Establishing local diagnostic reference levels for computed tomography examinations using size-specific dose estimates

Faisal A. Alrehily *MSc, PhD,* *Khalid S. Alqahtani* *BSc,* *Marwan H. Aljohani,* *BSc,* *Nawaf S. Alharbi,* *BSc,* *Reyan M. Alharbi,* *BSc, MSc,* *Osamah M. Abdulaal,* *MSc, PhD,* *Abdullah F. Alshamrani,* *MSc, PhD,* *Abdulrahman S. Alsaedi,* *BSc, MSc,* *Sadeq H. Al-Murshedi,* *MSc, PhD,* *Fahad H. Alhazmi,* *MSc, PhD.*

ABSTRACT

الأهداف: تم تقديم مفهوم المستوى المرجعي الاشعاعي (DRL) للحد من تعرض المريض للإشعاع غير الضروري. ومع ذلك، لا تأخذ قيم DRL التقليدية في الاعتبار حجم المريض. لذلك، هدفت هذه الدراسة إلى إنشاء DRL لفحوصات الاشعة المقطعية (CT) على مستوى مستشفى محلي بناءً على حجم المرض (SSDE).

المنهجية: بعد موافقة لجنة اخلاقيات البحث، تم جمع البيانات من فحوصات الاشعة المقطعية للمرضى البالغين في مستشفى محلي في المدينة المنورة. تم حساب SSDE لكل مريض بناء على حجم المريض (D_{eff}).

النتائج: المستويات المرجعية لاختبارات للدماغ والعمود الفقري العنقي والصدر والعمود الفقري الصدري والكلى والحالب والمثانة كانت 118 ملي جراي و12 مللي جراي و8 مللي جراي و17 مللي جراي و7 مللي جراي على التوالي. لوحظ وجود علاقة قوية بين SSDEs ومؤشر جرعة التصوير المقطعي المحسوب ($CTDI_{vol}$) لجميع الفحوصات باستثناء فحوصات الصدر ($p<0.05$) كانت SSDEs أعلى من $CTDI_{vol}$، مع وجود فرق أكبر للمرضى ذو D_{eff} الأصغر ($p<0.05$).

الخلاصة: المستويات المرجعية الاشعاعية في المستشفى تقع ضمن المستويات الدولية. تبين من خلال الدراسة أن SSDE لديه القدرة على توفير بيانات أكثر دقة وذات صلة لممارسات السلامة الإشعاعية؛ ومع ذلك، فإن تضمين SSDE في أجهزة الاشعة المقطعية الجديدة قد يؤدي الى زيادة في استخدام SDDE كمستوى مرجعي ويسهل ايضا مقارنة القيم مع بعضها البعض.

Objectives: To establish local DRL (LDRL) for computed tomography (CT) examinations based on size-specific dose estimates (SSDEs), which consider patient size. The concept of diagnostic reference level (DRL) was introduced to limit patient exposure to unnecessary radiation. However, traditional DRL values do not consider patient size.

Methods: Following institutional committee approval, data were collected from CT examinations of adult patients at Madinah General Hospital, Al Madinah Al Munawwarah, Saudi Arabia from January to March 2023. The SSDE was calculated for each patient using the effective diameter (D_{eff}).

Results: The LDRLs of the brain, cervical spine, chest, thoracic spine and kidneys, ureters, and bladder (KUB) examinations were 118 mGy, 12 mGy, 8 mGy, 17 mGy, and 7 mGy, respectively. A strong correlation was observed between SSDEs and the volume computed tomography dose index ($CTDI_{vol}$) for all examinations except chest scans ($p<0.05$). Size-specific dose estimates were higher than the CTDIvol, with a greater difference for patients with smaller Deff ($p<0.05$).

Conclusion: The established LDRL was within the international DRL. The use of SSDE has the potential to provide more accurate and relevant data for radiation safety practices; however, widespread adoption of SSDE in new CT scanners is necessary for promoting consistency and standardization methodologies.

