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RADIOLOGY PHYSICS

ORIGINAL ARTICLE

Institutional clinical indication-based typical dose values of multiphasic abdominopelvic computed tomography examinations

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PURPOSE

Our study aimed to obtain clinical indication-based typical dose values and size-specific dose estimates (SSDEs) for multiphasic abdominopelvic computed tomography (CT) examinations and to review our data with published diagnostic reference levels (DRLs).

METHODS

In this retrospective study, multiphasic liver, kidney, pancreas, and mesenteric ischemia protocol CT scans performed at our center between January 2018 and December 2021 were analyzed. The clinical indications were hepatocellular carcinoma, renal cell carcinoma, pancreas adenocarcinoma, and mesenteric ischemia. The computed tomography dose index volume ($CTDI_{vol}$) and dose-length product (DLP) values were recorded, and the SSDE and effective dose (ED) values were calculated. The water-equivalent diameter (Dw) value required for the SSDE calculation was measured using the automated calculation of the Dw program.

RESULTS

The total number of patients was 514, with 86 patients excluded from this study. The dose values were calculated for 426 patients (183 female and 243 male; 111 liver, 120 kidney, 85 pancreas, and 110 mesenteric). The median values for the $CTDI_{vol}$, DLP, SSDE, and ED were 6.86 mGy, 683.02 mGy.cm, 8.75 mGy, and 10.45 mSv for the liver CT; 8.37 mGy, 908.37 mGy.cm, 10.37 mGy, and 13.89 mSv for the kidney CT; 7.82 mGy, 517.98 mGy.cm, 10.01 mGy, and 7.92 mSv for the pancreas CT; and 9.48 mGy, 983.68 mGy.cm, 12.78 mGy, and 13.86 mSv for the mesenteric CT, respectively. All dose values were lower than the published DRLs.

CONCLUSION

The literature reveals large differences in the multiphasic abdominopelvic CT protocols, especially in the number of phases and scan length. This situation makes comparing dose values difficult. Dose studies revealing the protocol parameters in detail are needed so that institutions can compare and optimize their own protocols. Additionally, users should periodically check the dose values in their own institutions.

KEYWORDS

Clinical indication, computed tomography, diagnostic reference levels, multi-phase scan, size-specific dose estimate, water-equivalent diameter

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The frequency of computed tomography (CT) use and its contributions to diagnostic radiology have increased since the early 1970s. CT now constitutes a large part of the artificial radiation originating from medicine due to its increased prevalence and frequency of use.[1] This situation increases the cancer risk, and the optimization principle in radiation safety has become much more important. The diagnostic reference level (DRL) is used for diagnostic and interventional procedures to help optimize a patient's exposure to ionizing radiation. It is produced from radiation data collected locally, nationally, or regionally.[2] The use of CT scans should be reassessed and optimized when the patient's doses exceed the available DRLs.

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The computed tomography dose index volume ($CTDI_{vol}$) and dose-length product (DLP) are used to determine the DRL for CT examinations. These parameters are only an approximate estimate of the patient's dose. The $CTDI_{vol}$ is a dose index specific to phantom sizes and does not consider the patient's size, thickness, and length of the scanned volume.

The size-specific dose estimate (SSDE) has been proposed by the American Association of Physicists in Medicine (AAPM) to give the $CTDI_{vol}$ a more realistic dose value for the patient, considering the patient's size. In this method, the water-equivalent diameter (Dw) is calculated, and then the $CTDI_{vol}$ value is multiplied by the corresponding conversion factor to the Dw in the AAPM Report 220.[3]

In 2015, Ataç et al.[4] reported the first Turkish national DRLs for single-phase head, chest, abdominal, and pelvic CT examinations of adults and children. In the following years, Atlı et al.[5] reported institutional typical dose values for single-phase head, neck, thorax, and abdomen CT examinations. In these dose studies in Turkey, data from single-phase CT examinations were collected, but there have been no national patient dose studies for multiphasic CTs so far. Recent DRL studies for multiphasic abdominopelvic CTs exist in other countries.[6-11] The dose values for liver CT were given in all of these studies, and the dose values for kidney and pancreas CTs were given in a few. However, there is no dose data for mesenteric ischemia protocol CTs. Additionally, the SSDE was not evaluated in any of these studies. Some studies did not include information such as the $CTDI_{vol}$, effective dose (ED), scan length, and phase number.

