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Authors	Rawashdeh, Mohammad;Saade, Charbel;Zaitoun, Maha;Abdelrahman, Mostafa;Brennan, Patrick;Alewaidat, Haytham A.;McEntee, Mark F.
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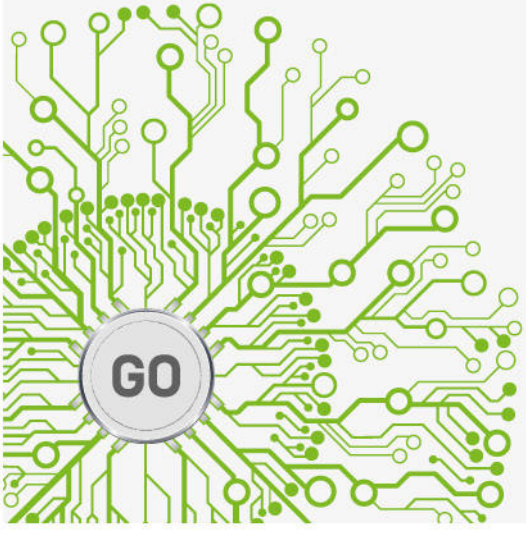


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MEDICAL IMAGING

WILEY

Establishment of diagnostic reference levels in cardiac computed tomography

Mohammad Rawashdeh[1] | Charbel Saade[2] | Maha Zaitoun[1] | Mostafa Abdelrahman[1] | Patrick Brennan[3] | Haytham Alewaidat[1] | Mark F. McEntee[4]

[1]Faculty of Applied Medical Sciences, Jordan University of Science and Technology, Irbid, Jordan

[2]Department of Diagnostic Radiology, American University of Beirut Medical Center, Beirut, Lebanon

[3]Faculty of Health Sciences, Medical Image Optimization and Perception Group (MIOPeG), and the Brain and Mind Centre, The University of Sydney, Sydney, NSW, Australia

[4]Discipline of Diagnostic Radiography, UG 12 Aras Watson, Brookfield Health Sciences, University College Cork, College Road, Cork, Ireland

Author to whom correspondence should be addressed. Mohammad Rawashdeh
E-mail: marawashdeh@just.edu.jo;
Telephone: +962795748313.

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Abstract

The aim of this study was to determine diagnostic reference levels (DRLs) for cardiac computed tomography (CCT) in Jordan. Volume computed tomography dose index ($CTDI_{vol}$) and dose–length product (DLP) were collected from 228 CCTs performed at seven Jordanian hospitals specialized in cardiac CT. DRLs for cardiac CT were defined at the 75th percentile of $CTDI_{vol}$ and DLP. $CTDI_{vol}$ and DLP were collected from 30 successive cardiac CT in each center except for one center (18 scans). The 75th percentile of the $CTDI_{vol}$ and the DLP of the centers calculated from mixed retrospective and prospective gated modes were 47.74 milligray (mGy) and 1035 mGy/cm, respectively. This study demonstrated wide dose variations among the surveyed hospitals for cardiac CT scans; there was a 5.1-fold difference between the highest and lowest median DLP with a range of 223.2–1146.7 mGy/cm. Differences were associated with variations in the mAs and kVp. This study confirmed large variability in $CTDI_{vol}$ and DLP for cardiac CT scans; variation was associated with acquisition protocols and highlights the need for dose optimization. DRLs are proposed for CCT; there remains substantial potential for optimization of cardiac CT examinations for adults in Jordan.

KEY WORDS
CCT, $CTDI_{vol}$, DLP, DRL, Jordan

1 | INTRODUCTION

Radiation doses differ between hospitals for standard-sized patients undergoing the same examination.[1] These dose variations are "primarily attributable to local choices regarding technical parameters, rather than patient, institution, or machine characteristics." Computed tomography (CT) has a large range of scanning options that lead to a large variation in patient radiation doses. Several factors affect radiation dose to patients undergoing cardiac computed tomography (CCT) procedures.[2] Concerns have been raised about the radiation exposure of CCT. Recently, prospective gated mode (PGM) was developed to reduce radiation dose. PGM, also known as "step-and-shoot" or "sequential scan mode,"[3] has been developed as an alternative mode to standard helical (spiral) scanning with retrospective electrocardiographic gating with the aim of decreasing radiation dose during CCT to patients with stable heart rates. Previous work by other authors has identified key contributors to variations in dose as radiographic settings, equipment factors, the level of quality assurance in place, radiographer training, radiographer experience, as well as patient body habitus.[4,5] Dose optimization requires identification of which factors are the greatest contributor to variations in dose. Once the contribution of factors is established, operators can consider corrective action in a cost-effective manner.[4]

