

REVIEW

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Diagnostic reference levels for routine computed tomography angiography examinations: a systematic review

Ali Bahny Alhailiy^{1*}

Abstract

Background This work aims to investigate existing methodologies that have been used to establish diagnostic reference levels (DRLs) for common computed tomography angiography (CTA) examinations in adult patients by analyzing published national and local DRL studies. A detailed search through Science Direct, Web of Science, EBSCO host, PubMed–Medline, and Google Scholar was conducted. The preferred reporting items for systematic review and meta-analyses methodology was also used to evaluate the selected articles. Studies were selected via the PICOS method and included only DRL studies established for CTA examinations. Case studies, posters, reviews, and meta-analyses were excluded. The literature review identified 21 publications, 15 proposed a national DRL survey, and 6 studies with local (facility) data.

Results A noticeable variation in DRL quantities for the same CTA procedures was noted among studies. Several factors contributed to this variability, including the methodologies used for establishing CTA DRLs, variations in scanning protocols, number of scanning phases, and scanner type.

Conclusion There is a need for a global standardization for DRL establishment methods aligned with recent recommendations from prominent international radiation protection bodies to facilitate accurate comparisons of radiation dose metrics both between and within CT imaging facilities.

Keywords Diagnostic reference levels, Computed tomography angiography, CTDI_{vol}, DLP

Background

Current advances in computed tomography (CT) technology, including the introduction of multislice row spiral CT systems with wider detector coverage and iterative reconstruction algorithms, have made imaging of the human vascular system feasible [1]. Compared with conventional angiography, for example, CT angiography (CTA) is less invasive and can provide diagnostic images of arteries with optimal image quality

in terms of spatial resolution. These images can be used to assess patients with suspected blood vessel disease with increased diagnostic accuracy while achieving this goal at a reduced cost [2]. CTA is broadly used to identify embolisms, dissection in the thoracic or abdominal aorta, cerebral arteriovenous malformations (AVMs), or aneurysms for endovascular intervention and presurgery planning [3]. With the wide implementation of CT imaging worldwide [4], several studies have reported that the increased radiation dose from CT is associated with an increased incidence of cancer in patients [5–8]. These studies clearly reveal the possible cancer risks associated with CT examinations and emphasize the need to monitor the radiation dose and ensure the minimization of radiation exposure while maintaining acceptable image quality for accurate diagnosis [9]. Furthermore,

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care must be taken with respect to the available dose optimization tools that can be implemented to overcome the concern of the considerably high radiation dose from CTA examinations [10]. Hence, the management of patient dose is essential and currently facilitated in most medical imaging practices through the use of a system of diagnostic reference levels (DRLs) [11]. The International Commission of Radiation Protection (ICRP) introduced the DRL system as a method of quality control for radiation dose in radiology practices by identifying particular imaging procedures where radiation doses are unusually high. When the resulting dose values exceed national DRL (NDRL) values, this triggers a call for local investigation to ensure that radiological practices use optimized and justified radiation doses in their daily practice [12, 13]. In 1997, the Council of the European Union issued Council Directive 97/43/Euratom, which updated their radiation safety standards and protocols to address the possible risks associated with exposure to ionizing radiation [14]. More importantly, they defined the concept of DRLs as “dose levels in medical radiodiagnostic practices or, in the case of radiopharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied” [14]. In CT departments, for example, the facility DRL (FDRL) value can be easily obtained by calculating 75th percentile values of the median facility volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) values of certain CT procedures [15–17]. The aim of this systematic review is to compare the published DRL values for most common CTA procedures, including cerebral, pulmonary, lower extremity (runoff), and aortic CTA examinations. Moreover, the review examines the variations and limitations in the methods that have been used to establish DRLs for CTA examinations globally.

Methods

Design

To ensure that this review is transparent and reliable, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to search for articles [18].

