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ORIGINAL ARTICLE

Radiation doses from head, neck, chest and abdominal CT examinations: an institutional dose report

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PURPOSE
We aimed to obtain typical values for head, neck, chest, and abdominal computed tomography (CT) examinations from routine patients in 2018, and to review our data with national and international diagnostic reference levels (DRLs).

METHODS
Single-phase head, neck, chest, and abdominal CT scans of adults performed in 64-slice CT in 2018 were included in this study. Radiation dose parameters of CT scans were obtained from the picture archiving and communication system of our hospital. Volumetric CT dose index ($CTDI_{vol}$) and dose length product (DLP) values were recorded. Effective dose (ED) and scan length was calculated. A 16 cm diameter phantom is referenced for head CT, and 32 cm diameter phantom is referenced for neck, chest, and abdominal CT. Descriptive statistics of the variables were given according to the normality testing.

RESULTS
Median $CTDI_{vol}$ value was 53 mGy for the head, 13.1 mGy for the neck, 8.3 mGy for the chest, and 8.6 mGy for the abdomen. Median DLP value was 988 mGy.cm for the head, 299 mGy.cm for the neck, 314 mGy.cm for the chest, and 457 mGy.cm for the abdomen. Median ED value was 2.07 mSv for the head, 1.76 mSv for the neck, 4.4 mSv for the chest, and 6.8 mSv for the abdomen. Considering national DRLs, median $CTDI_{vol}$ values of head, chest, and abdomen were lower, whereas median DLP and ED values of head and chest were higher. For the abdomen, the median DLP and ED values were lower.

CONCLUSION
Overall radiation dose parameters obtained in this study points out the need for optimization of head CT examinations in our institution.

Computed tomography (CT) is an evolving imaging modality that uses X-rays to create images, which is commonly used for diagnosis, and follow-up of various medical conditions in daily radiology practice. Day by day, increased usage of CT raises concern for cancer risk attributed to increased X-ray exposure, which is a primary limitation (1, 2). Although the number of CT examinations among all X-ray procedures are low, it contributes the largest portion of radiation exposure from medical sources: as much as 66% in the United States and 47% in the United Kingdom. Thus, needless usage should be avoided, and patients should be protected from the detrimental effects of X-rays from CT examinations (3–5). For this purpose, CT scan parameters should be optimized in every radiology clinic. As the first step for optimization, it is recommended to compare CT scan parameters and patient radiation doses with diagnostic reference levels (DRLs) (6). Radiology teams use national DRLs as a reference point to evaluate their radiation dose parameters and determine whether their radiation parameters are within the specified reference ranges. CT scans should be checked, and factors causing increased radiation doses should be adjusted when patient radiation dose parameters are higher than national DRLs (7).

In 2015, Ataç et al. (8) reported national DRLs for head, chest, abdominal, and pelvic CT examinations of adults and children, based on a nationally distributed survey analysis in Turkey, and their study was the first DRL study in Turkey. Therefore, there is a need for us to evaluate our CT radiation dose parameters in adults in comparison to national DRLs for CT,

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and if necessary, optimize our CT scanning protocols.

The main objective of this study was to obtain typical values for head, neck, chest, and abdominal CT examinations from routine patients in 2018, and to review our data with national and international DRLs.

Methods

Ethics committee approval was obtained for this retrospective study (protocol number: 2019/17). Informed consent was waived by the ethics committee.

Data collection and analysis

Single-phase diagnostic head, neck, chest, and abdominal (upper and lower abdomen) CT scans of adult patients performed at our hospital between January and December in 2018 were included in this study. Multi-phase CT scans were excluded. CT scans obtained with tube potential of 120 kV in our daily practice comprised the study group. Radiation dose parameters of CT scans were obtained retrospectively from the local picture archiving communications system (PACS). A 16 cm diameter phantom is referenced for head CT, and 32 cm diameter phantom is referenced for neck, chest, and abdominal CT. Volumetric CT dose index ($CTDI_{vol}$), and dose length product (DLP) values were recorded. Estimated effective dose (ED) was calculated by using k factor according to the formula ED = k × DLP (9). The scan length was calculated by dividing DLP by $CTDI_{vol}$.

