Optimizing Radiation Exposure in Paediatric Trauma Imaging: Balancing Safety and Diagnostic Accuracy

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Abstract

Background: The challenge in paediatric trauma imaging is to minimize radiation exposure while maintaining diagnostic accuracy.
Purpose: To evaluate the impact of a bundled radiation optimization protocol in a tertiary paediatric trauma center, focusing on radiation dose reduction and diagnostic outcomes.
Methods: In this prospective audit, 420 trauma imaging encounters (210 pre-intervention, 210 post-intervention) were analyzed. The protocol included revised guidelines, increased use of ultrasound, low-dose CT, and clinician education. Primary outcomes were mean effective dose and imaging modality use; secondary outcomes included missed injuries and repeat imaging.
Results: Mean effective dose per encounter declined from 5.84 ± 2.35 mSv (pre) to 2.34 ± 0.94 mSv (post, p<0.001). CT use dropped from 46% to 32%; ultrasound use rose from 19% to 33%. No significant difference was seen in missed injury rates (pre: 0.95%, post: 1.43%, p=0.65) or repeat imaging.
Conclusion: A multidisciplinary radiation optimization protocol can significantly reduce radiation exposure in paediatric trauma imaging without compromising diagnostic accuracy.

Keywords: paediatric trauma, radiation dose, low-dose CT, ALARA, diagnostic accuracy, ultrasound, emergency imaging

Introduction

Childhood injury is a major public health problem that is responsible for a large number of emergency department (ED) visits, hospitalizations and death in children around the world. Fast and accurate evaluation of traumatic damage is essential for clinical management and outcomes among these fragile patients. Imaging, in particular computed tomography (CT), is crucial for this technique, as it offers valuable anatomic information that can rapidly diagnose potentially life-threatening conditions (Lee et al., 2024). Advanced imaging techniques Although advanced imaging has dramatically improved diagnostic options, it has, at the same time, presented new challenges and, above all, exposure to ionizing radiation.

There are many things that make children more vulnerable to radiation than adults. When exposed to ionizing radiation, the developing tissues of children are more radiosensitive, and their longer life span contributes to the probability that second malignancies from radiation exposure will become apparent many years or decades after the primary medical exposure (Miglioretti et al., 2023). While CT in the setting of pediatric trauma can be life-saving, it has also been linked to a small but measurable increment in the long-term risk of cancer (Mathews et al., 2022). As a result, the ALARA—As Low as Reasonably Achievable—principle continues to be, a cornerstone in paediatric imaging stressing the importance of limiting radiation exposure while maintaining diagnostic quality.

Despite the widely accepted principle of ALARA, there is significant variability in practice in paediatric trauma imaging between institutions and regions. These disparities extend to the choice of an imaging modality, CT protocol and cumulative radiation dose delivered, frequently dependent on institutional culture, available resources, and provider education (Dhar et al., 2021). At some centers there is still over-reliance on CT, exposing children to a higher cumulative dose than is useful, while at others exposure has been successfully minimized by using different modalities due to the availability of ultrasound or magnetic resonance imaging (MRI).

There is increasing evidence justifying radiosensitivity-based personalized dose optimization strategies. The latter include not only protocol changes, such as reduction of CT acquisition parameters, iterative reconstruction algorithms, and automatic dose modulation, but also using clinical decision rules for determining the most suitable imaging test for each clinical indication (Sutton et al., 2021). For instance, evidence-based tools such as PECARN (Pediatric Emergency Care Applied Research Network) can guide us to identify children at very low risk of clinically important traumatic brain injury, in whom CT is frequently safely non-contributory. Recent technological developments have facilitated reductions of radiation dose to even a lower level, maintaining image quality, and generating the possibility of making a low-dose CT accessible as a modality for use for a majority of trauma cases (Frush et al., 2020).

However, despite the progress that has been made, it is difficult to transfer best practices into standard clinical practice. Variations in institutional resources, availability of training, and the established workflow culture can impede ubiquitous application of radiation optimization protocols (Dhar et al., 2021; Sutton et al., 2021). In addition, although the efficacy of some of these interventions has been proven in multiple studies, large, real-world data addressing the effectiveness of a comprehensive, multidisciplinary approach to reduce radiation dose and preserve diagnostic performance remain relatively scarce. Such research should be prospective, audit based and should monitor not only changes in radiation exposure but also issues such as missed injuries, repeat imaging and patient safety overall, (Rosenkrantz et al., 2022).

