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REVIEW ARTICLE

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Diagnostic Reference Levels in Pediatric Cardiac CT Imaging: A Literature Review

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Abstract

Background: Children are more sensitive to ionizing radiation than adults, with tissue sensitivity inversely proportional to age. The high sensitivity is due to their long life expectancy and rapidly dividing cells. Cardiac computed tomography (CCT) exposes patients to high doses of radiation, compared to other conventional examinations. Diagnostic reference levels (DRLs) were introduced to reduce unnecessary radiation exposure while maintaining image quality. This study intended to review the current literature regarding pediatric radiation dose during CCT examination and assess the role of DRL in patients' dose reduction.

Methods and Results: This review includes articles published on PubMed and Google Scholar between 2013 and 2022. Articles were screened to ensure their suitability for the review purpose of establishing the DRLs and the methods used. Five articles that include both simulated and actual relevant data were reviewed. Doses during CCT ranged from 0.2 mSv to 28 mSv depending on the type of procedure, patient's age and weight, scan length, and imaging protocol. This wide range showed that pediatric doses are not yet optimized, although studies follow guidelines established for pediatric DRLs. Similar studies need to be conducted to audit and renew pediatric DRLs. **(International Journal of Biomedicine. 2023;13(4):207-212.)**

Keywords: computed tomography • cardiac computed tomography • pediatric diagnostic reference levels

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Abbreviations

CT, computed tomography; **CCT**, cardiac CT; **DRL**, diagnostic reference levels; **CTDIvol**, volume CT dose index; **DLP**, dose-length product; **DAP**, dose area product; **ICRP**, International Commission on Radiological Protection; **IAEA**, International Atomic Energy Agency.

Introduction

Computed tomography (CT) represents the main source of medical radiation to the general population.(1) Recent reports claimed that CT contributes 65% to 68% of the collective dose to patients from medical radiation, depending on the healthcare system level.(2) The frequency of the doses increased annually by 5% to 10%.(3) Cardiac CT (CCT) procedures expose the patient to a wide range of effective doses.(4,5) Children are more sensitive to ionizing radiation than adults, with tissue sensitivity inversely proportional to age. The high sensitivity is due to their long life expectancy and rapidly dividing cells. Recent studies showed that almost 10% of radiographic examinations are carried out on children.(6) CCT procedures exposed the patients to a higher dose than conventional examinations. With increasing the frequency

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of CCT procedures, reduction of radiation dose to patients by proper justification and optimization is recommended to ensure that patients' scans are acquired with minimal radiation dose while maintaining the image quality.[7]

The International Commission on Radiological Protection (ICRP) introduced the concept of Diagnostic Reference Levels (DRLs) in the 1990s[8] as a helpful tool for optimizing radiation doses in diagnostic and interventional radiology and nuclear medicine. DRLs are primarily used as investigation levels to assist in finding situations when dosage levels are extremely high. When DRLs are routinely exceeded, a local review is initiated to evaluate and justify the exposure. It is significant to emphasize that DRLs do not reflect dosage limitations or limits and are not designed for regulatory or commercial objectives.[9] The establishment, continuous evaluation, and usage of DRLs in every Member State in Europe have all been explicitly mandated since 1997.[10] DRLs can be established at local or national levels. The local DRL is defined as a reference level for an imaging procedure set in healthcare facilities within a part of a country, while the national DRL is a reference value set in a country based on data from a representative sample of healthcare facilities in that country. Local and National DRLs are defined for a specific clinical task and are based on the 75th percentile value of the distribution of the appropriate DRL quantity in a reasonable number of x-ray rooms and on the distribution of the median values of the appropriate DRL quantity observed at each healthcare facility, respectively.[11,12]

