Radiation dose of head and abdomen-pelvis computed tomography examinations using size-specific dose estimate

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► ***Original article***

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Received: January 2020
Final revised: August 2021
Accepted: August 2021

Int. J. Radiat. Res., January 2021; 19(1): 185-189

DOI: 10.52547/ijrr.20.1.28

Keywords: *Head imaging, neuroradiology, abdominal imaging, SSDE, TG 204, TG 220.*

ABSTRACT

Background: Concern about radiation risk of computed tomography (CT) scan as a diagnostic modality has increased in recent years. Diagnostic reference levels (DRLs) is one of the tools to optimizing radiation dose of patients. CTDIv (Volume Computed tomography dose index) and DLP (Dose Length product) are used for assessment of DRLs. The CTDIv under/overestimate the patient dose. AAPM has introduced SSDE (Size-specific dose estimates) for estimation of patient. In this study, the DRLs of head and abdomen-pelvis CT examinations of adults is determined using CTDIv, DLP and SSDE. ***Materials and Methods***: 680 CT examinations of head and abdomen-pelvis were collected from PACS (Picture archiving and communication system) in Imam Khomeini and Mostafa Khomeini hospitals. The D_{eff}, CF and SSDE calculated using AAPM TG-204 and TG-220. Statistics analysis calculated using SPSS version 18. ***Results***: For abdomen-pelvis third quartile of $CTDI_V$, SSDE and DLP was 9.96, 13.58 and 527 and values of 27.62, 26.79 and 402.90 are determined for head, respectively that are lower than national DRLs. Also, calculated conversion factor (CF) for head and abdomen-pelvis was 0.97 ± 0.75and 1.45 ± 0.17, respectively. ***Conclusion***: DRLs were lower than other studies in this study. Using the AEC (Auto Exposure Control) and different kVp in this hospitals can help optimization of patient dose. The SSDE must be calculable by radiographers to more accurate estimation of patient dose using CFs.

INTRODUCTION

Nowadays, CT scan is known as a powerful modality for imaging of bone, soft tissue, and vessels. Application of CT scan for diagnosis of neurologic, gastrointestinal, urinary, traumatic injuries and other diseases is widely increased. Computed Tomography (CT) is responsible for 49% of cumulated absorbed dose from all medical exposures according to report No. 160 of National Council on Radiation Protection & Measurements (NCRP) in 2009, although it is accounted just for 16% of all medical imaging examinations [(1)]. The CTDIv and DLP are tow dosimetric index for comparison the scanner output exposure in a special phantom with the 16 or 32 cm diameter and can't be considered as the patient absorbed dose [2].

Today's researchers are interesting to using SSDE index for determining the DRLs in CT examinations [1, 3, 4]. The SSDE is more accurate than CTDIv for estimation of patient dose considering the patient size [5]. This index is produced by AAPM in 2011 year and suggested the physicist use the patient effective diameter (D_{eff}) for estimation of patient radiation dose (AAPM TG NO.204) [5]. Also, AAPM completed this method by introducing the water-equivalent diameter (D_w) in 2014 year (AAPM TG NO. 220) [6]. We can obtain a body diameter that is equal to the diameter of poly-methyl methacrylate (PMMA) phantom with using the mean CT number in transverse section area of body [6].

For the first time Imai *et al.* reported the DRLs based on SSDE in pediatric patients by measuring the geometric size [3]. Just two studies have investigated the CT scan DRLs based on SSDE in Iran. The first study carried out by *Mehdipour et al.* in Shiraz in the year 2019 year for adults [7] and second study was for pediatric patients for chest, head and abdomen-pelvis in Kermanshah city by Mohammadbeigi *et al.* [1]. Although the study of Mehdipour *et al.* was in adult but DRLs can be determined as "local" and even in every imaging center according to ICRP. If LDRLs (Local DRLs) be higher than National DRLs the optimization of protocols, education of radiographers or equipping of imaging centers is necessary [8].

There isn't any study for DRLs among all medical imaging modalities (Nuclear medicine, CT scan, Fluoroscopy, Angiography, Radiography and Mammography) in Ilam city. As we mentioned in first paragraph the CT scan is responsible for 49% of all medical exposure; thus, for the first DRLs establishment in Ilam we focused on CT scan as the more important modality in medical radiation exposures. Many studies have established the CT scan DRLs in different countries [9-12]; also same studies carried out in Iran [1, 7, 9, 13, 14]. Sohrabi *et al.* study is the most greatest study in Iran that was carried out in 157 scanner for assessment the radiation dose of head, sinus, chest, and abdomen-pelvis CT examinations to establishment the national DRLs [15].