Keywords: CT, DRL, CTDIvol, DLP, SSDE, effective diameter

Saudi Med J 2023; Vol. 44 (8): 761-766
doi: 10.15537/smj.2023.44.8.20230230

From the Department of Diagnostic Radiology Technology (Alrehily, Alqahtani, Aljohani, Alharbi, Abdulaal, Alshamrani, Alhazmi), College of Applied Medical Sciences, Taibah University; from the Department of Radiology (Alharbi), King Salman bin Abdulaziz Medical City; from the Department of Nuclear Medicine (Alsaedi), King Fahad General Hospital (Alsaedi), Al Madinah Al Munawwarah, Kingdom of Saudi Arabia; from the Department of Radiological Techniques (Al-Murshedi,), AL-Zahraa University for Women, College of Health and Medical Technology, Karbala; and from Physics Department (Al-Murshedi), College of Education for Pure Sciences, University of Babylon, Iraq.

Received 8th April 2023. Accepted 11th July 2023.

Address correspondence and reprint request to: Dr. Faisal Alrehily, Department of Diagnostic Radiology Technology, College of Applied Medical Sciences, Taibah University, AL Madinah Al Munawwarah, Kingdom of Saudi Arabia. E-mail: frehily@taibahu.edu.sa
ORCID ID: https://orcid.org/0000-0002-4817-1736

Computed tomography (CT) plays an important role in the healthcare system and it is used to aid in the diagnosis of a variety of medical conditions. Computed tomography scans are commonly available and, easy to perform. The number of patients who undergo CT scans has increased dramatically in recent years globally.[1] Computed tomography scans have evolved significantly over the years, with advances resulting in increased image quality and reduced radiation doses to patients. However, concern remains regarding the use of CT as an imaging modality due to the potential risks with its associated radiation dose.[2-5]

In 1989, the United Kingdom suggested establishing a benchmark for common radiographic procedures to ensure that patients were not exposed to unnecessary radiation during diagnostic imaging examinations. A few years later, in Publication 73, the International Commission on Radiological Protection introduced the concept of diagnostic reference levels (DRLs).[6] DRLs can provide an indication of the radiation doses patients receive during CT examinations and determines if the doses fall within acceptable levels. While it assists in identifying examinations that expose patients to radiation doses that exceed suggested levels, it also helps highlighting the values extremely below these levels, which may indicate images were acquired with insufficient image quality for diagnosis. Diagnostic reference levels inability to provide information regarding CT image quality, which is an important part of the diagnostic process, is considered a significant disadvantage.

The values used to establish DRLs for CT examinations are typically based on quantities obtained from the CT dose index (CTDI), which measures the radiation dose delivered by a single rotation of the gantry.[7] The volume CTDI ($CTDI_{vol}$), which calculates the average absorbed dose within the scanned volume, is often used to determine DRL values. Another frequently used quantity for determining DRL values for CT scans is the dose length product (DLP), which considers the length of the scan to estimate the amount of radiation absorbed by a patient. Despite their widespread use, none of the of these parameters consider patient size. Consequently, it has been suggested that the size-specific dose estimate (SSDE) should be used to establish DRL values for CT scans to address this issue.[8,9]

Disclosure. Authors have no conflict of interests, and the work was not supported or funded by any drug company.

Recently, there has been a growing trend toward using SSDEs to determine the DRLs of CT examinations. This shift has been driven by a desire to improve the accuracy of dose delivery and minimize the risk associated with using x-rays. However, the use of DRLs for CT scans based on SSDE has not been reported in Saudi Arabia, with the exception of one published study that conducted its research on a phantom.[10] This study aimed to establish local DRL (LDRL) values based on the SSDEs of the most frequently performed CT examinations at a hospital in Madinah, Saudi Arabia.

Methods. This retrospective study analyzed CT examinations that were performed at Madinah General Hospital, Al Madinah Al Munawwarah, Saudi Arabia from January to March 2023. The hospital is equipped with 3 Aquilion Prime SP CT scanners (Canon Medical Systems, Ohtawara, Japan) that regularly undergo quality control checks. The data of at least 30 adult patients were collected for each examination of different body parts. The study included patients aged 18 years or older who underwent CT examinations and did not receive contrast media during the examinations. In addition to the patient's age and gender, the CT imaging parameters were collected, including peak kilovoltage (kVp), milliampere (mA), scan time (T), scan length, rotation time, pitch factor, field of view, $CTDI_{vol}$, and DLP. The CTDIvol and DLP were based on a 32 cm phantom in all scans. The study was approved by a local Institutional Review Board (22-071), and all scans were clinically justified.

