Determination of Diagnostic Reference Level (DRL) in Common Computed Tomography Examinations with the Modified Quality Control-Based Dose Survey Method in Four University Centers: A Comparison of Methods

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ABSTRACT

Background: The diagnostic reference level (DRL) is measured with different methods in the common Computed tomography (CT) exams, but it has not been measured through the size-specific dose estimate (SSDE) method in Iran, yet.

Objective: This study aimed to calculate the local DRL (LDRL) using the new quality control-based dose survey method (QC) and patients' effective diameter (MQC) and compare them with a data collection method (DC) as well as local national DRLs (NDRL).

Material and Methods: In this cross-sectional study, LDRL, based on the third quartile of volumetric computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP) values, was calculated for the four common CT examinations in four CT scan centers affiliated with Shiraz University of Medical Sciences by DC, QC and MQC methods. The $CTDI_{vol}$ of each patient for each CT exam calculated with three methods was compared with paired t-test. Also, the LDRL using MQC method was compared with other national DRL studies.

Results: There was a significant difference between the $CTDI_{vol}$ values calculated with MQC and QC in all four examinations ($P < 0.001$). The LDRL based on $CTDI_{vol}$ obtained by the MQC method for head, sinus, chest, abdomen, and pelvis were (50, 18, 15, 19) mGy, respectively, and the calculated DLP values were also (735, 232, 519, 984) mGy.cm.

Conclusion: In MQC, LDRL based on $CTDI_{vol}$ was calculated with a mean difference percentage of (19.2 ± 11.6)% and (27.1 ± 8.1)% as compared to the QC and DC methods, respectively. This difference resulted from the use of the SSDE method and dose accuracy in the QC dose survey.

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Keywords

Diagnostic Reference Levels; Multidetector Computed Tomography; Quality Control-Based Dose Survey Method; Size-Specific Dose Estimate; Body Mass Index

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Introduction

Computed tomography (CT) is a high- and precision and speed cross-sectional imaging technique, used increasingly due to technological advances such as the spiral CT scan technique [1]. The

number of CT exams increases by 10%-50% every year and they account for approximately 49% of the collective dose of patients undergoing medical imaging in America [2]. In Iran, the exact number of CT exams and the collective dose is not known, but the number of CT devices increased by 100% in Fars Province within 15 years (2000-2015). Meanwhile, the number of these devices increased by 175 percent in Shiraz, the capital of Fars Province with a population standing at 1.7 million (6.5 CT scan per one million people in 2013). In the aforementioned period, most conventional and single-slice devices were replaced with dual-slice and Multi-Detector CT (MDCT) devices in the new institutions and teaching hospitals [3]. Therefore, the collective dose must have increased due to the use of CT scans in Shiraz.

Increasing the collective dose in society due to the use of CT Scans has increased a lifetime attributable risk (LAR) of cancer [4]. Diagnostic reference level (DRL) was introduced in 1996 by International Commission on Radiological Protection (ICRP) as a reference tool to protect patients from the possible effects of radiation, optimize the dose their doses, and obtain high-quality images for diagnosis with minimum radiation and patient protection in medical imaging [5]. Therefore, DRL was introduced by ICRP for dose optimization rather than dose limitation for patients, and its use was approved by the European Union [6], the American College of Radiology (ACR) [7], and the International Atomic Energy Agency (IAEA) [8].

Three methods or a combination of three methods have been used in the calculations of DRL [9,10]: the direct method (Di), the data collection method (DC), and the quality control-based dose survey method (QC). The Di method uses direct dose measurement in the head and body phantoms based on parameters of protocols used in the CT machine. In the DC method, the scan parameters and the dose indices displayed on the CT device console are collected by the questionnaires, use to measure the DRL. Both methods are time-consuming and costly. Regarding the QC method, proposed by Parsi et al. [11], it is claimed that due to the more accurate measurement of the $CTDI_w$ calculated through the quality control reports, the DRL was calculated with more validity than the DC method [12]. Considering the effective diameter of the patient, introduced as an important parameter when the dose was measured based on reports no. 204 of the American Association of Physicists in Medicine (AAPM-204) [13], this study used the size-specific dose estimate (SSDE) technique introduced in the aforementioned report and was recommended by ICRP for DRL measurements [14]. Given the lack of a comprehensive study to determine DRL for common CT exams at Shiraz University centers, the present research aimed to determine the Local DRL (LDRL) for the common CT exams using the DC, QC, and modified quality control method, hereinafter referred to as (MQC), for four university centers in Shiraz.

Material and Methods

This cross-sectional study was conducted from February 2020 to July 2020 in four CT scan centers affiliated with Shiraz University of Medical Sciences (Namazi, Shahid Faghihi, Shahid Chamran, and Emtiaz hospitals). These centers were selected due to the large number of patients and the diversity of the CT exams performed daily. A total of eight CT scanners were involved in this project: three 16-slice devices, one 8-slice device, three 2-slice devices, and one 128-slice device.