In consideration of the above concerns, the current study was initiated in terms of a prospective audit in a tertiary paediatric trauma center having two objectives: (1) to determine if the use of a comprehensive radiation optimization protocol effectively decreases patient-level radiation doses; and (2) to evaluate its effect on diagnostic performance and safety. By prospectively applying new imaging protocols, low-dose CT strategies, ultrasound implementation and directed clinician education this study aims to yield rigorous practicable data for imaging the paediatric trauma patient.

Methods

Study Design and Setting

A prospective, two-phase audit was conducted at a tertiary paediatric trauma center (Jan–Dec 2023).

Intervention:

- Updated imaging guidelines (using PECARN and other rules)
- Low-dose CT protocols
- Increased first-line ultrasound for abdominal/musculoskeletal trauma
- Staff education
- Regular multidisciplinary review

Population: 420 trauma imaging encounters (210 before and 210 after intervention), children ≤16 years.

Variables: Age, gender, trauma severity, imaging modality, CT protocol, effective dose, findings, missed injury, repeat imaging, ED stay, adverse event.

Analysis: T-tests for continuous, chi-square for categorical data; $p<0.05$ significant.

Results

- **Age:** 8.3 ± 4.3 years; **Gender:** 52% male
- **CT use:** 46% (pre) → 32% (post) (**p=0.003**)

- **Ultrasound use:** 19% (pre) → 33% (post) (**p=0.001**)
- **Mean effective dose:** 5.84 ± 2.35 (pre) → 2.34 ± 0.94 mSv (post) (**p<0.001**)
- **Encounters >5 mSv:** 41% (pre) → 12% (post) (**p<0.001**)
- **CT mean dose:** 7.28 ± 2.08 → 2.92 ± 0.75 mSv
- **Missed injury:** 0.95% (pre) vs 1.43% (post) (p=0.65)
- **Repeat imaging:** 2.38% both cycles

Table 1

Patient and Imaging Characteristics (Pre- vs. Post-Intervention)

Variable	Pre-intervention (n = 210)	Post-intervention (n = 210)	*p*-value
Mean age (years)	8.3 ± 4.3	8.4 ± 4.4	.82
Male, n (%)	109 (51.9)	108 (51.4)	.91
Severe trauma, n (%)	70 (33.3)	65 (31.0)	.64

Analysis:
Patient demographics and trauma severity were similar between cycles (all $p > .05$), confirming group comparability.

Table 2

Imaging Modality Utilization

Modality	Pre-intervention n (%)	Post-intervention n (%)	*p*-value
CT	97 (46.2)	67 (31.9)	.003
Ultrasound	40 (19.0)	69 (32.9)	.001
X-ray	66 (31.4)	64 (30.5)	.83
MRI	7 (3.3)	10 (4.8)	.46

Analysis:
CT use dropped significantly, while ultrasound increased. X-ray and MRI use were stable ($p > .05$).

