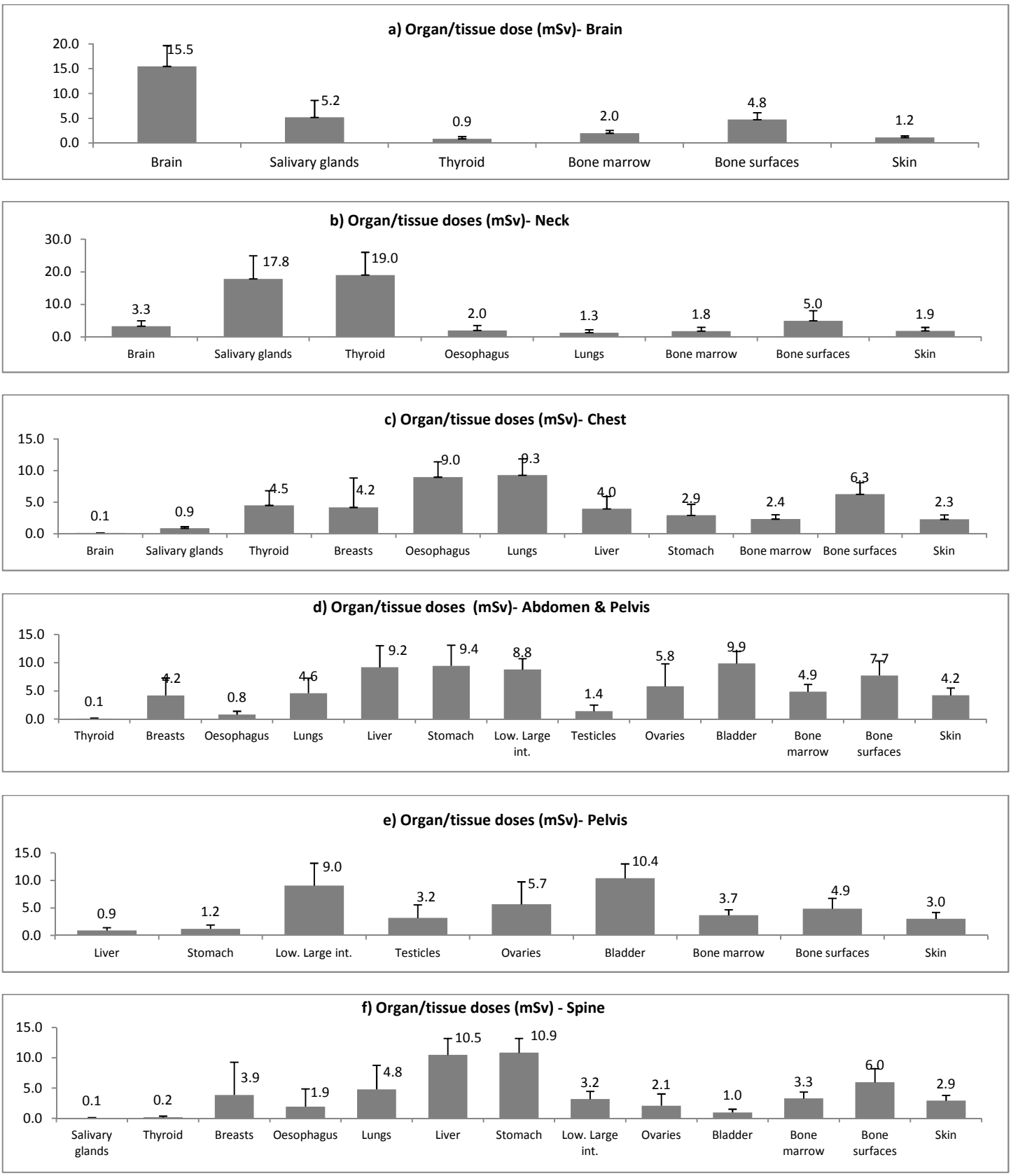

Figure 5. Calculated organs/tissues doses from various CT examination protocols: a: Brain, b: Neck, c: Chest, d:Abdomen-pelvis e: Pelvis, f: Spine scans (mean of male and female). Bar lines indicate one standard deviation.

Table 3. Comparison of our measured CTDIv (mGy) and DLP (mGy·cm) values with other reports.

