



Let's talk about radiation dose and radiation protection in children

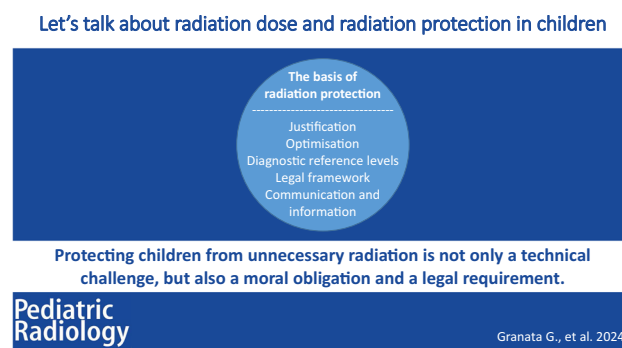
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Received: 7 May 2024 / Revised: 16 July 2024 / Accepted: 17 July 2024 / Published online: 3 August 2024
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Abstract

Children are more sensitive to ionizing radiation than adults. Even though the risk is very low, exposure from radiological examinations can possibly cause them long-term side effects. Recent large epidemiological studies involving children and young adults have added evidence suggesting that even small doses of radiation, such as those from computed tomography scans, might slightly increase the risk of developing cancer later in life. Therefore, even though radiologic studies are essential for an accurate diagnosis and management of various conditions, it is crucial to minimize radiation exposure. This article addresses radiation protection for children in the medical use of ionizing radiation and it is set in the context of the European legislative framework regarding radiation protection. It advocates for a holistic approach to paediatric radiological tests. This approach includes the key principles of radiation protection, such as the justification of imaging procedures supported by referral guidelines, as well as the optimization of techniques (according to the ALARA principle) and effective communication with parents about the benefits and the risks of radiologic procedures. Protecting children from unnecessary radiation is not only a technical challenge, but also a moral obligation and a legal requirement.

Graphical Abstract



Keywords Child · Diagnostic reference levels · Radiation protection · Radiology

Cancer risk from radiologic imaging: what we know

It is widely assumed that children are more susceptible than adults to the stochastic effects of radiation exposure, especially in terms of developing cancer later in life. This

increased vulnerability depends on the high frequency of mitosis in growing organisms with a consequent high risk of accumulating mutations, which can cause malignancies. Additionally, children have a longer life expectancy, hence a longer time window for these accumulated mutations to manifest as cancer. In fact, despite the body's DNA repair

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mechanisms, mutant cells that are not removed may become malignant after a latency of several years or decades [1].

The linear no-threshold model is universally adopted to protect people from radiation. This model assumes that even very small doses of ionizing radiation can increase the stochastic effect of cancer onset, with no safe threshold level below which the risk disappears. It is mainly based on linear extrapolation models of risk derived from studies of the higher exposures on Japanese atomic bomb survivors [2]. However, it is still not definitely proven as it might overestimate the risk of cancer induction from low doses (< 100–150 mSv) of radiation, which are typical in radiologic imaging. Nevertheless, the linear no-threshold model is adopted because it ensures the most conservative approach to radiation safety [3].

Nowadays, medical radiation is the most significant artificial source of radiation exposure to the general population, with computed tomography (CT) delivering the highest radiation dose in diagnostic imaging. To date, despite the availability of alternative modalities such as magnetic resonance imaging (MRI) and ultrasonography, CT examinations in children account for up to 7% of all CT studies performed in high-income countries [4]. Therefore, it is not surprising that studies on the correlation between radiation exposure from radiological imaging and cancer onset are mainly focused on patients who underwent CT scans during childhood.

About 20 years ago, Brenner et al. [5] raised great concerns about the potential cancer risks associated with CT scans in children. In their study, Brenner et al. estimated that the lifetime cancer mortality risk due to radiation exposure from an abdominal or head CT in a 1-year-old child was 0.18% and 0.07%, respectively. Since then, a series of cohort or case–control studies have been designed to estimate the risk of developing cancer following radiation exposure during CT scans.

