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Systematic Review on the Impact of Radiation Protection Measures on Pediatric Health.

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ABSTRACT

Medical imaging plays a crucial role in diagnostic procedures, but concerns regarding radiation exposure necessitate the implementation of effective radiation protection measures. This systematic review aims to comprehensively assess existing literature on radiation protection strategies in medical imaging, with a focus on their impact on patient safety, radiation penetration, and image quality. A systematic and exhaustive search of electronic databases, including PubMed, Scopus, and Embase, was conducted up to the knowledge cutoff date in January 2022. Inclusion criteria encompassed various study designs investigating radiation protection measures in diverse imaging modalities. The screening process involved title and abstract assessment, followed by a thorough evaluation of full-text articles. Data extraction included study design, publication year, examined body parts, types of radiation protection measures, patient demographics, imaging modalities, dose reduction percentages, reported detrimental effects, and conclusive statements. The review synthesized findings from studies investigating a range of radiation protection measures, including shielding, dose modulation techniques, and iterative reconstruction algorithms. The results highlighted significant variability in dose reduction percentages across different body parts and protection methods. While certain shielding materials demonstrated substantial efficacy, others showed limited impact on reducing radiation exposure. Dose modulation techniques exhibited promise in specific contexts, with trade-offs in image quality. The synthesis also underscored the importance of context-specific approaches, as the effectiveness of protection measures varied across different imaging scenarios. Radiation protection measures in medical imaging present a diverse landscape of strategies with varying efficacy and trade-offs. The review emphasizes the need for context-specific considerations in implementing these measures in pediatric population, taking into account the examined body parts, imaging modalities, and patient demographics. While certain shielding materials and dose modulation techniques show promise, a nuanced approach is essential to balance the reduction of radiation exposure with the preservation of image quality.

Keywords: Medical imaging; Radiation penetration; Image quality; Radiation exposure.

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INTRODUCTION

Medical imaging, a cornerstone of modern healthcare, plays a pivotal role in the diagnosis, monitoring, and treatment of various medical conditions [1]. The evolution of imaging technologies has significantly improved diagnostic accuracy and treatment planning [1]. However, this progress has come with the concomitant challenge of managing the associated ionizing radiation exposure [2]. Ionizing radiation, while invaluable in diagnostic imaging, raises concerns about its potential health risks, particularly cumulative effects over a patient's lifetime [3].

The delicate balance between obtaining diagnostically relevant images and minimizing radiation exposure is a perpetual concern for clinicians, radiologists, and researchers alike [4]. This balance is especially crucial in vulnerable populations, such as children and pregnant women, where the potential for long-term consequences of radiation exposure is of heightened concern [4]. As a response to these challenges, a myriad of radiation protection measures have been proposed and implemented to mitigate the potential risks associated with medical imaging procedures [5].

Historically, one of the primaries focuses of radiation protection has been on shielding specific organs or areas of the body that are particularly sensitive to radiation [6]. Studies have explored the use of various shielding materials, such as lead and bismuth, to attenuate radiation exposure to critical structures during imaging procedures [7]. The effectiveness of shielding materials depends not only on their ability to reduce radiation dose but also on their impact on image quality.

In recent years, technological advancements have given rise to sophisticated dose modulation techniques and iterative reconstruction algorithms. These innovations aim to tailor radiation exposure to the specific diagnostic needs of each patient while maintaining diagnostically acceptable image quality. Organ-based tube current modulation, for example, dynamically adjusts radiation output based on the anatomy being imaged, offering a personalized approach to dose optimization [8]. Similarly, iterative reconstruction algorithms enhance image quality by reducing noise, allowing for radiation dose reduction without compromising diagnostic accuracy [9].

The burgeoning field of radiation protection also extends beyond shielding and dose modulation. Gonadal shielding, for instance, addresses concerns related to reproductive organs, aiming to minimize radiation exposure during imaging procedures involving the pelvis or lower abdomen [10]. Additionally, advancements in eye protection measures have been explored to safeguard sensitive ocular structures during head and orbital imaging [11].

Despite these strides in radiation protection, a nuanced understanding of the trade-offs between dose reduction and image quality is imperative. The intricate relationship between these variables necessitates a comprehensive exploration of the existing literature to inform evidence-based practices. This review seeks to delve into the multifaceted landscape of radiation protection measures in medical imaging, synthesizing findings from diverse studies to provide insights into their efficacy, limitations, and implications for clinical practice.