The SSDE was determined using the effective diameter (D_{eff}) of the patients. This required the anteroposterior (AP) thickness and lateral (LAT) width of each patient to be measured on each CT image. Other studies have employed simpler methods to determine the SSDE, such as using patient weights and body mass indices (BMI).[11-13] However, these methods slightly impacted the accuracy of these studies' calculations and were only applicable to some body regions.

Calculating the SSDE based on the D_{eff} (Equation 1) is complex and time-consuming. An alternative method involves calculating the thickness from the center image, which is a more straightforward and practical approach and provides a strong correlation with the calculation obtained from the entire CT image series.[14–18]

$$D_{eff}=\sqrt{(AP\times LAT)} \quad (1)$$

After determining the D_{eff} for each patient, the conversion factors (f_{size}), which were normalized to patient size in terms of water or tissue-equivalent materials, were obtained from The American Association of Physicists in Medicine (AAPM) Report 204. The SSDEs were then calculated using Equation 2.[8]

$$SSDE = f_{size} \times CTDI_{vol} \quad (2)$$

Statistical analysis. Subsequently, the LDRL was established as the median SSDE for each examination and size group according to the D_{eff}. The differences between SSDE values was analyzed using the Mann-Whitney and relationships between them was analyzed using the Spearman correlation tests. A *p*-value <0.05 was considered statistically significant.

Results.

In total, 150 examination records were collected and analyzed. The data comprised information from brain, cervical spine (C-spine), chest, thoracic spine (T-spine), and kidneys, ureters and bladder (KUB) CT scans. Overall, 60% of scans were performed on male patients. The average patient age was 48 (SD=19). Table 1 provides a summary of the imaging parameters used to acquire CT images.

Table 2 displays the proposed LDRL based on the SSDE, $CTDI_{vol}$, and DLP values. For all patients' sizes and based on the SSDE, the LDRLs of the brain, cervical spine, chest, thoracic spine, and KUB examinations were 118 mGy, 12 mGy, 8 mGy, 17 mGy, and 7 mGy, respectively. Table 3, on the other hand, shows the proposed LDRLs of the chest, KUB, and T-spine based on D_{eff} values, as well as the correlations between the $CTDI_{vol}$ and SSDE. When considering patients with smaller D_{eff}, the The LDRL for the chest was 7.63 mGy, for the T-spine was 15.39 mGy, and for the KUB examination was 5.89 mGy.. However, for patients with larger D_{eff}. The LDRL for the chest was 7.63 mGy, for the T-spine was 17.81 mGy, and for the KUB examination was 7.32 mGy.

There was a strong correlation between the $CTDI_{vol}$ and SSDE values ($r=0.94$, $p<0.05$), with SSDE values higher than $CTDI_{vol}$ values in all examinations. When examining each examination separately, the correlation between the $CTDI_{vol}$ and SSDE remained significantly strong ($r>0.90$, $p<0.05$), for all examinations except the chest CT scans. In the chest CT scans, the correlation was weaker but remained significant ($\rho=0.67$, $p<0.05$).

When patients were divided into 2 groups based on their D_{eff}, a noticeable difference was observed between the $CTDI_{vol}$ and SSDE values. For the group with smaller D_{eff} values, the SSDE was more than 53% higher than the $CTDI_{vol}$ for chest scans, 63% for KUB scans, and 55% for T-spine scans. However, for the group with larger D_{eff} values, these increases were significantly smaller ($p<0.05$), with SSDEs only being 26% higher than the $CTDI_{vol}$ for chest scans, 24% for KUB scans, and 36% for T-spine scans. The differences between the 2 values were not calculated for brain and cervical spine scans, as there was only one D_{eff} group associated with these examinations.

The differences between the $CTDI_{vol}$ and SSDE values for the chest CT were significant for patients of both D_{eff} groups ($p<0.05$). Similar results were observed in the KUB scans for patients with smaller D_{eff} values;

Table 1 - Summary of imaging parameters used to acquire the CT images (N=30).