Berrington de Gonzales et al. [6] reviewed the epidemiological studies on the correlation between CT scans and cancer risk, incorporating research available up to 2020. Thirteen studies [7–20] with published risk estimates, mostly involving populations of children (< 18 years old) or children and young adults (< 21 years old), were deemed eligible for review. Despite considerable methodological variability among these studies, the authors [6] successfully compared the results from the subset of studies that evaluated leukemia or brain tumors.

Eight studies [10–12, 15–18, 20] investigated leukemia risk in relation to red bone marrow dose, effective dose, or number of CTs. Among these, seven studies reported a positive dose–response [10–12, 15–17, 20]. Similarly, six [11, 12, 16–18, 20] out of the seven studies [11, 12, 14, 16–18, 20] that focused on brain tumors also identified a positive dose–response. In a meta-analysis of all these studies on childhood exposure, the authors found

that the summary excess relative risk (ERR)/100 mGy was 1.05 (95% CI –0.58, 2.69) for leukemia/myelodysplastic syndrome and 0.80 (95% CI 0.48–1.12) for brain tumors. Based on these findings, the authors concluded that there is increasing evidence suggesting that CT scans might contribute to cancer development, although the actual risk for each patient is likely quite low [6]. Nevertheless, some doubt remains on the link between the risk of brain tumors or hematological malignancies and CT scans during childhood, due to methodological limitations in the available studies. These limitations include a small number of cases, the possibility of reverse causation, confounding by indication, and the lack of individual dose reconstruction [21].

Recent findings from the EPI-CT cohort study on brain tumors after radiation exposure from CT examinations in children and young adults provided further evidence that low-dose radiation exposure from head or neck CT scans may be associated with an increased risk of brain tumors [21]. This study is the largest multinational investigation of CT-related cancer risks to date, better addressing factors potentially biasing risk estimates that were the subject of criticism in previous research, including state-of-the-art dose reconstructions. The study involved nine European countries and 658,752 eligible individuals with no previous diagnosis of brain tumors, who underwent head or neck CT examination between 1977 and 2014. Over a median follow-up period of 5.6 years, 165 brain tumors were observed, three-quarters of which were gliomas. A significant linear dose–response relationship was observed for all brain tumors (ERR per 100 mGy 1.27 (95% CI 0.51–2.69)). The researchers estimated that for every 10,000 patients who underwent a single-head CT study, about one individual is expected to develop a brain tumor attributable to radiation exposure within 5 to 15 years following the CT examination.

Very recently, another EPI-CT cohort study, involving the same group of individuals as the previous brain tumor study [21], examined the risk of hematological malignancies resulting from CT scans in children, adolescents, and young adults [22]. This study estimated radiation doses to the active bone marrow by considering factors such as the body part scanned, patient characteristics, length of the study, and inferred CT technical parameters. The authors identified a significant connection between the cumulative dose of radiation and the risk of all hematological malignancies (ERR per 100 mGy 1.96 (95% CI 1.10–3.12)). These results suggest that for every 10,000 children currently undergoing CT examinations, approximately 1–2 individuals are expected to develop a hematological malignancy attributable to radiation exposure within the subsequent 12 years.

The findings from these two recent EPI-CT studies [21, 22], which employed robust data and methodologies, provide further support for the linear no-threshold model concerning

cancer risk from doses considerably lower than 100 mGy. As a result, the existing evidence strongly reinforces the importance of adhering to the two main principles of patient radiation protection: justification and optimization.

Another emerging concern in radiation protection relates to the prolonged survival of patients due to the effectiveness of new therapies for paediatric oncology malignancies and chronic diseases, such as cystic fibrosis and congenital heart disease. Prolonged survival necessitates more frequent imaging, including high radiation dose procedures like CT, fluoroscopy, and PET-CT. Patients with chronic conditions and/or recurrent diseases are likely to undergo repeated imaging, resulting in a high cumulative effective dose. Those with active or recent malignancy frequently require recurrent imaging to assess disease progression and monitor for potential recurrence. A recent study analyzing clinical indications for patients who received a cumulative effective dose of ≥ 100 mSv over a 5-year period found that approximately 90% of these patients had a history of malignancy [23]. To minimize lifetime cumulative effective dose in these patients, careful justification, dose optimization, and the use of alternative modalities without ionizing radiation where possible are crucial.

