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RADIOLOGY PHYSICS

ORIGINAL ARTICLE

Establishment of local diagnostic reference levels for computed tomography with cloud-based automated dose-tracking software in Türkiye

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PURPOSE

The purpose of this study is to establish local diagnostic reference levels (LDRLs) for computed tomography (CT) procedures using cloud-based automated dose-tracking software.

METHODS

The study includes the dose data obtained from a total of 104,272 examinations performed on adult patients (>18 years) using 8 CT scanners over 12 months. The protocols included in our study were as follows: head CT without contrast, cervical spine CT without contrast, neck CT with contrast, chest CT without contrast, abdomen–pelvis CT without contrast, lumbar spine CT without contrast, high-resolution computed tomography (HRCT) of the chest, and coronary CT angiography (CTA). Dose data were collected using cloud-based automatic dose-tracking software. The 75th percentiles of the distributions of the median volume CT dose index (CTDIvol) and dose length product (DLP) values were used to determine the LDRLs for each protocol. The LDRLs were compared with national DRLs (NDRLs) and DRLs set in other countries. Inter-CT scanner variability, which is a measure of how well clinical practices are standardized, was determined for each protocol. Median values for each protocol were compared with the LDRLs for dose optimization in each CT scanner.

RESULTS

The LDRLs (for DLP and CTDIvol, respectively) were 839 mGy.cm and 41.2 mGy for head CT without contrast, 530.6 mGy.cm and 19.8 mGy for cervical spine CT without contrast, 431.9 mGy.cm and 15.5 mGy for neck CT with contrast, 364.8 mGy.cm and 9.3 mGy for chest CT without contrast, 588.9 mGy.cm and 11.2 mGy for abdomen–pelvis CT without contrast, 713 mGy.cm and 24.3 mGy for lumbar spine CT without contrast, 326 mGy.cm and 9.5 mGy for HRCT, and 642.3 mGy.cm and 33.4 mGy for coronary CTA. The LDRLs were comparable to or lower than NDRLs and DRLs set in other countries for most protocols. The comparisons revealed the need for immediate initiation of an optimization process for CT protocols with higher dose distributions. Furthermore, protocols with high inter-CT scanner variability revealed the need for standardization.

CONCLUSION

There is a need to update the NDRLs for CT protocols in Türkiye. Until new NDRLs are established, local institutions in Türkiye can initiate the optimization process by comparing their dose distributions to the LDRLs established in our study. Automated dose-tracking software can play an important role in establishing DRLs by facilitating the collection and analysis of large datasets.

KEYWORDS

Computed tomography, diagnostic reference level, dose-tracking software, ionizing radiation, radiation dose

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Computed tomography (CT) is frequently preferred by clinicians, as it provides rapid and non-invasive imaging of patients and makes significant contributions to patient management. CT scanners have become widely used since their introduction, and the frequency of CT scans has expanded significantly, particularly in the last few decades. Thus, CT has become the imaging method with the highest proportion of radiation exposure among imaging methods. Despite accounting for only 10% of radiological procedures, it accounts for approximately 62% of the collective effective dose (ED).[1]

The International Commission on Radiological Protection (ICRP), which first introduced the term "diagnostic reference level (DRL)" in 1996, recommended the establishment of DRLs in Publication 103 to cope with increased medical exposure and optimize radiation dose.[2] Publication 135 provides clarification on the term DRL and how DRLs should be established.[3] DRLs provide periodic monitoring of radiation dose levels. The DRL process has made significant contributions to radiation dose optimization in many countries.[4]

The DRL is established as the 75th percentile (third quartile) of median dose values for each CT protocol. National DRLs (NDRLs) represent the entire country, whereas local DRLs (LDRLs) represent a group of healthcare facilities in an area. In theory, LDRL should not exceed NDRL, and if it does, the dose optimization process should begin immediately. The DRL process is completed in a short time with automated dose-tracking software that facilitates the collection and analysis of dose data. These software programs allow for the DRLs to be updated more frequently, contributing significantly to the process of dose optimization. Using these software packages, health center dose data can be easily monitored, and the optimization process can be started immediately when dose values exceed reference DRLs.[5]