Most existing DRLs report dose values based on anatomical regions, such as head, chest, and abdomen CTs. However, the protocols to be selected in CT examinations are determined according to the clinical preliminary diagnosis or clinical indication. Different imaging protocols are used for varying clinical indications in the same anatomical region. For example, in our clinic, a non-contrast single-phase abdominopelvic CT protocol is used for a patient being investigated for kidney stones. However, if the patient is suspected of having renal cell carcinoma (RCC), the kidney is scanned four times (a precontrast phase followed by post-contrast corticomedullary, nephrogram, and urogram phases) for lesion characterization. This reveals that one of the most important things affecting dose values is clinical indication. The clinical indication-based approach to DRLs was mentioned by the International Commission on Radiological Protection in 2017.[2]

Main points

- The protocols used in multiphasic abdominopelvic computed tomography (CT) vary significantly between institutions. This makes it difficult to compare institutional dose values to diagnostic reference levels.
- The number of phases and scan length are the most important parameters that cause differences in multiphasic abdominopelvic CT protocols.
- Institutions must determine their own dose values and check them at regular intervals.

In our study, we aimed to evaluate the clinical indication-based typical dose values and SSDEs for multiphasic abdominopelvic CTs and review our data with published DRLs.

Methods

In this retrospective study, after obtaining approval from the Bolu Abant İzzet Baysal University Clinical Research Ethics Committee (decision number: 2022/81), multiphasic liver, kidney, pancreas, and mesenteric CT scans taken at the İzzet Baysal Training and Research Hospital between January 2018 and December 2021 were examined. Informed consent was waived by the ethics committee. The clinical indications were hepatocellular carcinoma (HCC), RCC, pancreatic adenocarcinoma, and mesenteric ischemia. The examinations were obtained with a 64-detector CT device (2017 GE Revolution EVO 128 slice, China). Table 1 summarizes the CT input parameters for each protocol. Automatic tube current modulation was used in all protocols.

The patient's age, gender, and indication for the CT examination were obtained from the hospital's information archive system. The $CTDI_{vol}$ and DLP values were recorded from the picture archiving and communication system. The automated calculation of the Dw program was obtained from a free website (http://ctdose-iqurad.med.uoc.gr/) was used to calculate the Dw. For this, CT images of the patient were loaded into the program in the Digital Imaging and Communications in Medicine format, and then the program calculated the mean and median Dw values for each section (Figure 1). The Dw values were calculated from the median image, according to the AAPM Report 220, for each phase for each patient using this program. Afterward, the Dw value of that examination was calculated by taking the average of the Dw values obtained from each phase. For the SSDE calculation, the $CTDI_{vol}$ values were multiplied by the Dw-appropriate conversion factors in the AAPM Report 220. While calculating the total DLP, the DLP values of all phases and the DLP value of bolus tracking were added. The scan lengths were calculated separately for each phase with the $DLP/CTDI_{vol}$ ratio.

The ED was calculated by multiplying the DLP value with the conversion coefficients published in the International Commission on Radiological Protection (ICRP) 103. These coefficients were given as 0.0153 in an abdominal CT and 0.0141 in an abdominopelvic CT for a 120 kV tube current.[12] The average of the $CTDI_{vol}$ and SSDE values of each phase and the sum of the DLP and ED values were taken.