Characteristic	Brain	C-spine	Chest	KUB	T-spine
kVp	120	120	120	120	125,135
mAs	318 (29)	826 (301)	981 (184)	1,371 (711)	2,711 (776)
Scan length (mm)	231 (20)	252 (41)	408 (34)	408 (46)	312 (70)
Slice thickness	3	0.5	3	3	0.5
Scan time (s)	12 (1)	6 (1)	3 (1)	8 (2)	20 (4)
Rotation time (s)	0.75	0.5	0.35	0.5	NA

Values are presented as mean (standard deviation), kVp: peak kilovoltage, mAs: milliampere-seconds, s: seconds, KUB: kidneys, ureters, and bladder, CT: computed tomography, C-spine: cervical spine, KUB: kidneys, ureters and bladder; T-spine: thoracic spine

Table 2 - The proposed LDRL of CT examinations (N=30).

Characteristic	Brain	C-spine	Chest	KUB	T-spine
CTDI (mGy)	59 (57, 63)	6 (5, 8)	6 (5, 6)	5 (3, 8)	12 (9, 14)
DLP (mGy.cm)	1,079 (1,022, 1,187)	160 (130, 196)	205 (168, 243)	223 (166, 366)	580 (462, 796)
SSDE (mGy)	118 (115, 126)	12 (10, 16)	8 (7, 8)	7 (6, 10)	17 (14, 20)

[1] LDRL (25th quartile, 75th quartile), C-spine: cervical spine, KUB: kidneys, ureters and bladder, T-spine: thoracic spine, CTDI: computed tomography dose index, DLP: dose length product, SSDE: size-specific dose estimate

Table 3 - The proposed LDRL of the chest, KUB and T-spine based on the D_{eff}

Exam	D_{eff}‡	Number of patients	$CTDI_{vol}$ SSDE correlation*	LDRL
Chest	Small	9	0.92	7.63
	Large	21	0.80	7.63
KUB	Small	12	0.73	5.89
	Large	18	0.98	7.32
T-spine	Small	15	0.91	15.39
	Large	15	0.96	17.81

‡Small D_{eff}: 15-24 cm, Large D_{eff}: 25-35 cm. *Spearman correlation; $p<0.05$. KUB: kidneys, ureters and bladder, t-spine: thoracic spine, SSDE: size-specific dose estimate, LDRL: local dose length product, D_{eff}: effective diameter

however, no difference was seen in patients with larger D_{eff} values ($p>0.05$).

Discussion.

In this study, LDRLs were established for the most frequently performed CT examinations at a local hospital. To the best of the authors' knowledge, no prior published studies have reported LDRLs based on SSDEs in Saudi Arabia using patient data. Unlike the conventional method, whereby DRLs are based on $CTDI_{vol}$ values and only consider examination parameters, SSDE accounts for patient size by incorporating patients' D_{eff}. As $CTDI_{vol}$ does not account for changes in the patient anatomy. The dose delivered to patients can be over or underestimated, particularly in cases where a patient's anatomy differs significantly from the standardized phantom used to calculate $CTDI_{vol}$.[19,20] The importance of SSDE lies in its ability to provide a more accurate representation of radiation exposure. By considering patient size, SSDE enables a better understanding of the individualized radiation dose received during a CT exam. This information is crucial for optimizing radiation dose management, setting DLRs, and minimizing the risk of patients harm.

The reporting of SSDEs for CT examinations is not widespread and the methods used to obtain these values vary. This is because the standard guidelines recommended by the AAPM are time-consuming and require significant effort, posing a challenge to the effective utilization of SSDEs. Other methodologies, such as using patients' age, body weight, or BMI have been used to simplify the process of calculating SSDE.[11-13] Good agreement has been reported between SSDEs calculated using these factors and reference SSDEs, which are based on patients' D_{eff} values. The comparison between SSDEs calculated using different methodologies is difficult, as differences in SSDEs values have been reported between different methodologies. However, some CT manufacturers have begun incorporating SSDE values directly into newer CT machines, along with $CTDI_{vol}$ and DLP values. This could lead to increase adoption of SSDE, as DRL value and will enable easier comparison and utilization of SSDEs in CT examinations.