Calculating DRL with the DC and QC Methods

In the DC method, for each common CT exam, including the head and sinuses without contrast, and the chest, abdomen, and pelvis (abdomen/pelvis) with contrast, ten patients over the age of 18 years (five men and five women) with a body mass index (BMI) of

21.2-27.6 kg/m^2 for men and 20.2-27.1 kg/m^2 for women were selected. The weight and height of patients before the exams were measured using a special scale (Azmed AZ 200LP) and the patient's BMI was displayed on the device console. If the patient's age and BMI were within the standard range for data entering, the informed consent of the patient was obtained and the information was recorded. Each patient's scan information was directly extracted from the scanner protocol. This information included the scan length, miliamper second (mAs), kilovoltage (kVp), pitch number, and X-ray beam collimation. Afterward, the third quartile of $CTDI_{vol}$ and DLP [9] of patients displayed on the scanner console in all four examinations was calculated as LDRL using the DC method. The quality control examination has to be performed annually for each CT scanner according to the protocol suggested by the National Radiation Protection Department (NRPD) of the Atomic Energy Organization of Iran to evaluate the weighted computed tomography dose index ($CTDI_w$) in the air and the head and body phantoms ($CTDI_{w.H/B}$). In this study, all of the annual quality control reports of eight scanners were carefully examined to ensure they are equal to the IAEA [15] standard in each experiment with tolerance error of below 20%. Two 2- and 8-slice scanners had incomplete documents. The dosimetry was repeated using a phantom and a Piranha 657 dosimeter (RTI Electronics, Sweden) to complete the research. The $CTDI_{w.H/B}$ values and the scan parameters, including mAs, kVp, the collimation width, along with the slice thickness for each scanner were extracted from the quality control dosimetry reports of the same device. The normalized weighted computed tomography dose index value, $nCTDI_{w.H/B.ref}$ was used as the reference for the calculation of $nCTDI_{w.H/B}$ of all the head and body exams for each scanner. This dose index value, $nCTDI_{w.H/B}$ is calculated by placing the reference of kilovoltage value (U_{ref}) used in the same report and the patient protocol kilovoltage value (U), t in the Brix formula [16]:

$$\boldsymbol{nCTDI_{w.H/B} = nCTDI_{W(H/B.ref)} . k_{OB} . (\frac{U}{U_{ref}})^{2.5}} \quad (1)$$

where $\boldsymbol{k_{OB}}$ is the correction coefficient of collimation determined by the scanner type, and is calculated using the ratio of the number of the row and the width of the reference detector, the detector used in the examination, and the collimation X-ray overbeaming [16]. Afterward, the volume computed tomography dose index, ($CTDI_{vol(H/B)}$), for each type of exam (head or body) was calculated via the following equation:

$$\boldsymbol{CTDI_{vol(H/B)} = \frac{1}{Pitch} . nCTDI_{w(H/B)} . Qel} \quad (2)$$

In Equation 2, Qel represents mAs in the implemented protocol, and the pitch number shows the ratio of the CT couch motion in a gantry rotation to the width of the collimated beam. The DLP was calculated as follows based on Equation (3):

$$\boldsymbol{DLP = CTDI_{vol(H/B)} . L} \quad (3)$$

After calculating $CTDI_{vol}$ and DLP for ten patients in each head or body exam in all 8 scanners, the seventy-fifth percentile of the dose was calculated and introduced as the DRL based on $CTDI_{vol}$ and DLP for every given device by the QC method.

Calculating DRL with the MQC Method

In this method, for each patient (i.e. the same patients used in the QC method) in the common four examinations, the images of the patients in each examination were extracted from the picture archiving and communication system (PACS) and the slice with the largest anteroposterior (AP) and lateral diameter (Lat) in the axial scan was measured. The effective diameter was calculated as follows [13]:

$$\boldsymbol{Effetive\ Diameter = \sqrt{Ap . Lat}} \quad (4)$$

The conversion factor, f, was obtained for the 16 (head) and 32-cm (body) phantoms

from the AAPM report 204 [13]. The size-specific dose estimate (SSDE) is the product of the multiplication of the $CTDI_{vol}$ obtained by the QC method and the conversion factor, f. The third quartile of this dose and the resulting DLP in all the four common exams in the 8 devices were introduced as LDRL with the MQC method. The mean $CTDI_{vol}$ value obtained for each of the 10 patients in four CT examinations between the MQC with QC and DC methods was compared using the paired t-test method. Differences smaller than $P<0.05$ were considered statistically significant.

Results

The parameters of the common four examinations, performed in the spiral and conventional forms, and the mean dose indices showed in the scanner console, including $CTDI_{vol}$ and DLP, were recorded for all the examinations (Table 1). As seen, the head examination is performed conventionally in all 4 centers (except for one device in one center) and the other three examinations, except for the sinus exam, were conducted with the spiral method in one center. The scan length range in the head and sinus examinations was 11-26.4 and 7.7-17.6 cm, respectively. The scan length ranges for the chest examination in the centers varied between 26 and 49 cm, and was also between 56.6 and 24 cm for the abdomen/pelvis examinations. The pitch number also ranged from 0.33 to 1.75 in the spiral scans. Moreover, the mAs range for the head, sinus, chest, abdomen/pelvis examinations falls in the ranges 90-400, 23-200, 58-295, 78-339, and 90-400, respectively. Since not all of the four examinations (except the head) were performed at all eight CT devices, the dose indices were calculated for 230 patients (ten patients in each exam) in four CT centers.

In all three methods, the highest $CTDI_{vol}$ level was observed in the head and sinus examinations, while the highest DLP was observed in the abdomen, pelvis, and head examinations, respectively (Table 2). Figures 1 and 2 show the LDRL calculated based on $CTDI_{vol}$ and DLP using the DC, QC, and MQC methods. The difference between the DC and QC methods in calculating LDRL based on $CTDI_{vol}$ in the head, sinus, chest, and abdomen/pelvis examinations was 31.4%, 1.25%, 16.9%, and 4.6%, respectively. Based on DLP, the respective differences were 32%, 24.8%, 3%, and 6.8%, respectively. Calculation of LDRL based on $CTDI_{vol}$ in all examinations except for the head scan was in line with the IAEA acceptable tolerance error (±20%) [15]. In the paired t-test, the difference between the mean $CTDI_{vol}$ calculated by the DC and QC methods was significant ($P<0.001$) in 100% of the head and sinus examinations and 70% of the chest and abdomen/pelvis examinations.