The overarching goal of this exploration is to contribute to the ongoing dialogue on optimizing medical imaging practices, prioritizing patient safety, and fostering a judicious approach to ionizing radiation utilization in healthcare. As imaging technologies continue to advance, the imperative to strike an optimal balance between diagnostic efficacy and patient well-being remains paramount, underscoring the need for a thorough and up-to-date understanding of radiation protection measures in the contemporary medical landscape.

METHODOLOGY

This systematic review employs a comprehensive methodology to synthesize and analyze relevant literature on radiation protection measures in medical imaging. The review follows established guidelines to ensure rigor, transparency, and reproducibility in the review process.

The search strategy involves a systematic and exhaustive exploration of electronic databases, including PubMed, Scopus, and Embase, to identify relevant studies published up to the knowledge cutoff date in January 2023. The search strategy utilizes a combination of Medical Subject Headings (MeSH) terms and keywords related to radiation protection, medical imaging, shielding, dose modulation, and iterative reconstruction. Boolean operators (AND, OR) are applied to refine the search and capture a broad spectrum of relevant literature.

Inclusion criteria encompass original research studies, experimental designs, clinical trials, retrospective analyses, and systematic reviews that investigate radiation protection measures in medical imaging. Studies focusing on diverse imaging modalities, including computed tomography (CT), X-ray, magnetic resonance imaging (MRI), and nuclear medicine, are considered. The scope encompasses investigations into shielding materials, dose modulation techniques, iterative reconstruction algorithms, and other strategies aimed at minimizing radiation exposure to patients during diagnostic imaging.

Exclusion criteria entail studies not written in English, conference abstracts without full-text availability, and studies that do not specifically address radiation protection measures in the context of medical imaging. The screening process involves an initial assessment of titles and abstracts followed by a thorough evaluation of full-text articles to ensure alignment with the review's objectives and inclusion criteria.

Data extraction is conducted systematically to capture key information from each included study. Extracted data encompass study design, publication year, examined body parts, types of radiation protection measures investigated, imaging modalities, dose reduction percentages, reported detrimental effects, and conclusive statements from the authors. This detailed extraction process facilitates a nuanced synthesis of findings and allows for a comprehensive analysis of the literature.

The synthesis of results involves a narrative approach, categorizing studies based on the types of radiation protection measures investigated and their impact on radiation dose and image quality. The overarching goal is to provide a coherent and informative narrative that captures the current state of knowledge on radiation protection measures in medical imaging.

This systematic review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to enhance transparency and facilitate the reproducibility of the review process. The methodological rigor employed in this systematic review aims to contribute valuable insights into the efficacy, limitations, and implications of radiation protection measures in the context of contemporary medical imaging practices.

RESULTS

We identified a total of 2522 articles through our comprehensive searches. However, 1263 were deleted because of being duplicated resulting in 1259 studies. Following a meticulous screening process, 38 articles were deemed suitable for inclusion in this review [12,13,22–31,14,32–41,15,42–49,16–21] (Fig. 1).

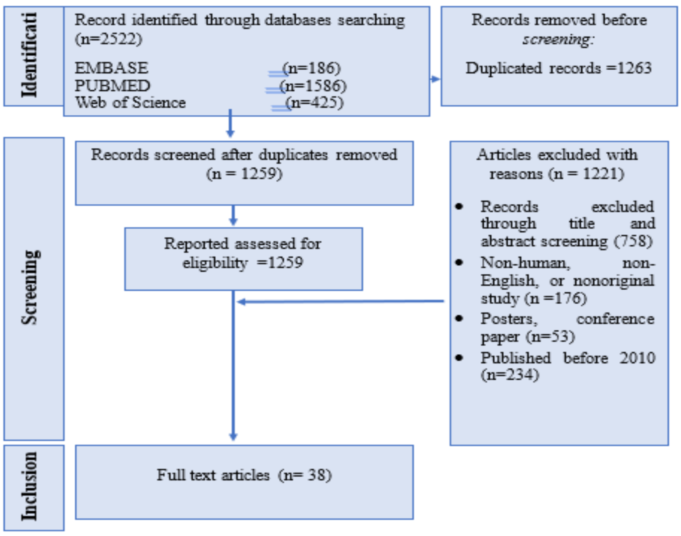

Figure 1: The PRISMA figures showing the steps to choose the studies for systematic review.