CT parameters

A 64-slice CT system (Optima CT 660, General Electric Medical Systems) was used for the study. CT parameters are summarized in Table 1 for each region.

Table 1. CT scanning parameters of relevant anatomic regions

Parameters	Head CT n=607 (34%)	Neck CT n=149 (8%)	Chest CT n=561 (32%)	Abdomen CT n=464 (26%)
Slice thickness (mm)	2.5	2.5	2.5	1.25
Detector coverage (mm)	20	40	40	40
Tube current (reference noise index) (mAs)[a]	170–500 (3.80)	80–400 (9.10)	90–400 (15.86)	80–450 (15.86)
Tube voltage (kV)	120	120	120	120
Gantry rotation time (s)	0.5	0.6	0.5	0.5
Pitch	0.53	0.98	1.37	1.37

n represents number of CT scans. Percentage represents the number of scans in that particular region within the total number of scans.
[a]Auto mAs was activated and iterative reconstruction was performed.

Table 2. The first, second, and third quartile values for $CTDI_{vol}$ (mGy)

Region	1st quartile	2nd quartile (Median)	3rd quartile
Head, n=607 (34%)	48.6	53	59.1
Neck, n=149 (8%)	11.4	13.1	14.8
Chest, n=561 (32%)	5.7	8.3	10.8
Abdomen, n=464 (26%)	5.9	8.6	12.5

n represents number of CT scans. Percentage represents the number of scans in that particular region within the total number of scans.
$CTDI_{vol}$, volumetric computed tomography dose index.

Main points

- CT scan parameters should be optimized in every radiology clinic for lower radiation dose parameters.
- As a first step in optimization, it is recommended to compare patient radiation dose outputs with diagnostic reference levels (DRLs).
- DRL is used as a reference point for comparing radiation dose parameters.
- Typical value is defined as the median of the distribution of the data for a DRL quantity from X-ray examinations in a particular healthcare institution.
- A new data set of typical values for common adult CT examinations were reported by one institution.

Statistical analysis

The Kolmogorov–Smirnov test was used to determine the normal distribution of continuous variables. Descriptive statistics of the categorical data are presented with n (%) and, for non-normalized variables are shown as median (interquartile range [IQR]), and normal distributions are shown as mean ± standard deviation (SD). Radiation dose parameters of the study were compared with the previous reported data using one sample Wilcoxon signed rank test. Scan length values of head and chest CT scans of the study were compared with the previously reported data using one-sample t test. Statistical package for social sciences (SPSS) version 23 software (IBM Corp.) was used in the statistical analysis. A value of $p < 0.05$ was considered statistically significant.

Results

Overall, 1781 CT scans were performed, including 607 head CT (34%), 149 neck CT (8%), 561 chest CT (32%), and 464 abdominal CT (26%) scans.

CT scans were performed in 1033 males (58%) and 748 females (42%): 318 males (52%) and 289 females (48%) received head CT, 82 males (55%) and 67 females (45%) received neck CT scans, 366 males (65%) and 195 females (35%) received chest CT scans, and 267 males (58%) and 197 females (42%) received abdominal CT scans.

The mean±SD age of the patients who underwent head, neck, chest, and abdominal CT was 52.5±19.8 years (18 to 91 years), 47.8±18.2 years (18 to 85 years), 54.5±16.8 years (18 to 93 years), and 48.2±17.5 years (18 to 93 years), respectively.