However, there wasn't any information about CT radiation dose from Ilam, Semnan and Golestan provinces in their study. Also, there wasn't any information about using SSDE and calculation the conversion factors (CF) in adults' head. Thus, the radiation dose of abdomen-pelvis and head examinations is determined based on SSDE.

MATERIALS AND METHODS

Hospitals & CT scanners

There are two hospitals in Ilam city, one of the western city of Iran, that both hospitals were included in this study. Imam Khomeini hospital has a 16 slice Siemens scanner (Siemens Healthcare, Somatom Emotion, Germany) and Mustafa Khomeini has a 16 slice Philips CT scanner (P hilips Healthcare, Brilliance, Netherland). All two hospitals were equipped with PACS and we had access to CT examination data in PACS viewer (PACSPLUS, South Korea).

Patients and examinations

We assessed head and abdomen-pelvis CT examinations as the most common and high exposure examinations(1). The head examinations were done in a sequential mod and single phase and abdomen-pelvis scans were performed in spiral mod. There wasn't any AEC in Philips scanner for head examination, also this option didn't select by radiographers in Siemens scanner. In contrast, the AEC was applied in both scanners for abdomen-pelvis examination.

Data acquisition

Information of protocols, patient diameters and dosimetric indexes were collected from February 2019 to September 2019. Patients with deformity of scanned region and trunked examinations were excluded. Examination data including demographic, age, sex, CTDIv, DLP, kVp, mAs, mA, Pitch and diameters were recorded in a single sheet for every patient.

Diameters measurement and SSDE calculation

The D_{eff} is obtained using caliper tool in PACS viewer (figures 1 and 2]. Also the mild-sagittal line in mild slice of whole scan considered for measurement the anterior-posterior diameter and mild-coronal line in mild-slice used for measurement the lateral diameter. D_{eff} calculated using the equation (1) that is recommended by the AAPM Task Group Report NO. 204 (5):

$$D_{eff} = \sqrt{(\text{AP diameter}) \times (\text{Lateral diameter})} \quad (1)$$

Conversion factors (CF) calculation

We need CF factor for calculation the SSDE. Equations 2 and 3 are acquired by experimental and Monte Carlo simulation for calculation the CF that are described in AAPM TG-204. CF describes difference between head or body size with default phantom size of scanner.

For head CT scans:

$$CF=1.8748\times e^{-0.0387D_{eff}} \quad (2)$$

For abdomen-pelvis:

$$CF=3.7043\times e^{-0.0367D_{eff}} \quad (3)$$

Where; the D_{eff} is effective diameter of the body in selected slice.

According to the AAPM TG-204 and TG-220 the SSDE can be obtained by multiplying the CF to $CTDI_V$ (equations 4 and 5).

The SSDE calculating equations recommended by AAPM Task Group Report NO.220 [(6)]:

$$SSDE= f_{size}^{32x} \times CTDI_V^{32} \quad (4)$$

$$SSDE= f_{size}^{16x} \times CTDI_V^{16} \quad (5)$$

Where; the f_{size}^{32x} is CF of abdomen-pelvis, f_{size}^{16x} is CF of 16-cm phantom.

DRLs determining

Median and third quartile of CTDIv, SSDE and DLP were considered for establishment of DRLs [1].

Statistical analysis

All statistical analysis is done using SPSS software (version 18.0, SPSS Inc., Chicago, IL). Kruskal-wallis as non-parametric test was used to compare the un-normal parameters with more than three groups and one-way ANOVA test used to compare parameters with normal distribution with more than three groups. Also, Mann-Whitney U test was used for comparison the tow un-normal distribution. Confidence interval of 95% was considered for all statistical tests.

[DOI: 10.52547/ijrr.20.1.28]

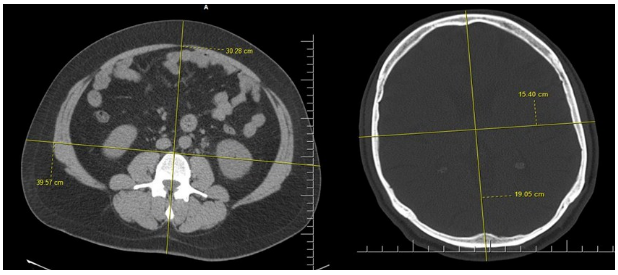

Figure 1. Measurement the lateral and anterior-posterior diameter of abdomen-pelvis and head region using caliper in PACS viewer.