In the comparison of the LDRL calculated based on $CTDI_{vol}$ and DLP using the MQC and QC methods in the head, sinus, chest, abdomen, and pelvic examinations, the dose difference was 7%, 11.6%, 27.3%, and 30.7% with a mean of (19.2 ± 11.6)%, 2.3%, 6.9%, 25.4% and 27% with a mean of (15.4 ± 12.6)%, respectively. These findings indicated the greater difference between these two methods in calculating the dose, especially in the body scan and revealing the effect of the patient's effective diameter. In the three examinations, the percentage difference in the MQC method and the head examination had an increasing and decreasing trend as compared to QC, respectively. Table 3 shows the patient effective diameter and factor f, and Figure 3 presents an example of measuring the patient effective diameter based on the CT images. The difference between the MQC and DC methods in calculating the two-dose indices was 26.2%, 11.7%, 39.6%, and 33.8% with a mean of (27.8 ± 12.1)% and 26.1%, 25.4%, 23.1%, 33.9% with a mean of (27.1 ± 4.7)%, respectively. However, in the comparison of the difference between the MQC and QC methods and the DC method, the seventy-fifth percentile of DRL and its median showed a higher estimate for both dose indices, a similar difference ex-

Table 1: Parameters of computed tomography (CT) scans performed with 8 scanners in Shiraz University CT centers. Computed tomography dose index ($CTDI_{vol}$), dose length product (DLP), Abd Pel, b and c stand for, the volume computed tomography dose index, dose length product, abdomen/pelvis examination, skull base and cerebrum, respectively.

CT scan type	CT Examination/ scanner mode	kVp	Average mAs (Range)	Pitch/ Interval (mm)	Scan Length (cm) (Range)	Beam Collimation (mm)	Average $CTDI_{vol}$ (mGy) (Range)	Average DLP (mGy.cm) (Range)
Siemens 16 Emotion	Head/Axial	130	90	22.1	15.29 (12-17.5)	19.2	19.9 (18.3-20.9)	303 (249-332)
	Chest/Spiral	110	89.8 (58-100)	1.395 (1.35-1.5)	41.14 (36-49.1)	19.2	6.7 (6.5-7.2)	276 (252-354)
	Abd,Pel/Spiral	130	113.2 (92-120)	1.46 (1.4-1.5)	53.7 (49.13-6)	19.2	12.7 (10.4-13.4	691 (539-767)
Neusoft 2	Head/Axial	120	189 (140-210)	6	13.86 (11-15.7)	5	20 (16.4-21.5)	275 (229-338)
GE 8 Bright Speed	Head/Axial	120	192 (180-240)	10.43 b 15.65 c	10.08 (8-12.8)	10 b15 c	35.2 (32.7-42.9)	469 (438-536)
	Sinus/Spiral	120	123 (87-161)	1.35	13.4 (11-15)	10	12.4 (5.7-19.2)	166 (68-306)
	Chest/Spiral	120	149 (105-239)	1.35	33.67 (29-41)	20	9.4 (6.1-15.9)	314 (189-519)
	Abd,Pel/Spiral	120	173 (143-224)	1.35	48.2 (40-55)	20	10.6 (7.5-14.7)	346 (334-747)
GE 16 Bright Speed	Head/Axial	120	265	22.09	14.13 (12-18)	20	41.7 (38.3-42.5)	595 (542-747)
	Sinus/Spiral	120	71 (40-200)	1.75	14.23 (12.4-17.7)	10	7.6 (4.8-27.1)	125 (62-480)
	Chest/Spiral	120	172 (117-294)	1.75	31.69 (27-35)	20	9.4 (6.3-15.6)	296 (196-517)
	Abd,Pel/Spiral	120	206 (123-294	1.75	45.58 (36-53)	20	9.5 (5.3-15.9)	456 (241-715)
Phillips 16 Brilliance	Head/Axial	120	265 (250,400)	18.9	13.85 (11.7-16.5)	18	31 (28.4-48.6)	439 (380-585)
	Sinus/Spiral	120	79 (24-200)	1.75	12.88 (11-16)	12	9.9 (11.6-27.1)	134 (18-301)
	Chest/Spiral	120	129 (85-227)	1.188	35 (27.5-42.6)	24	8 (5.2-14.1)	283 (176-486)
	Abd,Pel/Spiral	120	179 (133-234)	1.188	49.64 (46-56.4)	24	11.2 (8.3-14.5)	378 (396-821)
GE 2 Hi Speed	Head/Axial	120	225 b195 c	10.17 b 14.24 c	13.22 (12.1-15.2)	10 b14 c	34.6 (33.6-35.1)	358 (412-512)
Phillips 128 Ingenuity	Head/Spiral	120	166 (140-224)	0.328	20.87 (18.3-26.4)	40	21.4(18.8-28.9)	449 (333-597)
	Sinus/Spiral	120	26 (23-32)	0.399	17.37 (15.6-18.6)	40	3.4 (3-4.1)	58 (48-72)
	Chest/Spiral	120	139 (102-230)	1.2	34.3 (26-38.2)	40	9.1 (6.7-15.1)	313 (229-556)
	Abd,Pel/Spiral	120	173 (78-339)	0.797	51.2 (44.1-56.6)	40	8.3 (5.1-13.4)	431 (246-696)
Siemens 2 Sensation	Head/Axial	130	275 (260-290)	6 b 10 c	14.9 (13.6-17)	3 b10 c	38.5 (36.1-39.4)	573 (493-652)
	Sinus/Axial	130	90	5	10.08 (7.7-13.2)	5	16.5 (16.2,17.8)	167 (125-214)