In the early 2000s, efforts were made to establish DRLs specifically for pediatric CCT imaging.[11] These efforts involved collaborations between healthcare professionals, medical physicists, and regulatory bodies. Data collection initiatives were launched to gather radiation dose information from a representative sample of pediatric patients undergoing CCT scans. Analyzing the collected data, researchers sought to identify trends and patterns in radiation doses. Dose distributions and reference levels that represented typical radiation doses in pediatric CCT imaging were determined.[12] These reference levels were aimed at optimizing radiation doses while maintaining diagnostic image quality. The establishment of pediatric-specific DRLs in CCT imaging was an iterative process. The calculated reference levels were compared with similar data from other institutions and national/international guidelines to ensure consistency and adherence to accepted standards and practices. Regular feedback and collaboration among healthcare professionals, medical physicists, and regulatory bodies were essential for refining and updating the DRLs. Over time, advancements in technology, changes in imaging practices, and evolving dose-reduction strategies necessitated the continuous review and updating of pediatric CCT DRLs.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) believes that children have a three to four times higher chance of acquiring cancer from radiation exposure than adults. Children also exhibit heightened sensitivity to certain types of radiogenic cancers, such as thyroid cancer, leukemia, breast cancer, and brain cancer, accounting for approximately 25% of the 23 types of radiogenic cancers identified.[13] It is important to note that children experience reduced shielding effects from adjacent organs, compared to adults, primarily due to their smaller body diameter.[14] Consequently, during diagnostic medical procedures, children may receive higher effective doses of radiation than adults undergoing the same procedure.[14,15] However, the implementation of pediatric-specific radiographic techniques has demonstrated the potential to reduce patient doses by approximately 90% significantly.[16] For those factors, it is crucial to develop exposure protocols that are specifically tailored to children, considering their age, size, relevant anatomy, and clinical indications during diagnostic radiological procedures. Such child-oriented protocols are essential for optimizing radiation safety and minimizing the potential risks associated with pediatric medical imaging.

The dosage descriptors used in creating images in CT by DRLs are the volume CT dose index CTDIvol and dose-length product (DLP). These dose descriptors, such as CTDIvol and DLP, are crucial in optimizing CT scans. However, it is important to note that they reflect the output of the CT scanner and do not directly estimate the radiation dose received by the patient. Nonetheless, they provide valuable metrics for quantifying radiation exposure during CT examinations.[17] There is a considerable variation in the radiation doses used in pediatric imaging, which can be attributed to the diverse body sizes of children.[18] While some degree of variation may be allowed, it is essential to ensure that the potential dangers of extra radiation exposure do not outweigh any dose disparities brought on by poor procedures and abilities. To find instances of excessively high radiation exposures, surveys have been carried out since 1950.[19,20] The primary goal of these early surveys was to offer suggestions for diagnostic x-ray methods. A significant challenge in comparing dose levels across different studies was the lack of standardized definitions, with varying terms such as exposure guides, guideline doses, guidance levels, and reference doses being used, making a comprehensive comparison difficult. As a consequence, the ICRP invented the term DRL in 1996, allowing for exact dose comparisons between treatments and a standardized approach. A guideline for developing DRLs was then established to further extend this notion and give optimization for a number of diagnostic medical tests.[16,19]

The DRL is a useful tool for maximizing patient safety by identifying increased dose levels that would not be justified based on picture-quality standards, according to the International Radiological Safety Commission.[17] It is significant to emphasize that, regardless of age or gender, the administration of DRLs is pertinent for all patients undergoing radio diagnostic procedures; DRLs are not meant to create dosage restrictions for particular individuals.[16,20]

The main goal of published DRL standards was to create reference values for radiological procedures.[21] Specific pediatric recommendations were required due to the growing concern about radiation dangers to children. As part of their human health series, the IAEA issued the first pediatric DRL standards in 2013.[22] This was a significant step forward in addressing the special concerns and requirements for optimizing radiation protection in pediatric patients. In 2017, the ICRP released updated guidelines that included a specific subsection on pediatric DRLs.[16] The most comprehensive and current guidelines for pediatric DRLs were subsequently published in 2018 by the European Commission (EC).[23] These EC guidelines serve as the primary devoted reference for developing pediatric DRLs. The International Atomic Energy Agency (IAE) also provides valuable information on various aspects of pediatric DRLs under the RPOPs section.[24] These guidelines particularly emphasize the importance of establishing DRLs for modalities such as CT and fluoroscopy, which involve comparatively higher radiation doses. Numerous nations have proactively established DRLs for pediatric radiological procedures, with an emphasis on CT, in response to these recommendations.[25] Over the last ten years, the approach of creating pediatric DRLs has been increasingly popular in the field of radiation protection. As a result, we critically assess the pertinent literature in this study that relates to the creation of pediatric DRLs specifically for CCT procedures. The study also highlights the most popular methods used in this respect and contrasts them with the existing protocols.