Median $CTDI_{vol}$ values were as follows: head 53 mGy (IQR, 48.6–59.1 mGy); neck 13.1 mGy (IQR, 11.4–14.8 mGy); chest 8.3 mGy (IQR, 5.7–10.8 mGy); and abdomen 8.6 mGy (IQR, 5.9–12.5 mGy). Median DLP values were as follows: head 988 mGy.cm (IQR, 878–1129 mGy.cm); neck 299 mGy.cm (IQR, 244–378 mGy.cm); chest 314 mGy.cm (IQR, 214–416 mGy.cm); and abdomen 457 mGy.cm (IQR, 308–656 mGy.cm). Median ED values were as follows: head 2.07 mSv (IQR, 1.84–2.37 mSv); neck 1.76 mSv (IQR, 1.44–2.23 mSv); chest 4.40 mSv (IQR, 2.99–5.82 mSv); abdomen 6.85 mSv (IQR, 4.62–9.84 mSv). The first, second, and third quartile values for $CTDI_{vol}$, DLP, and ED are listed in Tables 2–4, respectively. For all regions, median $CTDI_{vol}$, DLP, and ED values of the study were lower than 3rd quartile national (8), European (10), and

USA data (11) ($p < 0.001$), except for median DLP value of head CTs compared to European data (10) ($p = 0.590$) (Table 5). For head, chest, and abdomen CT scans median $CTDI_{vol}$ and DLP values of the study were lower than 3rd quartile UK data (12) ($p < 0.001$), except for median DLP value of head CT ($p < 0.001$). Compared to 3rd quartile European Commission (EC) data (13), median DLP value of head CT was higher ($p < 0.001$), median DLP value of chest CT was lower ($p < 0.001$), and median DLP value of abdomen CT was similar ($p = 0.110$).

The mean±SD scan length of head, neck, chest, and abdomen CT scans were 18.1±1.7 cm, 23.4±3.9 cm, 38±3.9 cm, and 52.1±5.6 cm, respectively. Mean scan length values of head and chest CT scans were higher than previously reported data (14, 15) ($p < 0.001$).

Discussion

In this study, radiation dose parameters of the adult head, neck, chest, and abdominal CT examinations of a single center in Turkey was reported. Parameters of CT scans according to anatomic regions were also stated for better understanding. With this study, we contribute typical values from CT scans to our national DRLs, an area of limited existing data in our country, and offer comparable data for other centers. We hope that this study encourages other centers to report their radiation dose parameters including any X-ray imaging modality.

In the International Commission on Radiology Protection (ICRP) publication 135, the latest publication about DRLs in medical imaging, a DRL is defined as a form of investigation level used as a tool to aid in optimization of protection in the medical exposure of patients for diagnostic and interventional procedures including ionizing radiation. This evaluation provides whether the amount of radiation used for a specified examination is remarkably high or low in routine conditions. In this publication, typical value is defined as the median of the distribution of the data for a DRL quantity from X-ray examinations in a particular healthcare institution. The data for typical values are provided from local surveys or a review of local data. At least 10 institutions are needed to set local DRLs. Typical values then can be used for comparison with DRL data provided from one institution and may help further optimization. The DRL value is set at the 75th percentile (3rd quartile) of the distribution (16). However, the use of reported 1st quartile and median DRL values as the reference point is also recommended for lower radiation doses (8, 11). The effectiveness of DRLs documented in UK, and DRL values, as well as radiation doses, in the UK have decreased in surveys obtained over the last 30 years. To use DRLs for optimization of radiation protection, median values of specific X-ray medical imaging procedure in a radiology department should be compared with local, national, or regional DRL values to determine if data obtained from relevant imaging procedure is higher or lower. If the institutional DRL value is higher than the reference level, a research should be performed without delay to determine

Table 3. The first, second, and third quartile values for DLP (mGy.cm)

Region	1st quartile	2nd quartile (Median)	3rd quartile
Head, n=607 (34%)	878	988	1129
Neck, n=149 (8%)	244	299	378
Chest, n=561 (32%)	214	314	416
Abdomen n=464 (26%)	308	457	656

n represents number of CT scans. Percentage represents the number of scans in that particular region within the total number of scans.
DLP, dose length product.