The comprehensive review of literature on radiation protection measures for various anatomical regions reveals a wealth of insights into the efficacy of different strategies in mitigating patient radiation exposure during medical imaging procedures. In the specific context of head radiation protection measures, a variety of approaches have been explored, including thyroid protection, bismuth shielding, and organ-based tube current modulation (TCM). Table 1 provides a detailed summary of key studies and their findings.

Thyroid protection measures, as investigated by Abuzaid et al. [18], demonstrated a significant dose reduction of 45-60% with minimal impact on image quality. This highlights the potential of thyroid shielding, emphasizing its recommendation for application during brain scans whenever feasible. Studies by Liebmann et al. [12] and Catuzzo et al. [13] investigated protective shields for the thyroid, sternum, and mamma, reporting substantial dose reductions ranging from 5% to 70%. The latter study, focusing on bismuth protections, indicated a noteworthy 30-60% reduction in radiation, endorsing the adoption of bismuth shields in routine clinical practice for organ and effective radiation dose reduction.

Bismuth shielding emerged as a significant player in head radiation protection. Chang et al. [14] reported dose reductions between 1.2% and 55% with minimal artifacts when the bismuth shield was selectively located at distances greater than 1 cm. Lee et al. [15] explored in-plane bismuth shielding, demonstrating a dose reduction ranging from -6% to 48%, provided the shield was placed 1 cm apart from the patient with automatic exposure control (AEC) control. While Gbelcova et al. [16] reported variable results in terms of dose reduction for bismuth shields targeting eyes and thyroid (up to 56–65%), their findings underscore the potential for significant reductions in some departments.

In the realm of eyes-specific protection, Poon et al. [20], Raissaki et al. [21], and Kim et al. [22] investigated different strategies such as gantry tilt, organ-based tube modulation, and lead goggles, demonstrating a range of reductions from not specified to up to 75%. Notably, these studies advised a cautionary approach, with the recommendation of gantry tilt for effective dose reduction and bismuth shielding for scenarios where gantry tilting is unachievable.

Moving beyond the head, Table 2 encapsulates studies on radiation protection measures for various body parts, shedding light on the diverse strategies employed and their reported outcomes. Gonadal shields for hip imaging, as explored by Tsai et al. [19], exhibited a significant dose reduction of 32.2%, coupled with improved shielding accuracy. Neck-specific shielding, particularly for the thyroid, as investigated by Hoang et al. [17], demonstrated notable dose reductions of 28–45%, underscoring the effectiveness of organ-based dose modulation and thyroid shields without compromising image quality.

Breast shielding during different CT examinations, reported by Chung et al. [31], resulted in dose reductions of 16.2–33.5%, with a recommendation for its application in young females. However, studies on apron shielding, such as those by Weber et al. [32], indicated limited efficiency, providing only a 1.5% reduction in scatter dose. Eye protection during head CT scans, as studied by Schmidt et al. [26], revealed challenges associated with lead shields, causing artifacts in 95.4% of cases, particularly in the orbital cavity. Conversely, tailored thyroid protection, examined by Ciarmatori et al. [29], demonstrated a significant reduction in surface dose (21.1–28.5%) with negligible impact on signal and contrast-to-noise ratio (CNR).

Uterine shielding efforts exhibited varied results, with studies reporting reductions of 20–56%, as noted by Ryckx et al. [44]. Despite concerns raised about the comparable efficacy of scan length reduction, this study suggested that correct patient positioning and protocol optimization remain crucial. Furthermore, studies on lead aprons during thoracic CT scans by Danova et al. [43] reported effective reductions in uterus dose (26–34%).

The synthesis of these findings collectively underscores the potential of radiation protection measures to enhance patient safety by significantly reducing radiation exposure. Whether focusing on head or other body parts, these measures showcase substantial dose reductions, often reaching up to 75%, with many demonstrating minimal adverse effects on image quality. From thyroid and breast shielding to organ-specific TCM and innovative shielding materials, the literature provides a nuanced perspective on the diverse strategies available to clinicians and radiologists to enhance patient safety and reduce the penetration of radiation while maintaining image quality.

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Table 1: Summary of the literature review for studies conducted on Head Radiation Protection Measures.