Literature search strategy

A systematic literature search for relevant published studies was performed via several academic databases. These databases included Science Direct, Web of Science, EBSCO host, PubMed–Medline, and Google Scholar (manually searched), which focus on articles that

Table 1 The search terms used to find relevant articles

Intervention	Cohort	Other
DRL and DRLs	CT angiography	CAT scan
Diagnostic reference levels	Computed tomography	CT scan
Dose reference levels	angiography	
Dose reference value	CT angiography examinations	
Dose survey	CTA	
$CTDI_{vol}$		
DLP		

DRL diagnostic reference level, $CTDI_{vol}$ volume CT dose index, DLP dose-length product, CT computed tomography, CTA computed tomography angiography, CAT computerized axial tomography

Table 2 Participants intervention comparison and outcome framework for assessing study relevance

Characteristics	Criteria
Study time	1991–2023
Study type	Cohort studies
Population	Adults undergoing CTA
Intervention	Radiation dose quantities, DRLs
Comparator	Reliability and reproducibility of DRLs method in adult CTA examinations
Outcomes	DRLs for CTA examinations in adult

have proposed DRLs for CTA examinations. The search was limited to specific criteria of population (Adult), age (<15 years), and publication language (English). In addition, the publication year employed for searching for articles ranged from 1991, when the concept of DRLs was first established [19], to December 2023. The search terms for the identification of articles are shown in Table 1.

Selection criteria

For the data extraction, the inclusion and exclusion criteria were selected considering the participant intervention comparison and outcome (PICOS) method (Table 2). Articles were excluded from this review for the following reasons: DRL studies established for non-CTA examinations, case studies, posters, reviews, and meta-analyses. DRL data from coronary CTA were also excluded because they were systematically reviewed by the author [20]. An initial screening (titles and abstracts) of selected articles was conducted to identify articles that proposed DRL values for all CTA examinations. The data extraction process was performed by two independent reviewers who independently assessed and guaranteed that only selected articles that fulfilled the inclusion criteria were included in the literature. Finally, the review protocol cannot be accessed; therefore, a protocol was not prepared.

Quality assessment of the selected articles

Employing the effective public health practice project’s assessment tool, the reviewers assessed the quality of each article. This approach ensured consistent scoring, with each article categorized as either high (1) or moderate (2) in quality. Ultimately, 19 of the 21 articles met the criteria for a high-quality rating, whereas the remaining 2 were classified as moderate.

Results

Search result

A systemic search was conducted, and the search strategy identified 2035 citations: 1391 from Science Direct, 557 from Web of Science, 72 from Medline, 13 from EBSCO host, and 2 from manual searches via Google Scholar. These selected references were assessed for eligibility; of these, 2010 articles were excluded from the initial screening of titles and abstracts. After that, 25 articles were considered eligible for full intensive review. Four articles were excluded after full review assessment, as they proposed DRLs for CTA using only the size-specific dose estimate (SSDE) or the DRL quantities were established on the basis of body phantom calculations (Fig. 1). A total of 21 articles were ultimately retained for inclusion in this systematic review. Data related to the name of the author, year of publication, country of study, and type of

CTA examination were retrieved from each study. Additionally, details regarding the data collection protocols employed for sitting DRLs were collected. DRL quantities corresponding to the $CTDI_{vol}$ and DLP were also reported in terms of the 25th percentile, 75th percentile, and dose range information.

Characteristics of the included studies

The review included fifteen NDRL studies and six local (facility) DRL studies that covered diverse regions worldwide, with three studies in Germany, two each from Switzerland and Saudi Arabia; one each from the Netherlands, France, the UK, Japan, Ghana, Korea, Kenya, the USA, Qatar, Malaysia, Ireland, Singapore, and Greece; and one international study that provided data from fourteen European countries. NDRLs have been established in numerous studies over the past decade. A recent national survey in Switzerland revisited and updated their previously determined NDRLs. This 2020 NDRL survey indicated a significant reduction in radiation doses compared with the prior survey conducted in 2010 [21, 22]. The detailed key findings from the 21 studies are presented in Tables 3, 4, and 5.

In 57% of the studies, population sampling for the dose surveys employed a predefined clinical indication-based CT protocol approach [10, 21–23, 30, 31, 34, 35, 38–41],