CT: Computed tomography, $CTDI_{vol}$: Computed tomography dose index, DLP: Dose length product

Table 2: The local diagnostic reference level (LDRL) based on the volume computed tomography dose index ($CTDI_{vol}$), and dose length product (DLP) obtained for the four common computed tomography (CT) examinations in four University centers in Shiraz, using data collection (DC), quality control based (QC) and modified quality control based (MQC) methods, respectively.

CT examination	Dose Index	LDRL (Method)		
		DC	QC	MQC
Head	$CTDI_{vol}$ mGy	37.4	54.5	50.7
	DLP mGy.cm	543	718	735
Sinus	$CTDI_{vol}$ mGy	16.2	16	18.1
	DLP mGy.cm	173	216	232
Chest	$CTDI_{vol}$ mGy	9.3	11.2	15.4
	DLP mGy.cm	399	387	519
Abdomen/ Pelvis	$CTDI_{vol}$ mGy	12.5	13.1	18.9
	DLP mGy.cm	672	718	984

CT: Computed tomography, LDRL: Local diagnostic reference level, DC: Data collection, QC: Quality control based, MQC: Modified quality control based, $CTDI_{vol}$ Computed tomography dose index, DLP: Dose length product

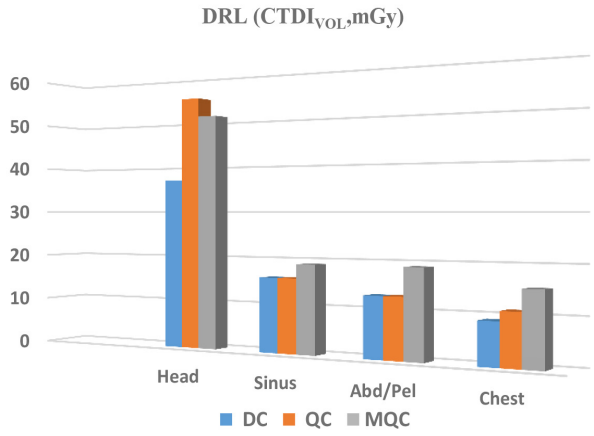

Figure 1: The diagnostic reference level (DRL) based on the volume computed tomography dose index ($CTDI_{vol}$) for the four common CT scan examinations in four university centers in Shiraz obtained using the data collection (DC), quality control based (QC), and modified quality control based (MQC) methods, respectively. Abd/Pel, represents the abdomen/pelvis examination.

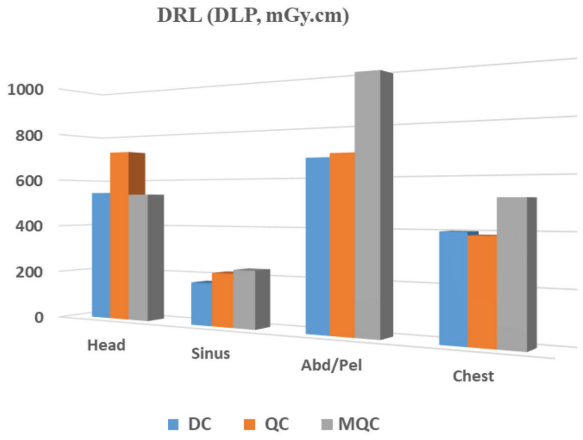

Figure 2: The diagnostic reference level (DRL) based on dose length product (DLP) for the four common computed tomography (CT) scan examinations in four University centers in Shiraz obtained using the data collection (DC), quality control based (QC), and modified quality control based (MQC) methods, respectively. Abd/Pel, represents the abdomen/pelvis examination.

isted between the MQC and QC methods.

In the statistical paired t-test, the difference between the mean values of $CTDI_{vol}$ in all groups in the four examinations using MQC and QC was statistically significant ($P<0.001$), observed in practice in the LDRL calculation with this method for the 4 examinations in the centers.

Discussion

The significant difference between the mean $CTDI_{vol}$ values from the DC and QC methods in all head and sinus examinations showed the difference between dose calculation of two methods ($P<0.001$), but this difference was only evident in the head LDRL. This significant difference was also seen in 70% of chest and abdomen/pelvis examinations in each scanner but only represented in the DRL of the chest by the two methods (18%) (Table 2). This can be attributed to fact that the DRL was

Table 3: The mean effective diameter (Eff Diameter (cm)) and conversion factor f with the standard deviation (SD) for the computed tomography (CT) examinations of the head, sinus, chest, abdomen and pelvis based on the American Association of Physicist in Medicine (AAPM) report 204 [13].