Statistical analysis

The mean, standard deviation (SD), median, and the first, second, and third quartiles

Table 1. Input parameters for each CT protocol

CT protocol	Phase	Slice thickness (mm)	Tube current (min–max mAs)	Tube voltage (kV)	Gantry rotation time (sec)	Pitch
Liver	Late arterial Portal venous Late	2.5 2.5 2.5	80–450 80–450 80–450	120	0.6	1.375
Kidney	Non-contrast Corticomedullary Nephrogram Urogram	5 2.5 2.5 2.5	100–350 140–450 140–450 140–450	120	0.6	1.375
Pancreas	Pancreatic Portal venous	2.5 2.5	100–400 100–400	120	0.6	1.375
Mesenteric	Arterial Portal venous	0.625 0.625	80–440 80–440	120	0.5	0.984

CT, computed tomography; kV, kilovoltage; mm, millimeter; mAs, milliampere-seconds; sec, second.

were calculated for the $CTDI_{vol}$, SSDE, DLP, and EDs using the Statistical Package for the Social Sciences (SPSS) for Windows (SPSS Inc., Chicago, Illinois, USA) version 26.0.

Results

The total number of patients was 514. Excluded from the study were 23 patients because their arms were in the imaging field, 16 patients who could not be positioned appropriately on the CT table, 6 patients who had metallic prostheses from lumbar stabilization surgery, and 1 patient who had a total hip prosthesis. Since the height and weight information of all the patients was not available, patients with the $CTDI_{vol}$ and DLP values between the minimum and maximum 5% for each protocol were not included in the calculation of the dose values, as recommended in the ICRP 135, to increase compliance with the standard patient definition.[2] As a result, 111 patients for liver CT [58 males (52%) and 53 females (48%)], 120 patients for kidney CT [81 males (67.5%) and 39 females (32.5%)], 85 patients for pancreas CT [46 males (54%) and 39 females (46%)], and 110 patients for mesenteric ischemia protocol CT [58 males (53%) and 52 females (47%)] were included in the study for the dose calculation. The mean ± SD age was 55.79 ± 14.76 years in liver CT patients, 62.35 ± 14.01 years in kidney CT patients, 62.74 ± 15.33 years in pancreatic CT patients, and 64.58 ± 14.14 years in mesenteric CT patients (Table 2).

The mean ± SD scan length was 32.3 ± 3.3 cm in liver CTs, 31.4 ± 4.8 cm in pancreas CTs, 51.8 ± 3.8 cm in mesenteric CTs, and equal for all phases in each protocol. The mean ± SD scan lengths in kidney CTs were 27.2 ± 4.4 cm in the non-contrast phase, 30.5 ± 2.8 cm in the corticomedullary and nephrogram phases, and 22.9 ± 3 cm in the urogram phase.

The mean ± SD and median values of the Dws were 29.63 ± 2.77 cm and 29 cm in the liver CT, 28.83 ± 2.44 cm and 29.51 cm in the kidney CT, 28.8 ± 2.25 cm and 28.85 cm in the pancreas CT, and 26.7 ± 2.32 cm and 26.75 cm in the mesenteric CT, respectively.

The median values for the $CTDI_{vol}$, DLP, SSDE, and ED were 6.86 mGy, 683.02 mGy.cm, 8.75 mGy, and 10.45 mSv for the liver CT; 8.37 mGy, 908.37 mGy.cm, 10.37 mGy, and 13.89 mSv for the kidney CT; 7.82 mGy, 517.98 mGy.cm, 10.01 mGy, and 7.92 mSv for the pancreas CT; 9.48 mGy, 983.68 mGy.cm, 12.78 mGy, and 13.86 mSv for the mesenteric CT, respectively. Tables 3, 4, and 5 detail the first, second, and third quartile values for the $CTDI_{vol}$, SSDE, DLP, and ED.

