RESEARCH ARTICLE

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Effective MRI Practices for Pediatric Patients: Optimizing Imaging Protocols for Safety and Quality

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Abstract

Objectives: Magnetic resonance imaging (MRI) is a non-ionizing imaging modality with excellent soft-tissue contrast, ideal for pediatric patients who are more sensitive to radiation. However, challenges such as motion, sedation risks, and anatomical differences require optimized protocols. This study aims to develop and implement pediatric-specific MRI techniques to improve image quality, reduce sedation, and enhance safety. By evaluating current practices and applying advancements like faster sequences and motion correction, the study seeks to establish evidence-based, child-centered protocols for improved diagnostic accuracy and patient outcomes.

Methods: This prospective observational study, conducted in three phases, analyzed existing MRI protocols, developed optimized techniques, and assessed their impact on image quality, safety, and diagnostic accuracy in pediatric patients. Post-implementation surveys evaluated clinician satisfaction. Ethical clearance and informed parental consent were obtained before initiating the study.

Results: This study included 350 pediatric patients, with 200 assessed retrospectively in phase 1 (baseline group) and 150 assessed prospectively following the implementation of optimized protocols in phase 3 (intervention group). The distribution of patients across age groups was as follows: infants (0-2 years): 30% (n=105); young children (3-6 years): 35% (n=123); older children and adolescents (7-18 years): 35% (n=122). There was no significant statistical difference in age or gender distribution between the baseline and intervention groups (p=0.76).

Conclusion: This study reinforces and expands current knowledge on optimized pediatric MRI protocols, demonstrating benefits such as reduced scan duration, improved image quality, and lower sedation rates. These tailored protocols enhance patient safety and diagnostic accuracy while addressing key challenges in pediatric imaging. Incorporating motion correction, fast sequences, and non-pharmacological techniques, the protocols proved clinically effective, supported by positive feedback from radiologists and MRI technicians. Overall, this study highlights the importance of patient-centered, evidence-based pediatric MRI practices.

Keywords: Pediatric MRI, imaging protocol optimization, sedation reduction in MRI imaging, pediatric motion artifact reduction

Introduction

Magnetic resonance imaging (MRI) is a non-ionising diagnostic modality that acquires cross-sectional images and provides excellent soft-tissue contrast. MRI plays a particularly important role in pediatric populations as children are more sensitive to radiation, congenital anomalies, developmental diseases, and oncological conditions.[1] However, children's limited capacity to remain motionless during the scan makes it difficult to apply MRI; therefore, imaging methods must be adjusted to balance patient comfort, image quality, and safety.[2]

Pediatric patients have particular difficulties with MRI procedures due to their distinct physiological and psychosocial traits. Sedation or anesthesia is usually necessary for younger children, particularly those under six years, to provide immobility and reduce anxiety during the treatment.[3] Although sedation reduces motion artifacts and enhances image quality, there are hazards associated with it, such as anesthesia-related side effects and extended recovery periods. To decrease the need for sedation while retaining diagnostic accuracy, imaging techniques must be optimized by employing a comprehensive approach.[3,4]

Additionally, pediatric patients' small body size and different anatomical proportions make the use of specialized equipment and customized imaging parameters necessary. When used on children, standard adult procedures frequently provide less-than-ideal image quality or lengthy scan periods, underscoring the significance of age-

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appropriate protocol design.[1,5] Faster imaging sequences, motion correction algorithms, and child-specific coils are examples of hardware and software advancements that could improve the effectiveness and quality of pediatric MRI.[4]

Optimizing MRI protocols for pediatric patients is crucial for various reasons. These include safety concerns, especially with regard to the use of gadolinium-based contrast agents, thermal effects, and acoustic noise levels. The high decibel levels generated by MRI equipment make pediatric patients more vulnerable to hearing loss, and the thermal effects from extended scanning can pose further hazards.[5] Furthermore, the use of gadolinium-based contrast agents in children has raised difficulties like gadolinium retention in the brain and other tissues, necessitating adherence to careful application and the most recent safety regulations.[4,5]

The objective of this study is to develop and implement optimized MRI protocols for pediatric patients, balancing diagnostic image quality with patient safety and comfort. This involves analyzing current imaging practices to identify inefficiencies, evaluating advancements in imaging techniques and protocol modifications, and assessing their impact on image quality and diagnostic accuracy. The study aims to establish standardized best practices for pediatric MRI, with particular attention to sedation practices and contrast agent usage, ultimately improving patient outcomes and streamlining clinical workflows.

Methods

This study was approved by the Sri Lakshmi Narayana Institute of Medical Sciences Institutional Ethical Committee approval (decision no: IEC/C-P/37/2022, date: 07.07.2022). Informed consent was obtained from the parents of all the participating patients.