Table 4. The first, second, and third quartile values for ED (mSv)

Region	1st quartile	2nd quartile (Median)	3rd quartile
Head, n=607 (34%)	1.84	2.07	2.37
Neck, n=149 (8%)	1.44	1.76	2.23
Chest, n=561 (32%)	2.99	4.40	5.82
Abdomen, n=464 (26%)	4.62	6.85	9.84

n represents number of CT scans. Percentage represents the number of scans in that particular region within the total number of scans.
ED, effective dose.

Table 5. Study data, national data and international data

	Study data[a]			National data[a](8)			European data[b] (10, 20)			USA data[a] (11)			Worldwide data[c] (20)
	$CTDI_{vol}$ mGy	DLP mGy.cm	ED mSv	$CTDI_{vol}$ mGy	DLP mGy.cm	ED mSv	$CTDI_{vol}$ mGy	DLP mGy.cm	ED mSv	$CTDI_{vol}$ mGy	DLP mGy.cm	ED mSv	Mean ED mSv
Head	53	988	2.07	66.4	810	1.7	60	1000[d]	1.9	62	1120	3	1.7
Neck	13.1	299	1.76	N/A	N/A	N/A	N/A	500	2.5	22	650	7	3
Chest	8.3	314	4.4	11.6	289	4.1	10	400	6.6	17	610	13	7
Abdomen	8.6	457	6.85	13.3	204	3.1	25	800	11.3	17	860	16	6.8

$CTDI_{vol}$, volumetric computed tomography dose index; DLP, dose length product; ED, effective dose; N/A, not applicable.
[a]Data of study are median values. Data of national and United States of America (USA) are 3rd quartile values.
[b]$CTDI_{vol}$ and DLP values in Dose Data of Med 2 (DDM2) study are the most common values in that report, representing the status of established diagnostic reference levels in Europe. Effective dose of DDM2 was taken given by Vilar Palop et al. (20).
[c]Since data of the study were expressed with median values, these values cannot be compared with mean values of worldwide data.
[d]All p values of the comparisons of the study data with national, European and USA data were $p < 0.001$, except for head DLP value of European data ($p = 0.590$).

the possible reasons. If relevant reasons are determined, corrections should be applied immediately. Any diagnostic examination should be of sufficient image quality to provide the diagnostic information required, and purpose of the examination cannot be sacrificed. This is known as "as low as reasonably achievable" principle (ALARA). According to the ALARA principle, X-ray examinations should be obtained at adequate image quality with lowest possible radiation dose exposure. In concordance with this principle there may be an increase in radiation dose in some cases (16).

In this study, we reported 1st, 2nd (median), and 3rd quartile radiation dose values, and we reviewed our results with published national and international data (Table 5), generally using the 2rd quartile (median) values. Since DRL values were obtained from periodical surveys or audits, reflecting the upper limits of average values, these results do not suggest poor medical practice (8).

We report three radiation dose parameters; two of them ($CTDI_{vol}$ and DLP) were CT radiation dose outputs directly taken from patient protocol, which are given by CT device, and the third was ED. $CTDI_{vol}$, DLP, and ED are measured in milligray (mGy), milligray.cm (mGy.cm), and millisievert (mSv), respectively. These three parameters can be easily and universally used for comparison of radiation doses with national and international DRLs in CT examinations. $CTDI_{vol}$ primarily indicates the intensity of the radiation emitted by a CT device and does not show how much radiation the patient is being exposed to. It expresses average per-section radiation exposure referenced to a 16 or 32 cm cylindric phantom. $CTDI_{vol}$ is not related to patient size, whereas DLP is the product of the $CTDI_{vol}$ and scan length. Thus, DLP expresses the total amount of radiation used to perform the CT scan. ED is another dose parameter that takes equivalent doses to all exposed organs into account. ED simply reflects biologic effects of radiation, and puts radiation doses into a comparable form, and allows comparison of CT radiation doses with other types of radiologic examinations, natural background exposures, and regulatory dose limits, such as 0.05 mSv for chest radiography, and 5 mSv for chest CT (17). We calculated ED by the following equation, $E = k \times DLP$, where the k factor is a specific coefficient for the scanned anatomic region in CT examinations. Using this method, ED may be underestimated by 4%–37% according to ICRP publication 60 and by up to 74% according to ICRP publication 103 (9). In another study regarding the estimation of ED with this method, ±15% variation has been reported relative to the gold standard organ-dose-based technique for CT scans obtained at 120 kV (18).