The first DRL study in Türkiye was conducted by Ataç et al.[6] NDRLs are yet to be established for many CT protocols, and existing NDRLs need to be updated as part of the ICRP recommendations. LDRLs may be set for procedures for which no NDRLs are available, according to the ICRP.[3]

In this context, in our study, LDRLs were determined for 8 CT protocols using cloud-based automated dose tracking software to initiate the dose optimization process in our institution's CT scanners and to contribute to the national CT dose optimization efforts in Türkiye.

Main points

- In many countries, the diagnostic reference level (DRL) process has made significant contributions to radiation dose optimization. DRL is established as the 75th percentile (third quartile) of the median dose values for each computed tomography (CT) protocol.
- In Türkiye, the national DRLs for CT protocols should be updated. Local institutions in Türkiye can begin the optimization process by comparing their dose distributions to the local DRLs established in the present study until new national DRLs are established.
- In establishing DRLs, automated dose-tracking software can be useful by making it easier to collect and analyze large datasets.

Methods

Computed tomography scanners and protocols

In total, the data of 104,272 doses were collected from CT examinations of adult patients over 18 years of age, performed between January 1, 2020, and December 31, 2020, using 8 CT scanners in 5 university hospitals. Different models of CT scanners from the three major CT manufacturers (Siemens, Toshiba, and GE) were used in the study. Details about the CT scanners are presented in Table 1. The CT protocols were as follows: head CT without contrast, cervical spine CT without contrast, neck CT with contrast, chest CT without contrast, abdomen–pelvis CT without contrast, lumbar spine CT without contrast, high-resolution CT (HRCT) of the chest, and coronary CT angiography (CTA). For the coronary CTA protocol, the data were collected from a total of 4 CT scanners. For the other 7 protocols, data were collected from all CT scanners, and single-phase acquisitions were included in the study. Automatic exposure control was used in all protocols. Quality control tests of all the CT scanners were completed in December 2019. For all protocols, the post-exposure volume CT dose index (CTDIvol) values provided by CT scanners were confirmed by direct measurements performed on standard polymethylmethacrylate CT phantoms with a diameter of 16 and 32 cm. A 16-cm phantom was used for head CT and a 32-cm phantom for other protocols. This study was approved by the institutional review board and Başkent University Institutional Review Board and Ethics Committee (project no: KA18/206, date of approval, 26/06/2018) and the need to obtain informed consent was waived.

Data collection

Before collecting the dose data, a standard protocol nomenclature was determined to ensure correct analysis of the study data. The dose data were collected with Teamplay (Siemens Healthineers, Erlangen, Germany), a cloud-based automated dose-tracking software. This software collects data from Radiation Dose Structured Report on Digital Imaging and Communications in Medicine which is the international standard primarly used for storing and transmitting medical images. The data collected were as follows; anonymous ID for each patient, patient age and sex, examination date, protocol name, anatomical site, CTDIvol, dose length product (DLP), health center name, CT scanner name, scanning parameters, and CTDI phantom. Anonymized data were transferred to Excel (Microsoft, Redmond, Wash.) file. Dose data from duplicated exams, exams including additional acquisitions, exams performed under a name other than the standardized protocol name, scout acquisitions, and bolus tracking acquisitions were not included. The correct use of phantoms was checked for

Table 1. Details of CT scanners

No	Manufacturer	Model	Number of detector rows	Year of installation	Iterative reconstruction
1	Siemens	Somatom Force	2 x 192	2018	Yes
2	Siemens	Somatom go.All	64	2018	Yes
3	Siemens	Sensation 64	64	2007	No
4	Siemens	Somatom Definition AS 64	64	2017	Yes
5	Toshiba	Aquilion CX	64	2012	No
6	Siemens	Sensation 16	16	2012	No
7	GE	BrightSpeed Elite Select 16	16	2012	No
8	GE	CT580 RT	16	2014	No

CT, computed tomography.

each examination. ICRP recommends weight standardization (mean 70 ± 5 kg) for adult patients if the number of patients is less than 50.[3] Since weight standardization could not be performed, dose data obtained from protocols with more than 50 patients were included in the study.