CT Exam	Eff. Diameter (cm)	Mean f Factor	SD
Head	16-18	0.99	± 0.03
Sinus	13-16	1.06	± 0.04
Chest	26-30	1.3	± 0.10
Abdomen/ Pelvis	23-29	1.43	± 0.14

CT: Computed tomography, SD: Standard deviation

the third quartile of the median $CTDI_{vol}$ value of the eight devices, whereas the statistical calculation was performed in each scanner for the mean $CTDI_{vol}$ calculated by two methods. Therefore, in addition to the dose differences calculated by two methods, the similarity and difference of the LDRL based on $CTDI_{vol}$ may be referred to other parameters that affect $CTDI_{vol}$ such as scan parameters, using tube current modulation (TCM) system or type of CT scanners. The DRL difference in head examination calculated by two methods in this study (34 mGy versus 54 mGy) could be due to high mAs values (Table 1) used for noise reduction in the brain CT images. For this reason,

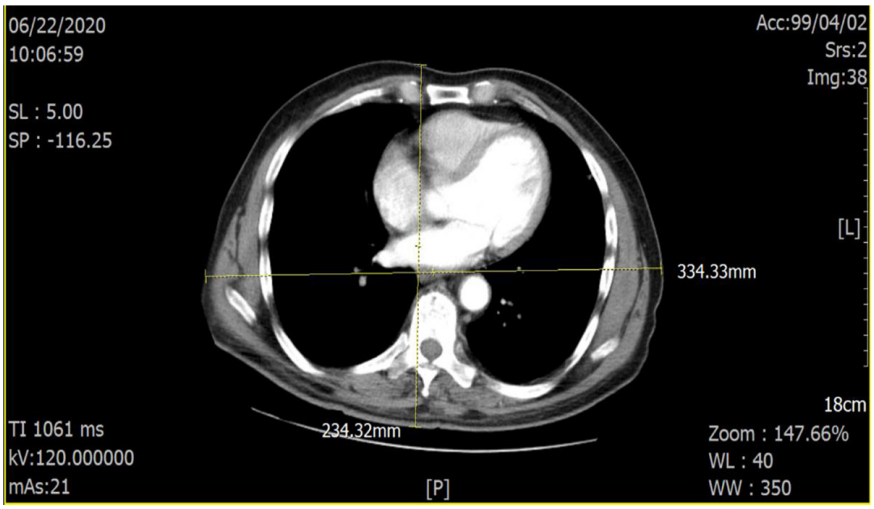

Figure 3: Measurements of the anteroposterior and lateral dimensions on the chest computed tomography (CT) scan images with contrast for the calculation of the patient effective diameter.

the head NDRL based on $CTDI_{vol}$ reported in studies in Ireland, Iran, England, and America [17-20] was higher than other routine CT exams like chest and abdomen/pelvis calculated by the DC method. In the study conducted by the Parsi et al. [11] LDRL based on the $CTDI_{vol}$ determined for the first time by the QC method in Tehran for 70 scanners, and the mean percentage difference between the QC and DC methods was reported (6.7 ± 5.7)% for four common CT exams. They reported that the DRL difference is attributed to the difference in the QC dose reports and dose indices displayed on the scanner console. In this present study, the difference was (13.5 ± 13.7)%, which is not only attributed to the differences between two-dose calculations but also could be resulted from scan parameters used in Brix formula for QC dose calculation (Tables 1 and 4).

Concerning the difference in LDRL based on DLP between the two methods in this study, patients are selected from the same BMI range. It could be mainly attributed to the CT-

Table 4: The comparison of the local diagnostic reference level (LDRL) values obtained based on the volume computed tomography dose index ($CTDI_{vol}$) and dose length product (DLP) in this study with the national and local values: Parsi et al. [11], Najafi et al. [18], Sohrabi et al. [21], Deevband et al. [22] and Sohrabi et al. [23]. The year mentioned in the table for each study is the study year, and the numbers in parentheses show the number of computed tomography (CT) scanners in each study. Besides, Abd/Pel, refer to the abdomen/pelvis examination, and quality control based (QC), modified quality control based (MQC), dual purpose quality control (DPQC), data collection (DC) and direct method (Di) stand for five methods: QC, MQC, DPQC, DC and Di, respectively.

CT Exam	Studies Dose Index	This Study Shiraz DC 2020 (8)	This Study Shiraz QC 2020 (8)	This Study Shiraz MQC 2020 (8)	Sohrabi Shiraz (DPQC) 2018 (5)	Parsi Tehran (QC) 2015 (70)	Najafi Iran (DC) 2014 (22)	Deevband Iran (Di) 2016 (120)
Head	$CTDI_{vol}$ (mGy)	37	55	51	57	59	43	44
	DLP (mGy.cm)	543	718	735	771	834	700	647
Sinus	$CTDI_{vol}$ (mGy)	16	16	18	19	29	22	9
	DLP (mGy.cm)	173	216	232	193	235	290	142
Chest	$CTDI_{vol}$ (mGy)	9	11	15	10	10	10	9
	DLP (mGy.cm)	399	387	519	280	233	330	289
Abd/Pel	$CTDI_{vol}$(mGy)	13	13	19	13	13	10	11
	DLP (mGy.cm)	672	718	984	552	522	550	513

CT: Computed tomography, DC: Data collection, QC: Quality control based, MQC: Modified quality control based, DPQC: Dual purpose quality control, $CTDI_{vol}$ Computed tomography dose index, DLP: Dose length product

DI_{vol} difference between the two methods rather than the difference between the scan lengths in different devices, especially the chest and abdomen/pelvis scans where the TCM system was used. Therefore, the effect of BMI, which must mostly be reflected in DRL based on DLP in body examinations, was not observed in this study as compared to Parsi's study [11] that failed to use a specific BMI. Besides, the calculated DRL values based on $CTDI_{vol}$ in abdomen/pelvis examinations are similar for both studies (13 mGy), and there is a 9% difference for the chest exam (Table 4).

