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Establishing local Diagnostic Reference Level for Adult Patients in Computed Tomography Examination in Kohgiluyeh and Boyer-Ahmad province

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ABSTRACT

Introduction: Nowadays, the absorbed dose of patients is on the rise due to the widespread use of computed tomography (CT) during the diagnosis process. Patients' doses for similar procedures are very different due to diversity in scanners and protocols. Hence, the purpose of this study was to determine the diagnostic reference levels for routine CT scan procedures in Kohgiluyeh and Boyer-Ahmad province, Iran.
Material and Methods: In this study, four common brain, sinus, chest and abdominopelvic procedures (overall 200 scans) in spiral mode were selected in five CT centers of Kohgiluyeh and Boyer-Ahmad province, Iran. Next, the doses were measured in head and body phantom, based on scan parameters of ten patients in each procedure at each centers (200scans). Then, the third quartile of $CTDI_w$ was considered as the diagnostic reference dose. Finally, considering the pitch factor and the mean scan length in each protocol, the diagnostic reference level values based on the third quartile of the dose length product (DLP) and volume CTDI ($CTDI_{vol}$) were determined.
Results: The dose reference level values according to $CTDI_w$ third quartile in the brain, sinus, chest and abdominopelvic procedures were 39.82, 20.88, 14.10 and 17.07 mGy, respectively. In terms of dose length product, the diagnostic reference level values in the above procedures were determined to be 702.75, 243.90, 422.02, 865.62 mGy.cm, respectively.
Conclusion: The DRLs of the $CTDI_W$, DLP and $CTDI_{vol}$ of brain and sinus scans calculated in this study, were comparable to other provinces, national DRL and eight other countries. However, the same quantities for the chest and abdominopelvic scans showed higher values compared to the mentioned studies, suggesting lowering mAs and increasing pitch number for patient's dose optimization. In some centers to preserve image quality, it is necessary to optimize radiation conditions, especially for chest and abdominopelvic scans.

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Introduction

Due to development of hardware and imaging techniques, patients absorbed dose is increasing. Amongst different imaging procedures, computerized scanning has the highest dose level [1]. Nowadays, the use of CT scans as a diagnostic tool has been increased dramatically, and its over useand misuse can increase the overall risk of cancer [2]. For some reasons, including variations in the type of scanners and the protocols (in terms of radiation factors, scan time, pitch factor, patient body thickness, device geometry) the patient dose for a similar procedure varies widely [3]. Therefore, it is necessary to use diagnostic reference levels as a dose optimization tool. The purpose of introducing DRL in diagnostic imaging is to help optimize the radiation protection of patients, while maintaining the quality of diagnostic images. DRL is a suitable measure to identify procedures with abnormal high radiation dose values. It can also be used to suggest appropriate strategies for reducing the dose to an acceptable level for comparing different protocols and to find cases where the dose is high [4]. The aim of this study was to determine and present diagnostic reference levels of absorbed dose in CT scan centers of Kohgiluyeh and Boyer-Ahmad province, Iran.

Materials and Methods

According to previous studies, it seems that there are many protocols being used in different centers and countries, which differ in type and structure. Two commonly used methods are "direct dose measurement method" and "data collection method [5]. Accordingly, this study was the first to be conducted at the hospitals in Kohgiluyeh and Boyer-Ahmad province, which requires a comprehensive review in order to provide the necessary bases for radiation protection. This study was

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conducted at five CT scan centers in Kohgiluyeh and Boyer-Ahmad province, Four most common CT scan procedures (brain, sinuses, chest and abdominopelvic) of the adult age group were considered, and overall 200 scans was scrutinized. The quality control tests were performed for all scanners from the five selected hospitals by experts in one year, and accredited by the quality service provider according to the International Atomic Energy Agency (IAEA) regulations. Questionnaires were designed to record the necessary information, consisting of three parts. In the first part, the following information was recorded; type of the CT scan, CT manufacture, number of detector slices, and the available dosimetry parameters. In the second part, the patient information (age, gender, and weight) and scan parameters were recorded, (such as, kVp, mAs, pitch factor, slice thickness, and scan length). In the third part, the results of dosimetry tests were recorded separately for the head and body phantoms from the central and lateral holes. At the end of each CT exam, the values of the two dose quantities parameters ($CTDI_{vol}$ & DLP) were recorded by all CT machines. The questionnaires were collected at the centers. The $CTDI_w$ values of ten patients (five males and five females) were collected for each routine protocol from each hospital. The average of the $CTDI_w$ of the ten patients in each protocol was used to design the adjusted protocol, which produced the same $CTDI_w$ on CT console. Each routine protocol was designed, using the mean $CTDI_w$, and then the radiation dose value of the protocol was measured, using a dosimeter and proper phantom.