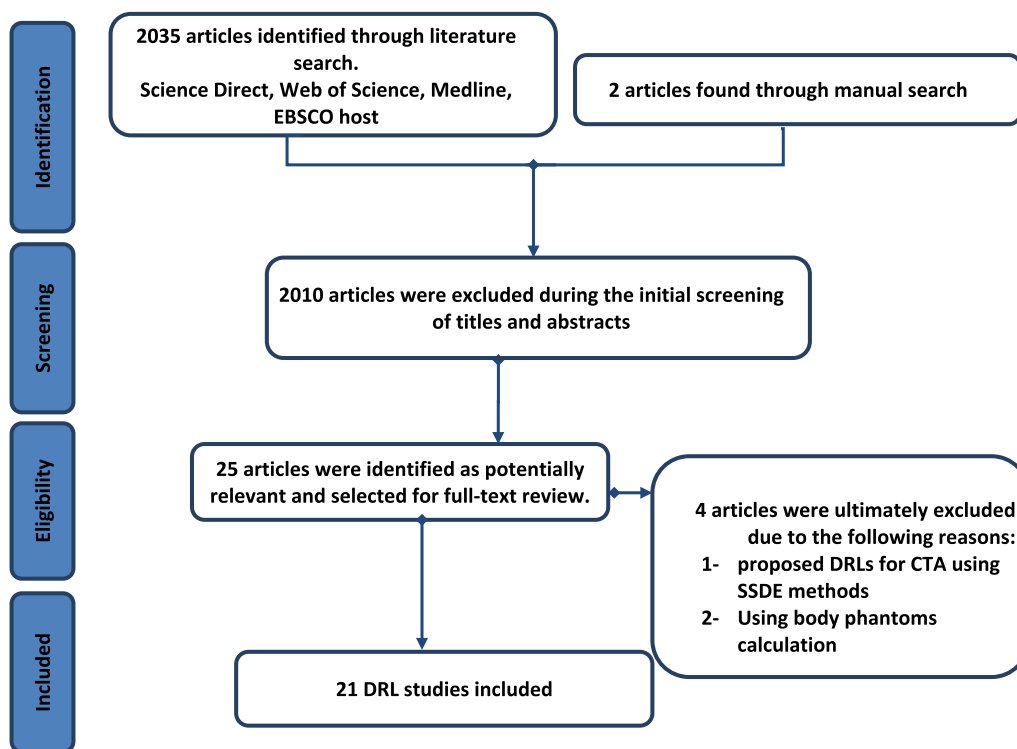


Fig. 1 Flow diagram illustrating the selection process for the studies included in this systematic review

Table 3 The key findings from the included citations for cerebral CTA examinations

DRL for cerebral CTA			
Author (Year)	Country	CTDI _{vol} (mGy)	DLP (mGy cm)
Zensen et al. [23]	Germany	13.7	478
Schegegerer et al. [24]	Germany	20	600
Treier et al. [22]	Switzerland	65	1134
Matsunaga et al. [25]	Japan	74	1224
Kim et al. [26]	Korea	43	1850
Korir et al. [27]	Kenya	50	4324
Alkhorayef et al. [10]	Saudi Arabia	70	1083
Metaxas et al. [28]	Greece	35	900

which was not applied in other studies [24–28, 32, 33, 36, 37]. Moreover, out of 21 DRL studies, seven studies clarified that dose quantities from a single acquisition (arterial phase) were included in the DRL survey [21, 25, 32, 35, 39–41], whereas five studies proposed DRLs on the basis of data derived from all scan phases acquired [26, 30, 31, 34, 37]. Other studies conducted in Greece [28], and European multicenter studies [38] reported separate DRLs from each phase per examination, whereas the remaining studies did not report the number of scans included or the dose quantities per phase in their DRL investigations.

This review revealed that only two studies provided objective image quality assessment via a signal-to-noise

ratio (SNR) analysis program for the selected CTA examinations included in the survey [31, 35], whereas the other four used subjective assessment tools, including scoring systems or visual evaluation by CT technologists or radiologists, to rate image quality [28, 34, 38, 41]. All other studies reported DRLs without intensive image quality considerations.

The CTDI_{vol} and DLP were the main dose indicators used for reporting DRLs in all included studies. The effective dose was also used as a DRL indicator in seven NDRL studies, in addition to several FDRL studies [10, 24, 26–28, 31, 34, 39, 40]. Other dose quantities, such as the size-specific dose estimate (SSDE), were calculated in two studies [24, 32]. Two main percentiles (25th and 75th) were the common values that were used as the DRL values. Five of the 15 reviewed NDRL studies included dose quantities from cerebral CTA examinations in their surveys [22, 24–27]. The DLP value for this examination varies significantly from 478 mGy cm [23] to 4324 mGy cm [27] (Table 3). In addition, pulmonary CTA examination was the most common angiographic CT protocol included in more than 85% of those NDRL studies, with DRL values ranging from 248 mGy cm to 942 mGy cm at the 75th percentile for DLP [31] (Table 4). On the other hand, only recent NDRLs in Germany and Switzerland included carotid and lower extremity (runoff) CTA examinations in their DRL survey [21, 24]. The overall distribution of DRLs reported for those examinations ranged from 360 to 600 mGy cm and from 730 to 1000 mGy cm, respectively (Table 5). Finally, nearly half (47%)

