SM Journal of Clinical and Medical Imaging

Research Article

© Simwaba G, et al. 2025

Comparative Efficacy of Effective Diameter Versus Water-Equivalent Diameter in Size-Specific Dose Estimation for Chest CT: A Retrospective Cohort Study on Patient-Specific Radiation Optimization

Ai Li[1,2], Qiyu Zhang[3], Miao Yu[2], Xiaohui Zhao[2], Lei Xu[2], Huijun Ma[1], Ziyin He[1], Nan Yang[2], and Hongtao Niu[1*]

[1]Medical Imaging Center, Qinhuangdao NO.1 Hospital, China.
[2]Department of Radiomedicine, Hebei Medical University, China.
[3]Department of Interventional Treatment, Beijing NO.6 Hospital, China.

Abstract

Purpose : To investigate the discrepancy between effective diameter (d_{EFF}) and water-equivalent diameter (d_W) in size-specific dose estimate (SSDE) calculations for chest CT examinations.

Methods : This retrospective study analyzed 201 patients undergoing chest CT. The volumetric CT dose index ($CTDI_{vol}$) was recorded for each case. Both d_{EFF} and d_W were calculated from the central axial image, with subsequent derivation of size conversion factors (f_{EFF}, f_W) and SSDE values ($SSDE_{EFF}$, $SSDE_W$). Patients were stratified into tertiles based on lateral chest diameter (d_{LAT}): Group A (d_{LAT}<32.955 cm), Group B (32.955-35.190 cm), and Group C (d_{LAT}>35.190 cm). The comparison between different dLAT groups was conducted using the Friedman rank sum test. All statistical analysis was significant as P <0.05.

Results : The mean $CTDI_{vol}$ was 10.42 ± 0.44 mGy. Significant discrepancies were observed between d_{EFF} and d_W (t = -16.24, $P < 0.001$), corresponding conversion factors (U = 5,030.50, $P < 0.001$), and SSDE values (U = 12,590.50, $P < 0.001$). Intergroup analysis revealed statistically significant differences across all parameters (ANOVA F = 134.000-357.249, all $P < 0.001$).

Conclusion : Water-equivalent diameter demonstrates superior accuracy over geometric measurements for SSDE calculation in chest CT, particularly for patient-specific dose optimization. These findings, while specific to GE scanners, highlight the clinical importance of attenuation-corrected metrics in radiation dose management.

Advances in knowledge : This study provides robust evidence for the feasibility and accuracy of attenuation-corrected dose calculations. The findings redefine personalized dosimetry paradigms, demonstrating that integrating inherent tissue attenuation variability significantly improves treatment planning reliability.

Keyword: Size-specific dose estimate; Effective diameter; Water-equivalent diameter; $CTDI_{vol}$

INTRODUCTION

The rapid evolution of medical imaging technologies has revolutionized diagnostic capabilities, with computed tomography (CT) emerging as a cornerstone modality due to its unparalleled spatial resolution and acquisition speed. However, this advancement comes with substantial radiation safety concerns. According to International Atomic Energy Agency (IAEA) reports, CT examinations account for merely 25% of all radiological procedures yet contribute 60-70% of the collective radiation dose [1]. The American College of Radiology (ACR) white paper further highlights that CT constitutes approximately 60% of total medical radiation exposure, underscoring the urgent need for dose optimization strategies. Current clinical practice predominantly employs the volumetric CT dose index ($CTDI_{vol}$) as a standardized metric, which demonstrates significant limitations in addressing individual variations. Notably, McCollough et al. revealed that obese patients receive up to 40% lower organ doses than lean counterparts under identical $CTDI_{vol}$ conditions ($P < 0.01$) [2], exposing the dissociation between conventional dosimetry and biological reality.

To address these challenges, automatic tube current modulation (ATCM) systems have been widely implemented in modern CT scanners [3], achieving theoretical dose reductions of 30%-50% through real-time z-axis current adjustments [4]. Nevertheless, their clinical effectiveness is constrained by two critical factors: (a) the nonlinear relationship between preset noise index (NI) thresholds and patient morphometric parameters, and (b) scout image artifacts caused by respiratory motion in approximately 15% of abdominal CT examinations, leading to ATCM algorithm failures [4]. These limitations have driven the development of second-generation personalized dosimetry—the size-specific dose

Submitted: 28 March, 2025 | **Accepted:** 29 April, 2025 | **Published:** 30 April, 2025

***Corresponding author:** Hongtao Niu, Medical Imaging Center, Qinhuangdao NO.1 Hospital, No. 258, Wenhua Road, Haigang District, Qinhuangdao City, 066000, Hebei Province, China..