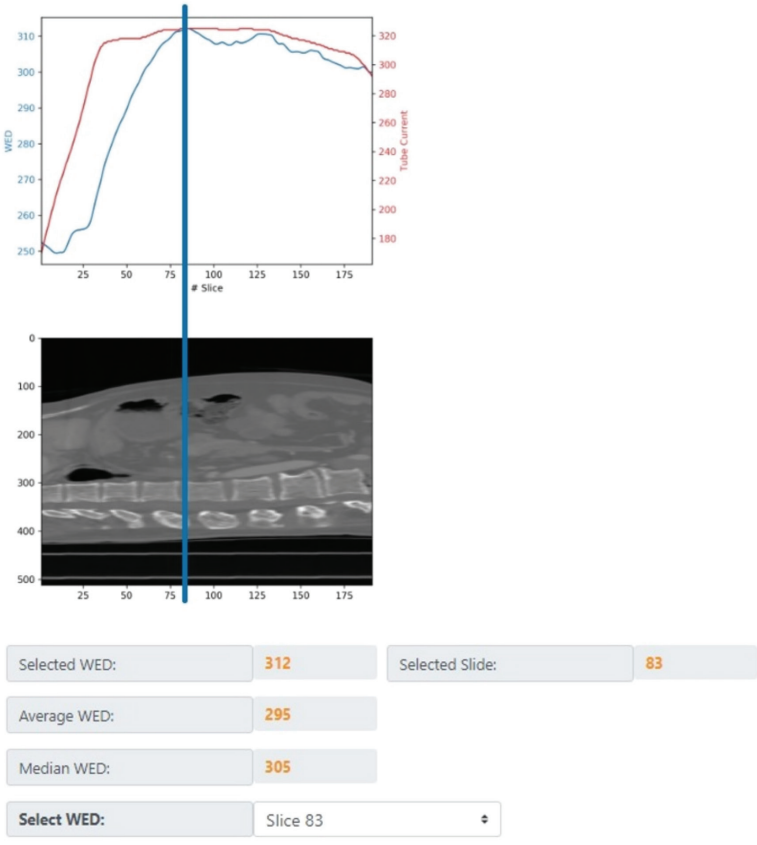

Figure 1. Water-equivalent diameter (Dw) measurement using the automated calculation of the Dw.

Table 2. Demographic data of the patients

	Patient numbers (percentage)		Age (mean years ± SD)
	Male	Female	
Liver CT	58 (52.3%)	53 (47.7%)	55.79 ± 14.76
Kidney CT	81 (67.5%)	39 (32.5%)	62.35 ± 14.01
Pancreas CT	46 (54.1%)	39 (45.9%)	62.74 ± 15.33
Mesenteric CT	58 (52.7%)	52 (47.3%)	64.58 ± 14.14

CT, computed tomography; SD, standard deviation.

Discussion

In our study, we found clinical indication-based typical dose values and SSDEs for multiphasic liver, kidney, pancreatic, and mesenteric CTs in 426 adult patients. Among the four indications we examined, the lowest ED value belonged to pancreatic adenocarcinoma. Our expectation was also in this direction because the scan length was shorter, and the number of phases was less compared with other protocols. We found that the clinical indication with the highest ED value was RCC. This was immediately followed by mesenteric ischemia. Although the highest DLP value was in mesenteric ischemia, the highest ED value was in RCC. This is because the conversion coefficient used in the ED calculation differs for these two indications (0.0153 in kidney CT and 0.0141 in mesenteric CT).[12]

Only a few dose studies have been conducted in Turkey.[4,5] In these studies, data for single-phase CT examinations were used. No studies in Turkey have been carried out with which we could compare our dose values for multiphasic abdominopelvic CTs.

