OPTIMIZING RADIATION EXPOSURE IN PEDIATRIC CT EXAMS

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Abstract: The use of computed tomography (CT) scans in pediatric patients has raised concerns regarding radiation exposure and associated long-term health risks. This study explores the strategies and methodologies employed for optimizing radiation doses in pediatric CT examinations while ensuring diagnostic accuracy.**Methods:** Through a comprehensive literature review, various optimization techniques and protocols were analyzed. This involved investigating the use of lower tube voltage, iterative reconstruction algorithms, shielding, and specialized pediatric protocols. Additionally, the impact of dose-tracking systems and education on radiographers and clinicians was examined to ensure adherence to best practices.
Results: The analysis revealed that employing lower tube voltage significantly reduces radiation exposure without compromising image quality, especially in children. Iterative reconstruction algorithms demonstrated promising results in maintaining image quality while reducing doses. Tailored pediatric protocols and dose-tracking systems further contributed to minimizing radiation exposure.
Discussion: Balancing diagnostic accuracy with radiation safety is paramount in pediatric CT imaging. While advancements in technology offer promising solutions, interdisciplinary collaboration, continuous education, and strict adherence to optimized protocols are imperative to mitigate radiation risks in children undergoing CT examinations.
Conclusion: Optimizing radiation exposure in pediatric CT exams involves a multifaceted approach, integrating technological advancements, protocol enhancements, and continuous education. Implementing these strategies ensures diagnostic efficacy while prioritizing the safety of pediatric patients.
Keywords: computed tomography, radiation exposure, optimization, tube voltage.

1. INTRODUCTION

In the realm of pediatric healthcare, computed tomography (CT) imaging stands as an invaluable tool, enabling precise diagnoses and guiding critical medical interventions. However, this indispensable technology comes with a conundrum: the looming concern over ionizing radiation exposure, especially concerning its potential impact on the vulnerable population of children ***(Bernier et al., 2018).***

The efficacy of CT scans in delineating intricate anatomical structures and identifying pathologies has revolutionized pediatric medicine. Yet, this innovation isn't without consequences. The cumulative effects of ionizing radiation, particularly in developing bodies, have raised persistent apprehensions regarding long-term health risks, including a potential increase in cancer incidence ***(Afzal et al., 2023; Kamdem at al., 2021).***

In ***2001***, ***Brenner et al***. conducted the initial assessment of the potential cancer risk over a lifetime due to ionizing radiation exposure from pediatric CT scans. They predicted that, based on the radiological practices of that time in the United States, about 500 children undergoing CT each year might eventually succumb to cancer attributable to ionizing radiation. More recently, ***Berrington de González et al***., and ***Miglioretti et al***., estimated that pediatric CT scans performed within a year in the United States could lead to 4350–4870 future cases of radiation-induced cancers. These projections are drawn from data derived from the Life Span Study of survivors of the atomic bombs in Japan. However, there's been debate over applying the increased risks observed in the Life Span Study directly to CT radiation due to differences in radiation sources, exposed populations, and assumptions regarding a linear non-threshold relationship at low doses (<100 mGy). Certain scientists argue that exposure to low-dose radiation may not elevate cancer risk and might even confer health benefits (like the hormetic effect)***(Tubiana et al., 2009).*** Given the uncertainties around hypothetical risk estimations, it's essential to analyze observational epidemiological data concerning patients exposed to CT scans for a more accurate assessment of risk.

The evolving landscape of pediatric CT imaging strives to navigate this delicate balance between diagnostic necessity and radiation safety. Over recent years, pioneering research and technological advancements have sought to mitigate radiation exposure without compromising diagnostic accuracy. Strategies encompassing dose modulation, advanced reconstruction algorithms, tailored imaging protocols, and meticulous dose-tracking systems have emerged as pivotal players in this quest for optimization ***(Khan et al., 2022).*** The growing awareness of potential harms has prompted efforts to justify and fine-tune CT scans, following the principle of minimizing radiation exposure to "as low as reasonably achievable" (ALARA).