Citation: Simwaba G, Hazell LJ, Motto J (2025) Perceptions of Radiographers on Reporting Chest Images at Public Hospitals in Malawi. SM J Clin Med Imaging 7: 5.

estimate (SSDE) framework.

SSDE incorporates size conversion factors (f-values) for anatomical-specific dose correction, with parameter selection centering on optimal equivalent diameter modeling. Current methodologies primarily adopt two distinct approaches: (1) geometric effective diameter (d_{EFF}), derived from anteroposterior (AP) and lateral (LAT) measurements to reflect anatomical morphology; (2) water-equivalent diameter (d_W), calculated from CT attenuation values to characterize radiation interaction physics. Although the AAPM TG-204/220 task groups have established standardized SSDE protocols, significant controversy persists regarding the dosimetric accuracy of these models. While d_{EFF} offers operational simplicity, it overlooks tissue heterogeneity; conversely, d_W provides theoretical superiority but lacks multicenter clinical validation.

This study leverages retrospective data from 201 chest CT examinations to systematically compare d_{EFF} and d_W in SSDE calculations. By developing a water-equivalent diameter-based dose prediction model, we aim to establish evidence-based guidelines for precision radiation dose management.

MATERIALS AND METHODS

Patients

This retrospective cohort study consecutively enrolled 201 patients undergoing non-contrast chest CT between December 2024 and January 2025. Demographic characteristics revealed male predominance (52.7%, 106/201) with mean age 57.37±2.24 years (range:18-89, normally distributed). Selection criteria were established in accordance with ICRP Publication 135 guidelines [5]: Inclusion Criteria: a)Clinical indication for chest CT (diagnostic or screening purposes); b)Adults (>18 years); c)Excellent image quality (Grade A per AAPM TG-233 visual scoring system); d)Scan coverage strictly limited to thoracic region. Exclusion Criteria: a)Metallic implants/foreign bodies (CT attenuation >2000 HU) in scan field; b)Cardiac pacemaker recipients; c)Positioning failure (e.g., poor respiratory compliance, inability to maintain standard upper limb positioning).

Scanning and calculation methods

All examinations were performed using a GE Healthcare Revolution 64-slice CT scanner. Patients were positioned supine with body midline aligned to the scanner's laser guidance system, arms raised above the head to minimize beam-hardening artifacts. Scans were acquired in craniocaudal direction during end-inspiratory breath-hold, covering from the thoracic inlet (jugular notch) to the posterior costophrenic angle. Key acquisition parameters included: 120 kV tube voltage, automatic tube current modulation (Smart mA, noise index NI=12) with reference mAs of 130, helical pitch 0.984, and rotation time 500 ms. Raw data were reconstructed using standard kernel with 1.25 mm slice thickness and 5 mm interval (60% overlap), 512×512 matrix, 380 mm reconstruction field-of-view (rFOV), incorporating model-based iterative reconstruction (MBIR, ASiR-V 50%).

After the scan is completed, all image data and dose parameters are automatically transferred to the Medical Image Archiving System (PACS) via the DICOM protocol. In accordance with the AAPM TG-204/TG-220 Technical Reporting Specification [6-8], the volumetric CT dose index ($CTDI_{vol}$) was read directly from the DICOM header file, and the central anatomical level was selected on the sagittal image of the chest scan range, which was jointly confirmed by two independent radiologists (≥ 5 years of experience in chest imaging diagnosis). Measurements are performed using FDA-approved dosimetry software: ROI is traced along the skin surface using a semi-automatic contour tracking tool; The smallest oval containing all anatomical structures was uniformly drawn on the measurement target image, and its left and right diameters (d_{LAT}, cm) and anterior-posterior diameters (d_{AP}, cm) were measured at the same level (Figure 1-a), and the effective diameter d_{EFF} (cm) and conversion factor f_{EFF} were calculated at the same time, and $SSDE_{EFF}$ (mGy) was calculated with reference to AAPM Report No. 204 [9], equation (1)~(3).