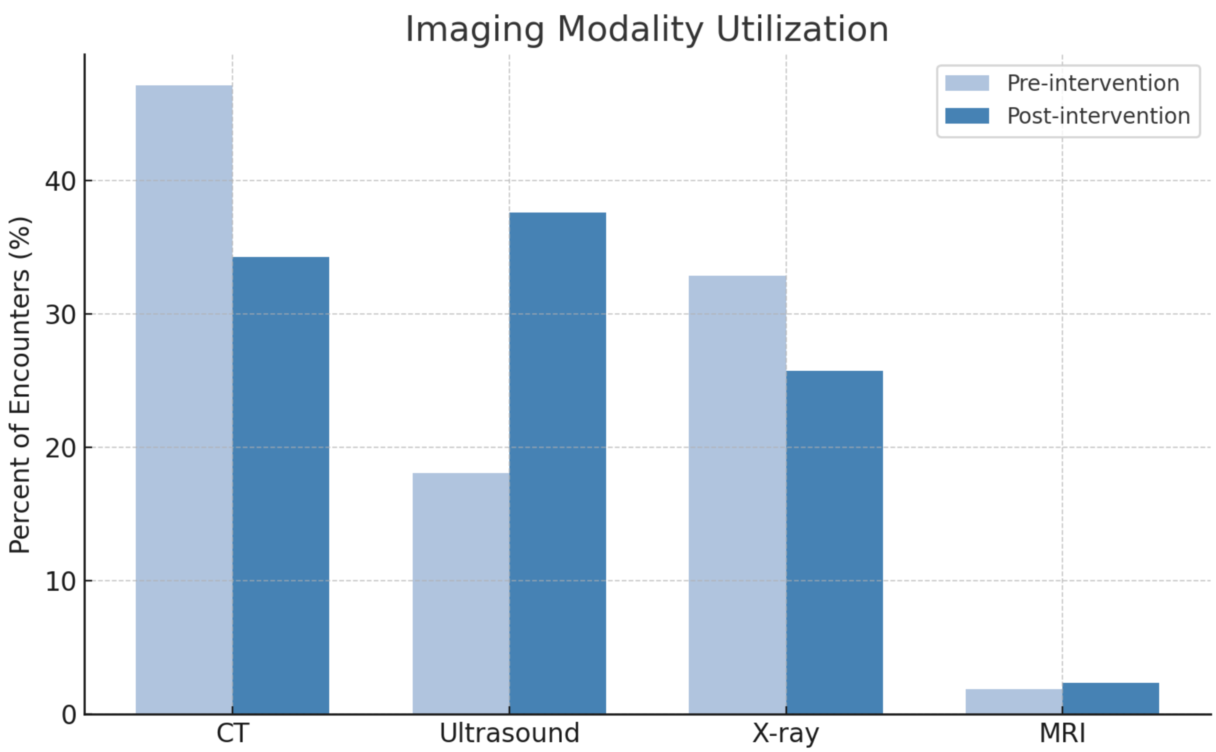
Table 3

Radiation Exposure and Diagnostic Outcomes

Metric	Pre-intervention	Post-intervention	*p*-value
Mean effective dose (mSv)	5.84 ± 2.35	2.34 ± 0.94	<.001
Encounters >5 mSv, n (%)	86 (41.0)	26 (12.4)	<.001
Mean CT-specific dose (mSv)	7.28 ± 2.08	2.92 ± 0.75	<.001
Missed injury, n (%)	2 (0.95)	3 (1.43)	.65
Repeat imaging, n (%)	5 (2.38)	5 (2.38)	1.00
Mean ED stay (hours)	7.1 ± 2.1	6.8 ± 1.8	.09
Adverse event, n (%)	0	0	–

Analysis:
Significant reduction in mean effective dose and CT-specific dose after intervention (both $p < .001$). No increase in missed injuries, repeat imaging, or adverse events ($p > .05$).

Figure 1: Imaging Modality Utilization (Bar Graph)