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In order to achieve optimization, guidance on appropriate levels of patient exposure is required. Basic safety standards have been provided by the International Commission on Radiological Protection (ICRP), World Health Organization (WHO), and International Atomic Energy Agency (IAEA) in order to optimize the protection of patients during all radiological procedures, including CT.[6] These include a recommendation for DRLs[7] or guidance levels to be put in place, monitored, and used to improved radiological procedures.[8] DRLs enhance patient protection and allow comparisons of the radiation dose of different CT systems, and procedures. DRLs offer a framework where dose levels from different hospitals can be compared and when DRLs are exceeded by a department, corrective strategies can be taken.

DRLs are not dose limits, but rather guidelines. Where they are regularly exceeded, corrective action should be taken. DRLs have been effective in reducing radiation dose, with radiation levels being reduced by 50% in the UK since their adoption.[9,10] As dose variation for the same examination can reach up to 23-fold between centers for non-CT X-ray examinations[2] and 13-fold for CT examinations.[11] Strategies such as DRLs are required to reduce dose variation between centers. The method of establishing DRLs starts with a determination of radiation dose levels delivered for specific examinations in several hospitals in an individual country (or state). These data are then used to compute examination-specific DRLs for that country, state or region, usually in terms of the 75th percentile of the dose distribution. Due to the differing ethnicities, procedures, and equipment across different countries, it is advisable that each country determine their own DRLs. While the requirement for DRLs have been described in legislative documents in Jordan and internationally, and their implementation for general examinations is seen in Europe and the US, national DRL values do not exist for cardiac CT examinations in Jordan. Cardiac CT examinations are among the highest dose examinations, with patients undergoing chest CT having doses ranging from 4 to 18 mSv but those undergoing cardiac CT receiving 5–32 for a coronary CT angiogram, and 12–18 mSv for a 64-slice coronary CT Angiography (CTA) with tube modulation. However, with good technique, a prospectively triggered coronary CTA patient can receive 2–4 mSv.[12] The dose for cardiac CT in Jordan is currently not known, so we cannot compare our performance internally or internationally. The current work aims to address this gap.

2 | MATERIALS AND METHODS

In 2018, a retrospective survey was performed across seven Jordanian hospitals that routinely perform CCT. Data from 228 cardiac CT scans were collected over a 3-month period from May to August. These cardiac CT scans were performed on a wide range of scanners with different number of slices from three manufacturers (GE, Siemens, and Philips). These are representative of CT scanners being used across Jordan. According to the Jordanian regulations, CT scanners undergo a quality control program that includes daily, monthly, quarterly, and annual checking of the assessment of the radiation dose.[13]

Dose in $CTDI_{vol}$ and DLP was provided in 30 successive cardiac CT scans in each center except for one, which provided 18 scans. There survey respondents used two scanning modes, prospective electrocardiographic (ECG) gating modes (PGM) where the scanner monitors the patient's ECG and retrospective ECG-gating modes (RGM) where the patient is scanned continuously, while only certain portions of the scan are used to reconstruct the image. Participants were all adults between 17 to 75 yr and all genders were included. In line with a methodology previously published,[9,14] protocol and scan sequence details were grouped in the survey (Table 1). A clinical coordinator with CT experience was appointed in each center to administer and receive the questionnaires. The survey focused on CTA performed for the assessment of coronary artery disease. CTA included one single scan per examination. Calcium scoring, evaluation bypass graft patency and preparation of trans catheter aortic valve implantation were excluded.