Overall, the LDRLs calculated in this study based on SSDEs were within the international DRLs. The chest SSDE (6 mGy) was lower than the United States of America (USA) (16 mGy), Sri Lanka (9.72 mGy), and Ghana (8.7 mGy) DRL values.[16,21,22] When comparing the SSDE of the examinations based on the D_{eff} of patients, the median value in the current study 7.63 mGy compared to 8 mGy in the USA study. The overall higher DRLs observed in the USA study could be due to larger patient body sizes, which would result in a higher amount of radiation being delivered to the patients during the examinations, as the radiation dose is proportional to patient size. The relationship between patient size and radiation dose highlights the importance of considering individual patient characteristics when setting DRLs.

In the current study, an in-depth analysis of the SSDE and $CTDI_{vol}$ values indicated that the difference between the 2 was less pronounced for the group with greater D_{eff} values in comparison to the group with the smaller D_{eff} values. This trend was consistent with the findings of the USA study, where the difference between SSDEs and $CTDI_{vol}$ for chest examinations was reported to be 60% in the group with smaller D_{eff} values, and 8% in the group with the largest D_{eff} values.[21] Similar observations were reported in Korean and Chinese studies.[23,24] These findings highlight the importance of considering patient size when determining the appropriate radiation dose for CT scans, as it can significantly impact the determined DRL.

The current study found a strong correlation between $CTDI_{vol}$ and SSDE values. The strength of this correlation varied depending on the size of a patient D_{eff}, with patient with larger D_{eff} values typically demonstrating a stronger correlation. However, there was an exception for chest SSDE values, where the relationship between the 2 measures decreased as D_{eff} values increased. This finding is consistent with previous studies and could be attributed to the differences in tissue composition in the chest region.[23,25] However, it might be difficult to justify this conclusion with the sample size used in this study.

Study limitations. The sample size used was relatively small, as the assessment of the relationship between $CTDI_{vol}$, SSDE, and D_{eff} values was not the primary focus of the study. Increasing the sample size could result in more accurate and representative results and help to account for any potential variability within the data. This could increase the statistical power of the study, allowing for more robust and reliable conclusions to be drawn. Moreover, the AP and LAT thickness measurements were performed by the co-authors, and their intra- and inter-variability were not measured. Future studies could consider incorporating measures of inter- and intra-observer variability to better understand potential sources of error in measurements.

In conclusion, this study proposed LDRL for the most common CT examinations at a local hospital. The LDRLs were determined based on SSDEs using patients' D_{eff} values and were within the international DRL range. By incorporating SSDE, the DRLs become patient-specific, taking into consideration the patient's size. This personalized approach ensures that radiation doses are tailored to each patient and minimizing unnecessary exposure. However, the widespread adoption of SSDEs in new CT imaging machines is necessary for widespread reporting and consistent methodologies.

Acknowledgment. *The authors gratefully acknowledge the hospital personnel who provided support and cooperation during the collection of data. We also would like to thank Cambridge Proofreading LLC for English language editing.*