RESULTS

Number of 680 CT examinations (including 340 head examinations and 340 abdomen-pelvis examinations) were obtained. In overall, the 36.5% of subjects were female and 63.5% were male. In head examination, 40.3% of subjects were female and 59.7% of subjects were male, also average age of patients was 48.27 ± 18.95. We evaluated number of 170 cases (50%) of every examination from Imam Khomeini hospital and 170 (50%) cases from Mostafa Khomeini hospital. Mean values of age, conversion factor, lateral diameter, AP diameter, D_{eff}, CTDIv, DLP and SSDE for head and abdomen-pelvis CT examinations are listed table 1. Also the comparison of present DRLs with other studies based on third quartile and median are summarized in table 2. Mean ± SD of CT parameters that are applied in every examination are listed in table 3, separately.

Table 1. Mean ± SD values of age, conversion factor, lateral diameter and AP diameter, Deff, CTDIv, DLP and SSDE for head and abdomen-pelvis examination.

	Examination	
	Head	**Abdomen-pelvis**
	Mean ± SD	Mean ± SD
Age (years)	48.31 ± 19.53	48.18 ± 18.30
Lateral Diameter (cm)	15.36 ± 0.75	31.41 ± 3.26
AP Diameter (cm)	18.96 ± 0.75	21.26 ± 3.28
Effective Diameter (cm)	17.06 ± 0.75	25.82 ± 3.21
Conversion Factor	0.97 ± 0.75	1.45 ± 0.17
CTDIv (mGy)	25.38 ± 3.05	8.30 ± 2.44
DLP (mGy.cm)	389.83 ± 35.81	435.76 ± 140.36
SSDE (mGy)	24.59 ± 3.02	11.73 ± 2.73

Note: AP = Anterior-to-posterior; CTDIv = Computed Tomography Dose Index; DLP = Dose Length Product, SSDE = Size-specific Dose Estimate.

Table 2. Comparison the DRLs of present study with other studies for CTDIv, DLP and SSDE.

	Abdomen-pelvis			Head		
	CTDIv	**SSDE**	**DLP**	**CTDIv**	**SSDE**	**DLP**
Median						
Present Study	8.40	12.12	437.8	26.08	24.43	387.0
America 2017 [12]	12	14	586	49	-	849
NDRLs 2017 [15]	9.73	-	447.22	44.31	-	472.50
Third quartile						
Present Study	9.96	13.58	527.0	27.62	26.79	402.90
America 2017 [12]	18	19	877	28	-	1011
Rafsanjan 2019 [7]	12.4	-	627.2	-	-	-
NDRLs 2017 [15]	13.84	-	643.60	57.32	-	751.20
Switzerland 2010 [11]	15	-	650	65	-	1000
France 2012 [19]	17	-	800	65	-	1050
Irland 2012 [10]	10.4	-	845	66.2	-	940

Note: CTDIv = Volume Computed Tomography Dose Index; DLP = Dose Length Product, SSDE = Size-specific Dose Estimates.

Table 3. Mean ± SD of CT parameters that are applied in every examination, separately.

Examination								
Brain				**Abdomen-pelvis**				
Rot. Time (S)	Thick (mm)	mAs	KVp	Rot. Time (S)	Pitch	Thick (mm)	mAs	KVp
1.02 ± 0.50	6.90 ± 1.23	189.07 ± 5.23	114.97 ± 5.01	0.55 ± 0.05	1.24 ± 0.12	5.00 ± 0	101.76 ± 57.33	124.62 ± 5.34

Note: Rotation Time; Thick = Thickness; Note: Rot. Time = Rotation Time.

DISCUSSION

Because of body sensitivity to X-ray and probability of genetic defects, assessment the radiation dose and determining the DRLs in CT examinations to management of patient dose is necessary. Also, considering that the CTDIv and DLP have underestimation to 270% [5] thus using the SSDE is more suitable. Because the CT scan has the highest accumulated radiation dose among all medical exposures it seems the SSDE will be placed on the CT console as a tools to establishment of DRLs and optimization of protocols in future; thus upgrading and using of this index is necessary. In this study for the first time the DRLs established for head and abdomen-pelvis CT examinations and compared with national DRL and other same studies in Iran [7, 15].