To standardize weight for the sampled population and in line with international recommendations, the survey included only those patients who weighed between 60 and 80 kg.[9]

2.A | Radiation dose data

On modern CT scanners $CTDI_{vol}$ and DLP are provided for every sequence and examination. However, on older equipment it was necessary to calculate the dose using exposure and procedural data. The patient dose data, $CTDI_{vol}$ and DLP values, were extracted from the picture archiving and communication system (PACS). A summary of the two relevant dose parameters is given below along with methods for calculating these factors. $CTDI_{vol}$ is defined as weighted CTDI ($CTDI_w$) divided by CT pitch and provide an estimation for average phantom dose for a complete spiral CT scan.[15]

2.B | Weighted CT Dose Index — $CTDI_w$

This describes the radiation dose delivered per unit cranio–caudal (z) axis thickness. Significant previous work has provided methodologies so that the baseline dose value $CTDI_w$ can be calculated for specific examinations and from this baseline value other important dose metrics can be calculated[4,7,16–22] and these are explained below. Using typical $CTDI_w$ values calculated from a dosimetry phantom for each CT scanner model, with specific exposure factors, the IMPACT group[14] has provided a calculator from which $CTDI_w$ can be calculated for any sequence, for any model using a range of exposure factors. This calculation is shown in Formula 1.

$$CTDI_w(mGy) = (n\,CTDI_w)_{scanner,phantom,kV,N\times T} \times (F_{N\times T})_{scanner} \times C \quad (1)$$

where $(n\ CTDI_w)_{scanner,\ phantom,\ kV,\ N\times T}$ is a coefficient based on the normalized dose [$CTDI_w$ for a specific scanner at a particular kV, slice number (N), and thickness (T)]; $(F_{N\times T})_{scanner}$ are dose coefficients

TABLE 1 Information about the scanners in each hospital.

Hospital	Manufacturer	Year of manufacture	CT model type	Year of installation	Gantry rotation	Capacity (slice No.)
A	Philips	2008	Brilliance ICT scan 256	2011	360	256
B	Siemens	2014	Somatom force	2016	360	384
C	Philips	2010	Philips multislices 64p/s	2010	360	65
D	Siemens	2010	Multislices 128	2011	360	128
E	Siemens	2006	Somatom sensation 64	2006	360	64
F	GE	2011	Optima 99 multislice	2012	360	180
G	Siemens	2008	Somatom sensation 64 dual Source	2008	360	128

for all other slice number and thicknesses; C is the mAs or effective mAs if pitch correction was included

2.C | Volumetric CT dose index - $CTDI_{vol}$

Since $CTDI_w$ does not consider whether axial slices are contiguous, noncontiguous, or overlapping, a "pitch" correction must be added which provides a more representative volume CTDI or $CTDI_{vol}$ (Formula 2).

$$CTDI_{vol}(mGy) = \frac{CTDI_w}{\text{Pitch factor}} \quad (2)$$

where pitch factor is the distance the table moves in the z axis divided by the slice number and each slice thickness.

$CTDI_w$ is calculated from Formula 1.

2.D | Dose Length Product (DLP)

The dose measurements above do not consider the total length of the patient who has been irradiated during each examination sequence. This is calculated using Formula 3.

$$DLP(mGy \cdot cm) = CTDI_{vol} \times \text{Scan length} \quad (3)$$

where $CTDI_{vol}$ is calculated from Formula 2.

2.E | Data analysis

The minimum, maximum, and the first, second, and third quartiles were calculated for $CTDI_{vol}$, and DLP using Statistical Package for the Social Sciences (SPSS) software (SPSS for Windows, version 22.0, SPSS Inc.). Stepwise regressions were performed to find which exposure factors were associated with high dose and the level of contribution of each factor. The following factors were included: kVp, mAs, pitch, slice thickness, and number of slices. In addition, international DRLs were compared to the current national DRL level established in the current work.

3 | RESULTS

Seven hospitals (four public, one university, and two private) participated in the study. Recordings from a total of 228 CCT examinations were collected, of which 60 CCT were performed using PGM and 168 using RGM. Sixty-one percent of patients were males and 39% were females and the mean weight for both of them was 70.1 kg (Min = 60; Max = 80, SD = 8.93). Data were collected from seven scanners, of which two and five centers acquired image data in 256 and 128 slices. This represents approximately 31% of cardiac CT units in Jordan and exceeds the sample sizes used previously to establish reference levels in other countries.[5,7] A sample size calculation indicated a difference <5% in dose would be detected at 0.8 power. Patient and equipment characteristics and cardiac CT protocols are shown in Table 2. A summary of DRLs per scan mode (PGM, RGM, and Mixed Modes) and per center is shown Table 3.