The mainstays of radiation protection and the European legislative framework

In all European Union member states, the European Directive 2013/59/Euratom [24] serves as the legal framework for safeguarding against the risks associated with exposure to ionizing radiation. This Directive sets out consistent fundamental safety standards aimed at protecting the health of individuals exposed to ionizing radiation in occupational, medical, and public settings. Specifically, it regulates medical exposure through nine articles, ensuring standardized measures for minimizing risks associated with medical procedures involving ionizing radiation.

Justification

Article 55 mandates the justification of a radiological procedure. In radiology, justification is the first step in radiation protection. It involves the process where a healthcare provider, typically a radiologist and/or a referring physician, evaluates the necessity and appropriateness of ordering a radiological examination or procedure for a patient. This assessment entails balancing the potential benefits of the imaging study against its risks, including radiation exposure and any potential adverse effects [25]. Justification is a fundamental principle in radiology aimed at ensuring that imaging studies are used appropriately and responsibly to

optimize patient care while minimizing unnecessary exposure to ionizing radiation and healthcare costs.

While the concept of justification may seem straightforward, its practical application in clinical settings poses a significant challenge. Recent studies suggest that between 20 and 50% of radiological procedures performed are deemed inappropriate, with variations based on the healthcare system, type of imaging modality, and availability of imaging referral guidelines [26, 27]. Contributing factors to this issue likely include a lack of awareness among healthcare professionals, clinical pressures, and defensive medical practices.

Referral guidelines

The availability of imaging referral guidelines based on solid criteria is crucial for ensuring appropriate justification of radiological procedures. In fact, according to Article 58 of the [24], the justification of a radiological procedure should rely on specific referral guidelines for medical imaging provided to referrers.

Justification of CT studies is particularly important, as CT imaging accounts for about 7–11% of all radiologic examinations in Europe but is the cause of about 60–70% of the cumulative radiation exposure [28]. The large availability of CT scanners allowing fast examinations with good image quality has increased the use of CT in children in the last two decades, nowadays accounting for about 10% of all CT examinations [29, 30]. A multinational study launched by IAEA in 2010 examined the usage of CT in children across developing countries in Africa, Asia, and Eastern Europe. The study revealed that CT scans were performed in 20%, 16%, and 5% of children in Africa, Asia, and Eastern Europe respectively. According to this study, the very high percentages observed in Africa and Asia were likely to be attributed to the limited availability of alternative imaging modalities such as MRI and ultrasound, as well as potential challenges in appropriately justifying CT procedures for children [31].

In 2014, the European Commission published the results of a survey on *Referral Guidelines for Medical Imaging Availability and Use in the European Union* [32]. The results of the survey showed that, although referral guidelines for adults were available in the majority of European Union or European Economic Area countries, information about the presence and use of separate imaging guidelines for children was often unavailable in several countries [32]. More recently, a European-wide survey on *Referral Guidelines for Medical Imaging in Children: an ESR-EuroSafe Imaging on availability, awareness and use in clinical practice among European Radiologists* found that effective and widespread adoption of imaging referral guidelines, particularly for children, was lacking. Furthermore, even when available, their utilization was hindered by challenges such as limited accessibility, lack of trust among referrers, and inadequate

updates [33]. To address these issues, the European Society of Radiology (ESR) developed the ESR iGuide that includes guidance for paediatric imaging. This software-based clinical decision support system for imaging referral guidelines was designed to integrate seamlessly into electronic requesting systems, making it user-friendly for referring physicians [34, 35].

Despite these efforts, effective adoption of imaging referral guidelines, particularly in paediatric settings, remains suboptimal, and a widespread integration of CDS systems within the electronic requesting software is yet to be realized.