$$d_{EFF} = \sqrt{d_{AP} \times d_{LAT}} \ldots.(1)$$

$$f_{EFF} = a \times e^{(-b \times d_{EFF})} \ldots..(2)$$

$$SSDE_{EFF} = f_{EFF} \times CTDI_{vol} \ldots.(3)$$

The cross-sectional area (A_{ROI}, cm2) and CT value (HU_{ROI}, HU) of the area of interest were measured (Figure 1-b) with the covering cross-sectional profile as the area of interest (excluding the bed slat), and the water equivalent diameter d_W (cm), conversion factor f_W and $SSDE_W$ (mGy) were calculated with reference to AAPM No. 220 report, and equations (4)~(6).

$$Dw = 2 \times \sqrt{1 + \frac{HUROI}{1000} X \frac{AreaROI}{\pi}} \qquad (4)$$

$$f_{36xize}^{32} = 4.3781 \times e^{-0.0433 \times D15} \qquad (5)$$

$$SSDEw = CTDI_{vol} \times f_{36xize}^{32} \qquad (6)$$

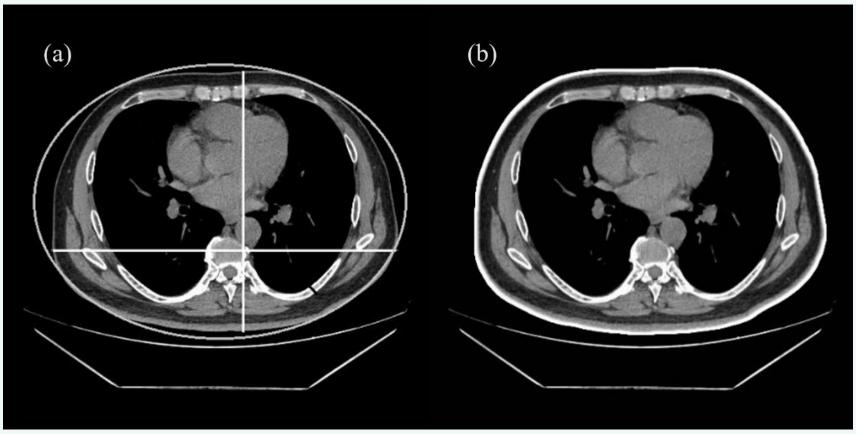

Figure 1: Quantitative Measurement of Anatomical Structures in Axial CT Images. (a)Measurement of left and right diameters (d_{LAT}) and anteriorposterior diameters (d_{AP}) using the minimum enclosing elliptical method on axial CT images. (b) ROI delineation covering all anatomical structures in the cross sectional profile and measurement of cross sectional area (A_{ROI})and mean CT value (CT_{ROI}).

Statistical Analysis

For parametric data meeting normality, independent t-tests were employed with results expressed as mean±standard deviation ($\bar{x}$±s). Non-normally distributed data were analyzed using Mann-Whitney U tests, presented as median (interquartile range) [M ±(IQR)]. To evaluate the impact of lateral body diameter (d_{LAT}) on dosimetric parameters, subjects were stratified into tertiles: low (T1: <32.955 cm), medium (T2: 32.955-35.190 cm), and high (T3: >35.190 cm). The comparison between different d_{LAT} groups was conducted using the Friedman rank sum test. Statistical analyses were performed using SPSS 26.0. All statistical analysis was significant as $P < 0.05$.

RESULTS

This study enrolled 201 patients (106 males, 55.2%; 95 females, 44.8%). Figure 1-a illustrates the measurement methodology for d_{AP} and d_{LAT} dimensions using the minimum enclosing elliptical method on axial CT images. Figure 1-b demonstrates the protocol for ROI delineation, excluding the scanner table, to quantify cross-sectional area (A_{ROI}) and mean CT value (HU_{ROI}). Comparative analysis of diameter measurements, conversion factors, and SSDE between the two methodologies is presented in Table 1. The d_W measurements (24.644±2.498 cm) demonstrated significantly lower values than d_{EFF} measurements (28.485±2.238 cm, $p<0.001$). Conversion factor analysis showed significantly higher values for f_W (1.514±0.164) versus f_{EFF} (1.270±0.160, $p<0.001$). $SSDE_W$ calculations yielded higher radiation dose estimates (14.840±5.922 mGy) compared to $SSDE_{EFF}$ (12.620±5.053 mGy, $p<0.001$). Dose distribution patterns across $SSDE_{EFF}$, $SSDE_W$, and $CTDI_{vol}$ parameters are visualized in Figure 2 and Table 2.