The difference between measurement of national DRL (NDRL) with QC method in the study conducted by Sohrabi et al. [21] and this study that used the same method for calculating DRL based on $CTDI_{vol}$ was 6%, 44%, 6.6%, and 6.4%, respectively. This difference shows an ascending trend in all examinations (Table 4). Also, in the present study, the DRL result is closer to the NDRL obtained for $CTDI_{vol}$ with QC than the DC and Di methods used in NDRL study conducted by Najafi et al. [18], and Deevband et al. [22] studies, respectively. In another study, besides the QC method, the dual purpose quality control method was used for DRL calculation of five CT scanners by changing the QC method in Shiraz, but the centers were not identified [23]. In this method, after calculation of $CTDI_{vol}$ based on $CTDI_{air}$ and the conversion factor P, the DRL for five CT examinations was calculated through high-precision dosimetry by the QC report parameter, pitch number, and a radiologist's approval of image quality [23]. The DRL for $CTDI_{vol}$ in the present study differs with a mean value of 10.3% and 6.6% with the QC and dual-purpose QC methods in the same study, as well as 27.7% and 17% for DLP (Table 4).

All these differences in calculating LDRL and NDRL by QC methods in comparison to this study could be attributed to the scan pa-

rameters, especially for the head and sinus exams, and the diversity of the CT scanners (Table 4). Moreover, the DRL calculation by the QC method needs the scan parameters for the Brix formula, and this requirement has only been mentioned in Parsi's study [11], where this information was directly obtained by the devices, like QC and DC method in the present study. Consequently, the implementation time increased, but it is more cost-effective and less time-consuming than DC and Di methods for collecting information through questionnaires and direct measurement, respectively [11, 21]. If we add the patient effective diameter to the cause of the difference in the calculated $CTDI_{vol}$ and the scan parameters in QC method respected to DC method, reflected more in the chest and abdomen/pelvis examinations, it reveals the cause of the statistically significant difference between MQC and QC method in each examination ($P<0.001$). Also, the DRL calculated based on $CTDI_{vol}$ and DLP for four examinations was higher than (except for sinus) all studies conducted with QC method [11,23] and NDRL studies with the QC and DC methods [18,21] (Table 4 and Figure 4). The decrease in the sinus examination dose in studies using QC (2, 3) and dual-purpose QC methods [23] is not particularly linked to the patient size and it may be originated from the low values of the mAs in this examination, also in the present study (Table 1).

An American study conducted by Kanal et al. [20] is the only study, used the SSDE method to measure NDRL. Based on the measurement of the water equivalent diameters of the CT images of the organs of 1,300,000 patients, which obtained from the National Radiology Data Registry (NRDR) through ACR, NDRLs with normalized $CTDI_{vol}$ of the 16- and 32-

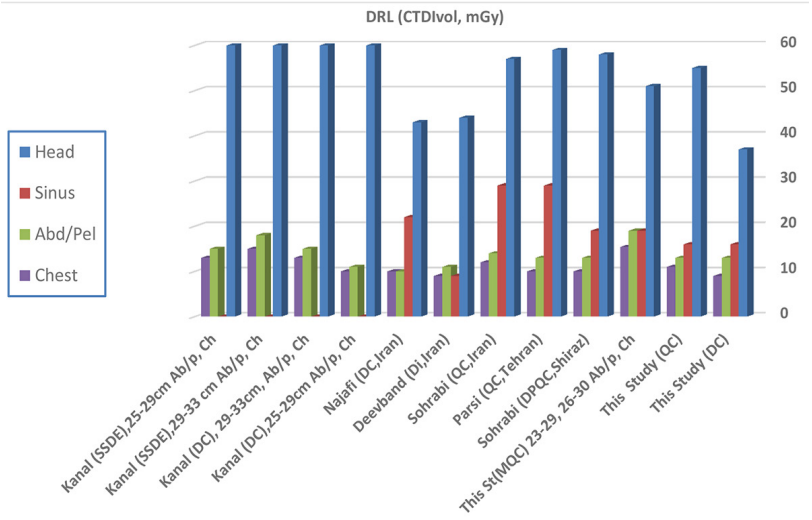

Figure 4: The diagram shows diagnostic reference levels (DRL) of four routine examination based on the volume computed tomography dose index ($CTDI_{vol}$) calculated with different methods in this study and the national and local studies conducted by Parsi et al. [11], Najafi et al. [18], Sohrabi et al. [21, 23], Deevband et al. [22], respectively. The MQC, QC, DPQC, DC and Di stand for: modified quality control based, quality control based, dual purpose quality control based, data collection and direct methods, respectively. The American national study carried out by Kanal et al. [20] that used size specific dose estimate (SSDE) method with two water effective diameters in the chest, abdomen/pelvis, and the lateral diameter of the skull also included for comparison. The sinus examination is not included in the American study. Ab/p and Ch, represent the abdomen/pelvis and chest examinations, respectively.

cm phantoms (SSDE and AAPM report 220) [24] were calculated for five protocols of abdomen/pelvis, chest, head and neck examinations, and the results were compared with the DC method. The DRL calculated in the body examinations was higher than the DC results due to the water equivalent diameters of the patients. For patients with a water equivalent diameter of 29-33 cm the DRL is highly close to patients with an effective diameter of 26-30 and 23-29 cm in the chest and abdomen/pelvis exam in this study, respectively, confirming the difference from the DC method in both studies (Table 5). The lower the water equivalent diameter and the effective diameter of the patient, the higher the SSDE and DRL of the dose indices [25]. The DRL difference of head exam based on $CTDI_{vol}$ with the SSDE and acceptable quality dose (AC), in the study carried out by Kanal et al. was 13%, and for the MQC and QC methods in the study was 6.9%. The former used the lateral diameter of the head from CT localizer and the latter used the head effective diameter of the axial slice in the same range (16-18 cm) (Table 2). The mean difference percentage of DRL based on DLP in the present study with QC and MQC equals %25 and %27, and in Kanal's study it was equivalent to 30% and 21% with DC and SSDE for chest, abdomen/pelvis examinations, respectively, indicating the effective diameter, and water equivalent diameter impact (Table 5). Figure 4 shows the effect of the patients' effective and water equivalent diameters with SSDE and MQC and other DRL calculation methods. The sinus examination is not included in the study which was conducted by Kanal et al. [20].