Optimization

Optimization is the second mainstay of radiation protection. Optimization in radiologic imaging refers to the meticulous adjustment of imaging techniques and protocols to minimize radiation exposure while maintaining diagnostic image quality, which is crucial especially in paediatric patients. Overall, optimization in imaging prioritizes patient safety by minimizing radiation exposure without compromising diagnostic accuracy, thereby supporting the principle of ALARA (As Low As Reasonably Achievable).

Optimization is regulated by Article 56 of the European Directive 2013/59 [24], which mandates that member states ensure all doses from medical exposure for radiodiagnostic, interventional radiology, planning, guiding, and verification purposes are kept as low as reasonably achievable while still obtaining the required medical information.

A number of strategies for each radiologic modality exist in order to optimize a procedure and to comply with the ALARA principle. In children, paediatric-specific protocols should be developed and utilized taking into account age, size, and clinical condition.

Optimization of computed tomography studies in children

When a CT study is justified, the imaging technique should be optimized. Several technical parameters and factors should be considered in the optimization of a CT examination in a child.

Scout length and scan length Scout length and scan length should be limited to the area of interest to reduce dose exposure.

Tube current Tube current is directly proportional to the number of X-ray photons emitted from the X-ray tube per unit time, and thus, to the radiation dose. Increasing tube current reduces image noise, but this relationship is roughly quadratic. In other words, to halve image noise, the tube

current should be quadrupled. In general, tube current can be decreased in paediatric CT protocols compared to adult protocols, as children have smaller body sizes. For CT studies of the chest, abdomen, and pelvis in children, tube current should be established based on the child's weight rather than age, as weight — and consequently, the density of the region being studied — can vary greatly among children of the same age.

Tube peak kilo-voltage (kVp) Increasing the peak kilo-voltage (kVp) raises the energy of the X-ray photons, making the X-ray beam more penetrating. This is beneficial for imaging thicker heavier patients or high-density body regions like the head. The relationship between kVp and dose is exponential; decreasing kVp by 20 will reduce the dose by about 35–40%. It is often feasible to lower kVp from the standard 120 kV to 100 or even 80 kV for chest and abdomen studies in non-obese children. Lowering kVp can also enhance contrast resolution with iodine contrast media, allowing for a reduction in the quantity injected. However, excessively low kVp may lead to beam-hardening and photon-starvation artefacts, compromising image quality.

Pitch Pitch represents the ratio of table feed per gantry rotation to the total collimated beam. A higher pitch means faster table movement relative to the X-ray beam width, enabling quicker scan times but potentially reducing image quality. Conversely, a lower pitch results in slower table movement, longer scan times, but potentially higher image quality. In general, a high pitch with fast gantry rotation time is preferred for paediatric studies to minimize scan duration, motion artefacts, and dose exposure. However, excessively high pitch and gantry rotation time can lead to image artefacts and loss of image resolution.

Automatic exposure control Automatic exposure control should always be utilized in both adults and children. Its purpose is to maintain consistent image quality throughout the scan by modulating the tube current based on variations in the thickness and density of the anatomical region being imaged. The effectiveness of automatic exposure control relies heavily on the accurate acquisition of the scout scan.

The relationship of the above CT scanning parameters with dose exposure and image quality is summarized in Table 1.

Patient positioning Patient positioning is critical, ensuring the patient is at the isocenter of the gantry for an even distribution of the X-ray beam. Incorrect positioning, especially in children, can result in distorted images. Additionally, improper compensation by the scanner's bowtie filters may lead to uneven penetration of X-ray beams, with more

Table 1 Computed tomography scanning parameters and their relationship with dose exposure and image quality