Statistical analysis

The 25th, 50th, and 75th percentiles of the distribution of medians for each protocol were calculated using SPSS v.27.0 (IBM Corp., Armonk, United States). The LDRLs for CTDIvol and the DLP for each protocol were determined as the 75th percentile (third quartile) of the distribution of medians according to ICRP recommendations.[3] Descriptive comparisons were made with NDRLs and DRLs set in other countries. Statistical comparisons were not performed because of the methodological variations between countries and insufficient data. The interquartile range (IQR) for each protocol was divided into the median (50th percentile) to determine inter-CT scanner variability. The median values for each protocol were compared with LDRLs for dose optimization in each CT scanner.

Results

Of the 104,272 CT exams performed, 51.6% were on male patients, while 48.4 % were on female patients. The mean age of the patients was 58.4 years, with a range of 18 to 103. Chest CT without contrast was the most common protocol (n = 50984, 48.9%), whereas cervical spine CT without contrast was the least common (n = 1270, 1.2%) (Table 2). Since weight standardization could not be performed, the dose data from a total of 167 CT examinations from protocols with fewer than 50 examinations were excluded from the study.

Table 3 shows the LDRLs, 25th and 50th percentiles, and IQR/50th percentile values. Table 4 compares the LDRLs, NDRLs, and DRLs set in other countries. Among the compared DRLs, NDRLs from the UK, EU, and Switzerland were established based on clinical indications, while DRLs from other countries were set based on anatomical location.[6-14] Four of the eight protocols–head CT, chest CT, HRCT, and abdomen CT–were comparable to NDRLs. The LDRLs were comparable to or lower than NDRLs for most comparable protocols. For all four comparable protocols, the LDRLs for CTDIvol were lower than the NDRLs. The LDRLs for DLP were higher than the comparable two protocols (abdomen and chest CT) from the NDRLs.[6] The LDRLs for CTDIvol and DLP were lower than the NDRLs of the US, Japan, and Canada for all comparable protocols.[7-9] The LDRLs were comparable or lower than the UK, EU, German, Swiss, and Korean NDRLs for most comparable protocols.[10-14]

In Figure 1, the median values of the doses obtained from all CT scanners for each protocol are compared with the LDRLs. Median dose values were higher than LDRLs in CT 4, CT 5, and CT 7 scanners for head CT, CT 5 and CT 7 scanners for cervical spine CT, CT 5 and CT 6 scanners for neck CT, CT 5 and CT 8 scanners for chest CT, CT5 scanner for abdomen–pelvis CT, CT 2 and CT 5 scanners for lumbar spine CT, CT 5, CT 7 and CT 8 scanners for HRCT, and CT 5 scanner for coronary CTA.

Discussion

The ICRP introduced the term DRL in 1996.[15] The establishment of DRLs was the first step in the radiation dose optimization process. DRL enables units and hospitals to compare radiation doses to identify variations among them. Accordingly, it helps to maintain radiation doses at an acceptable level and aids in their optimization. DRLs are not strict dose limits or concepts generated to establish legal standards but should be used to determine whether doses are high. The DRL process begins with the collection of dose data. The collected data is then plotted in a histogram and the 75th percentile of the histogram is determined as the DRL.[3] The DRL process has become popular in many countries, and the use of DRLs has led to a decrease in both radiation dose and the range of radiation doses, resulting in successful outcomes in radiation dose optimization.[4,16]

NDRLs represent the entire country, while LDRLs represent several healthcare facilities in an area. The first NDRLs in Türkiye were published in 2015 by Ataç et al.[6] NDRLs were established for single-phase CT protocols. The ICRP recommends that NDRLs be updated every three to five years. It is also recommended that the process of updating DRLs be both flexible and dynamic. Flexibility is necessary for procedures with limited data or where data can be obtained from only one or a few centers. Initial DRLs can be established using the limited data available before conducting more comprehensive DRL studies.