Dose measurement

A red piranha 657 dosimetry kit (RTI Electronics, Mölndal, Sweden) was used in this study. This comprehensive dosimetry kit can measure all CTDI parameters (CTDI, $CTDI_w$, $CTDI_{vol}$), DLP, geometric efficiency and full width at half maximum (FWHM) of the dose profile. This is done, using the ocean dosimeter software installed on a laptop or tablet, and it is connected to the Piranha dosimeter *via* the Bluetooth. It is measurable and observable in real time and can be used in all diagnostic X-ray techniques including simple radiography, CT scanning, fluoroscopy and mammography. A pen ionization chamber is used for dosimetry in CT scans. This chamber has an active length of 100 mm, and is designed for dosimetry and quality control in CT scans. Two cylindrical phantoms made from PMMA with a length of 15 cm were used. The smaller phantom (16 cm in diameter) was the head phantom and the larger phantom (32 cm in diameter) was the body phantom. These cylinders have a hole in the center and four holes in the surroundings at 3, 6, 9 and 12 o'clock positions. Since $CTDI_W$ measurement is considered as the dosimeter quantity, the method of dose calculation is unique to the measurement and calculation of this quantity (Equation 1) [6, 7].

$$CTDI_W = \frac{1}{3}CTDI_P + \frac{2}{3}CTDI_C \quad (mGy) \tag{1}$$

where peripheral CT dose index ($CTDI_P$) is the average of the four CTDI measured in the phantom environment at 3, 6, 9 and 12 o'clock and central CT dose index ($CTDI_C$) is the measured dose in the central phantom cavity [7].

$CTDI_{vol}$ was introduced by the International Electro Technical Commission (IEC) in 2001 for spiral multi slice scanners, which determines the dose value in a tube circulation. This quantity considers the variation of the dose value in the z-axis, when the pitch value is not equal to one, and the dose unit is expressed in mGy.

$$CTDI_{Vol} = \frac{CTDI_W}{Pitch} \quad (mGy) \tag{2}$$

For spiral scanners (multi or single-slice), the value of $CTDI_W$ is equal to $CTDI_{VOL}$, if the pitch number is equal to one.

The DLP is used to calculate the entire test dose; the dose unit expressed in mGy.cm, which is defined in the equation 3.

$$DLP = CTDIvol \times scan\ length \tag{3}$$

To measure CTDI in the head and body phantoms, it must be placed in head holder and on the top of patient's table, respectively. In order to calculate the $CTDI_c$ value, the ionization chamber (pen dosimeter) is inserted into the central hole and the other holes are filled with phantom rods. To calculate the $CTDI_p$ value, the chamber is placed in one of the peripheral holes, respectively, and the other holes are filled with phantom rods. The dosage readings are recorded in four positions, and the mean of the four readings is considered as $CTDI_p$. For maximum accuracy, when the detector is turned on, the first measurement is not recorded. In this study, each measurement was performed twice and in case of gross error and discrepancy, the measurement was repeated for the third time and the mean of the two nearest numbers was recorded as the correct dose [8]. The dosimetry kit (Piranha 657) consists of pen dosimeter, and electrometer used in this study was validated for calibration, using another kit of the same model. It is worth mentioning that the pen dosimeter was calibrated by the Karaj secondary standard dosimetry laboratory (SSDL) in Iran. Then, for brain and sinus procedures, head phantom, and for chest and abdominopelvic procedures, body phantom was used in all the mentioned research centers. The Piranha dosimetry kit was connected to a tablet *via* Bluetooth and was able to measure CTDI, $CTDI_W$ and $CTDI_{VOL}$ per scan, using ocean 2014 software. The phantoms were accurately positioned at the isocenter point of the device based on the AP and lateral scanograms and with the help of the naked eye and adjustable lasers. Eventually, the selected protocol parameters from the average value of scanning ten patients in each center were accurately recorded on the ocean software, and then scans and dosimetry were performed. The obtained CTDI values were recorded in each hole. Finally, $CTDI_W$ was calculated from Equation 1. Dosimetry was performed on five CT scanners located in the five mentioned centers in the province, and the third quartile of CTDIw was determined as the DRL of the CT scan. The products of the CTDIs volume ($CTDI_W$/pitch) of four scans, and mean scan length of ten patients in each scan were considered as DLPs of four routine protocols in each center. Then, the third quartile of DLP was determined as the DRL of DLP in the five centers. In Table 2, the values of the third quartile of $CTDI_w$ and DLP are suggested as the reference dose for the mentioned protocols in the adult age group in Kohgiluyeh and Boyer-Ahmad province.