Parameter	Effect on dose	Effect on image quality
Tube current	Directly proportional: • doubling the current doubles the dose • halving the current halves the dose	Effect on image noise is quadratic: • Quadrupling the dose halves image noise, and vice versa
Tube peak kilo-voltage (kVp)	Exponential relationship between kVp and dose	Increasing kVp reduces: • Image noise • Beam hardening and photo-starvation artifacts • Contrast resolution in contrast enhanced studies and vice versa
Pitch	In modern CT scanners changes in pitch have no effect on dose exposure, as current tube is automatically modified to maintain the same dose	High pitch (>1) • Decreased resolution • Potential for image artifacts • Faster scanning Low pitch (<1) • Increased resolution • Better image quality • Longer scan time
Automatic exposure control (AEC)	Real time optimization of dose exposure based on the variable density along the body region being imaged	Consistent image quality of the body region being scanned

X-rays penetrating thinner peripheral portions of the body and less X-rays penetrating in the central, thicker portion of the patient [36].

Clinical indication-based computed tomography protocols Clinical indication-based CT protocols should be tailored not only to the body site to be imaged, but also to the clinical indication of the study. For example, low-dose CT techniques may be suitable for detecting high-contrast lesions like renal stones without compromising detection.

Number of phases Unlike adults, children typically require only a single-phase acquisition [37]. Multiple acquisitions should be reserved for specific indications, i.e., the characterization of liver lesions. However, in such cases, MRI studies with a hepatic-specific contrast medium should be preferred.

Image reconstruction From the introduction of the first CT scanners and for about three decades thereafter, filtered back-projection (FBP) was the standard algorithm for reconstructing CT images, providing fast image reconstruction with a high computational efficiency. However, the primary limitation of FBP lies in its restricted ability to handle noise in CT images, especially evident with low-dose protocols aimed at minimizing patient radiation exposure. In such scenarios, the reconstruction process fails to adequately suppress or control noise, leading to suboptimal image quality and diminished diagnostic confidence. To address this issue, iterative reconstruction (IR) algorithms for CT imaging were introduced in the early 2000s. Unlike FBP, which reconstructs images in a single

step, IR is a computational method which refines images from raw projection data through multiple iterative steps, adjusting the image at each iteration based on acquired projection data and a mathematical model of the imaging process of an ideal CT system's behavior. IR algorithms were designed to reduce dose exposure, thanks to their capability of reducing noise, enhancing artefact suppression, and improving image quality and contrast resolution, even in complex imaging scenarios. However, even the most advanced IR algorithms are based on simplified models that rely on a relatively limited number of parameters. As a consequence, some of these algorithms, although successful in reducing patient radiation dose, may produce images with a “plastic-looking” texture [38], which can affect image quality and potentially diagnostic interpretation.

Recently, significant advances in computational power have enabled the development of new image reconstruction methods based on artificial intelligence (AI) founded on deep and convolutional neural networks. The design of such systems involves creating layers of mathematical equations that enable the neural networks to handle a huge number of parameters. These networks are trained with an extensive ground truth training set based on real-world high-dose, high-quality images, which are used as reference to remove noise, preserve noise texture, and maintain anatomical details in images acquired with a lower dose. AI-based systems based on neural networks are already commercially available and may offer a dose reduction of up to 80% when compared to FBP [39]. This is particularly beneficial in paediatric imaging.

Optimization in fluoroscopy and interventional radiology

The good practice rules are not different from those applied in adults, when performing fluoroscopic studies and interventional procedures in children. Fluoroscopy time should be limited as much as possible, utilizing pulsed fluoroscopy (3–8 images per second are often sufficient). Still images, acquired using last-image hold, should be used to review findings instead of repeated exposure [25]. The fluoroscopy table should be positioned as far from the X-ray tube as possible to reduce entrance dose to the skin. Conversely, the image intensifier should be as close to the patient as possible to minimize the image penumbra. Collimation of the X-ray beam is fundamental to reduce the exposed area to the field of interest, keeping radiosensitive areas (breast, eyes, thyroid gland, and gonads) away from the X-ray beam, if feasible. Magnification should be kept to a minimum as it increases the dose. Runs should be avoided or reduced as much as possible. Patient dose should be recorded. In interventional radiology, the dose exposure can be very high in case of complex procedures and deterministic effects may be observed. Suggested trigger levels requiring monitoring for deterministic effects on the skin are a skin dose of at least 3 Gy, a dose-area product of 500 Gy cm², or an air kerma of 5 Gy at the patient entrance reference point [40].