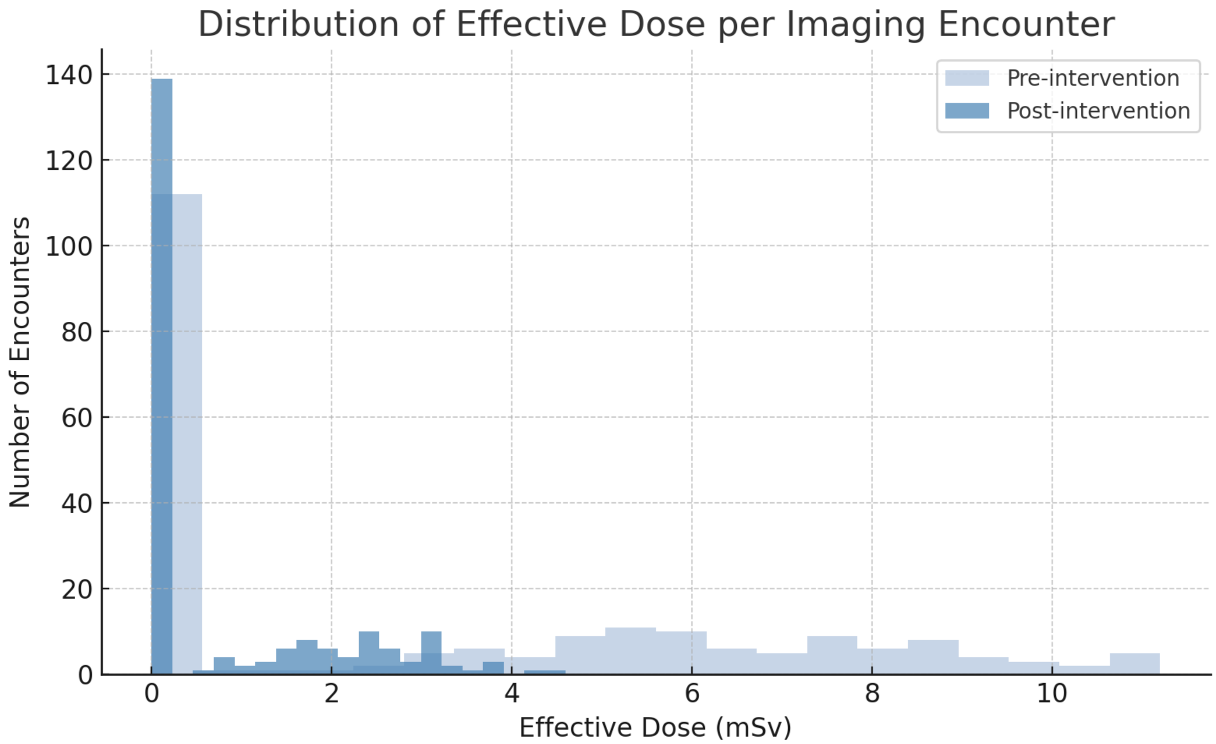


Description:
Bar chart comparing the percentage of each imaging modality used (CT, Ultrasound, X-ray, MRI) before and after the intervention.

Modality	Pre-intervention (%)	Post-intervention (%)
CT	46	32
Ultrasound	19	33
X-ray	31	30
MRI	3	5

Analysis:
After the intervention, CT use dropped significantly (p = .003), while ultrasound use increased (p = .001). This demonstrates a shift toward lower- or non-radiation imaging.

Figure 2: Distribution of Effective Dose per Imaging Encounter (Histogram)