Results

Table 1 shows the protocol details for all the five examined hospitals. Scan parameters for the same examinations are different among hospitals, especially in hospital E, where scanner was a dual detector CT relative to the 16 slice scanners (centers A to D). Therefore, the scan parameters of this device were very different from the other scanners in this study, such as; kVp, mAs, and collimation (beam width). On the other hand, the routine kV_p was used to scan a typical patient in scanner A (Siemens, Emotion was 130 for four scan protocols, but the selected kVp in three other scanners were 120 (B and C: Philips, D: Toshiba). The relationship between dose and kVp is nonlinear; therefore, in spite of high mAs selection in the three mentioned scanners, the measured $CTDI_W$ of scanner A in three out of four protocols was higher than the other scanners (Table 1) (Figure 1). Also, scan length is different among CT centers, especially for chest and abdominopelvic procedures (Table 1).

Diversity of scan parameters selection led to different $CTDI_w$ and DLP in four protocols amongst the five CT scanners in this study. The $CTDI_w$ values presented in Figure 1 were obtained, using phantom for CT scans of the adult age groups in Kohgiluyeh and Boyer-Ahmad province. The closeness of $CTDI_w$ of brain scan in two centers (B and C) was due to identical scan parameters selection. There was a clear change in the dose values measured in the phantom; since different mAs setting in the sinus test, results in a significant difference in $CTDI_w$ values.

Table 1. CT protocols used for adults at the five centers. All five protocols were taken in spiral mode and by one phase.

Center	Exam	Thickness (mm)	L (mm)	Pitch	mAs	Collimation (mm)	Rotation time	kVP
A	Brain	8	120	1	320	16	1.5	130
	Sinus	6	100	0.8	135	19.2	1	130
	Chest	5	280	0.8	114	19.2	0.6	130
	Abdomen pelvic	5	425	0.8	125	19.2	0.6	130
B	Brain	5	128	0.563	400	12	0.5	120
	Sinus	5	88	0.813	200	12	0.5	120
	Chest	3	277	0.813	200	24	0.5	120
	Abdomen pelvic	3	423	0.813	146	24	0.75	120
C	Brain	5	126	0.567	400	12	1	120
	Sinus	5	90	0.813	100	12	0.5	120
	Chest	3	282	1.063	93	24	0.5	120
	Abdomen pelvic	3	420	0.938	191	24	0.75	120
D	Brain	5	140	0.938	160	16	0.75	120
	Sinus	3	105	0.688	76	16	0.75	120
	Chest	5	270	1.438	156	16	0.75	120
	Abdomen pelvic	5	430	0.938	240	16	0.75	120
E	Brain	5	125	1	200	10	1	110
	Sinus	5	98	1	200	10	1	110
	Chest	8	275	1.45	101	10	0.8	110
	Abdomen pelvic	10	415	2	78	10	0.8	110