Conventional radiology

In conventional radiology, optimizing imaging for children involves adhering to several golden rules. In general, it is advisable to limit the number of radiographic projections whenever possible. When performing radiographs of long bones in children, avoid imaging the opposite limb unless necessary, and refrain from routine comparison. For chest radiographs, a lateral projection is typically unnecessary in most cases. During follow-up examinations, restrict the number of projections to evaluate previous findings [41].

Anti-scatter grids should be avoided in children under 8 years, as the small improvement in image quality does not justify the increase in dose. Instead, utilize added copper filtration to enhance image quality while minimizing dose [42].

The use of the automatic exposure control is typically not recommended in children because the sensors are usually designed for adult patients. Instead, it is recommended to utilize adequate collimation and exposure charts that correspond to the radiographic technique and the size of the paediatric patient. Achieving a good image detail involves striking a balance between using a small focal spot size and a short exposure time [42].

Diagnostic reference levels

According to the EURATOM directive 2013/59 [24], diagnostic reference levels (DRLs) mean dose levels in medical diagnostic or interventional radiology practices for typical radiologic examinations or procedures for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. DRLs represent reference values and should be established for at least the most common radiologic examinations and procedure in each country, based on a national review of dose levels from a wide range of facilities for specific examinations.

DRLs serve as benchmarks rather than dose limits, enabling healthcare providers to compare their performance against established standards and identify opportunities for dose reduction without compromising diagnostic efficacy. They are regulated by Article 56 of the EURATOM directive 2013/59 [24], which requires member states to establish, regularly review, and use DRLs for diagnostic radiology examinations and, where appropriate, for interventional radiology procedures, and to ensure the availability of guidance for this purpose. The same Article also requires that appropriate local reviews are undertaken whenever diagnostic reference levels are consistently exceeded and that appropriate corrective actions are taken without undue delay.

When applying DRLs to paediatric imaging, unique challenges arise due to the considerable variation in size among children, ranging from neonates to teenagers. Unlike adults, the one-size-fits-all methodology does not apply. This diversity necessitates a more granular approach to DRLs, based on weight rather than applying a single standard for all. For example, the dose for a chest X-ray in a neonate significantly differs from that for an adolescent. Therefore, paediatric DRLs must accommodate this range by establishing more stratified reference levels that can accurately guide dose optimization for patients of varying sizes.

However, until recently, there was a lack of national DRLs for paediatric imaging, and existing DRLs greatly varied in methodology, making mutual comparison difficult. To address this, the European Commission launched a project in 2015 to establish European Guidelines on Diagnostic Reference Levels for Paediatric Imaging. Led by the European Society of Radiology in collaboration with the European Society of Paediatric Radiology and other European stakeholders involved in the radiation protection of children, the project aimed to establish European DRLs to be used by countries without their own national paediatric DRLs and to provide a consistent method for establishing new DRLs in the future. These European guidelines were endorsed by the European Commission and published in issue No. 185 of the Radiation Protection series [43]. The paediatric European DRLs for radiography, fluoroscopy, and computed

Table 2 European diagnostic reference levels for radiography and fluoroscopy (from: European Commission Radiation Protection N° 185 (2018) European Guidelines on Diagnostic Reference Levels for Paediatric Imaging [43])