The mean $CTDI_{vol}$ and DLP per CCT examination were calculated for each site and used to compare doses across CCT centers (Table 4). Wide variations were found between hospitals surveyed, with 1- to 5.1-fold differences in mean $CTDI_{vol}$ and DLP reported for the examinations surveyed.

Comparisons of the findings with DRLs published from other countries are shown in Table 5.[18-24]

Multiple regression analysis for the Mixed Modes suggested that mAs, kVp, and number of slices were more accurately predictive of $CTDI_{vol}$ than any individual variable alone, with R^2 of 0.530 ($P \leq 0.001$). The results of the regression also showed that combination of mAs, kVp, and number of slices could significantly predicate DLP. All factors had a significant positive predictor value, with a

TABLE 2 Patients and equipment's characteristics and cardiac computed tomography (CT) protocols (n = 228).

Characteristics	n (%) or mean (IQR)
Gender	
Male	139 (61.0%)
Female	89 (39.0%)
Age (years)	50.72 (41–61)
Weight (kg)	70.1 (66.2–80.0)
Body mass index (kg/m^2)	30 (28–32)
Scan mode	
PGM	60 (26.3%)
RGM	168 (73.7%)
CT model (slice)	
Philips	59 (25.9%)
Siemens	138 (60.5%)
GE Optima 99	31 (13.6%)

comparatively low R^2 of 0.364 ($P \leq 0.001$). The equations were

$$CTDI_{vol} = -72.00 + 0.03\,A + 0.800\,B - 0.013\,C$$

where A is mAs, B is kVp, and C is the number of slices.

$$DLP = -1352.19 + 0.549\,A + 16.794\,B - 0.233\,C$$

where A is mAs, B is kVp, and C is the number of slices.

In the PGM mode, the results from the multiple linear regressions demonstrated that mAs was more accurately predictive of $CTDI_{vol}$ than any other variable, with R^2 of 0.646 ($P \leq 0.001$), while for the case of the DLP, kVp, number of slices, and mAs could significantly predicate DLP, with R^2 of 0.820 ($P \leq 0.001$), which is significantly higher (Table 6).

$$CTDI_{vol} = -8.238 + 0.070\,A$$

where A is mAs

$$DLP = -1475.37 + 17.685\,A - 1.049\,B + 0.750\,C$$

where A is kVp, B is the number of slices, and C is mAs

TABLE 3 Diagnostic reference levels (DRLs) for mixed, prospective gating mode (PGM), and respective gating modes (RGM) cardiac computed tomography (CT) scans in Jordan.

Scan type	Mixed modes	PGM (n = 60)	RGM (n = 168)
$CTDI_{vol}$			
Minimum	2.00	2.00	6.60
25th	13.71	4.50	21.00
Median	31.93	7.84	40.42
75th	47.74	33.37	64.54
Maximum	86.64	33.80	86.64
DLP			
Minimum	27.60	27.60	216.00
25th	329.58	151.80	431.97
Median	727.00	626.60	888.30
75th	1035.00	692.95	1141.50
Maximum	2865.00	740.00	2865.00

For the RGM mode, the results from the multiple linear regressions demonstrated that kVp, pitch, mAs, number of slices, and slice thickness were the predictive factors of $CTDI_{vol}$, with R^2 of 0.635 ($P \leq 0.001$), while mAs, kVp, and number of slices were the predictive factors of DLP with R^2 of 0.268 ($P \leq 0.001$), which is relatively lower as demonstrated in the following two formulas.

$$CTDI_{vol} = -57.091 + 0.908A - 30.433B + 0.023C - 0.011D - 4.307E$$

where A is kVp, B is pitch, C is mAs, D is the number of slices, and E is the slice thickness.

$$DLP = -1244.8 + 0.417A + 17.03B - 0.228C$$

where A is mAs, B is kVp, and C is the number of slices.

4 | DISCUSSION

DRLs were first proposed by the International Commission on Radiological Protection in 1991. They are defined as "dose levels in radio diagnostic practices for typical examinations for patient groups or standard phantoms for broadly defined groups of equipment."[9,25,26] Patient radiation doses that exceed established DRLs should be investigated to identify potential reasons for higher dose and to allow better management of the radiation dose of similar procedures in the future.[21,27] With the significant amount of studies that have been conducted to establish the DRL levels in other countries and in the different CT scans,[4,7,16–22] this is the first study to establish DRLs in CCT in Jordan.