Internationally, there are few DRL studies with which we could compare our data. van der Molen et al.[6] used data from 186 standard-sized patients for the DRLs of the 21 most frequently taken CT protocols in the Netherlands. The DRLs were only given for the DLP and ED, and the 75th percentile dose values of liver, kidney, and pancreatic CTs were higher than ours. The fact that the phase numbers and scan lengths of the CT protocols used in this study are higher than

Table 3. The first, second, and third quartile values for the $CTDI_{vol}$ and SSDE (mGy)

Protocol	Phase	1st quartile	2nd quartile (median)	3rd quartile
Liver	Late arterial	4.82 (6.49)	7.00 (8.77)	11.09 (12.75)
	Portal venous	4.89 (6.52)	6.96 (8.80)	11.44 (13.22)
	Late	4.90 (6.44)	6.94 (8.74)	10.99 (13.04)
	Average	**4.88 (6.48)**	**6.86 (8.75)**	**11.19 (12.94)**
Kidney	Non-contrast	5.28 (7.25)	7.71 (9.48)	9.23 (11.12)
	Corticomedullary	6.25 (8.50)	8.33 (10.27)	10.25 (12.16)
	Nephrogram	6.25 (8.52)	8.47 (10.48)	10.16 (12.11)
	Urogram	6.24 (8.77)	8.84 (10.92)	10.67 (12.99)
	Average	**6.03 (8.25)**	**8.37 (10.37)**	**10.12 (12.14)**
Pancreas	Pancreatic	6.64 (9.16)	7.67 (10.01)	10.23 (12.09)
	Portal venous	6.77 (9.11)	7.71 (10.01)	10.00 (12.00)
	Average	**6.70 (9.17)**	**7.82 (10.01)**	**10.07 (12.09)**
Mesenteric	Arterial	6.56 (9.88)	9.49 (12.73)	11.26 (15.17)
	Portal venous	6.59 (9.86)	9.47 (12.75)	11.28 (15.09)
	Average	**6.57 (9.85)**	**9.48 (12.78)**	**11.27 (15.10)**

Values in the parentheses represent the SSDEs. $CTDI_{vol}$, computed tomography dose index volume; mGy, milligray; SSDE, size-specific dose estimate.

Table 4. The first, second, and third quartile values for the DLP (mGy.cm)

Protocol	1st quartile	2nd quartile (median)	3rd quartile
Liver	493.45	683.02	1074.31
Kidney	681.02	908.37	1163.16
Pancreas	418.11	517.98	701.26
Mesenteric	681.24	983.68	1212.62

DLP, dose length product; mGy, milligray.

Table 5. The first, second, and third quartile values for the ED (mSv)

Protocol	1st quartile	2nd quartile (median)	3rd quartile
Liver	7.54	10.45	16.43
Kidney	10.41	13.89	17.79
Pancreas	6.39	7.92	10.72
Mesenteric	9.60	13.86	17.09

ED, effective dose; mSv, millisievert.

ours may explain the higher dose values. In the national DRL study of Kim et al.[7] in South Korea, the data of 14,620 adult patients were used. In the study, the 75th percentile $CTDI_{vol}$, DLP, and ED values were higher than ours for liver, kidney, and pancreas CTs. In this study, these CTs were defined as "2–4 phase," and data such as phase and scan length of the protocols are unknown.[7] Tsapaki et al.[8] used data obtained from 14 European countries, and 10 clinical indications were given in the European Study on Clinical Diagnostic Reference Levels for X-ray Medical Imaging (EUCLID). The DRL values varied significantly between hospitals. This was mainly due to the technical protocol and variable phase number/scan lengths.[8] In the study of the DRL by Salama et al.[9] in Egypt, the $CTDI_{vol}$ value was the highest in the literature. This may be due to the high body weights of the patients, the low pitch values, and the fact that the automatic tube current was not used in all patients.[9] In the DRL study by Aberle et al.[10] in Switzerland, the CT scans for HCC were taken in 2–4 phases, and our dose values were lower than in this study. In the study by Bos et al.[11], the DRLs were calculated for 10 clinical indications (EUCLID) from the CT scans of 3.7 million adult patients from seven countries. The dose values of CTs taken with the indication of HCC are higher than ours.