Examination	Age or weight group	EDRL	
		$K_{a,e}$, mGy	P_{KA} , mGy cm ²
Head AP/PA	3 months–< 1 y		215
	1–< 6 y		295
	≥ 6 y		350
Head lateral	3 months–< 1 y		200
	1–< 6 y		250
Thorax AP/PA ^a	< 5 kg		15
	5–< 15 kg	0.06	22
	15–< 30 kg	0.08	50
	30–< 50 kg	0.11	70
	50–< 80 kg		87
Abdomen AP	< 5 kg		45
	5–< 15 kg		150
	15–< 30 kg	0.40	250
	30–< 50 kg	0.75	475
	50–< 80 kg		700
Pelvis AP	15–< 30 kg		180
	30–< 50 kg		310
MCU	< 5 kg		300
	5–< 15 kg		700
	15–< 30 kg		800
	30–< 50 kg		750 ^b

^aAP/PA: DRL applies to both AP and PA projections. ^bBased on four NDRLs, range 400–2,000 mGy cm². AP antero-posterior, DRL diagnostic reference level, EDRL European diagnostic reference level, MCU micturating cysto-uretrography, NDRL national diagnostic reference level, PA postero-anterior

tomography published in this publication are provided for reference in Tables 2 and 3 [43].

Communication and information

Patients and families should have access to discussions about the benefits and risks of healthcare interventions in a way that enables them to best understand and utilize the information. This dialogue is particularly crucial in paediatric imaging, where effective communication of radiation risks contributes to ensuring the greatest benefit with the lowest risk possible.

Regulated by Article 57 of the EURATOM directive 2013/59 [24], communication with patients and families mandates that, whenever feasible and prior to exposure, practitioners or referrers ensure patients or their representatives receive adequate information regarding the benefits and risks associated with the radiation dose from medical exposure.

Table 3 European diagnostic references levels for computed tomography (from: European Commission Radiation Protection N° 185 (2018) European Guidelines on Diagnostic Reference Levels for Paediatric Imaging [43])

Computed tomography			
Exam	Age or weight group	EDRL	
		CTDI _{vol} , mGy	DLP mGy cm
Head	0–< 3 months	24	300
	3 months–< 1 y	28	385
	1–< 6 y	40	505
	≥ 6 y	50	650
Thorax	< 5 kg	1.4	35
	5–< 15 kg	1.8	50
	15–< 30 kg	2.7	70
	30–< 50 kg	3.7	115
	50–< 80 kg	5.4	200
	< 5 kg		45
Abdomen	5–< 15 kg	3.5	120
	15–< 30 kg	5.4	150
	30–< 50 kg	7.3	210
	50–< 80 kg	13	480

EDRLs for head computed tomography (CT) refer to 16-cm phantom and EDRLs for thorax and abdomen for 32-cm phantom. EDRLs refer to a complete routine CT examination (one scan series). CTDI_{vol} volume computed tomography dose index, DLP dose length product, EDRL European diagnostic reference level

When discussing radiation risks with parents, it is essential to strike a delicate balance between providing information and avoiding unnecessary alarm [44].

Simplifying the content of communication while emphasizing its importance is key. Highlighting the medical necessity of the procedure and explaining how it contributes to diagnosis or treatment can help parents understand its value.

The risk of exposure should be demystified and made more relatable: for example, it could be explained that for every 2 days lived on earth, the natural background radiation exposes an individual to a dose equivalent of a chest X-ray, or that the dose from a head CT is equivalent to about 200 days of natural background radiation [45].

Tailoring the conversation to each child's specific situation, considering factors like age, type of exam, and previous exposures, ensures parents feel understood and reinforces the partnership between healthcare providers and families in the child's care.

Encouraging parents to ask questions and express concerns is vital for clarifying misunderstandings and building trust. Providing written materials and posters can also be helpful in conveying basic knowledge about the radiologic procedure to be performed. This comprehensive approach ensures parents are well-informed and empowered to participate in decision-making regarding their child's healthcare.

Shielding

Patient shielding

For decades, patient contact shielding has been utilized during X-ray studies to protect radiosensitive organs from unnecessary radiation exposure [46]. Initially, shielding was primarily employed to safeguard the gonads [47], but it later extended to protect other radiosensitive organs like the thyroid gland, breast, and eye lens [46].