Table 4 The key findings from the included citations for pulmonary CTA examinations

DRL for pulmonary CTA			
Author (Year)	Country	CTDI _{vol} (mGy)	DLP (mGy cm)
Treier et al. [22]	Switzerland	15	450
Aberle et al. [21]	Switzerland (updated)	8	300
Habib Geryes et al. [29]	France	8	310
Public Health England. [30]	UK	9	310
Botwe et al. [31]	Ghana	14	942
Korir et al. [27]	Kenya	13	767
Kanal et al. [32]	US	18	557
Klosterkemper et al. [33]	Germany	11.8	–
AlNaemi et al. [34]	Qatar	8	510
Harun et al. [35]	Malaysia	9	329
Qurashi et al. [36]	Saudi Arabia	18	480
Alkhorayef et al. [10]	Saudi Arabia	31	582
Foley et al. [37]	Ireland	13	430
Tsapaki et al. [38]	European Survey	9	364
Arlany et al. [39]	Singapore	7	248
Metaxas et al. [28]	Greece	9	250

Table 5 The key findings from the included citations for CTA examinations (aortic, lower extremity, and carotid)

Author (Year)	Country	DRL for aortic CTA		DRL for Runoff CTA		DRL for Carotid CTA	
		CTDI _{vol} (mGy)	DLP (mGy cm)	CTDI _{vol} (mGy)	DLP (mGy cm)	CTDI _{vol} (mGy)	DLP (mGy cm)
Schegegerer et al. [24]	Germany	13	800*	8	1000	20	600
Treier et al. [22]	Switzerland	15	500	–	–	–	–
Aberle et al. [21]	Switzerland (updated)	11	530	10	730	11	360
Van der Molen et al. [40]	Netherlands	–	837**	–	–	–	–
Kim et al. [26]	Korea	15	1998	–	–	–	–
Korir et al. [27]	Kenya	18	2495	–	–	–	–
Klosterkemper et al. [33]	Germany	8	–	6.4	–	–	–
AlNaemi et al. [34]	Qatar	7	780	–	–	–	–
Alkhorayef et al. [10]	Saudi Arabia	38	516	15	438	–	–
Metaxas et al. [28]	Greece	8	450	–	–	8	300

*Includes the abdominal and pelvic areas; **Includes the thoracic, abdomen, and pelvic areas

of the included studies provided data on aortic CTA examinations. The DRL values for these studies ranged from 450 to 2495 mGy cm, as shown in Table 5.

Discussion

The established DRL values and the methodologies implemented for common CTA examinations have been systematically reviewed in the literature. The results revealed that, out of all the studies surveyed, seven studies applied anatomical location as a method to report DRL values, whereas seven studies established DRLs on the basis of clinical indications. Despite the fact that most of the current DRL studies have been published on the basis of anatomical locations during CT imaging, this approach seems to be limited. Within the same anatomical region, diverse clinical indications may necessitate different imaging protocols and scanning phases, resulting in variations in dose quantities [29]. For example, our analysis revealed that the NDRL survey in Korea did not provide clear information about the clinical indications or scanning protocols included in the DRL survey for cerebral CTA [26]. Therefore, it is not surprising that significant variation in DLP values was noted in this study, with values greater than tenfold (299–3168). On the other hand, Swiss NDRL data that used indication-based methods presented much lower variation in DLP values than did the results of a Korean NDRL study with twofold (547–1134) mGy cm [22]. Thus, our review suggests that sitting DRLs via indication-based methods is needed to adequately account for correct and representative DRL measurements. This approach was recently recommended by the ICRP Publication (ICRP Publication 135) [42]. These updated guidelines highlighted the possibility of an adverse effect on comparing DRL values of

the same anatomical region but with different scanning parameters as a result of different indications. Therefore, it is crucial that recording data for DRL quantities must come from selected imaging examinations for a specific clinical purpose through all contributing imaging centers [42]. Moreover, indication-based DRL methods were also supported by Roch et al. [43]. They argued that not considering clinical indications is the ugly side of the concept of DRLs.