Our study has some limitations. The first is that the study was made from the data of a single CT device in a single center, and the number of patients was relatively small. Second, the height and weight information of all patients is not known. Third, multiphasic abdominopelvic CT protocols vary in different institutions due to specific parameters, such as phase numbers and the scan length on the z-axis. This situation causes difficulties in comparing the obtained data with the literature.

In our study, we reported the clinical indication-based typical dose values and SSDE's of multiphasic abdominopelvic CT protocols and compared our results with the published international data (Table 6). There are very few DRL studies of multiphasic abdominopelvic CTs in the literature, and none of these studies presented the SSDE data that would help us understand the impact of patient size on radiation dose.

In conclusion, additionally, until our study, no dose data for mesenteric ischemia protocol CTs were published. The DRL is a recommendation, and the purpose is to detect unusually high and low levels and to provide the necessary optimizations. Standard protocols are not used for multiphasic CTs, resulting in large differences in dose values between different devices, institutions, and countries. Studies that reveal the protocol parameters in detail are needed so that institutions can compare and optimize their protocols. Users should periodically evaluate dose values in their institutions to detect unforeseen deviations in doses in routine clinical practices and to take measures to correct them. The adequacy of the diagnostic image quality should be considered if the dose values are lower than the available DRLs. More studies are needed to evaluate clinical indication-based dose values in multiphasic abdominopelvic CTs. In our country, DRLs of single-phase CT examinations have been reported in pioneering studies, and similar DRL studies should be performed for multiphasic CTs.

Table 6. Comparison of the dose values (median) with the diagnostic reference values

Protocols	The authors' institution	van der Molen et al.[6]	Kim et al.[7]	Tsapaki et al.[8]	Salama et al.[9]	Aberle et al.[10]	Bos et al.[11]
Liver							
Number of phases	3	4	2–4*	4**	3	3.2***	-
Indication	HCC	Tx	-	HCC	Metastasis	HCC	HCC
$CTDI_{vol}$	6.86	-	14.70	9	31	11	14.60
DLP	683.02	1496.6	1693	1327	1425	1170	2032
ED	10.45	22.40	25.40	-	-	-	-
SSDE	8.75	-	-	-	-	-	-
SL (mean)	32.30	41.90	-	37	-	-	-
Kidney							
Number of phases	4	4	2–4*	-	-	-	-
Indication	RCC	RCC	-	-	-	-	-
$CTDI_{vol}$	8.37	-	14.20	-	-	-	-
DLP	908.37	1371.20	2100	-	-	-	-
ED	13.89	20.20	31.50	-	-	-	-
SSDE	10.37	-	-	-	-	-	-
SL (mean)	27.70	38.10	-	-	-	-	-
Pancreas							
Number of phases	2	3	2–4*	-	-	-	-
Indication	Adenoca	Adenoca	-	-	-	-	-
$CTDI_{vol}$	7.82	-	14	-	-	-	-
DLP	517.98	1000	1531	-	-	-	-
ED	7.92	14.70	23	-	-	-	-
SSDE	10.01	-	-	-	-	-	-
SL (mean)	31.4	40.90	-	-	-	-	-
Mesenteric							
Number of phases	2	-	-	-	-	-	-
Indication	Ischemia	-	-	-	-	-	-
$CTDI_{vol}$	9.48	-	-	-	-	-	-
DLP	983.68	-	-	-	-	-	-
ED	13.86	-	-	-	-	-	-
SSDE	12.78	-	-	-	-	-	-
SL (mean)	51.80	-	-	-	-	-	-

*Phase numbers not specified; **the number of phases was given as "4" most frequently; ***average number of phases. Adenoca, adenocarcinoma; $CTDI_{vol}$, computed tomography dose index volume; DLP, dose length product; ED, effective dose; HCC, hepatocellular carcinoma; RCC, renal cell carcinoma; SL, scan length (cm); SSDE, size-specific dose estimate; Tx, transplantation.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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