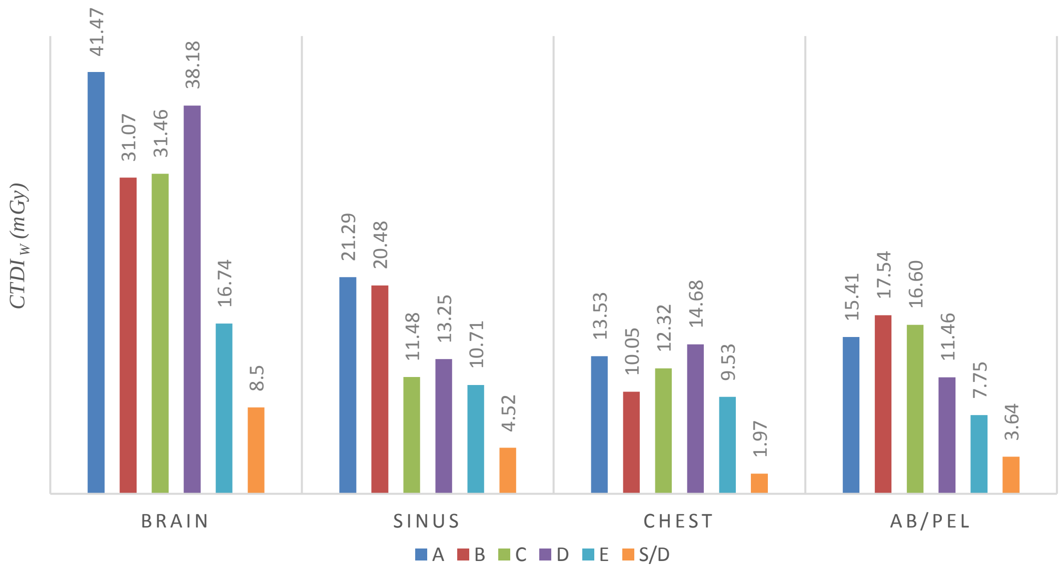

Figure 1. CTDIw chart measured for all spiral examinations in the five CT centers

Table 2. DRL (Based on CTDIW third quartile) in adult age group in Kohgiluyeh and Boyer-Ahmad Province

Study region	CTDIw (mGy)				
	DRL (Third Quartile)	Mean	Minimum	Maximum	Standard Deviation
Brain	39.82	31.38	16.74	41.47	8.5
Sinus	20.88	15.44	10.71	21.29	4.52
Chest	14.10	12.02	9.53	14.68	1.97
Abdomen/Pelvis	17.07	13.75	7.75	17.54	3.64

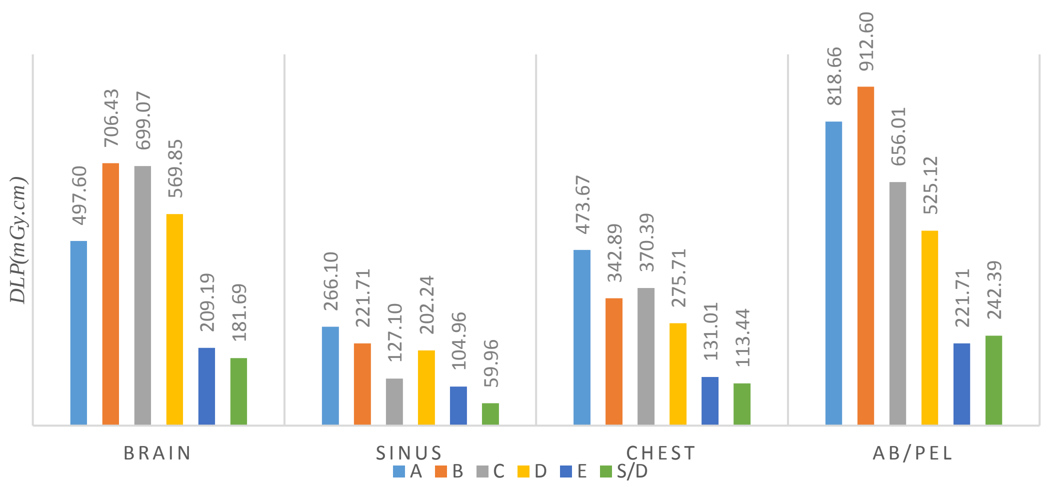

Figure 2. DLP chart for adult age group in Kohgiluyeh and Boyer-Ahmad Province

In addition, for the chest and abdominopelvic scans, the standard deviations (SD) of the CTDI$_w$ values of the five scanners are smaller than SD of the brain and sinus scans. In these scans, the differences in calculated CTDI are based on scan parameters; mAs, kVp, beam width (collimation), and type of scanner (Table 2).

Given that the third quartile of CTDI$_w$ is determined as the reference dose of CT scans, the table 2 indicates the third quartile of this quantity as the reference dose of these procedures in the adult age group in Kohgiluyeh and Boyer-Ahmad province. As the figure 1 shows, the highest values obtained in each center are related to the brain.