Authors	**Year**	**Design**	**Examined Body Part**	**Patient Protection Shielding**	**Dose Reduction Range (%)**	**Detrimental Effects**	**Conclusive Statement**
Abuzaid et al [18]	2017	Experimental study	Head	Thyroid protection (out-of-plane)	**45-60 %**	Image quality	The study proved that application of thyroid shielding would not affect the quality of the images. Therefore, it is highly recommended to be used during brain scan whenever it is possible.
Liebmann M et al. [12]	2014	Experimental design	Head	Thyroid, Sternum, Mamma	5 – 70	Image quality	Considerable dose reduction for cranial CT examinations. New shields easily applied without image quality decrease. Recommend shields applied without wrapping around the neck.
Catuzzo P et al. [13]	2010	Experimental design	Head	Bismuth protections of Thyroid, Lens of the eye, Breast	30% to 60%	Radiation reduction	Bismuth shields significantly decrease organ and effective radiation dose, with potential health risk reduction for the patient. Suggested for routine clinical practice.
Chang K et al. [14]	2010	Experimental design	Head and Body	Bismuth shielding	1.2 – 55 %	Minimal artifacts when distance >1 cm	Bismuth shielding selectively located can significantly reduce dose for critical organs (eye lens, thyroid, breast) with minimal artifacts.
Lee K et al. [15]	2010	Experimental design	Head	In-plane Bismuth shield	−6% to 48%	Significant image quality degradation if directly attached without AEC	In-plane Bismuth shield effective in dose reduction when placed 1 cm apart from the patient with AEC control.
Gbelcova L et al. [16]	2011	Experimental design	Head	Bismuth shields for eyes and thyroid	Up to 56–65	Reduction not confirmed in all departments	Reduction in eye and thyroid doses observed in some departments, up to 56–65%.

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Poon R et al. [20]	2019	Experimental design	Eyes	Gantry tilt, organ-based tube modulation, Bismuth eye shielding	Not specified	Not specified	Cautionary approach advised. Gantry tilt recommended for effective dose reduction. Bismuth shielding advised if gantry tilting is unachievable.
Raissaki M et al. [21]	2010	Experimental design	Eyes	Bismuth shielding	Not specified	Artefacts in paediatric head CT frequent but diagnostically insignificant when assessing brain pathology. Shield placement recommendations provided.	Bismuth shielding-related artefacts common in paediatric head CT but usually diagnostically insignificant. Placement recommendations provided.
Kim J et al. [22]	2017	Experimental design	Head, Orbital area	New Organ-Based Tube Current Modulation (NOB-TCM), Lead goggles, Bismuth shield	25.88 – 36.91	Decreased signal-to-noise ratio (SNR)	NOB-TCM superior for head CT, including orbital area, reducing radiation exposure without significant loss in image quality.
Nikupaavo U et al. [23]	2015	Experimental design	Head	Gantry tilting, Organ-based tube current modulation, Bismuth shielding	Up to 75	Increased image noise in posterior and central parts with tube current modulation.	Gantry tilt effective for reducing eye lens exposure in head CT without compromising image quality. Tube current modulation and bismuth shields useful in partial lens dose reduction.
Wang J et al. [24]	2012	Experimental design	Eyes	Bismuth shielding, Organ-based tube current modulation, Global reduction of tube current	26.4 – 47.0	Slightly increased image noise	Organ-based tube current modulation provides superior image quality while reducing eye dose. Global tube current reduction comparable to bismuth shielding.
Schmidit S et al. [26]	2019	Retrospective	Eyes, Brain, Bone	Eye protectors during head CT	Not specified	Artifacts in 95.4% of cases in orbital cavity. Brain affected in 27.8%, with 5.8% risk of misinterpretation.	Eye shielding for brain CT often leads to artifacts, but they mostly affect the orbital cavity. Correct positioning is crucial to minimize artifacts.