Taylor et al. (19) evaluated variability of $CTDI_{vol}$ and DLP data, and determined a minimum sample size for obtaining an expected sensitivity. They found that variability of mean $CTDI_{vol}$ and DLP decreased with increasing sample size for all body regions. In our study, the number of CT scans of the relevant regions was higher than the recommended numbers, except for the number of neck CT scans.

In reference to the national data, our median $CTDI_{vol}$ values were lower than 3rd quartile data for head (53 vs. 66.4 mGy) and chest (8.3 vs. 11.6 mGy), while median DLP and ED values were higher than national 3rd quartile data for head (988 vs. 810 mGy.cm; 2.07 vs. 1.7 mSv, respectively), and chest (314 vs. 289 mGy.cm and 4.4 vs. 4.1 mSv, respectively) (8). For abdominal CT, median $CTDI_{vol}$, DLP and ED values were lower than 3rd quartile values of national data (8.6 mGy, 457 mGy.cm and 6.8 mSv vs. 13.3 mGy, 625 mGy.cm and 9.4 mSv, respectively) (8). Overall for head and chest, our median $CTDI_{vol}$ values were lower than the national DRLs, whereas median DLP and ED values were higher; for the abdomen, our median $CTDI_{vol}$, DLP, and ED values were lower than the national DRLs. In our institution the scan area was between vertex and C1 vertebral corpus in head CT scans, between skull base and T2 vertebral corpus in neck CT scans, between supraclavicular fossa and midportion of kidneys in chest CT scans, and between lung bases and inguinal regions in abdominal CT scans. The scan area of these regions, as well as scan length, were reported lesser according to our study (14). In our study higher median DLP and ED values in head and chest CT scans compared with the national data are most likely associated with higher scan length. The mean scan length of head and chest CT scans in our study were 18.1 and 38 cm, respectively. Whereas in the study of Badawy et al. (14) standard head and chest CT scan lengths were 11.4 cm and 34.1 cm, respectively, which are shorter than the values in our study. Median scan length of chest CT scan was reported as 33 cm by Singh et al. (15), and was shorter than our study. Shortening the scan length based on clinical indication may further reduce the radiation dose parameters, including both DLP and ED.