Research to date has demonstrated a maximum potential dose reduction in CT scan between 60% and 80%.[28–31] However, it is important to appropriately balance the need to achieve low radiation dose with the likelihood of creating useful diagnostic CT images. Low radiation exposure for a certain patient during CCT scan may result high image noise; however, it needs to be acknowledged that while high radiation exposure may increase image quality and reduce image noise, this does not automatically mean additional diagnostic information.[32] The current work highlighting wide dose variations for

TABLE 4 Diagnostic reference levels (DRLs) for cardiac computed tomography (CT) scans performed with Mixed Modes per center.

Center	1 (n = 30)	2 (n = 45)	3 (n = 29)	4 (n = 45)	5 (n = 18)	6 (n = 31)	7 (n = 30)
$CTDI_{vol}$							
Minimum	7.84	24.06	21.0	4.50	13.55	2.63	2.0
25th	10.78	38.85	31.93	4.50	13.55	64.54	5.80
Median	12.69	43.89	64.54	9.90	18.37	64.54	19.59
75th	19.15	47.87	79.43	33.80	22.30	64.54	21.70
Maximum	44.73	79.43	86.64	33.80	22.30	64.56	21.9
DLP							
Minimum	146.90	385.00	583.9	151.80	329.58	35.50	27.60
25th	189.10	807.40	831.20	618.10	329.58	1126.20	140.00
Median	223.20	888.30	1035.00	653.60	431.97	1146.70	251.05
75th	583.90	934.60	1435.00	726.50	1267.07	1236.80	293.00
Maximum	933.40	1441.90	1549.00	740.00	1267.07	1356.10	2865.00

TABLE 5 Cardiac computed tomography (CT) diagnostic reference levels (DRLs) in Jordan compared with other international cardiac CT DRLs.

	Iran[18]	France[19]	Italy[23]	Netherlands[20]	Japan[21]	Switzerland[24]	KSA[22]	Jordan (current study)
$CTDI_{vol}$								
Mixed	66.5	–	61	–	–	50	–	47.74
PGM	–	26	–	–	–	–	29	33.37
RGM	–	44	–	–	–	–	43	64.54
DLP								
Mixed	1073	–	1208	671	1510	1000	–	1035.0
PGM	–	370	–	–	–	–	343	692.95
RGM	–	870	–	–	–	–	808	1141.50

cardiac CT scans were shown across hospitals. With a range of 223.2–1146.7 mGy cm, the highest mean DLP was 5.1 times higher than the median value. These differences were primarily attributable to local choices regarding technical parameters, rather than patient, institution, or machine characteristics. Changes in $CTDI_{vol}$ were associated with variations in the mAs, kVp pitch, and slice thickness. Multiple regression analysis predicted that low DLP was most dependent on mAs, kVp, mode of scan, and number of slices.

The current study reports that PGM allowed a significant dose reduction with $CTDI_{vol}$ of 60.4% compared with the RGM mode. These wide dose variations between modes emphasize the need to analyze the $CTDI_{vol}$ and DLP individually and, therefore, establish DRL for each mode.[22] The current work did not compare the diagnostic performance of PGM with RGM. However, the reduction in radiation dose with PGM scanning was larger than the effect of other radiation dose-reduction techniques. The 75th DLP in scanned average-sized patients was only 692.95 mGy cm. Among those centers using PGM, the lowest median DLP was 223.2 mGy cm in Centre A, this dose was in contrast with 75th DLP of RGM 1146.60 mGy cm. This finding supports the use of PGM as an effective tool in comprehensive radiation dose-reduction technique. The current work shows that a reduction of 26.3% in the DLP in CT scanning within participating centers is achievable with PGM, this is a larger decrease in dose than reported in other works.[2,19,22]

Compared with nationwide surveys from other countries, Jordanian CCT centers generally appear to employ higher doses than those countries previously surveyed; therefore, there is a large potential for optimization of CCT examinations for adults in Jordan. Variation in radiation dose shown in the current work highlights the need for the adoption of DRLs that radiologists or radiographers need to optimize their CCT protocols and that interest in dose optimization must be improved. The work also demonstrates the need for periodic reassessment of DRLs at short-time intervals. Clinical audits should also identify further causal agents, eliminate unjustified examinations, and optimize procedures.