Auto exposure control (AEC) adjusts the tube current according the attenuation data from localizer [16]. The AEC was inactive for both hospitals for head examinations; in fact, this option that called DoseRight in Philips systems was not active for sequential head examinations. However, although head protocol of Siemens scanner is equipped to AEC as a name CareDose, but the radiographers didn't choose this option in their routine clinical usage. Inactivation of this option cause to same exposure for different head size and homogeneity. Thus, CTDIv fall out of proportional to the X-ray attenuation in whole scan length and unnecessary dose increased in some slices and image quality decreases in some other slices [17]. The conversion factor obtained 0.97±0.02 for head examination, in overall. Huda and Tipinis calculated the CF 0.93 for adults head examinations in age group of 15-18 years old [18] that is lower than

[DOI: 10.52547/ijrr.20.1.28]

our results. Main differences of Huda and Tipinis [18] study that cause to obtain lower values for CF in head examination is the type of calculated diameter, in fact they calculated D_w for head but we calculated D_{eff}. Another effective factor for this differences is the age, in other words the age groups of Huda and Tipinis [18] just was 15-18 but our study patients had the range of 18-97 years old. Calculated CF was close to one, this means average head size of patients is about 16 cm and a default phantom with size of 16 cm is suitable for estimation of patients' radiation dose in adults' head, thus the difference between CTDIv and SSDE will be very low. Every CF factor is lower than one, the estimated CTDIv in CT scanner is higher than patient absorbed dose.

For abdomen-pelvis CT examinations the AEC was active in both hospitals, thus the output exposure was adapted according to attenuation data of localizer. Using three various kVp in Siemens (80, 110 and 140) and Philips (90, 120 and 140) scanner devices can be very helpful for dose optimization. We except radiographers choose various kVp in patients with large size or small size to accuracy of optimization[2]. However, there wasn't difference between the kVp of three age groups; and same kVp was used for all patient in both hospitals. The conversion factor is obtained 1.45 ± 0.17 for abdomen-pelvis that using it we can eliminate the effect of body size on estimation of patient absorbed dose [table 2]. This factor show the CTDIv can be different 45% with SSDE in abdomen-pelvic region. This diversity originated from that the default phantom for abdomen-pelvis is 32 cm but the mean values of measured D_{eff} is 25.5 cm and this is cause of high difference of CTDIv with SSDE.

Second and third quartile of DLP, CTDIv and SSDE was lower than all previous studies are listed in table 3 (America [12] , Switzerland [11], France [19], Irland [10], Rafsanjan [7] and Iran national DRLs [15]). Although this values shows the scanners exposure of ilam was lower than other studies, but this isn't mean imaging standards is higher in Ilam; because evaluation of image quality and diagnostic value of images is necessary for comparison of imaging standards between different imaging centers [19]. The third quartile values of DLP, CTDIv and SSDE was lower than other studies (Switzerland [11], France [19], Irland [10], Rafsanjan [7] and Iran national DRLs). The DRLs of head examination was 48% lower than NDRLs in this study and DRLs of abdomen-pelvis was 31% of NDRLs. Scanner designing quality is the most effective factor on the patient dose; it itself includes some technical parameters such as filtration type, isocenter distance, collimation, detector efficiency, X-ray tube efficiency as well as reconstruction algorithm. Second effective factor on the patient dose is scan protocol which is selected by the technologist that involves mAs, kV_p, pitch number, and slice thickness [20]. Thus, variation of these factors is cause of different patient doses in different CT scanners and medical imaging centers. Third effective factor is related to the patient's body including geometry (size) and tissues homogeneity [6].

Our study had some limitations, in this study we used D_{eff} for calculating the CFs and SSDE in chest region, however, using the D_w cause to more accurate estimation of patient dose with considering the tissue density and heterogeneity [21]. The D_w uses the average CT number of cross section of body and tissue attenuation to make more accuracy in dose estimation. Another limitation was the low number of hospitals included in this study, but as we mentioned in materials and methods the Ilam city just had two hospitals and this study gives a suitable overview about dose management.

CONCLUSION

Although DRLs was lower than other studies but optimization of protocols especially AEC using and choosing various kVp for different body size is necessary. CFs showed that difference between abdomen-pelvis size and 32-cm phantom affect the patient dose estimates. The SSDE must be calculable easily by radiographers of scanner to assessment more accurate patient dose.

ACKNOWLEDGEMENTS

None.

Ethical Consideration: The study is done accordance to the supervision of the ethics committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran.

Conflict of interest: All authors declared that there isn't any conflict of interest.

Founding: No Found.

Author contribution: All authors contributed to the study conception and design. (M.A.): Data collection, drafting the manuscript; (A.M.), (M.B.) and (K.K.): study design: (M.B.) and (K.K.): Statistical analysis; (M.B.): Final revision of manuscript and supervision All authors read and approved the final manuscript.