Compared with data from European countries, our median $CTDI_{vol}$ value for the head was lower than 3rd quartile UK data (53 mGy vs. 63 mGy) (12). Compared with Dose Data of Med 2 (DDM2) study, which included DRLs of 36 European countries with national experience in conducting surveys of dose distributions from medical diagnostic procedures, our median $CTDI_{vol}$ value was lower than that reported by DDM2, where the most common value was 60 mGy, ranging from 50 to 75 mGy.cm (10). Median DLP value was higher than 3rd quartile UK data (12) (988 vs. 973 mGy.cm) and 3rd quartile EC data (988 vs. 733 mGy.cm) (13). The most common value of DLP in DDM2 was 1000 mGy.cm, ranging from 760 to 1300 mGy.cm, and our value was similar with most common value of DDM2, within reported values as well (10). Median ED value was higher than the DDM2 data (2.07 vs. and 1.9 mSv) (20). For neck, median DLP value was 299 mGy.cm and lower than DDM2 data (most common value is 500 mGy.cm, ranging from 440 to 500 mGy.cm) (10). Median ED value for neck was lower than DDM2 data (1.76 vs. 2.5 mSv) (20). For chest, median $CTDI_{vol}$ value was lower than 3rd quartile UK data (8.3 vs. 12 mGy) (12). Median $CTDI_{vol}$ value was lower than reported by DDM2, and the most common value was 10 mGy, ranging from 10 to 30 mGy.cm (10). Median DLP value was lower than 3rd quartile UK data (12) and 3rd quartile EC data (13) (314 vs. 614 and 394 mGy.cm). The most common value of DLP in DDM2 was 400 mGy.cm, ranging from 270 to 700 mGy.cm, and higher than our median value as well (10). Median ED value was lower than reported by DDM2 study (4.4 vs. 6.6 mSv) (20). For the abdomen, our median $CTDI_{vol}$ value was lower than 3rd quartile UK data (8.6 vs. 15 mGy) (12). Median $CTDI_{vol}$ value was lower than that reported by DDM2; the most common value was 25 mGy, ranging from 13 to 35 mGy.cm (10). Our median DLP value was lower than the 3rd quartile UK (12) and similar to 3rd quartile EC data (457 vs. 745 and 464 mGy) (13). Median DLP (457 mGy.cm) value was also lower than that reported by DDM2; the most common value was 800 mGy.cm, ranging from 460 to 1200 mGy.cm (10). Median ED value was lower than DDM2 data (6.8 vs. 11.3 mSv) (20). Overall our results in reference to European DRLs can be summarized as follows: for the head, our median $CTDI_{vol}$ value was lower than UK and DDM2 data, DLP value was slightly higher than UK data and similar to DDM2 data, and median ED value was slightly higher than DDM2 data. For the neck, our median DLP and ED values were lower. For the chest and the abdomen, our median $CTDI_{vol}$, DLP, and ED values were lower.

Considering 3rd quartile USA data for head, neck, chest and abdomen, our median $CTDI_{vol}$, DLP, and ED values were lower: for the head, 53 vs. 62 mGy, 988 vs. 1120 mGy, and 2.07 vs. 3 mSv, respectively; for the neck, 13.1 vs. 22 mGy, 299 vs. 650 mGy.cm, 1.76 vs. 7 mSv, respectively; for the chest, 8.3 vs. 17 mGy, 314 vs. 610 mGy.cm, 4.4 vs. 13 mSv, respectively; and for the abdomen, 8.6 vs. 17 mGy, 457 vs. 860 mGy.cm, 6.8 vs. 16 mSv, respectively (11).

In another study including global data, Vilar Palop et al. (20) reported mean ED values as 1.7, 3, 7, and 6.8 mSv for the head, neck, chest, and abdomen, whereas our median values in these regions were 2.07, 1.76, 4.4, and 6.8 mSv, respectively.

This study has some limitations. First, only CT examinations obtained at 120 kV were reported in this study since the number of CT scans obtained at 80 or 140 kV was very low in our institution. Second, pediatric CT scans were not included due to the same reason aforementioned. Third, we calculated ED by using the following equation, $E = k \times DLP$. ED calculated with this method could be an underestimation according to the gold standard organ-dose-based technique, but this method is convenient and easy to apply. Finally, this was a single-center study; however, the data provided can potentially contribute to the formation of local or national DRLs.

In conclusion, we reported typical values for the adult head, neck, chest, and abdominal CT examinations from one year of CT scan experiences in one institution in Turkey. Overall, this study points out the need for optimization of head CT examinations in our institution. The reported typical values of 2018 determined our condition in terms of CT radiation dose and will contribute to radiation dose reduction in our center by adjusting the scanning parameters. We hope that other institutions may be encouraged to report their status in terms of CT radiation dose, which would eventually help to establish local DRLs.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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