Table 2. Number of examinations

	CT 1	CT 2	CT 3	CT 4	CT 5	CT 6	CT 7	CT 8	Total	Percentage
Head	2662	1981	1030	748	2795	9353	951	86	19606	18.80%
Cervical spine	325	221	57	31	50	544	34	8	1270	1.22%
Neck	89	22	50	60	50	314	612	409	1606	1.54%
Chest	8703	8639	3000	4105	8395	9567	4456	4119	50984	48.90%
Abdomen	6085	3207	1030	542	1920	4596	3544	3645	24569	23.56%
Lumbar spine	303	165	50	174	100	594	52	17	1455	1.40%
HRCT	242	197	30	25	75	1818	166	67	2620	2.51%
Coronary CTA	946	-	430	686	100	-	-	-	2162	2.07%

CT, computed tomography; HRCT, high-resolution computed tomography; CTA, computed tomography angiography.

Table 3. Local diagnostic reference levels (75th percentile), 50th percentile, 25th percentile, and IQR/median values for CTDIvol (mGy) and DLP (mGy.cm)

	25th percentile		50th percentile		75th percentile (DRL)		IQR/median	
	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP	CTDIvol	DLP
Head	33.7	673.3	38.1	752.2	41.2	839	0.20	0.22
Cervical spine	10.7	250.8	16.2	379.4	19.8	530.6	0.56	0.74
Neck	7.9	236.3	9.3	287.7	15.5	431.9	0.82	0.68
Chest	4.3	160.3	6	230.6	9.3	364.8	0.83	0.89
Abdomen	6.5	319.5	8.1	426.7	11.2	588.9	0.58	0.63
Lumbar spine	14.7	384.7	19.6	536.6	24.3	713	0.49	0.61
HRCT	6.1	204.2	7.5	256.4	9.5	326	0.45	0.48
Coronary CTA	11.9	190.1	26.1	405.8	33.4	642.3	0.82	1.11

CTDIvol, volume computed tomography dose index; mGy, milligray; DLP, dose length product; mGy.cm, milligray centimeter; DRL, diagnostic reference level; IQR, interquartile range; HRCT, high-resolution computed tomography; CTA, computed tomography angiography.

Table 4. Comparison of the LDRLs with the NDRLs and DRLs set in other countries for CTDIvol (mGy) and DLP (mGy.cm)

		Head	Cervical spine	Neck	Abdomen	Chest	HRCT	Lumbar spine	Coronary CTA
LDRL (this study)	**CTDIvol**	41.2	19.8	15.5	11.2	9.3	9.5	24.3	33.4
	DLP	839	530.6	431.9	588.9	364.8	326	713	642.3
Türkiye (NDRL)[6]	**CTDIvol**	66.4	-	-	13.3	11.6	11.3	-	-
	DLP	810	-	-	204	289	283	-	-
US[7]	**CTDIvol**	57	28	20	20	15	-	-	-
	DLP	1011	602	572	1004	545	-	-	-
UK[10]	**CTDIvol**	47	16	-	10	8.5	8	-	-
	DLP	790	400	-	530	290	300	-	-
EU[11]	**CTDIvol**	48	17	-	9	9	-	-	25
	DLP	1386	495	-	874	364	-	-	459
Germany[12]	**CTDIvol**	60	20	15	15	10	3	10	-
	DLP	850	300	330	700	350	100	180	-
Japan[8]	**CTDIvol**	77	-	-	18	13	-	-	66
	DLP	1350	-	-	880	510	-	-	1300
Switzerland[13]	**CTDIvol**	51	17	16	11	7	-	-	-
	DLP	890	360	410	540	250	-	-	-
Korea[14]	**CTDIvol**	52.2	20.9	13.4	10.3	7.6	-	20.6	19.2
	DLP	969.8	508.7	597.1	558.5	324.2	-	738.5	326.9
Canada[9]	**CTDIvol**	82	-	-	18	14	-	-	-
	DLP	1302	-	-	874	521	-	-	-

LDRLs, local diagnostic reference levels; NDRLs, national diagnostic reference levels; DRLs, diagnostic reference levels; CTDIvol, volume computed tomography dose index; mGy, milligray; DLP, dose length product; mGy.cm, milligray centimeter; HRCT, high-resolution computed tomography; CTA, computed tomography angiography; US, United States; UK, United Kingdom; EU, European Union.