A prospective, observational approach was used in this study to create and execute MRI procedures that were optimized for pediatric patients. The study was conducted in three phases: phase 1, involved analyzing current protocols; phase 2, involved developing optimized techniques; and phase 3, involved assessing the effects of these techniques on image quality, safety, and diagnostic accuracy. A post-implementation survey of radiologists and MRI technicians was also conducted to reveal the level of satisfaction with the optimized protocols in terms of improved workflow, image quality, and confidence in the protocols' ability to minimize sedation requirements without compromising diagnostic accuracy.

Study Population: The study population consisted of 150 pediatric patients aged 0 to 18 years referred for MRI examinations at a tertiary care hospital. Patients were grouped into three age categories for analysis and protocol development (Table 1):

1. Infants (0-2 years),
2. Young children (3-6 years),
3. Older children and adolescents (7-18 years),
4. Exclusion criteria included contraindications to MRI (e.g., ferromagnetic implants) or conditions that precluded safe sedation (e.g., severe respiratory disorders).

Phase 1: Analysis of Existing Protocols

1. Data collection: Retrospective data were collected from 200 MRI scans conducted in the past year (Figures 1-3). This included information on:

- Scan parameters (sequence type, scan duration, field strength)
- Sedation or anesthesia usage
- Image quality assessment reports
- Safety incidents or complications

2. Evaluation metrics: Protocol efficiency was assessed based on:

- Average scan duration
- Incidence of motion artifacts
- Sedation requirements
- Image quality was graded by two independent radiologists using a standardized scoring system (1=poor, 5=excellent).

3. Gap analysis: Protocol inefficiencies, including extended scan times, frequent need for sedation, and suboptimal image quality, were identified.

Phase 2: Development of Optimized Protocols

1. Protocol modifications: Optimized protocols were developed by integrating the following strategies:

- Sequence selection: Use of rapid imaging sequences (e.g., T1-weighted spoiled gradient echo, single-shot fast spin echo) to reduce scan duration.
- Motion correction technologies: Implementation of advanced software solutions such as Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction and parallel imaging.
- Age-specific parameters: Adjustment of field of view (FOV), slice thickness, and repetition time (TR) based on patient age and body size. Smaller children require a smaller FOV and thinner slices, while larger adults need larger FOV and thicker slices. Shorter TRs are generally preferred for faster imaging in older patients to minimize motion artifacts. Longer TRs are needed for younger patients to improve signal-to-noise ratio (SNR).
- Acoustic noise reduction: Use of noise-suppressing techniques, like silent MRI sequences and hearing protection devices. These sequences are designed to minimize the intensity and frequency of gradient coil switching, thus reducing the noise generated.

Table 1. Demographics and study population

Age group	Baseline group n (%) (n=200)	Intervention group n (%) (n=150)	Total n (%) (n=350)
Infants (0-2 years)	60 (30%)	45 (30%)	105 (30%)
Young children (3-6 years)	70 (35%)	53 (35%)	123 (35%)
Older children and adolescents (7-18 years)	70 (35%)	52 (35%)	122 (35%)