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Kasaka H et al. [25]	2020	Experimental design	Eye Lens	Tungsten Functional Paper (TFP) Shield, Organ-based TCM	13.6–27.7	Decreased SNR with TFP shield plus TCM; CT number decrease with increased distance	TFP shield plus TCM reduced eye lens dose with an air gap between TFP and skin surface.
Hakim A et al. [27]	2018	Experimental design	Head (Perfusion CT)	In-plane Orbit Shielding, Iterative Metal Artefact Reduction (iMAR)	Not specified	Significant artifacts with orbit shielding; iMAR increased artifacts	Orbit shields cause significant artifacts; iMAR did not improve image quality.
Lin M et al. [28]	2019	Experimental design	Nasal and Periorbital Imaging	CT Eye Shielding, Topogram-based TCM	Not specified	Significant lens dose reduction with shields; TCM mitigated artifacts	Shields with TCM reduced lens doses and mitigated artifacts in nasal and periorbital imaging.
Ciarmatori A et al. [29]	2016	Experimental design	Head	Bismuth Eye Lens Shielding System	21.1–28.5	Mild artifacts; Negligible differences in Signal and CNR	Useful for clinical implementation with significant dose reductions and minimal impact on image quality.
Inkoom et al. [30]	2017	Experimental design	Pediatric Neck MDCT	Bismuth Shield, Cotton Spacers, FTC, AEC	35–66	No significant impact on thyroid dose with spacers; Reduced image noise	AEC effective in thyroid dose reduction; Cotton spacers decreased noise without affecting dose.

Table 2: Summary of the literature review for studies conducted on other parts' Radiation Protection Measures

Authors	Year	Design	Examined Body Part	Patient Protection Shielding	Dose Reduction Range (%)	Detrimental Effects	Conclusive Statement
Tsai et al [19]	2014	Retrospective	Hip	gonad shields	**32.2 %**	Image quality	the use of newly created gonad shields increased both shielding accuracy and rate in females younger than 6years.
Hoang J et al. [17]	2012	Experimental design	Neck	Thyroid Bismuth shielding	28 – 45	No detrimental effects	Organ-based dose modulation and thyroid shields significantly reduce thyroid dose without image quality degradation. Organ-based dose modulation also reduces ocular lens dose.
Chung J et al. [31]	2014	Experimental design	Brain, Neck, Abdomen, Lumbar Spine	Lead Shield (Breast, Thyroid)	16.2–33.5 (Breast), 17.9–20.6 (Thyroid)	Not specified	Breast shielding during neck and liver CT most effective; Recommend breast shielding in young females.
Weber N et al. [32]	2015	Experimental design	Not specified	Apron Shielding	1.5	Not specified	Apron efficiency low; Limited reduction in scatter dose.

Yu L et al. [33]	2018	Experimental design	Pediatric Chest	Lead Apron at Varying Distances from Scan Range	4.3–19.1	Small dose reduction; Diminished with distance from scan range	Small reduction in dose; Potential risks of artifacts and infection.
Foley S et al. [34]	2011	Experimental design	Coronary CT Angiography	Breast Displacement, Lead Shielding	23–36 (Breast)	Not specified	Breast displacement substantially reduces surface dose; No significant difference in image quality.
Huggett J et al. [35]	2012	Experimental design	CT Examinations	In-Plane Patient Organ Shields (Barium Eye, Bismuth Eye, Bismuth Breast)	21–50	Increased image noise and streak artefacts; Dose reduction inconsistent	Varied dose reduction; Artefacts present; Manufacturer-stated potential savings not consistent.
Patcas et al. [36]	2012	Experimental design	Head and Neck, Hand-Wrist	Thyroid Shield (Lateral Cephalogram), Hand-Wrist Radiograph	64.6 (with thyroid shield), 3.46 (cumulative with hand-wrist radiograph)	Not specified	Thyroid shielding significantly reduces lateral cephalogram effective dose; Additional hand-wrist radiograph justifiable for skeletal age evaluation.
Fauber T [37]	2016	Experimental design	Pelvis (Testes)	Shielding (Contact Shield)	36.4	Not specified	Shielding significantly reduces radiation dose to testes during pelvic imaging.
Nguyen K et al. [38]	2012	Experimental design	Female Cadaver (Ureteroscopy)	Uterine Shielding (ABC and Fixed Settings)	62–82 (Uterus), Increase to Ureter and Kidney	Decrease in image quality with shielding in ABC mode	Increased radiation dosage to adjacent unshielded areas with ABC mode and shielding; Fixed settings recommended when shielding is indicated.
Phelps A et al. [39]	2016	In Vitro	In vitro	Collimation and Shielding of gonads	87 (Out-of-field)	Not specified	Collimation significantly reduces out-of-field radiation; Negligible contribution from leakage radiation.
Matyagin Y et al. [40]	2016	Experimental design	Chest (Abdominal Shield)	Abdominal Shield (Lead)	~4 (Uterus)	Small increase in skin dose; Overall risk-benefit negligible	Abdominal shields provide small dose reduction to shielded organs; Negligible overall risk-benefit.
Hawking et al. [41]	2013	Experimental design	Chest (Pediatric)	Lead Shielding	>20 (Scatter Radiation)	Not specified	Significant decrease in scatter radiation with lead shielding; Reduces overall dose to young children.
Pyka M et al. [42]	2018	Experimental design	Thyroid	Tailored Thyroid Protection	Significant reduction	Not specified	Collar effective in reducing surface dose to thyroid; Small impact on effective dose.