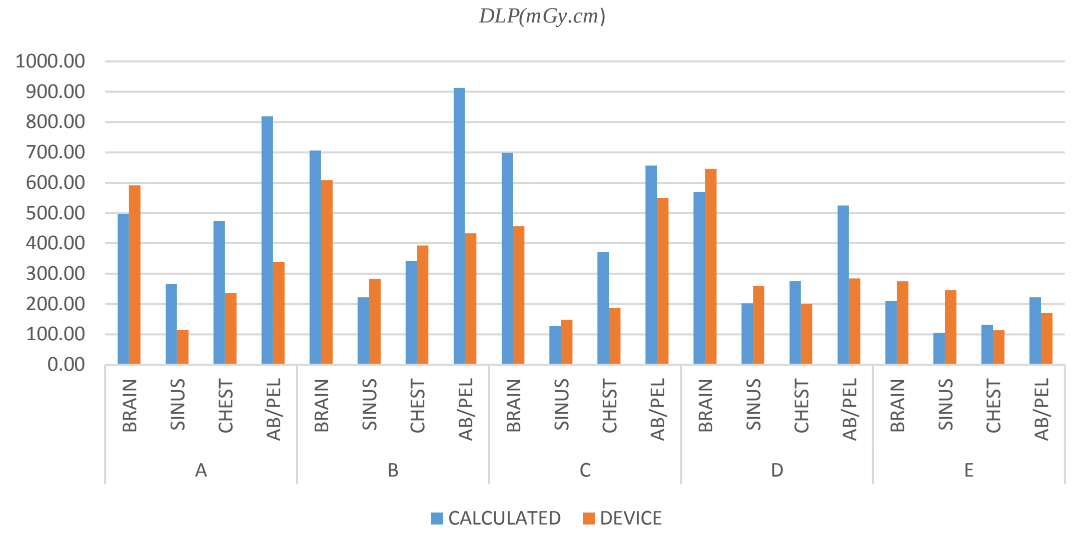

Figure 3. Comparison of calculated DLP in this study (blue column) with DLP provided by CT scan devices (red column) at the end of the protocol

Since the DLP parameter depends on the value of $CTDI_W$, the pitch factor and the scan length, the high DLP values are related to the abdominopelvic exams in all five hospitals, because of high scan length. However, in all hospitals, except E, the higher $CTDI_W$ values of brain scan caused high DLP values, despite low scan length (Table 1& Figure 2).

The comparison between the calculated DLP and DLP values provided by CT machines shows that the DLP values were overestimated by the scanners software itself in 11 out of 20 tests performed in these 5 centers. The main reason for the observed difference was the different method of dose calculation between calculated and machine provided DLP in both approaches (Figure 3). It is due to, CTDI measurement in this study based on selected technical parameters, which produced average $CTDI_{vol}$ used for scan of ten patients in each four procedures in phantoms. But machine provided $CTDI_{vol}$ acquired in head and body phantoms in the manufactures with defined technical parameters, such as kVp and mAs for each scan. Therefore, the product of different $CTDI_{vol}$ with the same scan length leads to different DLP.

Discussion

DRL as a level used in medical imaging is necessary to indicate whether, in routine conditions, the dose to the patient in a specified medical imaging is unusually high or unusually low for that procedure. Determination of DRL, allows policy makers to aware any machine or protocols which do not meet the ALARA (as low as reasonably achievable) principle, thus enabling to provide the acceptable quality images with the low level of radiation to the patient.

Determining DRL is a necessary tool for optimization of dose, and should not be used as a dose limiting factor. The DRL also used as a periodic process for further optimization [9]. Therefore, this study designed to survey the DRL in routine CT procedures in Kuhgiluyeh and Boyer-Ahmad province compared with other surveys in Iran and eight other countries. In this regard, the DRL in the terms of $CTDI_w$, $CTDI_{vol}$, and DLP were measured for the first time in comprehensive study in the province for optimization of patient dose.