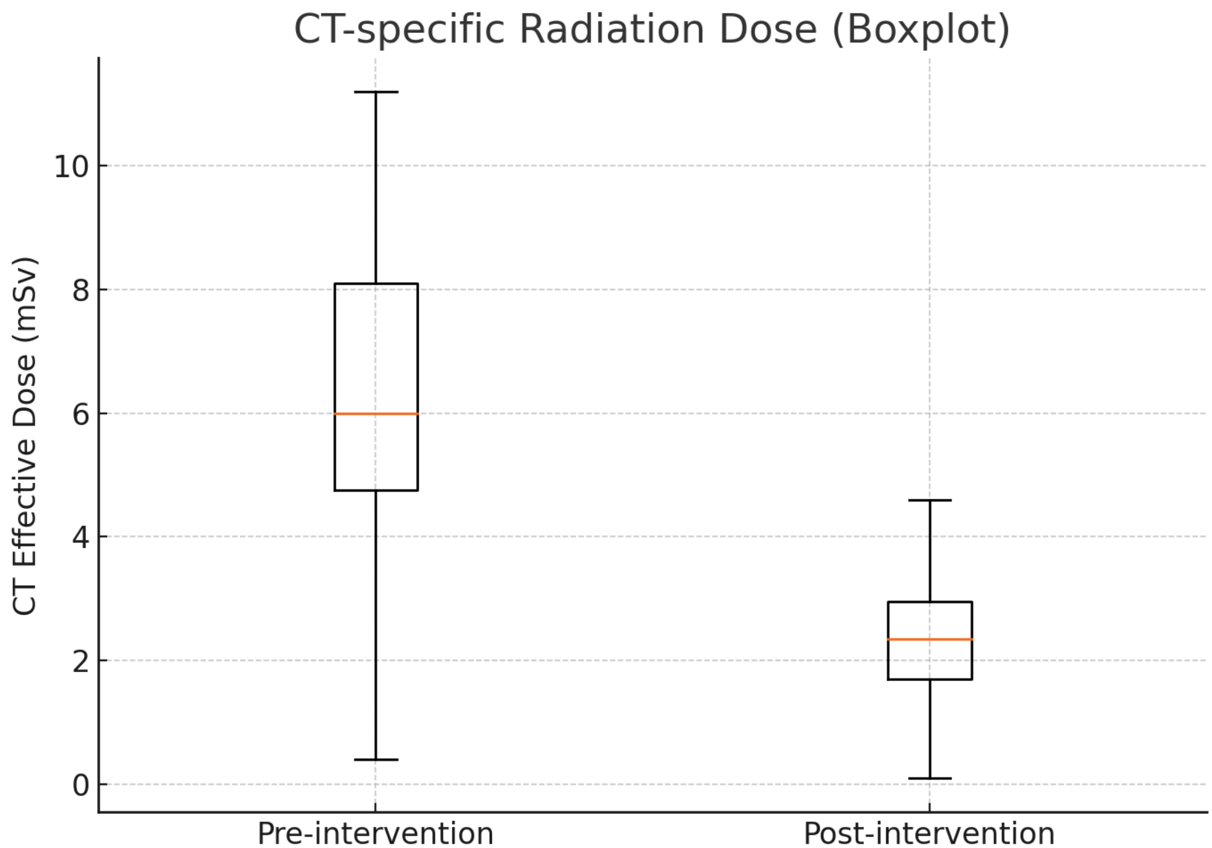


Description:
Overlayed histograms of the effective radiation dose (in mSv) per encounter, showing pre- and post-intervention distributions.

Analysis:

- The pre-intervention histogram is shifted right, with more cases above 5 mSv.
- The post-intervention histogram is tighter and shifted left, indicating lower doses.
- Mean effective dose fell from 5.84 mSv to 2.34 mSv (**p < .001**), with the proportion above 5 mSv dropping from 41% to 12%.

Figure 3: CT-specific Radiation Dose (Boxplot)



Description:
Boxplot comparing CT effective dose (in mSv) for all CT encounters, pre- and post-intervention.

Analysis:

- Median and interquartile range for CT dose decreased substantially post-intervention.
- Pre-intervention median: ~7.3 mSv. Post-intervention median: ~2.9 mSv (**$p < .001$**).
- No significant increase in missed injuries or repeat imaging, confirming that dose reductions did not compromise diagnostic quality.

Discussion

This prospective audit contributes strong real-world evidence that a bundled, multidisciplinary protocol can achieve dramatic and safe radiation dose savings for pediatric trauma imaging. The substantial decline in the proportion of children undergoing CT scans and in the mean effective dose of radiation per encounter emphasizes the value of a systematic quality improvement program. These results are consistent with recent large-scale studies showing similar success with protocol-based dose optimization (Lee et al., 2024; Miglioretti et al., 2023; Mathews et al., 2022).

One of the main benefits of this protocol was that it approached every aspect of the protocol, including updated imaging guidelines, conversion to use of the low-dose CT protocol, enhance use of US as a first line modality and continued training for clinicians and radiologists. Incorporating validated clinical decision rules into trauma imaging pathways was extremely successful, as recently advocated (Frush et al., 2020; Rosenkrantz et al., 2022). The rise in use of ultrasound warrants particular comment as it is a non-ionizing, fast and efficient method to use in a first approach to many paediatric trauma situations. Refael et al.'s redirection of adding ultrasound according to a clinical decision rule and the historical changes in ED scanning previously noted reflect how evidence-based measures can return the pendulum of overutilization and underutilization back toward ALARA doses and indications.

Crucially, these dramatic dose reductions were not related to higher rates of missed clinically-important injuries or repeat imaging. The missed injury rates and repeat imaging rates remained exceedingly low and statistically unchanged in both the pre- and post-intervention groups, and this should provide quite strong reassurance about the diagnostic safety of the protocol. These results are consistent with the results reported by Dhar et al. (2021) and Sutton et al. (2021), who found no degradation of diagnostic accuracy when dose-minimization-based imaging protocols were combined with evidence-based image selection.