Once the clinical necessity and rationale are established, adjusting imaging parameters becomes crucial to attain necessary clinical insights while minimizing radiation exposure. It's imperative to steer clear of adopting adult scanning protocols for children as this significantly escalates the effective dose without enhancing diagnostic benefits. Opting for single-phase scans whenever they suffice for diagnosis can remarkably slash radiation exposure; for instance, avoiding multiphase scanning like non- enhanced CT. Limiting the scanning area to the specific concern helps eradicate unnecessary radiation. A spectrum of techniques—automated exposure control, reduction of tube current and voltage, high-pitch acquisition, and employment of IR algorithms—stands poised to cut down radiation doses or enhance image quality in low-dose pediatric CT scans.

This article embarks on an exploration of these multifaceted approaches, delving into the nuanced strategies employed to minimize radiation exposure while preserving the diagnostic integrity of pediatric CT imaging. By elucidating the latest advancements and their implications, this discourse aims to illuminate the path toward safer and more efficient clinical practices, ensuring that the invaluable diagnostic benefits of CT imaging are harnessed while prioritizing the well-being of our youngest patients.

2. METHODS

A comprehensive review of literature on pediatric CT imaging optimization strategies revealed significant advancements. Lower tube voltage utilization has emerged as a promising approach, showcasing substantial dose reductions without compromising image quality ***(Mahrooqi et al., 2015).*** The amount of radiation emitted corresponds exponentially to the square of tube voltage, while it maintains a linear correlation with tube current. This implies that a slight decrease in tube voltage results in a significantly greater reduction in dose compared to altering tube current. For instance, theoretically lowering tube voltage from 120 kVp to 100 kVp or 80 kVp can yield dose reductions of 33% and 65%, respectively, provided all other parameters remain constant. Even if adjustments are made to tube current and exposure time to compensate for reduced photon flux, employing low tube voltage scans typically reduces radiation exposure in most pediatric CT exams while upholding diagnostic image quality.

Iterative reconstruction algorithms, including Adaptive Statistical Iterative Reconstruction (ASIR) and Sinogram Affirmed Iterative Reconstruction (SAFIRE), have shown remarkable potential in reducing noise and preserving image quality at lower doses ***(Noid et al., 2017; Maxfield et al., 2012; Nie et al., 2014).*** Different methods of reconstructing images have a significant impact on both image quality and radiation dose. Filtered back projection (FBP), the long-standing CT image reconstruction method, is quick and simple but struggles with complexities like scatter, leading to increased image noise in low-dose CT scans. In contrast, iterative reconstruction (IR) algorithms require fewer projection views than FBP while maintaining acceptable image quality. IR enhances image quality through an iterative cycle:

- An initial image approximation is created from measured projection data.
- New projection data is simulated from the initial approximation using forward projection, incorporating statistical noise and system models.
- Comparison between the new and original projection data prompts updates to the initial image approximation based on the algorithm's characteristics. This cycle repeats until minimal differences or predefined image quality is achieved.

Mathematically demanding, IR wasn't practical for clinical use until recently. However, advancements in computing power have made IR a feasible choice in most modern clinical CT scanners.

Specialized pediatric protocols incorporating organ-based tube current modulation have demonstrated dose reductions of up to 40% ***(Papadakis et al., 2020).***

Furthermore, the implementation of dose-tracking systems has enabled continuous monitoring and optimization, resulting in notable dose reductions across various pediatric CT examinations ***(Franck et al., 2018).***

3. RESULTS

We conducted a retrospective study (January to December 2023) that reviewed 100 head trauma cases with dose reduced CT's and compared them with another 50 head trauma cases of non- optimized CT's from January to July, 2022. This investigation focused on pediatric patients aged 0 to 14 years. Age categories included infants (<1 year), toddlers (1–4 years), middle childhood (5–9 years), and early adolescence (10–14 years).