Further work should investigate size-specific dose estimate (SSDE). SSDE accounts for patient parameters establishment of DRLs and removes the requirement to limit the average of the sample to between 60 and 80 kg. Additional studies should to be conducted on the SSDE application to DLP so that scan length can be considered for in the equation of patient dose.

TABLE 6 Predictive of $CTDI_{vol}$, and dose–length product (DLP) from exposure factors using stepwise regression factors for Mixed Modes, prospective gated mode (PGM), and retrospective ECG-gating modes (RGM).

	R^2	*P*-value
Mixed modes		
$CTDI_{vol}$		
mAs	0.414	≤0.001
kVp	0.496	≤0.001
Number of slices	0.530	≤0.001
DLP		
mAs	0.243	≤0.001
kVp	0.335	≤0.001
Number of slices	0.364	≤0.001
PGM		
$CTDI_{vol}$		
mAs	0.646	≤0.001
DLP		
kVp	0.585	≤0.001
Number of slices	0.711	≤0.001
mAs	0.820	≤0.001
RGM		
$CTDI_{vol}$		
kVp	0.342	≤0.001
Pitch	0.506	≤0.001
mAs	0.600	≤0.001
Number of slices	0.625	≤0.001
Slices thickness	0.635	≤0.001
DLP		
mAs	0.167	≤0.001
kVp	0.232	≤0.001
Number of slices	0.268	≤0.001

There are several noteworthy limitations to our study. First, as our analysis was retrospective, we could not obtain information on several parameters that possibly influence the radiation dose such as beam collimation, rotation time, and patients' diameter. Second, we did not assess the CT scan indications; hence, the parameters of these CT scans may not represent the routine protocols of the

respective institutions. Third, since our analysis was conducted on only seven institutions, bias could have been introduced, even though the CT scans we obtained were from various centers geographically dispersed throughout Jordan.

This study demonstrates large variability in $CTDI_{vol}$ and DLP during CCT examinations in Jordan and highlights the need for doses to be reduced. PGM is clearly an effective dose-reduction technique for cardiac CT examinations and the use of this mode should be encouraged. Local DRL results should be communicated back to each CT center to encourage optimization of scan parameters and develop more proactive comparisons with national DRL and other CT centers.

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CONFLICT OF INTEREST

There is no conflict of interest declared in this article.