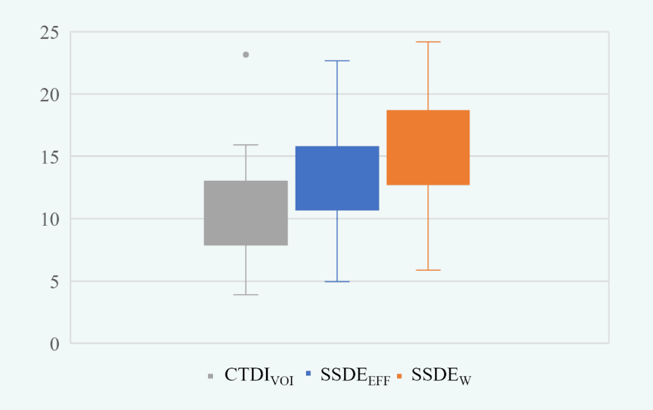

Figure 2: Dose distribution patterns for $SSDE_{EFF}$, $SSDE_W$ and $CTDI_{VOI}$.

DISCUSSION

Since 2002, all modern CT scanners have incorporated $CTDI_{vol}$ and dose-length product (DLP) metrics, which are displayed on CT dose reports. The SSDE methodology improves radiation dose accuracy by accounting for patient morphometric variations [10]. Our findings demonstrate the superior performance of d_W-based $SSDE_W$ over d_{EFF}-based $SSDE_{EFF}$ in dose estimation accuracy ($p<0.001$). This conclusion is further reinforced by d_{LAT} subgroup analyses, highlighting the critical role of body habitus in radiation dose assessment. Notably, the d_W methodology exhibited enhanced clinical applicability across diverse patient morphologies [11-13].

The results revealed statistically superior performance of d_W-based $SSDE_W$ compared to d_{EFF}-based $SSDE_{EFF}$ across all parameters. The d_W measurements (24.644±2.498 cm) demonstrated significantly lower values than d_{EFF} measurements (28.485±2.238 cm, $p<0.001$), indicating better anatomical representation through water-equivalent modeling. Conversion factor analysis showed significantly higher values for f_W (1.514±0.164) versus f_{EFF} (1.270±0.160, $p<0.001$), suggesting improved dose adjustment accuracy. Importantly, $SSDE_W$ calculations yielded higher radiation dose estimates (14.840±5.922 mGy) compared to $SSDE_{EFF}$ (12.620±5.053 mGy, $p<0.001$), highlighting the enhanced clinical relevance of water-equivalent diameter in patient-specific dose estimation. As shown in Figure 2, both $SSDE_{EFF}$ and $CTDI_{vol}$ underestimated radiation doses compared to $SSDE_W$. Quantitative analysis revealed 14.96% underestimation by $SSDE_{EFF}$ and 31.20% by $CTDI_{vol}$ relative to $SSDE_W$. These observations align with Zancopè et al.'s report of up to 10% SSDE underestimation in thoracic/abdominal CT scans [14], though our study demonstrates greater discrepancies [15]. The variability in underestimation magnitudes may stem from differences in CT scanner models or acquisition parameters (e.g., tube voltage, tube current, gantry rotation time, pitch) [16]. Importantly, while $CTDI_{vol}$ relies on standardized phantoms that disregard patient-specific attenuation characteristics, and $SSDE_{EFF}$ considers only geometric dimensions, $SSDE_W$ incorporates both anatomical size and tissue-specific X-ray attenuation properties [17], explaining its superior accuracy.

As shown in Figure 3, a progressive increase in d_{EFF}, d_W, f_{EFF}, f_W, $SSDE_{EFF}$, and $SSDE_W$ was observed with d_{LAT} enlargement ($p<0.01$), accompanied by widening disparities between $SSDE_{EFF}$ and $SSDE_W$. This dose-body size relationship corroborates Leng et al.'s findings [4], where automated exposure control systems increased $CTDI_{vol}$ at z-axis positions with larger dW values, thereby elevating SSDE estimates. Our results are further validated by Monte Carlo simulations [18], confirming the validity of SSDE methodology for radiation risk stratification in large-bodied patients.

Table 1: Comparison of Diameter (d), Conversion Factor (f), and SSDE Results Under Two Methods $(\overline{x} \pm s)$.