Compared to 2022, the radiation dose results in 2023 showed a decline. Specifically, $CTDI_{Vol\%}$ decreased by 27.15% for children under 1 year, 38.35% for children aged 1–4 years, and 19% for children aged 5–9 years. Additionally, DLP decreased by 26.27%, 38.13%, and 19.75% for children under 1 year, 1–4 years, and 5–9 years, respectively, for skull (trauma) examinations.

The application of lower tube voltage in pediatric CT scans yielded significant reductions in effective doses, ranging from 30% to 50%, while maintaining diagnostic image quality ***(Nagayama et al., 2018***), ***(Table 1).***

Table 1. Variable Scan Settings and Their Influence on Radiation Exposure

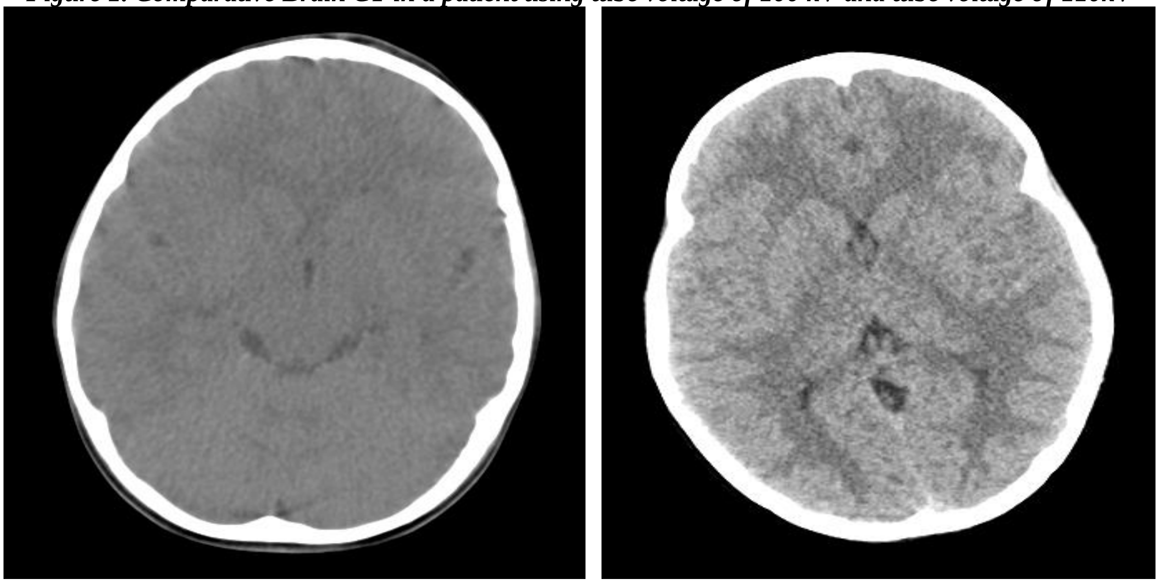
Scan Parameter	Impact on Radiation Dose
X-ray Beam Energy	Increased energy elevates radiation dose (with matched current)
Tube Current	Higher current raises radiation dose
Gantry Rotation Speed	Faster rotation lowers radiation dose
Section Thickness	Thinner slices relate to increased dose
Pitch	Higher pitch decreases radiation dose (with matched current)
X-ray Tube to CT Isocenter Distance	Optimized positioning reduces radiation dose
Scan Length	Longer scans amplify radiation dose

Iterative reconstruction techniques have showcased up to a 60% reduction in radiation doses, accompanied by noise reductions of approximately 45% ***(den Harder et al., 2015), (Table 2, Figure 1).*** Organ-based tube current modulation in specialized pediatric protocols led to dose reductions of around 30% in abdominal scans without compromising diagnostic confidence ***(Papadakis et al., 2020)***.