REFERENCES

1. Mohammadbeigi A, Khoshgard K, Haghparast A, Eivazi MT (2019) Local drls for paediatric ct examinations based on size-specific dose estimates in Kermanshah, Iran. *Radiat Prot Dosimetry,* ***186****(4): 496–506*.
2. Strauss KJ, Goske MJ, Towbin AJ (2017) Pediatric chest CT diagnostic reference ranges. *Development and Application,* ***284****(1): 219-27*.
3. Imai R, Miyazaki O, Horiuchi T, Kurosawa H, Nosaka S (2015) Local diagnostic reference level based on size-specific dose estimates: assessment of pediatric abdominal/pelvic computed tomography at a Japanese national children's hospital. *Pediatr Radiol,* ***45****(3): 345-53*.
4. Abdollahi H, Shiri I, Salimi Y, Sarebani M, Mehdinia R, Deevband MR, *et al*. (2016) Radiation dose in cardiac SPECT/CT: An estimation of and effective dose. *European J Radiology,* ***85****(12): 2257-61*.
5. Boone J, Strauss K, Cody D (2014) Size-specific dose estimates (SSDE) in pediatric and adult body CT examinations: report of AAPM task group 204. American Association of Physicists in Medi-

cine website. https://www.aapm.org/pubs/reports/detail.asp?docid=143 (2014).
6. Medicine AAoPi (2014) Use of SSDE water equivalent diameter for calculating patient size and size-specific dose estimates (SSDE) in CT. *The Report of AAPM Task Group, **220**: 6–23*.
7. Mehdipour A, Parsi M, Khorram FS (2019) Patient dose survey based on size-specific dose estimate and acceptable quality dose in chest and abdomen/pelvis ct examinations. *Radiat Prot Dosimetry, **185**(2): 176-182*.
8. Anam C, Haryanto F, Widita R, Arif I, Dougherty G (2016) A fully automated calculation of size-specific dose estimates (SSDE) in thoracic and head CT examinations. Conf. Ser.; *J Phys, **694** (12).*
9. Najafi M, Deevband MR, Ahmadi M, Kardan MR (2015) Establishment of diagnostic reference levels for common multi-detector computed tomography examinations in Iran. *Australasian Physical & Engineering Sciences in Medicine, **38**(4): 603-9*.
10. Foley SJ, McEntee MF, Rainford LA (2012) Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol, **85**(1018): 1390-7.*
11. Treier R, Aroua A, Verdun FR, Samara E, Stuessi A, Trueb PR (2010) Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels. *Radiat Prot Dosimetry, **142** (2-4): 244-54*.
12. Kanal KM, Butler PF, Sengupta D, Bhargavan-Chatfield M, Coombs LP, Morin RL (2017) U.S. Diagnostic Reference Levels and Achievable Doses for 10 Adult CT Examinations. *Radiology, **284**(1): 120-33*.
13. Toori AJ, Shabestani-Monfared A, Deevband M, Abdi R, Nabahati M (2015) Dose assessment in computed tomography examination and establishment of local diagnostic reference levels in Mazandaran, Iran. *Journal of Biomedical Physics & Engineering, **5**(4): 177*.
14. Granata C, Origgi D, Palorini F, Matranga D, Salerno S (2015) Radiation dose from multidetector CT studies in children: results from the first Italian nationwide survey. *Pediatr Radiol, **45**(5): 695-705*.
15. Sohrabi M, Parsi M, Mianji F (2018) DEtermination of national diagnostic reference levels in computed tomography examinations of iran by a new quality control-based dose survey method. *Radiat Prot Dosimetry, **179**(3): 206-15*.
16. Healthcare P (2009) The Brilliance iCT and DoseWise strategies. *Healthcarepapers, **2009**: 1-24*.
17. Angel E, Yaghmai N, Jude CM, DeMarco JJ, Cagnon CH, Goldin JG, *et al.* (2009) Dose to radiosensitive organs during routine chest CT: effects of tube current modulation. *AJR Am J Roentgenol, **193**(5): 1340-5*.
18. Huda W and Tipnis SV (2016) Doses metrics and patient age in CT. *Radiat Prot Dosimetry, **168**(3): 374-80*.
19. Roch P and Aubert B (2013) French diagnostic reference levels in diagnostic radiology, computed tomography and nuclear medicine: 2004-2008 review. *Radiat Prot Dosimetry, **154**(1): 52-75*.
20. Koller C, Eatough J, Bettridge A (2003) Variations in radiation dose between the same model of multislice CT scanner at different hospitals. *The British Journal of Radiology, **76**(911): 798-802*.
21. Rezaei M, Mohammadbeigi A, Khoshgard K, Haghparast A (2017) CT images and radiotherapy treatment planning of patients with breast cancer: a dataset. *Data in brief, **13**: 390-5*.

[DOI: 10.52547/ijrr.20.1.28]

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