In most of the five scanners in the mentioned centers, mAs used in brain scans were higher than mAs used in other spiral scans. The dosimetry in the low diameter of the phantom of the head results in greater dose uniformity, and dose distribution in a smaller volume than the body phantom [7]. For these reasons, radiation dose in head procedures is higher in comparison with other exams. According to the Table 3, the DRL of $CTDI_w$ value of brain in this study was lower than the DRL of three other provinces of Iran, but due to high level of mAs (320-400) for brain CT in the three centers (A, B and C); it could be optimized, if image quality was not influenced. In addition, due to usage of low pitch number (<1) in the centers (B, C & D), the obtained $CTDI_{vol}$ of brain was higher than $CTDI_w$, but compared to international DRL of $CTDI_{vol}$ calculated for adults (58.1 mGy) [10], the obtained DRL of CTDIvol was lower in our study (55mGy). Therefore, increasing the pitch number could decrease the $CTDI_{vol}$ and optimize the dose. Also, the DRL of $CTDI_{vol}$ and DLP values of the brain scan were compared with other countries (Table 3).

Table 3. Comparison of DRLs based on the third (DLP&CTDIV) quartiles in this study with those calculated in other countries

Abdomen/Pelvic		Chest		Sinus		Brain		
CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	CTDIv	DLP	
20	865	15	422	26	244	55	703	This study 2020
16	781	13	469	-	-	56	962	USA 2017
13	650	10	350	14	250	46	850	France 2017
15	745	12	610	-	-	60	1000	UK 2014
20	1000	15	550	-	-	85	1350	Japan 2015
15	700	10	350	8	200	60	850	Germany 2016
-	-	8.5	290	-	-	53	962	Belgium 2016
15	650	15	450	25	350	65	1000	Switzerland 2010
16	760	14	480	52	605	67	1055	Greece2015

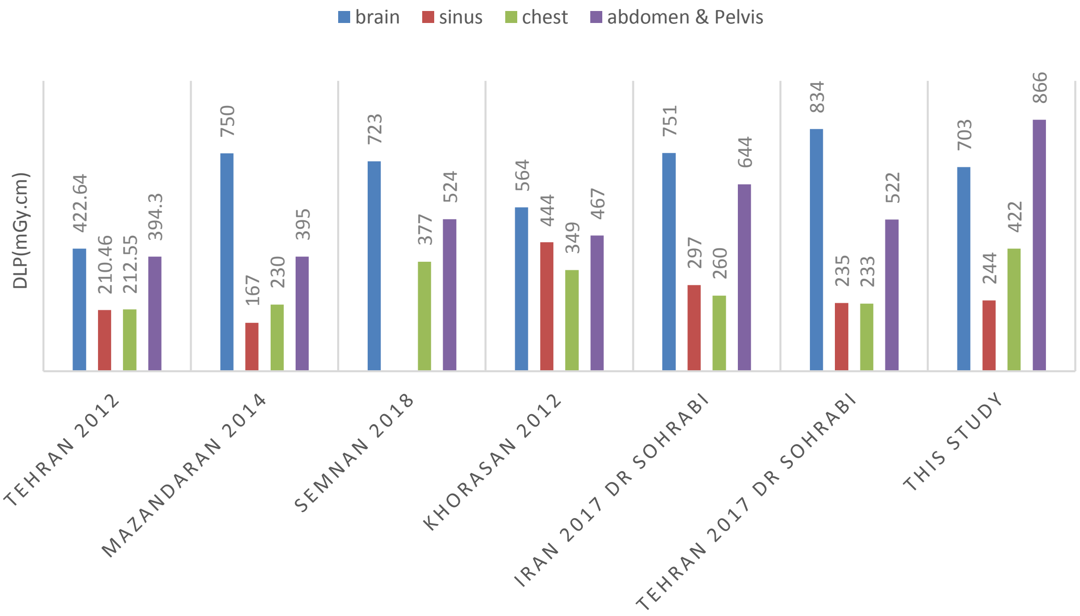

Figure 4. DRL (third quartile of DLP) in this study and NDRL (Dr. Sohrabi Iran) and other provinces [5, 17-22]

Table 4. Amounts of DRL in Kohgiluyeh and Boyer-Ahmad province in comparison with other provinces of Iran [18-21]

EXAMS	CTDIw				
	Semnan 2018	Isfahan 2014	Mazandaran 2014	Tehran 2012	This study 2020
Brain	46.1	28.76	59.5	50.87	39.82
Sinus	-	26.86	17	38.27	20.88
Chest	13.8	12.9	7.8	8.05	14.10
Abdomen/Pelvic	14.9	12.85	11	9.11	17.07