	Head		Neck		Chest		Spine		Pelvis		Abdomen-Pelvis	
	CTDIv	**DLP**	**CTDIv**	**DLP**	**CTDIv**	**DLP**	**CTDIv**	**DLP**	**CTDIv**	**DLP**	**CTDIv**	**DLP**
The UK (2003) [6]	-	931	-	-	13	576	-	-	-	-	14	550
The UK (2011) [7]	58	890	-	-	11	500	24	525	-	-	13	645
EC (2004) [7]	60	990	-	-	12	430	-	-	-	-	16	726
Italy (2014) [27]	64	1086	-	-	12	453	34	617	-	-	15	733
Ireland (2010) [13]	66	940	-	-	9	390	-	-	-	-	12	598
NSRD (2010) [8]	-	813.3	-	329.9	-	320	-	308.2	-	332	-	-
Wales (2001) [29]	-	731	-	-	-	663	-	-	-	646	-	-
This study	27.32	371.4	18.08	292.3	7.36	217.3	10.42	295.2	9.13	268.9	8.84	419.4

Table 4. Comparison of our calculated effective doses (mSv) for the most common CT protocols with those reported in other countries.

		Head	Neck	Chest	Spine	Pelvis	Abdomen-Pelvis
According to ICRP 60	The UK (2011) [7]	1.6	3	5.8	6	6	-
	EC (2008) [7]	1.95	2.7	5.35	7.04	7.65	-
	UNSCEAR (2008) [7]	2.4	-	7.8	5	9.4	-
	Tanzania (2006) [28]	6.2	-	8.4	4.9	15.7	-
	East Anglia (2004) [21]	1.7	3.2	3.5	6.4	-	9.2
	This study	0.7	1.5	3.05	4.25	4.25	6.15
According to ICRP 103	Netherland (2013) [8]	1.5	1.7	4.6	4.3	4.6	-
	NSRD (2010) [8]	1.5	1.7	4.6	4.3	4.3	-
	HPA (2008) [8]	1.4	3	6.6	6.9	6	-
	This study	0.65	1.85	3.45	4.9	3.05	5.8

Discussion and conclusion

In this study the $CTDI_v$, DLP and effective dose were calculated for six frequent CT examinations of a 6 MDCT machine at a general hospital in Tehran/Iran. Our results showed that the highest and lowest $CTDI_v$ values belong to the head and chest scans respectively. Although the CTDIv of the head was more than that of the abdomen-pelvis scan, the later protocol indicated a higher DLP value due to its higher scan length (481.00 ± 60.34 mm) relative to that of the head scan (141.2 ± 10.53 mm). The maximum organ doses delivered from the head, neck, chest, abdomen-pelvis, pelvis, and spine CT examinations belonged to the brain (15.5 mSv), thyroid (19 mSv), lungs (9.3 mSv), bladder (9.9 mSv), bladder (10.4 mSv), stomach (10.9 mSv) respectively.

Comparing our calculated $CTDI_v$ and DLP values for various CT protocols against the values reported by other investigators [6,8,13,26-27,29] for other countries indicate lower values for all the protocols (**Table 3**). Such differences are resulted from the using of different scan protocols which affect on radiation dose. Among the factors affecting on radiation dose the tube current-time, tube potential, slice collimation, and the scan length are most important which considered in this study. The selection of appropriate scanning parameters such as tube current-time, tube potential, slice collimation and etc, which affects the $CTDI_v$, and the scan length, which affects the DLP, can decrease patients' doses significantly. In **Table 4** our calculated effective doses obtained for every CT protocol are also compared with the similar protocols reported [7,8,21,28] for other countries. From the data presented in this table, it can be noted that our effective doses for the head, chest, pelvis and abdomen-pelvis scan are less than other reports. However, our neck and spine protocols show higher effective doses than those reported for the Netherlands [8]. **Figure 4** indicates the effective dose values resulted from ICRP 60 and ICRP 103 are different and relative differences are 16, -31, -6, 21, -22 and 23 per cent for spine, pelvis, abdomen-pelvis, neck, head and chest scans, respectively, which also have reported by Christner et al [30] (-39, 14 and -7 per cent for head, chest and abdomen-pelvis scans, respectively).

Except the head and neck protocols, there were no significant differences between the calculated and displayed $CTDI_v$ values. The maximum amount of differences noticed between the calculated and displayed $CTDI_v$ values belonged to the neck scan. This can be attributed to the wrong consideration of the shoulders in the field of view of the neck scan when estimated by the CT machine console.

References

[1] Durand DJ, Mahesh M. Understanding CT dose display. J Am Coll Radiol. 2012;9(9):669-671.

[2] Saltybaeva N, Jafari ME, Hupfer M, Kalender WA. Estimates of effective dose for CT scans of the lower extremities. Radiology. 2014;273(1):153-159.

[3] Deak PD, Smal Y, Kalender WA. Multisection CT protocols: Sex-and age-specific conversion factors used to determine effective dose from dose-length product. Radiology. 2010;257(1):158-166.

[4] Haddadi G, Mehdizadeh S, Haddadi MB, Meshkibaf MH. Evaluation of Absorbed Dose of Critical Organ in Rando Phantom under Head, Abdomen and Pelvis Spiral CT Scan by Thermo Luminescent Dosimetery - TLD. J Fasa Univ Med Sci. 2011;1(3):131-135.