Table 2. Comparative Reduction in Radiation Doses

Optimization Technique	Average Dose Reduction (%)	Impact on Image Quality
Lower Tube Voltage	30 - 50	Maintained
Iterative Reconstruction	Up to 60	Reduced noise by 45%
Pediatric Protocols	Up to 40	Maintained
Dose-Tracking Systems	25	N/A

Figure 1. Comparative Brain CT in a patient using tube voltage of 100 kV and tube voltage of 110kV



Additionally, dose-tracking systems exhibited an average dose reduction of 25% across various pediatric CT exams through continuous monitoring and optimization ***(de Bondt et al., 2017; Abdulail et al., 2023), (Table 3&4, Figure 2).***

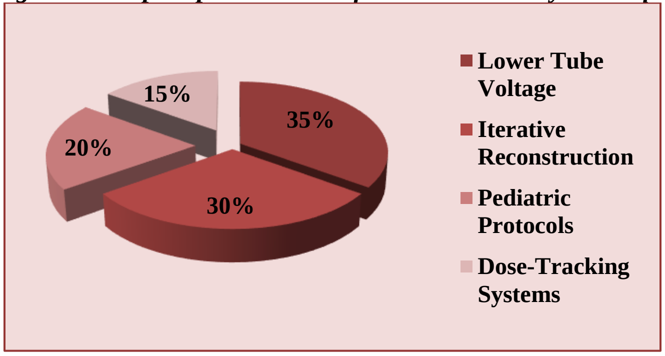
Table 3. Advantages of dose- tracking systems

Benefits	Impact
Continuous monitoring of radiation doses	25% reduction achieved
Optimization of protocols based on real-time data	Enhanced dose control
Compliance with optimized imaging guidelines	Sustained dose reductions

Table 4. Data for distribution of dose reduction by technique

Optimization Technique	Percentage Contribution (%)
Lower Tube Voltage	35
Iterative Reconstruction	30
Pediatric Protocols	20
Dose-Tracking Systems	15

Figure 2. Graphic presentation of dose reduction by technique



4. DISCUSSION

The findings underscore the significance of a multi-faceted approach to minimize radiation exposure in pediatric CT imaging. Lower tube voltage, iterative reconstruction algorithms, specialized pediatric protocols, and dose-tracking systems collectively offer substantial opportunities to mitigate radiation risks while preserving diagnostic efficacy.

Implementing lower tube voltage not only reduces radiation doses by significant margins but also enhances patient safety, particularly in pediatric populations susceptible to potential long-term effects of ionizing radiation ***(Mahrooqi et al., 2015).*** Iterative reconstruction algorithms, such as ASIR and SAFIRE, have revolutionized image processing by enabling substantial noise reduction without compromising image quality, thereby allowing for dose reductions while maintaining diagnostic confidence ***(Noid et al., 2017; Maxfield et al., 2012; Nie et al., 2014).***

Specialized pediatric protocols incorporating organ-based tube current modulation have emerged as a tailored approach to minimize radiation exposure in specific anatomical regions without compromising diagnostic accuracy ***(Papadakis et al., 2020).*** Furthermore, the integration of dose-tracking systems into clinical practice facilitates continuous monitoring and optimization, ensuring adherence to optimized protocols and contributing significantly to dose reduction across various pediatric CT exams ***(Franck et al., 2018).***

5. CONCLUSION

The continuous advancements in technology and protocols for optimizing radiation exposure in pediatric CT imaging offer a promising trajectory toward safer and more efficient clinical practices. However, their effective implementation necessitates collaborative efforts among radiologists, physicists, technologists, and clinicians. Education, strict adherence to optimized protocols, and ongoing research are crucial to further enhance these strategies and prioritize the safety of pediatric patients undergoing CT examinations.

The amalgamation of lower tube voltage utilization, iterative reconstruction algorithms, specialized pediatric protocols, and dose-tracking systems heralds a new era in pediatric CT imaging, promising reduced radiation exposure while safeguarding diagnostic accuracy and the well-being of young patients.

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