A comparison of DRL based on $CTDI_{vol}$ and DLP in the present study with the QC and MQC methods performed by Deevband et al. [22], based on the protocols in the four common CT scan examinations with 120 devices in Iran (400 patients) using Di method, revealed the underestimation of the dose indices. The difference between the third quartile of DRL based on $CTDI_{vol}$ in this study and the four head, sinus, chest, and abdomen/pelvis examinations was 13.7%, 50%, 40%, and 42.1%, respectively (Table 5). These results indicate the MQC method overestimated DRL based on $CTDI_{vol}$ in all examinations except the head compared to Di method in the mentioned study (Figure 4). The decrease in the DRL based on DLP in four examinations in the same study can be attributed to the $CTDI_{vol}$

Table 5: Comparison of diagnostic reference levels (DRL) based on the volume computed tomography dose index method ($CTDI_{vol}$) and dose length product (DLP) in the chest, abdomen and pelvis examinations in the American (USA) national study conducted by Kanal et al. [20] using the size specific dose estimate (SSDE) and data collection (DC) methods, respectively, with the present study using the modified quality control based (MQC), quality control based (QC), and DC methods, respectively. The Ab, Ch and Abd/Pel stand for abdomen and chest effective diameter in present study, and the abdomen/pelvis examination in both studies, respectively.

	DRL [$CTDI_{vol}$ mGy, (DLP mGy.cm)]						
	Shiraz (Effective Diameter) cm			USA (Water Equivalent Diameter) cm			
Method CT Exam	MQC 26-30 Ch 23-29 Ab	QC 26-30 Ch 23-29 Ab	DC 26-30 ch 23-29Ab	SSDE 25-29	SSDE 29-33	DC 25-29	DC 29-33
Chest	15 (519)	11 (387)	9 (399)	13 (366)	15 (469)	10 (238)	13 (353)
Abd/Pel	19 (984)	13 (718)	13 (672)	15 (524)	18 (755)	11 (409)	15 (608)

DRL: Diagnostic reference level, $CTDI_{vol}$ Computed tomography dose index, DLP: Dose length product, CT: Computed tomography, MQC: Modified quality control based, QC: Quality control based, SSDE: Size specific dose estimate, DC: Data collection

calculation type that did not include the patient's effective diameter [9].

Compared with mentioned national and local studies, the overestimation of DRL of the routine chest and abdomen/pelvis examination by the MQC methods in this study shows that the protocols should be optimized in Shiraz University CT centers. The study limitation was its time-consuming process caused by direct extraction of the examination parameters per patient, which could be reduced by running the computer software.

Conclusion

The diagnostic reference level (DRL) has been measured with different methods for the common CT exams on the local and national levels, but it has not been measured through the size-specific dose estimate (SSDE) method in Iran. The current study showed that the mean difference percentage of LDRL based on $CTDI_{vol}$ calculated by quality control-based survey method (QC) was (13.1 ± 5.7)% in the four common CT exams as compared to the data collection (DC) method, linked to the difference between the dose displayed on scanner console and the QC dose report, as well as scan parameters. The LDRL based on $CTDI_{vol}$ obtained by the modified QC method (MQC) for head, sinus, chest, abdomen, and pelvis was (50, 18, 15, 19) mGy, respectively. The calculated DLP values were also (735, 232, 519, 984) mGy.cm. The LDRL based on $CTDI_{vol}$ showed overestimation with a mean difference percentage of (19.2 ± 11.6)% in four routine examinations as compared to the QC method (except the head), and with a mean difference percentage of (27.8 ± 12.1)% in all the examinations compared to the DC method, respectively. In addition, the LDRLs overestimation of chest and abdomen /pelvis examinations compared to the national and local studies using QC and DC methods shows that the protocols of Shiraz University CT centers should be optimized in this regard. Therefore, the combination of the patient effective diameter and normalized $CTDI_w$ from QC-based survey measurements can be used for more accurate determination of the local and institutional DRL in the routine CT examinations.