The literature has shown a variation in the methodology used for sitting DRLs. This includes the number of scan acquisitions (phases) used to acquire the CTA images. Importantly, the number of phases required in the imaging protocol of CTA strongly depends on the specific clinical indication. This is exemplified by cerebral CTA, which typically requires at least two phases (nonenhanced and arterial phases) up to three phases (including perfusion CT) [23]. In 50% of the DRL studies reviewed, the number of scanning series included in the dose survey from cerebral CTA examinations was not included. Consistent with expectations, the DLP DRL value for this examination significantly varied from 478 to 4324 mGy cm.

Moreover, although the pulmonary CTA protocol was almost identical in most imaging facilities, significant differences in dose quantities were still observed among studies (threefold). Compared with those of other published DRL studies, the DLP values derived from NDRLs in Ghana [31] and Qatar [34] for pulmonary CTA were the highest, at 942 mGy cm and 510 mGy cm, respectively, compared with those of other studies presented in Table 4. The possible explanation is that two scan phases (noncontrast and arterial scans) were routinely performed during the examination in those

imaging practices, whereas only one arterial scan phase was used and recorded in other DRL surveys included in our literature. Notably, a significant number of studies have failed to provide a clear and detailed methodology for proposing multiphase CTA examinations [10, 22, 24, 27]. Consequently, the variation in the number of scan series incorporated within CTA protocols may have a significant influence on the number of CTA DRLs reported throughout the literature. This underscores the importance of standardizing data reporting by focusing solely on the arterial phases of all CTA examinations included in DRL dose surveys to ensure data independence during the data collection process [42].

The dose metrics $CTDI_{vol}$ and DLP, which are the standardized dose measurements recommended by the International Atomic Energy Agency (ICRP) and the European Commission [12, 14], are the current DRL quantities found in this review. These dose metrics are displayed on the final dose report, which can be easily sent to the picture archiving and communication system (PACS) for long-term storage [32]. The SSDE was only calculated as a DRL quantity in two studies [24, 32]. The inclusion of SSDE values in the NDRL survey and any future optimization process was recommended by several guidelines, including ICRP Publication 135 and the American Association of Physicists in Medicine (AAPM-Report 220) [44]. This current CT dose metric may correctly enable estimation of patient doses that take patient size into account and can be a more accurate dose measurement indicator than $CTDI_{vol}$, especially for patients with various body habitus. SSDE achieves this by incorporating size-related parameters into the dose estimation process [45].

This study revealed that the DRL values for all angiographic CT examinations were significantly lower in the latest studies than in the older studies. This can be manifestly evident in Swiss DRL studies [21, 22]. An updated Swiss DRL study [21] published in 2020 showed a clear trend toward dose optimization compared with a previous DRL survey in 2010 [22]. The DRLs for the $CTDI_{vol}$ and DLP values were 30% and 22% lower, respectively. Specifically, the average changes in the 75th percentile DLP for pulmonary and carotid CTAs were 37% and 28%, respectively. Aberle and colleagues argued that this substantial average reduction in dose quantities in the updated Swiss DRLs survey was attributed to the implementation of state-of-the-art CT scanners with dedicated dose-saving software tools such as tube current modulation technology and iterative reconstruction [21].

The concept of facility (FDRL) acknowledges the influence of variations in technology and scanning protocols employed by different CT scanner manufacturers. The recent ICRP Publication 135

emphasized the importance of considering the effects of the CT scanner brand and technology when proposing FDRL results [42]. This recommendation aligns with our findings in the literature where a limited number of studies have reported brand-specific FDRLs [21, 23, 28]. Notably, one study categorized the included CT scanners into three groups on the basis of the number of detectors, reporting DRLs for each category to account for technological variations [26]. Building on these findings and the ICRP recommendations, a more detailed approach to reporting DRLs is suggested. This approach involves providing summaries of DRL quantity distributions for each CT scanner model employed at the facility. These summaries could be presented in the form of boxplots or other visual aids for easier comparison across scanner models.