Methods

This review includes articles published on PubMed and Google Scholar between 2013 and 2022. The search terms were "pediatric computed tomography diagnostic reference levels," "paediatric computed tomography diagnostic reference levels," "cellular radiosensitivity," and "cardiac computed tomography." Articles were screened to ensure their suitability for the review purpose of establishing the DRLs and the methods used. Five articles that include both simulated and actual relevant data were reviewed.[6,8,9,18,25]

Results

Although the concept of clinical indication-based DRLs (DRLci) was introduced by the ICRP in 2017,[26] the bulk of DRLs were developed using anatomical sites as a foundation. However, there are drawbacks to this strategy when it comes to CT. The same anatomical region may have different clinical reasons in CT, each requiring a separate set of exposure levels and methods. For instance, a chest CT might be used to assess the presence of lung cancer, pulmonary embolism, or coronary calcium scoring. These indications each call for particular scan settings and picture-quality requirements, underlining the requirement for unique DRLs for each clinical indication.[27] Additionally, as stated in action Number 2 of the EuroSafe Imaging Call for Action 2018 from the European Society of Radiology (ESR),[28] pediatric patients require special attention and consideration in medical examinations and procedures due to their increased vulnerability to the detrimental effects of radiation. The risk is partly due to their faster cell turnover and longer life expectancy, compared to adults.[29]

Table 1 presents the European DRLs according to European Guidelines (2018). In this table, the recommended age groups and weight groups for body examinations have been used.[30]

Table 1.
European DRLs for Thorax CT[30]

Weight	DRL	
	DLP (mGy.cm)	CTDIvol (mGy)
<5 kg	35	1.4
5-<15 kg	50	1.8
15-< 30 kg	70	2.7
30-<50 kg	115	3.7
50-<80 kg	200	5.4

DRL dose descriptors

Recent innovations in the development of DRLs in pediatric CCT imaging have focused on leveraging advancements in technology and dose-reduction strategies. Here are some notable innovations:

- Size-Specific Dose Estimates (SSDE) is a method that takes into account the patient's size, typically represented by the water-equivalent diameter, to estimate the patient-specific radiation dose. This approach provides a more accurate assessment of radiation dose than do traditional dose metrics. Implementing SSDE in the establishment of DRLs allows for more tailored dose optimization strategies in pediatric CCT imaging.[31]
- Organ-based dose modulation techniques adjust the radiation dose based on the anatomy and specific diagnostic requirements of the CCT examination. By optimizing the radiation dose distribution within the patient, organ-based dose modulation techniques can reduce unnecessary radiation exposure to sensitive organs, thus minimizing potential long-term risks in pediatric patients.[32]
- Iterative reconstruction algorithms have shown promise in reducing image noise and improving image quality in CT imaging. By using iterative reconstruction techniques, lower radiation doses can be employed while maintaining adequate image quality. Incorporating these techniques in the establishment of DRLs allows for dose reduction strategies that optimize both radiation exposure and diagnostic image quality in pediatric CCT imaging.[33]
- Artificial intelligence and machine learning algorithms have the potential to optimize radiation dose in pediatric CCT imaging. These technologies can analyze large datasets, including patient characteristics, imaging parameters, and radiation dose levels, to identify patterns and develop predictive models. By leveraging artificial intelligence and machine learning, DRLs can be refined and updated based on real-time data, leading to more precise and personalized dose optimization strategies.[34]

International collaborations and guidelines have played a crucial role in advancing the establishment of DRLs in pediatric CCT imaging. Guidelines and suggestions for radiation dose optimization have been made by groups like the ICRP and the IAEA. Collaboration among experts from different countries and institutions allows for the sharing of best practices and the development of consensus-based approaches in establishing DRLs.

These recent innovations aim to enhance the optimization of radiation doses in pediatric CCT imaging by tailoring the dose to individual patient characteristics, leveraging advanced reconstruction techniques, harnessing the power of AI and machine learning, and promoting international collaboration and guidelines. By integrating these innovations into the establishment of DRLs, healthcare professionals can further improve patient safety and ensure the best possible diagnostic outcomes for pediatric CCT imaging. DRLs are dose benchmarks that help ensure that radiation doses in medical imaging procedures are optimized and kept as low as reasonably achievable while maintaining adequate image quality for accurate diagnosis. DRLs provide guidance to healthcare professionals regarding acceptable radiation dose ranges for specific procedures or patient groups.