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Conflict of Interest

None

References

1. Bushberg JT, Boone JM. The essential physics of medical imaging. Lippincott Williams & Wilkins; 2011.
2. Bolus NE. NCRP report 160 and what it means for medical imaging and nuclear medicine. *J Nucl Med Technol.* 2013;**41**(4):255-60. doi: 10.2967/jnmt.113.128728. PubMed PMID: 24179182.
3. Mahdavi M, Rahimi S, Eghlidospoor M. Evaluation of some spiral and sequential computed tomography protocols of adults used in three hospitals in Shiraz, Iran with American College of Radiology and European Commission guidelines. *Pol J Radiol.* 2018;**83**:297-305. doi: 10.5114/pjr.2018.77023. PubMed PMID: 30627250. PubMed PMCID: PMC6323603.
4. Smith-Bindman R, Lipson J, Marcus R, Kim KP, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Arch Intern Med.* 2009;**169**(22):2078-86. doi: 10.1001/archinternmed.2009.427. PubMed PMID: 20008690. PubMed PMCID: PMC4635397.
5. Protection ICoR. ICRP Publication 105: Radiation protection in medicine. *Ann ICRP.* 2007;**37**:1-63. doi: 10.1016/j.icrp.2008.08.001. PubMed PMID: 18762065.
6. Bongartz G, Golding SJ, Jurik AG, et al. European guidelines on quality criteria for computed tomography, Chapter 1: Quality criteria for computed tomogrpahy. Report EUR 16262 EN; Brussels: EU

publications; 1998.

7. American College of Radiology. ACR practice guideline for diagnostic reference levels in medical x-ray imaging. ACR; 2008. p. 799-804.
8. Tsapaki V, Aldrich JE, Sharma R, et al. Dose reduction in CT while maintaining diagnostic confidence: diagnostic reference levels at routine head, chest, and abdominal CT—IAEA-coordinated research project. *Radiology.* 2006;**240**(3):828-34. doi: 10.1148/radiol.2403050993. PubMed PMID: 16837668.
9. Charles MW. ICRP Publication 103: Recommendations of the ICRP. Oxford University Press; 2008.
10. Protection R. 109: Guidance on diagnostic reference levels (DRLs) for Medical Exposures. Luxembourg: European Communities; 1999.
11. Parsi M, Sohrabi M, Mianji F, Paydar R. Determination of Examination-Specific Diagnostic Reference Level in Computed Tomography by A New Quality Control-Based Dose Survey Method. *Health Phys.* 2018;**114**(3):273-81. doi: 10.1097/HP.0000000000000758. PubMed PMID: 29360705.
12. Parsi M, Sohrabi M, Mianji F, Paydar R. A "quality-control-based correction method" for displayed dose indices on CT scanner consoles in patient dose surveys. *Phys Med.* 2017;**38**:88-92. doi: 10.1016/j.ejmp.2017.05.054. PubMed PMID: 28610702.
13. Medicine AAoPi. Size-specific dose estimates (SSDE) in pediatric and adult body CT examinations. Report of AAPM Task Group 204; AAPM; 2011.
14. Vañó E, Miller D, Martin C, Rehani M, et al. ICRP Publication 135: Diagnostic reference levels in medical imaging. *Ann ICRP.* 2017;**46**(1):1-144. doi: 10.1177/0146645317717209. PubMed PMID: 29065694.
15. McLean I. Quality assurance programme for computed tomography: diagnostic and therapy applications. IAEA Human Health; 2012.
16. Brix G, Lechel U, Veit R, Truckenbrodt R, et al. Assessment of a theoretical formalism for dose estimation in CT: an anthropomorphic phantom study. *Eur Radiol.* 2004;**14**(7):1275-84. doi: 10.1007/s00330-004-2267-7. PubMed PMID: 15034744.
17. Foley SJ, McEntee MF, Rainford LA. Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol.* 2012;**85**(1018):1390-7. doi: 10.1259/bjr/15839549. PubMed PMID: 22595497. PubMed PMCID: PMC3474022.
18. Najafi M, Deevband MR, Ahmadi M, Kardan MR. Establishment of diagnostic reference levels for common multi-detector computed tomography examinations in Iran. *Australas Phys Eng Sci Med.* 2015;**38**(4):603-9. doi: 10.1007/s13246-015-0388-8. PubMed PMID: 26507898.
19. Shrimpton P, Hillier M, Lewis M, Dunn M. National survey of doses from CT in the UK: 2003. *Br J Radiol.* 2006;**79**(948):968-80. doi: 10.1259/bjr/93277434. PubMed PMID: 17213302.
20. Kanal KM, Butler PF, Sengupta D, et al. US diagnostic reference levels and achievable doses for 10 adult CT examinations. *Radiology.* 2017;**284**(1):120-33. doi: 10.1148/radiol.201716191. PubMed PMID: 28221093.
21. Sohrabi M, Parsi M, Mianji F. Determination of national diagnostic reference levels in computed tomography examinations of Iran by a new quality control-based dose survey method. *Radiat Prot Dosimetry*. 2017;**179**(3):206-15. doi: 10.1093/rpd/ncx252. PubMed PMID: 29136248.
22. Deevband MR, Ghorbani M, Eshraghi A, Salimi Y, et al. Patient effective dose estimation for routine computed tomography examinations in Iran. *International Journal of Radiation Research*. 2021;**19**(1):63-73. doi:10.29252/ijrr.19.1.63.
23. Sohrabi M, Parsi M, Sina S. A New Dual-purpose Quality Control Dosimetry Protocol for Diagnostic Reference-level Determination in Computed Tomography. *Health Phys*. 2018;**115**(2):252-8. doi: 10.1097/HP.0000000000000872. PubMed PMID: 29781838.
24. McCollough C, Bakalyar DM, Bostani M, Brady S, et al. Use of water equivalent diameter for calculating patient size and size-specific dose estimates (SSDE) in CT: the report of AAPM Task Group 220. *AAPM Rep.* 2016;**2014**:6-23. PubMed PMID: 27546949. PubMed PMCID: PMC4991550.
25. McCollough C, Cody D, Edyvean S, Rich G, et al. The measurement, reporting, and management of radiation dose in CT. Report of AAPM Task Group 23; AAPM; 2008.