The scanning length plays an important role in the radiation dose during CTA. The total DLP value is highly influenced by the scan length as the start and end location lengths increase, leading to a corresponding increase in the calculated DLP value. These findings were consistent with the review results. DRL values quoted in the Swiss and Netherlands NDRL studies revealed that when almost the same multidetector CT (MDCT) systems and scanning parameters were used in aortic CTA examinations, DLP was 25% greater in the Netherlands, as the aortic scan length was 48% greater than that reported in the Swiss survey. On the other hand, an NDRL study in Germany reported closer DRL quantities for aortic CTA examinations to those in Switzerland, with DLP values of 800 mGy cm and 837 mGy cm, respectively, because a typical scan length (66 cm) was noted in both studies. Although the scanning length can be adjusted depending on the clinical indication, standardization of the scan length for CTA examinations at each CT facility is necessary [46]. By focusing on restricting the scan length to the anatomical region of interest, unnecessary radiation exposure can be effectively minimized. To link this with the DRL process toward dose optimization, we suggest reviewing the scan length only if the $CTDI_{vol}$ value for the CTA imaging protocol in the CT facility is below its NDRL value, while the DLP value exceeds the NDRL value of the DLP for the same protocol [32].

It is essential that performing CT examinations at lower doses without compromising image quality and sufficient for clinical purposes is the main factor in improving the benefits and safety standards of imaging examinations [47]. Quality control of MDCT scanners is crucial before DRL data collection can be acquired. This ensures accurate measurements of the dose quantity and image quality suitable for clinical tasks. The review revealed that only DRL studies in Ghana and Malaysia

intensively assessed objective image quality via SNR analysis prior to data collection [31, 35]. All other DRL studies did not conduct any strict assessment of image quality. However, most of those studies assumed that all included CTAs accomplished an independent assessment of image quality before being interpreted by radiologists and therefore met the image quality standards and accreditation [32, 48]. Thus, further research assessing image quality on the basis of the resulting DRL values could be suggested. A facility assessment of image quality is warranted if the local 75th percentile FDRL value falls below the national 25th percentile. This suggests that the optimization of CT protocols via DRL methods should consider including both the 25th and 75th percentiles of DRL values [21, 24, 42].

This review suggests that inconsistent proposed DRL values across clinical settings create a ripple effect of scientific concern. First, it reduced the effectiveness of dose optimization. DRLs are meant to be benchmarks for optimizing radiation doses in medical imaging procedures. Significant variations between facilities or regions can make it difficult to determine if a specific dose is effectively optimized, potentially leading to unnecessarily high exposures for some patients. Second, DRL studies based on facilities with specific DRLs may not be generalizable to others, hindering the development of standardized methodologies for setting DRLs in clinical practice. Furthermore, comparing dose quantities and identifying outliers becomes challenging, making it difficult to promote best practices across the board. Finally, clinicians unfamiliar with their FDRLs might misinterpret them as absolute limits, hindering further dose reduction even when possible with current dose-saving technologies. Overall, variations in DRL results create a barrier to achieving consistent, optimized radiation use in clinical settings.

Recommendations

The burgeoning utilization of CTA examinations, coupled with their inherently higher radiation doses than those of routine CT procedures, underscores the growing importance of establishing DRLs for common CTA examinations within local and national DRL projects. Our analysis of existing methodologies utilized for proposing CTA DRLs suggests the need for standardized data collection protocols. Establishing a common framework for conducting surveys to establish DRLs would facilitate the development of comparable DRL models, ultimately leading to greater consistency in proposed DRL values globally and thereby reducing dose variation among DRL studies. Furthermore, with the current advancements in CT

technology, which enables imaging, several types of clinical indications that may require optimum image qualities and therefore greater exposure, demonstrating clinical indications and the number of scan series during the setting of DRL surveys is valuable. Finally, this literature search suggests that the assessment of image quality must be considered if the FDRL value is below the 25th percentile.

Conclusions

In conclusion, this review reveals substantial inconsistencies in the methodology used to establish DRLs and therefore significant variation in the reported DRL values between hospitals, which may not accurately represent a standardized national effective dose. Furthermore, the number of scan phases included in CTA examination protocols and the application of the latest dose-saving technology (both software and hardware) suggestively contribute to the observed differences in reported DRLs.

Abbreviations

DRLs	Diagnostic reference levels
CTA	Computed tomography angiography
AVMs	Cerebral arteriovenous malformations
ICRP	The International Commission of Radiation Protection
CTDI _{vol}	Volume CT dose index
DLP	Dose-length product
MDCT	Multidetector CT
SNR	Signal-to-noise ratio
SSDE	Size-specific dose estimate
PACS	Picture archiving and communication system

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Author contributions

Ali B Alhailiy conducted the data analysis and interpretation. He then drafted the manuscript. Finally, Ali Alhailiy reviewed and approved the final version of the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The author declares no conflict of interest.

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