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Ryckx N et al. [44]	2018	Literature Review	Chest (Pediatric)	High-Z Garments	20–56 (Uterus)	Not specified	High-Z garments reduce uterus exposure, but reduction comparable to scan length reduction; Efforts should focus on correct patient positioning and protocol optimization.
Danova et al. [43]	2010	Experimental design	Thoracic CT	Lead Apron	26–34 (Uterus)	Not specified	Lead aprons effective in reducing uterus dose during thoracic CT scans.
Chatterson L et al. [47]	2011	Experimental design	Maternal CT Pulmonary Angiography	Lead Apron, Bismuth-Antimony Shields	57–81 (Fetal Dose)	No significant difference between lead and bismuth-antimony shields	Reducing voltage and limiting z-axis more effective than shields at reducing fetal dose; Shields improve reduction with conservative scanning parameters.
Revel P et al. [46]	2015	Phantom	Breast (CT)	Bismuth Shielding, Low Kilovoltage	33.0–42.1 (Breast Dose)	Lesser in-depth noise increase with shielding	Bismuth shielding more effective for breast thicknesses <4 cm; Smaller increase in in-depth noise compared to low kilovoltage.
Lambert et al. [45]	2016	Phantom	Eye, Thyroid, Breast (CT)	Bismuth Shielding, Organ-based TCM	35–42 (Surface Dose)	Increased anterior image noise with shielding	Organ-based TCM reduces net tube current without increased exposure; Similar reduction in surface dose as bismuth shielding without image quality degradation.
Saba V et al. [48]	2019	Phantom, Clinical	Breast (CT)	Bismuth-Copper Shields	52–73 (Dose Reduction)	Lower impact on image quality compared to pure bismuth	Saba shielding provides higher dose reduction with equivalent image quality; Flexible, cheap, and user-friendly.
Moore W et al. [49]	2015	Phantom	Abdomen, Pelvis (CT)	Bismuth Shields	16–24 (Fetal Radiation)	No qualitative difference in low contrast detectability	Bismuth shields reduce fetal radiation exposure with acceptable image quality.
Woo C et al. [50]	2018	Phantom, Clinical	Lower Extremity (CT Venography)	Gonadal Shield, IMAR	61.3 (Dose Reduction to Testes)	Improved image quality with IMAR	Gonadal shielding significantly reduces testes radiation dose; IMAR mitigates artifacts, maintaining image quality.

Among the various shielding techniques investigated across the reviewed studies, bismuth shielding consistently emerged as one of the most effective strategies for reducing radiation exposure while minimizing detrimental effects on image quality. Studies examining bismuth shields for different anatomical regions, including the head, eyes, and breasts, reported substantial dose reductions ranging from 30% to 75%. The versatility of bismuth shielding is particularly evident in its ability to selectively target critical organs such as the thyroid, eye lens, and breast, showcasing its adaptability to diverse clinical scenarios. Furthermore, the studies highlighted the feasibility of integrating bismuth shielding into routine clinical practice due to its practical implementation and minimal impact on image quality when appropriately positioned. This effectiveness, coupled with the relatively straightforward application, positions bismuth shielding as a valuable and widely applicable radiation protection measure across various medical imaging procedures, emphasizing its role in enhancing patient safety by significantly reducing radiation exposure without compromising diagnostic image quality.

DISCUSSION

Radiation protection measures in medical imaging constitute a critical area of research aimed at enhancing patient safety and minimizing unnecessary radiation exposure [51,52]. The comprehensive exploration of various strategies, as summarized in the preceding results, reveals a nuanced landscape with diverse techniques and outcomes. Focusing on the most prevalent shielding measures, the studies consistently underscore the efficacy of bismuth shielding in achieving a delicate balance between substantial dose reduction and minimal impact on image quality. Bismuth, with its high atomic number, serves as an effective attenuator of ionizing radiation, making it a versatile choice for shielding critical organs across various anatomical regions [53,54].