Surveys in the US, France, England, Japan, Germany, Belgium, Switzerland, and Greece, 2015 to 2017, and DRL values were determined based on DLP and $CTDI_{vol}$ third quartiles [11-16]. The results of these surveys are shown in Table 4. The 75 percentile of the brain $CTDI_{vol}$ of this study was lower than six countries and only higher than France and Belgium; 46 and 53 mGy, respectively. The brain scan length in this study was in the range of 120-140 mm, consequently the high DRL of DLP of brain pertained to $CTDI_{vol}$. Nevertheless, this quantity in Kouhgyluyeh and Boyer-Ahmad (703 mGy.cm) was lower than four Iranian provinces, National DRL (NDRL) (Figure 4) and eight countries (Table 3).

The DRL (based on $CTDI_{vol}$) of sinus was similar to Switzerland, higher than Germany and France and half of the Greece (Table 3). The DRL (based on DLP) of sinus in this study was higher than three provinces, but lower than Khorasan province and NDRL (Figure 2). The mean scan length of the sinus protocols in the five centers was calculated to be 94 mm, which is in the reasonable anatomic range, and that is why, the values of DRL (based on DLP) in this study are lower than France, Switzerland and Greece. In addition, reduction of DRL (based on DLP) was achievable by mitigation of $CTDI_{vol}$, and not the scan length. If the pitch number could not be manipulated by the operator, due to high subject contrast of Sinus (high difference of CT number of air and soft tissue); reduction of the mAs could diminish the $CTDI_{vol}$, which led to decrease patient dose in the five CT centers of the province.

The $CTDI_w$ of the sinus CT in the centers A and B was calculated to be higher than the other centers in this study, which pertained to high mAs used in these two centers. The DRL ($CTDI_w$ based) of sinus CT was calculated 20.88 mGy, which were 1.8 and 1.2 times less than the Tehran and Isfahan provinces, and 1.2 times more than the Mazandaran, respectively. The least DRL (based on $CTDI_w$ of four protocol belonged to the chest CT in the five centers (14.1 mGy), but in comparison with other provinces, it rated first (Table 4).

The pitch number in chest CT of three centers out of the five was less than unit (0.8), which leads to high $CTDI_{Vol}$ (15 mGy) in this study. Also, in comparison with international DRL of $CTDI_{vol}$ of six countries out of eight (8.5-13 mGy), the DRL (based on $CTDI_{Vol}$) was higher, which led to increasing patient dose. On the other hand, the 3rd quartile of DLP of our study (422 mGy) was lower than mean DRL of eight countries (450mGy) (Table 3), shows that scan length was in reasonable range. Therefore, decreasing the dose should be applied with reduction of the $CTDI_{vol}$ and $CTDI_W$, by increasing pitch, and decreasing mAs and collimation, respectively, especially in the four CT centers with 16 slice scanner (A-D).

The third quartile based on $CTDI_w$ of abdominopelvic CT in the five centers (17.07 mGy), was 1.15 to 1.55 times higher than the same quantity in the four provinces (Table 4). Also, the high DRL (based on $CTDI_{vol}$) of the procedure was comparable with seven out of eight countries (Table 3). This may be due to using low pitch number (<1) used in four centers out of five. Also, in comparison with DRL of DLP with four provinces and NDRL (DLP), the 3rd quartile of DLP (866mGy.cm) was 1.66-2.19 and 1.3 times higher, respectively. These comparison shows that the protocol of abdominopelvic CT should be optimized, especially for pitch number and scan length.

Conclusion

High absorption dose indices reported in several general centers of the Kohgiluyeh and Boyer-Ahmad province were compared with other centers. The DRLs of the $CTDI_W$, $CTDI_{vol}$ and DLP of brain and sinus scans calculated in this study were comparable to other provinces, national DRL and eight other countries. However, the same quantities for the chest and abdominopelvic scans showed higher values compared to all the above mentioned studies, suggestive of lowering mAs and increasing pitch number for optimization of the patient dose. In order to preserve image quality, sometimes it is necessary to optimize radiation conditions, especially for chest and abdominopelvic scans.

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