Algorithm	*n*	d(cm)	f	SSDE(mGy)
$SSDE_{EFF}$	201	28.485 ± 2.238	1.270 ± 0.160	12.620±5.053
$SSDE_W$	201	24.644 ± 2.498	1.515 ± 0.164	14.840±5.922
t/u	-	T=-16.24	U=5030.50	U=12590.50
P	-	<0.01	<0.01	<0.01

Table 2: Comparison of d_{LAT} ,d_{EFF},d_W,f_{EFF} ,f_W ,$SSDE_{EFF}$ and $SSDE_W$ Among Different d_{LAT} Groups $(\bar{x} \pm s)$.

Group	n	d_{LAT}(cm)	d_{EFF}(cm)	d_W(cm)	f_{EFF}	f_W	$SSDE_{EFF}$(mGy)	$SSDE_W$(mGy)
A	67	31.560±1.792	26.408±1.683	22.541±1.904	1.399±0.103	1.655±0.138	10.670±3.117	12.400±3.708*
B	67	34.170±1.080	28.374±1.073	24.593±1.587	1.283±0.059	1.513±0.104	13.011±2.450	14.640±3.715*
C	67	36.720±1.873	30.674±1.392	26.580±2.397	1.162±0.069	1.376±0.110	15.820±3.860	18.700±4.608*
F	-	134	357.249	154.935	357.249	149.707	44.468	47.461
P	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

*The comparison between SSDEw and SSDEEFF showed a t-value of −3.928, −5.055, −6.251(P<0.01).

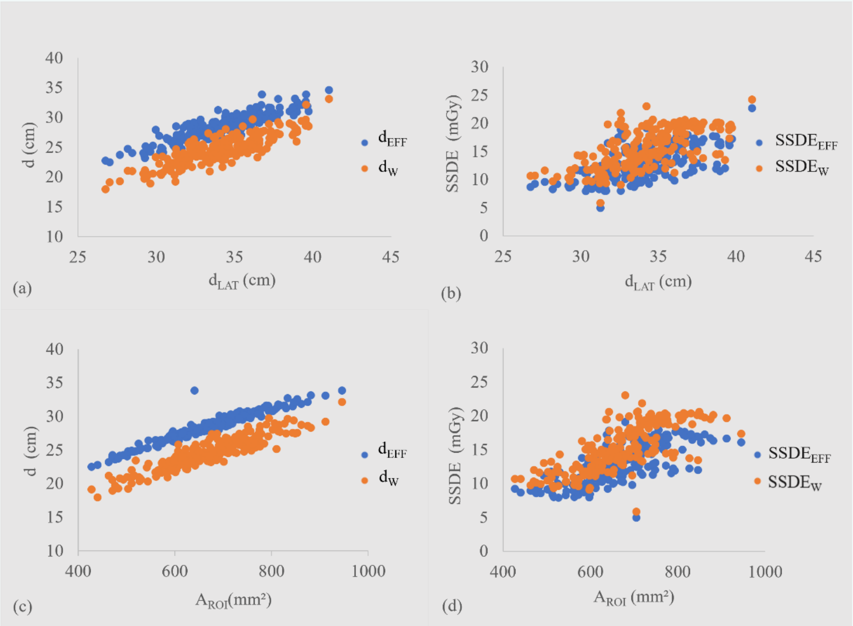

Figure 3: The functional relationship between d_{EFF} , d_W , $SSDE_{EFF}$, $SSDE_W$ and lateral patient diameter(d_{LAT}/ ROI cross-sectional area (A_{ROI}) (p < 0.01).

CONCLUSION

In the chest scan, the SSDE calculated by d_W can more accurately reflect the actual radiation dose received by the patient, which provides an empirical basis for the implementation of personalized d_W dose optimization, and calls for the establishment of a multidisciplinary collaboration mechanism to develop a standardized radiation protection program [19].

8. Ethics approval and consent

Data extraction was performed using Medical Image Archiving System (PACS) to retrieve information about patients. As this was a retrospective study with data from the PACS database and did not involve direct patient intervention, therefore no additional ethics committee approval was required.