REFERENCES

1. Smith-Bindman R, Wang Y, Chu P, et al. International variation in radiation dose for computed tomography examinations: prospective cohort study. *BMJ*. 2019;364:k4931.
2. Jangland L, Sanner E, Persliden J. Dose reduction in computed tomography by individualized scan protocols. *Acta Radiol*. 2004;45:301–307.
3. Rehani MM. I am confused about the cancer risks associated with CT: how can we summarize what is currently known? *Am J Roentgenol*. 2015;205:W2–W3.
4. Koller C, Eatough J, Bettridge A. Variations in radiation dose between the same model of multislice CT scanner at different hospitals. *Br J Radiol*. 2003;76:798–802.
5. Rawashdeh M, McEntee MF, Zaitoun M, et al. Knowledge and practice of computed tomography exposure parameters amongst radiographers in Jordan. *Comput Biol Med*. 2018;102:132–137.
6. Mettler FA Jr, Wiest PW, Locken JA, Kelsey CA. CT scanning: patterns of use and dose. *J Radiol Prot*. 2000;20:353.
7. Johnston D, Brennan P. Reference dose levels for patients undergoing common diagnostic X-ray examinations in Irish hospitals. *Br J Radiol*. 2000;73:396–402.
8. Tsai H, Tung C, Huang M, Wan Y. Analyses and applications of single scan dose profiles in computed tomography. *Med Phys*. 2003;30:1982–1989.
9. IPSM N. CoR. Institute of Physical Sciences in Medicine, National Radiological Protection Board and College of Radiographers. National protocol for patient dose measurements in diagnostic radiology Chilton, UK: Dosimetry Working Party of the IPSM; 1992.
10. Hart D, Wall B. *Radiation Exposure of the UK Population from Medical and Dental X-ray Examinations*. Chilton, UK: NRPB; 2002.
11. Smith-Bindman R, Lipson J, Marcus R, et al. Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Arch Intern Med*. 2009;169:2078–2086.
12. Gerber TC, Kantor B, McCollough CH. Radiation dose and safety in cardiac computed tomography. *Cardiol Clin*. 2009;27:665–677.
13. Al Ewaidat H, Zheng X, Khader Y, et al. Assessment of radiation dose and image quality of multidetector computed tomography. *Iranian Journal of Radiology*. 2018;15:e59554.
14. Shrimpton P, Hillier M, Lewis M, Dunn M. *Doses from computed tomography (CT) examinations in the UK-2003 review*. Vol 67. London, UK: NRPB Chilton; 2005.
15. Lee E, Lamart S, Little MP, Lee C. Database of normalised computed tomography dose index for retrospective CT dosimetry. *J Radiol Prot*. 2014;34:363.
16. Toori AJ, Shabestani-Monfared A, Deevband M, Abdi R, Nabahati M. Dose assessment in computed tomography examination and establishment of local diagnostic reference levels in Mazandaran, Iran. *J Biomed Phys Eng*. 2015;5:177.
17. 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;240:828–834.
18. Hosseini Nasab SMB, Shabestani-Monfared A, Deevband MR, Paydar R, Nabahati M. Estimation of cardiac CT angiography radiation dose toward the establishment of national diagnostic reference level for CCTA in Iran. *Radiat Prot Dosimetry*. 2017;174:551–557.
19. Mafalanka F, Etard C, Rehel J, et al. Establishment of diagnostic reference levels in cardiac CT in France: a need for patient dose optimisation. *Radiat Prot Dosimetry*. 2014;164:116–119.
20. Van der Molen A, Schilham A, Stoop P, Prokop M, Geleijns J. A national survey on radiation dose in CT in The Netherlands. *Insights Imaging*. 2013;4:383–390.
21. Fukushima Y, Tsushima Y, Takei H, Taketomi-Takahashi A, Otake H, Endo K. Diagnostic reference level of computed tomography (CT) in Japan. *Radiat Prot Dosimetry*. 2011;151:51–57.
22. Alhailiy AB, Kench PL, McEntee MF, Brennan PC, Ryan EA. Establishing diagnostic reference levels for cardiac computed tomography angiography in Saudi Arabia. *Radiat Prot Dosimetry*. 2018;181:129–134.
23. Palorini F, Origgi D, Granata C, Matranga D, Salerno S. Adult exposures from MDCT including multiphase studies: first Italian nationwide survey. *Eur Radiol*. 2014;24:469–483.
24. Treier R, Aroua A, Verdun F, Samara E, Stuessi A, Trueb PR. Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels. *Radiat Prot Dosimetry*. 2010;142:244–254.
25. Clarke R, Fry F, Stather J, Webb G. 1990 recommendations of the international commission on radiological protection. *Documents of the NRPB*. 1993;4:1–5.
26. Valentin J. Radiation and your patient: A guide for medical practitioners: ICRP Supporting Guidance 2: Approved by ICRP Committee 3 in September 2001. In: SAGE Publications Sage UK: London, England; 2001.
27. Valentin J. *The 2007 Recommendations of the International Commission on Radiological Protection*. Oxford: Elsevier; 2007.
28. Kudo T, Ideguchi R. The effects of medical radiation. *Ann Nucl Cardiol*. 2015;1:35–42.
29. Hirai N, Horiguchi J, Fujioka C, et al. Prospective versus retrospective ECG-gated 64-detector coronary CT angiography: assessment of image quality, stenosis, and radiation dose. *Radiology*. 2008;248:424–430.
30. Rybicki FJ, Otero HJ, Steigner ML, et al. Initial evaluation of coronary images from 320-detector row computed tomography. *Int J Cardiovasc Imaging*. 2008;24:535–546.
31. Hausleiter J, Meyer T, Hermann F, et al. Estimated radiation dose associated with cardiac CT angiography. *JAMA*. 2009;301:500–507.
32. Weigold WG, Abbara S, Achenbach S, et al. Standardized medical terminology for cardiac computed tomography: a report of the Society of Cardiovascular Computed Tomography. *J Cardiovasc Comput Tomogr*. 2011;5:136–144.