However, advancements in radiologic technology as well as the development of more sophisticated imaging equipment have substantially reduced radiation doses in most procedures, lessening the need for additional protective measures such as contact shielding. Furthermore, an increasing body of evidence indicates that employing contact shielding, especially in paediatric radiology, may not confer the anticipated benefits and, in certain cases, could compromise the quality of care [47–50].

A major concern is the potential for contact shielding to compromise the diagnostic quality of radiologic images. In fact, misplaced shields can obscure important anatomical details or pathology, leading to the need for repeated examinations. Additionally, shielding may interfere with automatic exposure control systems, paradoxically increasing the child's radiation exposure.

Another consideration is the false sense of security provided by contact shielding. While it may reassure parents and patients, this physical barrier does not necessarily enhance safety. Relying solely on contact shielding may divert attention from more effective radiation protection measures, such as proper justification and optimization of imaging procedures.

On these premises, the representatives of the most important European scientific and professional societies have recently issued a consensus on patient contact shielding, recommending that this practice is not necessary anymore in most circumstances [51]. However, a recent survey among European radiology departments showed that about 50% of the participating centers still use shielding in at least one radiological modality in both adult and children [52]. According to this survey, the most important obstacles to the application of a no-shielding policy were expectations of patients and carers, and scepticism among professionals that shielding only provides limited benefits [52].

Transitioning away from patient shielding represents a notable cultural shift in radiology practice. Education campaigns targeting radiologists, radiographers, and other healthcare professionals involved in imaging are essential. Equally important is building trust between healthcare providers and patients: transparent communication about how

patient safety is ensured without physical shielding can help mitigate concerns and promote understanding among patients.

Staff shielding

In contrast to patients, shielding of operators is still of the utmost importance during fluoroscopic examinations and interventional procedures. Despite advances in equipment and techniques to reduce exposure, operators can still accumulate a considerable dose over time due to the cumulative effect of repeated exposures during numerous procedures.

During fluoroscopic procedures, the primary source of radiation exposure to the operators is scatter radiation from the patient's body [53]. Therefore, shielding is essential to protect the operators against this scattered radiation. Operator shielding includes the use of lead aprons, thyroid shield, ceiling suspended shields, and lead eyewear [54]. Besides shielding of the operators, reducing fluoroscopy time and number of images taken, correct patient positioning, and optimization of the operating parameters of the imaging system according to the ALARA principle are pivotal to reduce dose exposure to both patient and radiological staff [53].

Conclusions

In conclusion, safeguarding children from the potential risks linked to radiation exposure during radiologic imaging is paramount due to their heightened radiosensitivity. Thus, it is crucial to implement rigorous radiation protection measures tailored specifically to children. The principles of justification, optimization, and adherence to specific DRLs are essential to ensure that the benefits of radiologic procedures outweigh the risks, while minimizing radiation dose without compromising diagnostic accuracy and quality.

Moreover, technological advancements and the development of paediatric-specific protocols have significantly contributed to reducing radiation doses in children's imaging. Nevertheless, continuous education and training among healthcare professionals regarding radiation risks and protection measures are imperative. Collaboration across disciplines and active involvement of parents and guardians in decision-making processes are vital for creating an environment prioritizing children's safety.

Future research should focus on long-term outcomes of radiation exposure in children, alternative imaging modalities not reliant on ionizing radiation, and ongoing enhancement of radiologic techniques to further reduce exposure. Additionally, raising awareness of radiation risks and protection strategies among healthcare providers, parents, and the public is crucial to ensure that children receive safe and effective care.

Protecting children from unnecessary radiation exposure transcends mere technical hurdles; it embodies a moral obligation and legal requirement. By prioritizing the health and safety of our youngest patients, we honor our pledge to deliver healthcare that is thoughtful, secure, and in the best interests of those under our care.

Author contribution C.G. collated the references and drafted the initial manuscript. C.S., M.F., M.K., J.K.B., R.A.J.N., B.S.O., C.O., S.S., E.S., and I.A. supported the drafting and review of the manuscript. All authors approved the final version.

Declarations

Conflicts of interest None

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