REFERENCES

1. Mihailidis D, Tsapaki V, Tomara P. A simple manual method to estimate water-equivalent diameter for calculating size-specific dose estimate in chest computed tomography. Br J Radiol. 2021; 94: 20200473.
2. Hu X, Gou J, Yang F, Guo D. Body physical parameters instead of water equivalent diameter to calculate size-specific dose estimate in adult chest CT. Sci Rep. 2024; 14: 17053.
3. Tabari A, Li X, Kai Yang K, Bob Liu B, Michael SG, Sjirk JW. Patient-level dose monitoring in computed tomography: tracking cumulative dose from multiple multi-sequence exams with tube current modulation in children. Pediatr Radiol. 2021; 51: 2498-2506.

4. Leng S, Shiung M, Duan X, Lifeng Y, Zhang Y, Cynthia HM. Size-specific dose estimates for chest, abdominal, and pelvic CT: effect of intrapatient variability in water-equivalent diameter. Radiol. 2015; 276: 184-190.
5. Vañó E, Miller DL, Martin CJ, Rehani MM, Kang K, Rosenstein M,. ICRP Publication 135: Diagnostic Reference Levels in Medical Imaging. Ann ICRP. 2017; 46: 1-144.
6. Burton CS, Szczykutowicz TP. Evaluation of AAPM Reports 204 and 220: Estimation of effective diameter, water-equivalent diameter, and ellipticity ratios for chest, abdomen, pelvis, and head CT scans. J Appl Clin Med Phys. 2018; 19: 228-238.
7. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. Automated Calculation of Water-equivalent Diameter (DW) Based on AAPM Task Group 220. J Appl Clin Med Phys. 2016; 17: 320-333.
8. Hardy AJ, Bostani M, Grace HJK, Christopher HC, Maria AZ, McNitt-Gray M. Evaluating Size-Specific Dose Estimate (SSDE) as an estimate of organ doses from routine CT exams derived from Monte Carlo simulations. Med Phys. 2021; 48: 6160-6173.
9. Noferini L, Fulcheri C, Taddeucci A, Bartolini M, Gori C. Considerations on the practical application of the size-specific dose estimation (SSDE) method of AAPM Report 204. Radiol Phys Technol. 2014; 7: 296-302.
10. Sabiniewicz-Ziajka D, Szarmach A, Grzywińska M, Gać P, Piskunowicz M. Redefining radiation metrics: evaluating actual doses in computed tomography scans. Biomed. 2024; 12: 600.
11. Seibert JA, Boone JM, Wootton-Gorges SL, Lamba R. Dose is not always what it seems: where very misleading values can result from volume CT dose index and dose length product. J Am Coll Radiol. 2014; 11: 233-237.
12. Anam C, Mahdani FR, Dewi WK, Sutanto H, Pandji T, Freddy H, et al. An improved method for automated calculation of the water-equivalent diameter for estimating size-specific dose in CT. J Appl Clin Med Phys. 2021; 22: 313-323.
13. Franck C, Vandevoorde C, Ingeborg G, Peter S, Eric A, Koenraad V, et al. The role of size-specific dose estimate (SSDE) in patient-specific organ dose and cancer risk estimation in paediatric chest and abdominopelvic CT examinations. Eur Radio. 2016; 26: 2646-2655.
14. Zancopè N, Francesca DM, Erica S, Angelo G, Riccardo L, Alessandro M, et al. Validation of SSDE calculation in a modern CT scanner and correlation with effective dose. Sci Rep. 2025; 15: 6091.
15. Klosterkemper Y, Elisabeth A, Thomas C. Tailoring CT Dose to Patient Size. Academic Radiol. 2018; 25: 1624-1631.
16. Li B, Behrman RH. Comment on the “report of AAPM TG 204: size-specific dose estimates (SSDE) in pediatric and adult body CT examinations” [report of AAPM TG 204, 2011]: comment on the report of AAPM TG 204. Med Phys. 2012; 39: 4613-4614.
17. Gabusi M, Riccardi L, Aliberti C, Vio S, Paiusco M. Radiation dose in chest CT: assessment of size-specific dose estimates based on water-equivalent correction. Phys Med. 2016; 32: 393-397.
18. Hardy AJ. Evaluating size-specific dose estimate (SSDE) as an estimate of organ doses from routine CT exams derived from monte carlo simulations. Med Phys. 2021; 48: 6160-6173.
19. Valeri G, Cegna S, Mari A, Luigi LR, Giovanni M, Stefania M, et al. Evaluating the appropriateness of dosimetric indices in body CT. Radiol Med. 2015; 120: 466-473.