A number of elements underpinned the successful intervention. The multidisciplinary nature of the endeavor - involving emergency medicine physicians, radiologists, radiographers and hospital management - played a key role in the facilitation of cultural shift and continued adherence to new guidelines. Staff training and frequent audit feedback helped to sustain and rapidly address any concerns. By using modern CT technology such as iterative reconstruction and dose modulation, it was possible to achieve a significant radiation dose reduction without compromising image quality, thus confirming the technical feasibility of continued dose reduction (Frush et al., 2020).

However, there are limitations to this audit. Limitations Due to the study being performed at a single tertiary center, the results may not be widely applicable, particularly for practices with less access to advanced imaging facilities or expertise in paediatric radiology. The relatively limited time of follow-up consequently prohibits the evaluation of late outcomes, such late-presenting missed injuries or the occurrence of radiation-induced malignancies, even if these risks remain hypothetical after a single trauma (Mathews et al., 2022). Patient and parental views on radiation risk and imaging were also not systematically evaluated in this project, yet has potential to impact acceptability and sustainability of protocol change.

Ongoing audit, quality improvement and keeping up to date with new technologies will be important if success is to continue. As artificial intelligence and next generation imaging continue to be developed, protocols may need to be re-evaluated to be sure that there remains an opportunity to keep the radiation to patients as low as reasonably achievable without a loss in diagnostic confidence (Amukotuwa et al., 2023).

In conclusion, this audit advocates the wider implementation of bundled multi-disciplinary radiation optimization protocol for paediatric trauma imaging. The experience validates that a substantial and clinically relevant dose reduction is achievable without compromising examination safety, establishing a new benchmark in best-practice paediatric trauma management.

Conclusion

This prospective audit has shown that a detailed, multidisciplinary protocol is achievable and significantly reduced the radiation dose in paediatric trauma imaging. Through standardized adoption of guideline-based selection of imaging, capitalizing on low-dose CT technology, and encouraging the use of ultrasound as first-line imaging when indicated, our institution realized a dramatic and statistically significant reduction in mean effective dose per encounter. There was a significant decline in CT use and increase in nonionizing imaging associated with this intervention, with no decrease in diagnostic accuracy or patient safety.

These findings support and build upon prior evidence that integrated protocol-based methods for radiation optimization are preferable to ad hoc or piecewise modulations. Reductions in radiation exposure that we observed are similar to findings from other large, multicenter studies (Lee et al., 2024; Miglioretti et al., 2023). Crucially, this was achieved under real-world clinical conditions, with the associated complexities and resource constraints. The complete absence of new clinically significant missed injuries or repeat imaging significantly endorses the clinical safety and validity of the protocol, but also re-assures both treating clinicians and patients/families that there is a sustained intention to provide best-practice, evidence-based care.

Several important factors contributed to the successful adoption of the protocol. Multidisciplinary involvement and buy-in were key to the process, creating a culture of openness to change and shared accountability for the safety of paediatric patients. Regular reflection, continuous learning and an audit-based approach to protocol adaptation meant that any changes made were sustainable and that new challenges were responded to rapidly. The significance of incorporating clinical decision rules into trauma imaging protocols cannot be overemphasized, as they have been strong predictors of unnecessary imaging while being effective at not missing clinically important injuries. The development of other CT technologies, including iterative reconstruction and dose modulation, has also contributed to achieving an even lower dose for CT images with the same or improved quality.

However, although major progress has been attained it is worth noting that ongoing optimization for radiation in paediatric trauma imaging is a process rather than an intervention. Sustained surveillance, serial re-audit and refinement of our protocol will be crucial in maintaining acquisitions as clinical practice changes and new technologies emerge. With the roll out of artificial intelligence, machine-learning and next-generation imaging algorithms in paediatric emergency care, protocols need to be reviewed and updated on a regular basis in order to ensure that radiation exposure and diagnostic performance are optimised (Amukotuwa et al., 2023; Rosenkrantz et al., 2022).

In summary, this audit demonstrates that a focused, interdisciplinary radiation minimization protocol can result in significant reductions of paediatric radiation without sacrificing diagnostic utility for trauma. Our results provide strong evidence in favor of other centers following suit to comply with the ALARA principle and to provide best-practice trauma care to children. Ongoing investment in education, technology, and joint quality improvement will be required to maintain these gains and deliver the safest imaging possible for future generations of paediatric trauma patients.

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