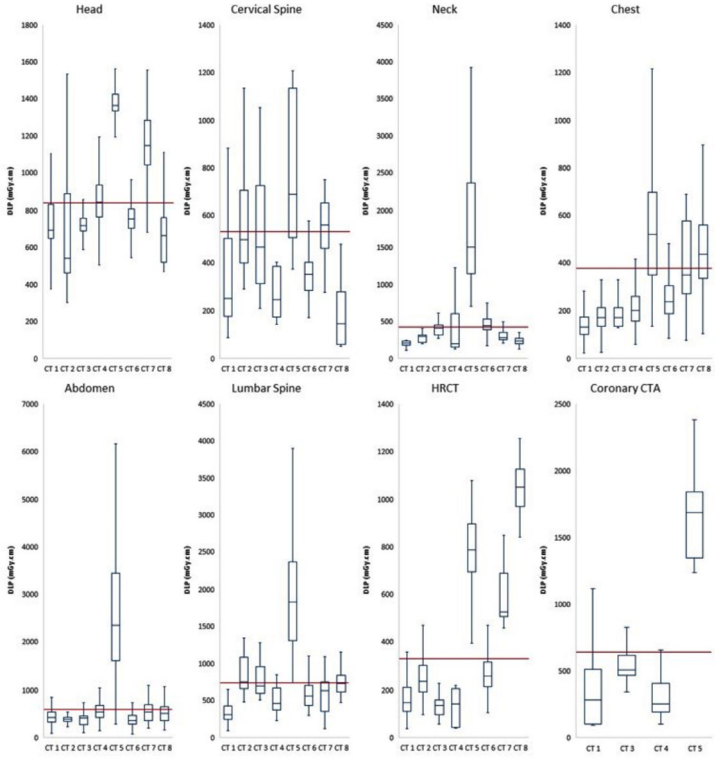

Figure 1. Boxplots of DLP distributions for CT protocols, performed on 8 CT scanners. The upper, central, and lower lines of each box correspond to the 25th, 50th, and 75th percentiles, respectively. The vertical red lines show the 75th percentiles of the distribution of the median values (LDRLs). DLP, dose length product; CT, computed tomography; LDRLs, local diagnostic reference levels; HRCT, high-resolution computed tomography; CTA, computed tomography angiography.

Furthermore, it has been noted that LDRLs can be set for procedures for which no NDRLs are available.[3] There is a need to update NDRLs and establish NDRLs for many other CT protocols. In this context, LDRLs were established in our study using automatic dose monitoring software to begin the dose optimization process in our institution's CT scanners by comparing them to the NDRLs and to contribute to the national dose optimization efforts. Until new NDRLs are established, local institutions in Türkiye can initiate the optimization process by comparing their dose distributions to the LDRLs established in our study.

The LDRLs were comparable to or lower than NDRLs and DRLs set in other countries for most comparable protocols. This situation can be attributed to the use of CT scanners or software with newer technology in our study. New CT technologies, including iterative reconstruction algorithms, automatic exposure control devices, new noise reduction techniques, and detectors with high quantum detective efficiency, can significantly reduce radiation dose.[17-19] The ICRP recommends updating DRLs with the use of new technologies and software.[3] The high LDRLs indicated that the optimization process

should be initiated immediately. The LDRLs for DLP were higher than the comparable two protocols (abdomen and chest CT) from NDRLs. Since DLP is related to scan length, this situation was attributed to the high scan length of the CT examinations performed in our institution. This problem can be solved by reducing the scan lengths.