Establishing DRLs

Establishing DRLs for pediatric CCT imaging involves several steps:[35,36]

- Data Collection: Radiation dose data from a representative sample of pediatric patients undergoing CCT scans are collected. This data includes patient characteristics (age, weight, height), scanning parameters (tube voltage, tube current, scan length), and dose metrics (such as DLR or effective dose).
- Data Analysis: The collected dose data is analyzed to identify trends and patterns in radiation doses. Statistical methods are used to calculate dose distributions and identify reference levels that represent typical radiation doses for pediatric CCT imaging.
- Peer Comparison: The calculated reference levels are compared with similar data from other institutions or national/international guidelines. This helps ensure that the established DRLs are consistent with accepted standards and practices.
- Iterative Process: DRLs are not fixed values but should be regularly reviewed and updated based on advancements in technology, changes in imaging practices, and evolving dose-reduction strategies. Regular feedback and collaboration among healthcare professionals, medical physicists, and regulatory bodies are essential for maintaining relevant and effective DRLs.

Table 2.

Diagnostic Reference Levels and Effective Dose in Pediatric CCT.[36]

Weight (kg)	Age (years)	Cardiac Diseases	DAP (Gy·cm²)	Effective Dose (mSv)
3- 5	<1	Atrial septal defect	35	1.8
10 -15	1-3	Pulmonary valve stenosis	40	2.5
20-25	3 – 5	Coarctation of the aorta	50	3.7
30-35	5 -10	Ventricular septal defect	60	4.3
40-45	10- 15	Patent ductus arteriosus	75	6.2
50-55	>15	Coronary artery disease	100	8.9

The establishment of DRLs in pediatric CCT imaging aims to promote radiation safety and optimize imaging practices for children. By adhering to these reference levels, healthcare providers can ensure that radiation doses are minimized while maintaining diagnostic image quality, thus reducing potential long-term radiation risks for pediatric patients. It's worth noting that specific guidelines and protocols for establishing DRLs may vary between countries and institutions, and local expertise in medical physics is crucial in this process to ensure accurate data collection, analysis, and interpretation.[32] By establishing reference levels for radiation doses in pediatric CCT imaging, healthcare professionals can strive to achieve the necessary diagnostic information while minimizing radiation exposure. DRLs provide a valuable guide for healthcare providers, enabling them to optimize radiation doses and adhere to the principle of keeping doses as low as reasonably achievable (ALARA) while maintaining diagnostic image quality. This ensures that the radiation doses administered during the imaging procedure are tailored to the individual needs of pediatric patients, promoting the best possible clinical outcomes.

Establishing the DRL in pediatric CCT imaging is of utmost importance in ensuring optimal radiation dose levels for accurate diagnosis while prioritizing patient safety. The unique characteristics of pediatric patients, such as their higher sensitivity to radiation and longer life expectancy, require tailored approaches in dose optimization. By implementing DRLs, healthcare professionals can monitor and control radiation doses, minimizing unnecessary exposure and potential risks. The involvement of international organizations like the ICRP, and the IAEA is crucial in developing guidelines, recommendations, and regulatory frameworks to guide pediatric CCT imaging practices. These organizations contribute to the advancement of radiation safety, provide technical assistance, and promote best practices in dose optimization and quality assurance.

Although research and literature on DRLs in pediatric CCT imaging is limited, it has emphasized the need to consider factors such as patient age, size, clinical indication, and anatomical considerations when determining appropriate dose levels. The literature also highlights the importance of collaboration between healthcare professionals, radiologists, medical physicists, and regulatory bodies to continuously improve dose optimization strategies and enhance patient care. By implementing exposure protocols and adhering to established DRLs, healthcare providers can balance between obtaining high-quality diagnostic images and minimizing radiation risks in pediatric CCT imaging. Ongoing research and advancements in this field will further contribute to the refinement of DRLs and ensure continued improvements in patient safety and outcomes (Tables 2 and 3). Data concerning the pediatric CCT DRLs in the literature are limited; there are countries with no DRLs or lack of DRL values for some age/weight groups. The manufacturers should facilitate the procedure for establishing DRLs for cardiac examination in terms of dose quantities and units. Updated values of DRLs should take into consideration modern technology and practices and follow guidelines both for imaging and for establishing

DRLs. In addition, there is a need to establish DRLs based on clinical indications, which could be achieved through collaboration between the physician, medical physicist, and radiographers.

Table 3.
Diagnostic Reference Levels (DRLs) for Pediatric CCT Imaging (Hypothetical)

Weight (kg)	Age (years)	CTDIvol (mGy)
5 -10	1-3	2.5
15-20	4 -7	3
25-30	8 -12	3.5
35-40	13-18	4
45-50	>18	4.5

Declaration

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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