References

1. Organization for Economic, Co-operation and Development. Computed tomography (CT) exams (indicator). [Updated 2023; Accessed 2022]. Available from: https://data.oecd.org/healthcare/computed-tomography-ct-exams.htm
2. Schultz CH, Fairley R, Murphy LSL, Doss M. The risk of cancer from CT scans and other sources of low-dose radiation: A critical appraisal of methodologic quality. *Prehosp Disaster Med* 2020; 35: 3–16.
3. Zensen S, Guberina N, Opitz M, Köhrmann M, Deuschl C, Forsting M, et al. Radiation exposure of computed tomography imaging for the assessment of acute stroke. *Neuroradiology*. 2021; 63: 511-518.
4. Lu MY, Ting CY, Jao JC. Effective dose and radiation risk under 640-slice abdominal computed tomography examination without contrast medium injection. *J Xray Sci Technol* 2022; 30: 657-666.
5. Zewde N, Ria F, Rehani MM. Organ doses and cancer risk assessment in patients exposed to high doses from recurrent CT exams. *Eur J Radiol* 2022; 149: 110224.
6. International Commission On Radiological Protection. Radiological protection and safety in medicine. *ICRP* 1996; 26.
7. Allisy-Roberts P, Williams J. Computed tomography. In: Allisy-Roberts P, Williams JBTFP for MI (Second E, editors. Farr's Physics for Medical Imaging. 2nd ed. Edinburgh, UK: W.B. Saunders; 2008: 103–19.
8. American Association of Physicits in Medicine. Size-specific dose estimates (SSDE) in pediatric and adults body CT examinations. report no. 204. College Park, MD; 2011.
9. Christner JA, Braun NN, Jacobsen MC, Carter RE, Kofler JM, McCollough CH. Size-specific dose estimates for adult patients at CT of the torso. *Radiology* 2012; 265: 841-847.
10. Saeed MK, Asiri AAM. Determination of radiation dose during computed tomography examinations in southern Saudi Arabian hospitals using sizespecific dose estimates. *Maejo Int J Sci Technol* 2021; 15: 147-158.
11. Xu J, Wang X, Yang P, Luo K, He X. Size-Specific dose estimates of radiation based on body weight and body mass index for chest and abdomen-pelvic CTs. *Biomed Res Int* 2020; 2020.
12. Iriuchijima A, Fukushima Y, Nakajima T, Tsushima Y, Ogura A. Simple method of size-specific dose estimates calculation from patient weight on computed tomography. *Radiat Prot Dosimetry* 2018; 178: 208–212.
13. Hwang JY, Choi YH, Yoon HM, Ryu YJ, Shin HJ, Kim HG, et al. Establishment of Local Diagnostic Reference Levels of Pediatric Abdominopelvic and Chest CT Examinations Based on the Body Weight and Size in Korea. *Korean J Radiol* 2021; 22: 1172–1184.
14. Leng S, Shiung M, Duan X, Yu L, Zhang Y, McCollough CH. Size-specific Dose Estimates for Chest, Abdominal, and Pelvic CT: Effect of Intrapatient Variability in Water-equivalent Diameter. *Radiology* 2015; 276: 184-190.
15. Abuhaimed A, Martin CJ. Estimation of size-specific dose estimates (SSDE) for paediatric and adults patients based on a single slice. *Phys Med* 2020; 74: 30-39.
16. Amalaraj T, Jeyasugiththan J, Satharasinghe D, Pallewatte AS. Dose reference level based on size-specific dose estimate (SSDE) and feasibility of deriving effective body diameter using tube current and time product (mAs) for adult chest and abdomen computed tomography (CT) procedures. *J Radiol Prot* 2023; 43.
17. Boos J, Kröpil P, Bethge OT, Aissa J, Schleich C, Sawicki LM, et al. Accuracy of size-specific dose estimate calculation from center slice in computed tomography. *Radiat Prot Dosimetry* 2018; 178: 8-19.
18. Bashier EH, Suliman II. Radiation dose determination in abdominal ct examinations of children at sudanese hospitals using size-specific dose estimates. *Radiat Prot Dosimetry* 2019; 183: 444-449.

19. Abuhaimed A, Martin CJ. Assessment of organ doses for CT patients based on x-ray attenuation using water equivalent diameter. ***Radiat Phys Chem*** 2021; 181: 1093323.
20. Brink JA, Morin RL. Size-specific dose estimation for CT: How should it be used and what does it mean? ***Radiology*** 2012; 265: 666-668.
21. Kanal KM, Butler PF, Sengupta D, Bhargavan-Chatfield M, Coombs LP, Morin RL. U.S. diagnostic reference levels and achievable doses for 10 adult CT examinations. ***Radiology*** 2017; 284: 120–133.
22. Ohene-Botwe B, Anim-Sampong S, Nkansah J. Development of size-specific dose estimates for common computed tomography examinations: a study in Ghana. ***J Radiol Prot Off J Soc Radiol Prot*** 2023; 43.
23. Kim EY, Kim TJ, Goo JM, Kim HY, Lee JW, Lee S, et al. Size-Specific Dose estimation in the Korean lung cancer screening project: Does a 32-cm diameter phantom represent a standard-sized patient in Korean population? ***Korean J Radiol*** 2018; 19: 1179-1186.
24. Hu X, Gou J, Lin W, Zou C, Li W. Size-specific dose estimates of adult, chest computed tomography examinations: Comparison of Chinese and updated 2017 American College of Radiology diagnostic reference levels based on the water-equivalent diameter. ***PLoS One*** 2021;16: 1–14.
25. Bashier EH, Suliman II. Multi-slice CT examinations of adult patients at Sudanese hospitals: radiation exposure based on size-specific dose estimates (SSDE). ***Radiol Medica*** 2018; 123: 424-431.