IQR (Q3–Q1) is a measure of the distribution of data. Inter-CT scanner variability (in terms of IQR/median) is an indicator of the standardization of clinical practice for a particular protocol.[13] The lack of protocol standardization leads to wide variations in radiation, even within the same healthcare facility.[20] The high inter-CT scanner variability observed in chest and neck CT, as well as coronary CTA protocols, indicates the need for standardizing these protocols.

The median values (50th percentile) of doses obtained from CT scanners are considered as "achievable or typical doses".[3,21] If the median value of doses obtained from the CT scanner for a specific protocol exceeds the reference DRL, it indicates the need for dose optimization.[3] As an example from our study, CT scanners, including CT 4, CT 5, and CT 7, require optimization for head CT (Figure 1).

The findings of our study showed that there were significant dose variations between the CT scanners (Figure 1). Dose variations may result from scanners, scanning protocols, and radiographer training and experience.[22] Dose optimization can be improved by staff training.[23,24] Staff training should be provided to ensure proper collimation and the correct use of equipment, and appropriate scanning parameters should be established and continuously monitored.

Ataç et al.[6] reported that the response rate to questionnaires was lower than expected during the establishment of DRLs. It has been suggested that the use of systems that enhance inter-institutional communication, such as internet-based questionnaires, could be beneficial in dose studies.[6] The cloud-based nature of the software we used in our study facilitated access to dose data from different centers. The use of cloud-based dose-tracking systems in DRL studies can enable the easy acquisition of data from numerous CT scanners.

We observed significant variations in protocol names before collecting dose data. It should be ensured that each CT examination is performed with common names before establishing DRLs. The common nomenclature for each protocol is crucial for data validation. Kanal et al.[7] highlighted that improper labeling of CT protocols could lead to problems with dose data; they suggested standardizing the protocol names according to Radlex terminology as a solution.[25] In our study, before collecting dose data, we standardized the CT protocol names through collaboration among radiologists, radiographers, and technologists. If the common protocol names were not used, the number of dose data would be reduced while the LDRLs would be increased due to the inclusion of dose data from multiphase examinations.

There are several limitations to our study, which was conducted using dose data obtained from three among four major CT scanner manufacturers (Philips was not available). Most of the dose data were obtained from head and chest CT, as well as abdomen-pelvis CT protocols. For other protocols, a smaller amount of dose data was available (Table 2). This study can be strengthened by including dose data from all CT scanner manufacturers over a longer period. LDRLs were established for single-phase protocols to enable comparison with NDRLs; however, DRLs for multiphase protocols, which constitute a significant portion of routine practice, were not established. Although we established DRLs for four protocols in addition to NDRL protocols, it is necessary to include many others, including multi-phase protocols, in future DRL studies.

DRLs are dose levels in radio-diagnostic practices for standard-sized patient groups. To ensure meaningful comparisons of DRLs, it is recommended that dose data from standard-sized patient groups be included when establishing DRLs.[15] However, in ICRP Publication 135, it is stated that if an automated data collection system is used, DRLs can be established using all dose data, and it may be possible to relax weight restrictions.[3] In our study, dose data were collected using the automated dose tracking software, Teamplay, including all dose data without weight standardization. Automated dose tracking software enables the rapid collection of large amounts of dose data, thereby contributing to the dose optimization process and making it possible to update DRLs at more frequent intervals. These types of software allow for the efficient monitoring of health center dose data and prompt initiation of the optimization process when dose values exceed reference DRLs.[5]

Several recent studies have shown that DRLs established based on patient size and clinical indications could significantly contribute to dose optimization.[7,13,26-28] Clinical indication-based DRLs are established using dose data obtained from examinations performed for various indications and requiring different image quality. In the study conducted by Aberle et al.[13], the DRL for an abdomen CT protocol performed for the exclusion of kidney stones was found to be 45% lower than the DRLs for abdomen CT protocols for other indications. It has been noted that DRLs are strongly dependent on clinical indications.[13] The ICRP also emphasized the significance of clinical indications-based DRLs.[3] The European Society of Radiology initiated the European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging project for the establishment of clinical indication-based DRLs.[26] Due to the lack of protocols created for different clinical indications in our institution, clinical indication-based DRLs could not be established in our study. To conduct future DRL studies based on clinical indications and to improve the success of the dose optimization process, it is necessary to develop protocols according to different clinical indications.