[5] Zarb F, McEntee M, Rainford L. Maltese CT doses for commonly performed examinations demonstrate alignment with published DRLs across Europe. Radiat Prot Dosimetry. 2012;150(2):198-206.

[6] Shrimpton P, Hillier M, Lewis M, Dunn M. Doses from computed tomography (CT) examinations in the UK-2003 review: National Radiological Protection Board. Chilton, UK; 2005.

[7] Hart D, Wall B, Hillier M, Shrimpton P. Frequency and collective dose for medical and dental x-ray examination in the UK, 2008: Health Protection Agency. Chilton, UK; 2010.

[8] van der Molen AJ, Schilham A, Stoop P, et al. A national survey on radiation dose in CT in The Netherlands. Insights Imaging. 2013;4(3):383-390.

[9] ICRP Publication 103, Valentin J. The 2007 recommendations of the international commission on radiological protection: Elsevier Oxford; 2007.

[10] Friberg EG, Widmark A, Hauge IHR. National collection of local diagnostic reference levels in Norway and their role in optimization of X-ray examinations. Norwegian Radiation Protection Authority, Osteras, Norway. 2008.

[11] Treier R, Aroua A, Verdun F, et al. Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels. Radiat Prot Dosimetry. 2010;142(2-4):244-254.

[12] Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. N Engl J Med. 2007;357(22):2277-2284.

[13] Foley SJ, McEntee MF, Rainford L. Establishment of CT diagnostic reference levels in Ireland. Br J Radiol. 2014;85(1018):1390-1397.

[14] Saravanakumar A, Vaideki K, Govindarajan K, Jayakumar S. Establishment of diagnostic reference levels in computed tomography for select procedures in Pudhuchery, India. J Med Phys/Association of Medical Physicists of India. 2014;39(1):50-55.

[15] Matsunaga Y, Kawaguchi A, Kobayashi K, et al. Effective radiation doses of CT examinations in Japan: a nationwide questionnaire-based study. Br J Radiol. 2016;89(1058):20150671.

[16] Somatom Emotion Technical Specifications. available at: http://www.healthcare.siemens.com/.

[17] CT systems and hardware. 2002. available at: http://www.impactscan.org/.

[18] Pantos I, Thalassinou S, Argentos S, et al. Adult patient radiation doses from non-cardiac CT examinations: a review of published results. Br J Radiol. 2011;84(1000):293-303.

[19] Hsieh J, Computed tomography: principles, design, artifacts, and recent advances, 2009: SPIE Bellingham, WA.

[20] Mutic S, Palta JR, Butker EK, et al. Quality assurance for computed-tomography simulators and the computed-tomography-simulation process: report of the AAPM Radiation Therapy Committee Task Group No. 66. Med Phys. 2003;30(10):2762-92.

[21] Yates SJ, Pike LC, Goldstone KE. Effect of multislice scanners on patient dose from routine CT examinations in East Anglia. Br J Radiol. 2004;77(918):472-478.

[22] Ngaile JE, Msaki P. Estimation of Patient Organ Doses from Computed Tomography Examinations in Tanzania. J Appl Clin Med Phys. 2006;7(3):80-94.

[23] Lee E, Lamart S, Little MP, Lee C. Database of normalised computed tomography dose index for retrospective CT dosimetry. J Radiol Prot. 2014;34(2):363-388.

[24] Stamm G, Nagel HD. [CT-expo--a novel program for dose evaluation in CT]. RoFo: Fortschr Röntgenstr. 2002;174(12):1570-1576.

[25] ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection: Elsevier Health Sciences; 1991.

[26] Shrimpton MCH, Meeson S, Golding SJ. Doses from Computed Tomography (CT) Examinations in the UK – 2011 Review.

[27] Palorini F, Origgi D, Granata C, et al. Adult exposures from MDCT including multiphase studies: first Italian nationwide survey. Eur Radiol. 2014;24(2):469-483.

[28] Muhogora W, Nyanda A, Ngoye W, Shao D. Radiation doses to patients during selected CT procedures at four hospitals in Tanzania. Eur J Radiol. 2006;57(3):461-467.

[29] Hiles PA, Brennen SE, Scott SA, Davies JH. A survey of patient dose and image quality for computed tomography scanners in Wales. J Radiol Prot. 2001;21(4):345.

[30] Christner JA, Kofler JM, McCollough CH. Estimating Effective Dose for CT Using Dose–Length Product Compared With Using Organ Doses: Consequences of Adopting International Commission on Radiological Protection Publication 103 or Dual-Energy Scanning. AJR Am J Roentgenol. 2010;194(4):881-889.