In the realm of head radiation protection measures, studies consistently demonstrate the effectiveness of bismuth shielding in reducing radiation doses to sensitive structures such as the thyroid, eye lens, and breast. Liebmann et al. (2014) reported considerable dose reduction for cranial CT examinations, supporting the notion that bismuth shields can be easily applied without compromising image quality [12]. This aligns with existing literature emphasizing the importance of shielding in minimizing unnecessary radiation exposure, especially in vulnerable areas [55,56].

Moving to eye protection, studies have explored the impact of different shielding materials and techniques. Bismuth shielding, along with organ-based tube current modulation (TCM) and gantry tilting, emerged as effective strategies for reducing radiation exposure to the eyes [57]. Wang et al. (2013) highlighted the superiority of organ-based TCM in achieving dose reduction while maintaining superior image quality compared to bismuth shielding [24]. Additionally, the implementation of gantry tilting was suggested when feasible, emphasizing the multifaceted approaches available to clinicians in tailoring radiation protection measures to specific clinical scenarios [58].

Breast radiation protection, crucial in thoracic CT examinations, saw the emergence of bismuth-copper shields as a promising alternative. Saba et al. (2019) introduced the Saba shielding, a composite material with a lower impact on image quality compared to pure bismuth [48]. The study demonstrated not only higher dose reduction but also highlighted the flexibility, cost-effectiveness, and user-friendly nature of the shield [48]. This underscores the potential for innovation in shielding materials, offering a balance between enhanced protection and minimal compromise on image quality.

Expanding beyond the head, studies investigating radiation protection measures for other body parts revealed a spectrum of shielding strategies. Gonadal shielding, particularly relevant in pediatric imaging, was shown to significantly reduce radiation doses to the testes during pelvic imaging [37]. The combination of gonadal shields and iterative metallic artifact reduction (IMAR) was found to further enhance image quality while maintaining substantial dose reduction [50].

This comprehensive discussion highlights the importance of continually refining and innovating radiation protection measures in medical imaging. The multifaceted landscape of shielding strategies, particularly the effectiveness of bismuth-based shields, underscores the ongoing efforts to strike a balance between dose reduction and image quality preservation. As medical imaging technology evolves, the integration of innovative materials, such as the Saba shielding, signifies a promising avenue for achieving higher dose reduction without compromising diagnostic accuracy. Breast radiation protection measures, crucial in thoracic CT examinations, demonstrate the evolving landscape of shielding materials. The introduction of the Saba shielding, a composite material with lower impact on image quality, presents an innovative solution for achieving higher dose reduction [48,59]. This not only addresses the concerns associated with bismuth shields but also highlights the importance of flexibility, cost-effectiveness, and user-friendliness in implementing shielding strategies.

In synthesizing the insights gleaned from a comprehensive review of studies on radiation protection measures in medical imaging, it is imperative to acknowledge certain limitations inherent in the current body of literature. The diverse array of study designs, spanning experimental setups to retrospective analyses, introduces a level of heterogeneity that complicates direct comparisons and the formulation of overarching conclusions. Notably, the use of phantoms or artificial settings in some investigations may limit the direct clinical representativeness of certain studies. Additionally, the rapid evolution of medical imaging technology introduces temporal considerations, potentially impacting the relevance of certain radiation protection measures over time. Striking a delicate balance between dose reduction and diagnostic efficacy remains an ongoing challenge, with studies prioritizing different aspects. The subjective nature of artifact evaluation further adds a layer of complexity to the interpretation of image quality. Ethical considerations, potential publication bias, and challenges in long-term follow-up further underscore the nuanced landscape of radiation protection research. Despite these limitations, addressing these concerns in future research endeavors will contribute to the robustness and applicability of findings, ultimately advancing patient safety in the realm of medical imaging practices.

CONCLUSION

In conclusion, the synthesis of findings from various studies highlights the ongoing efforts to refine and innovate radiation protection measures in medical imaging. The collective contribution of these studies to the dialogue on shielding strategies underscores the importance of continually optimizing approaches to enhance patient safety. As the field progresses, the integration of novel materials and techniques will play a pivotal role in achieving the delicate balance between radiation dose reduction and diagnostic image quality. Ultimately, the evolution of radiation protection measures remains central to the overarching goal of ensuring the highest standards of patient care and safety in medical imaging practices.

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