Klosterkemper et al.[27] showed significant variations in radiation doses based on patient sizes. Kanal et al.[7] established the NDRLs for the 10 most common CT examinations for adults in the United States, based on patient size (achievable dose according to water-equivalent diameter). In their prospective multicenter study, Brat et al.[28] established LDRLs for chest and abdomen CT examinations based on clinical indications and body mass index (BMI) class. Different dose levels were identified in different BMI classes, and particularly high variations were observed in doses for patients with a BMI ≥25.[28] DRLs could not be established based on patient sizes in our study due to the lack of weight information for the patients in our dataset. DRLs that are established based on patient sizes can contribute to the optimization of protocols and the prevention of unnecessary radiation exposure by reducing dose variations.

CTDIvol and DLP are indirect measurements of patient radiation dose. It is well-known that patient size affects radiation dose. To improve the accuracy of dose exposure measurements, patient size should also be considered.[7,29] Size-specific dose estimate (SSDE) is a method that recalculates the CTDIvol based on patient size, providing a more accurate prediction of the patient's radiation dose.[30] The ED is a quantity that represents the stochastic risk caused by radiation.[31]

In our study, the SSDE and ED, which were automatically calculated by the Teamplay software, were obtained from dose reports. However, SSDE values could not be verified due to the unavailability of patient height and weight data. There is currently no study validating the calculations used by the Teamplay software for determining ED. Therefore, SSDE and ED were not included in our study. The ICRP recommends establishing DRLs for pediatric examinations based on patient weight.[3] Hence, pediatric examinations were not included in the study. By obtaining patient size information, pediatric DRLs could be established, and dose metrics such as SSDE could be included in future studies.

To reduce radiation dose in coronary CTA, prospective gating mode (PGM) has been developed as an alternative to retrospective gating mode (RGM) for patients with stable heart rates. PGM has shown a significant dose reduction compared to RGM.[32] Therefore, in current coronary CTA DRL studies, separate DRLs for each mode have been established.[33] In our study, information regarding the mode in which coronary CTAs were performed was unavailable; thus, DRLs based on imaging mode could not be established. LDLRs for coronary CTA were compared with mixed-mode DRLs from other countries (Table 4). This issue could be resolved by labeling the different coronary CTA modes with separate protocol names.

Diagnostic quality should be preserved in parallel with doses being reduced during the optimization process. DRL studies not only establish radiation dose values that should not be exceeded but also demonstrate the minimum dose levels that can provide diagnostic quality. In cases where local dose levels are below the 25th percentile, image quality should be assessed.[3] One of the limitations of our study is that the image quality was not evaluated.

Despite its limitations, our study emphasizes the need for the re-establishment of NDRLs. Individual healthcare facilities should initiate the optimization process by monitoring their dose data.

In conclusion, LDRLs for CT were established from substantial dose data using dose-tracking software. There is a need to update the NDRLs for CT protocols in Türkiye. Until new NDRLs are established, local institutions in Türkiye can initiate the optimization process by comparing their dose distributions to the LDRLs established in our study. The LDRLs were comparable to or lower than NDRLs and DRLs set in other countries for most protocols. Automated dose-tracking software can play an important role in establishing DRLs by facilitating the collection and analysis of large datasets. The establishment and use of DRLs, as well as radiation dose optimization, can be achieved through the collaborative and coordinated efforts of radiologists, medical physicists, radiographers, and radiological safety officers. We hope that our study can contribute to radiation dose optimization efforts in Türkiye.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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