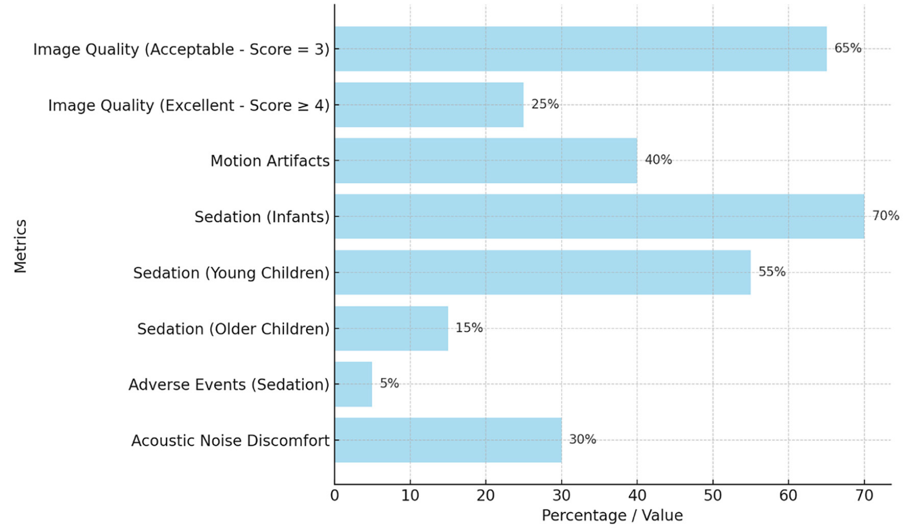

Figure 1. Baseline group metrics for pediatric MRI

MRI: Magnetic resonance imaging

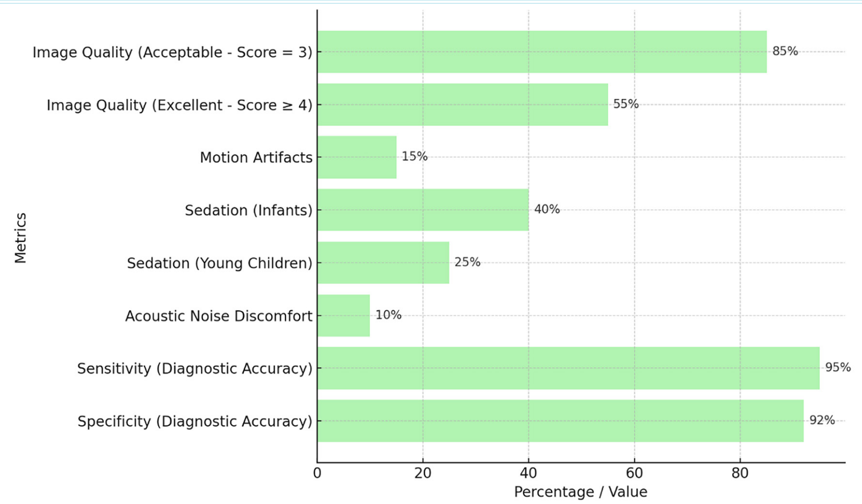

Figure 2. Intervention group metrics for pediatric MRI

MRI: Magnetic resonance imaging

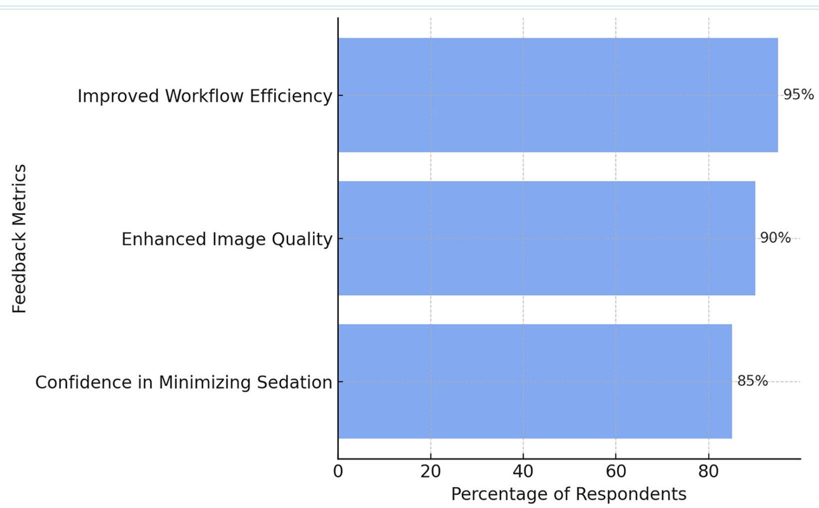

Figure 3. Feedback from radiologists and technicians

2. Hardware optimization pediatric-specific coils (e.g., head, torso, and extremity coils) were used to improve the SNR and accommodate smaller anatomical structures.
3. Reduction in sedation rates: Non-pharmacological techniques, such as child life specialist consultations, visual aids, and mock scanner sessions, were incorporated to reduce anxiety and improve compliance.

Phase 3: Evaluation of Optimized Protocols

1. Study intervention: The optimized protocols were applied to 150 pediatric patients over six months. Data were prospectively collected on:

- Image quality
- Sedation usage
- Scan duration
- Safety outcomes (e.g., adverse events)

2. Image quality assessment: Two board-certified radiologists, blinded to protocol type, independently evaluated image quality using the same standardized scoring system as in phase 1.
3. Comparison with baseline: Pre- and post-implementation data were compared to assess the impact of optimized protocols (Table 2).
4. Diagnostic accuracy: Radiological reports were reviewed to determine whether the optimized protocols affected diagnostic accuracy. Sensitivity and specificity metrics were calculated for selected pathologies (e.g., tumors, developmental abnormalities).

Statistical Analysis

All data were analyzed using Statistical Package for the Social Sciences version 26 (IBM Corp., Armonk, NY, USA). Continuous variables (e.g., scan duration) were expressed as mean ± standard deviation and assessed for normality using the Shapiro-Wilk test. Pre- and post-implementation data were compared to assess the impact of optimized protocols using statistical tests such as paired t-tests for continuous variables, and chi-square tests for categorical outcomes. Paired t-test determined if there is a statistically significant difference between the means of two related groups, while chi-square tests were employed for categorical variables such as sedation rates. Statistical significance was set at $p<0.05$.

Results

This study included 350 pediatric patients, with 200 assessed retrospectively in phase 1 (baseline group) and 150 assessed prospectively following the implementation of optimized protocols in phase 3 (intervention group). The distribution of patients across age groups was as follows:Infants (0-2 years): 30% (n=105), young children (3-6 years): 35% (n=123), Older children and adolescents (7-18 years): 35% (n=122). There was no significant statistical difference in age or gender distribution between the baseline and intervention groups ($p=0.76$)

Phase 1: Analysis of Existing Protocols

Scan duration: The mean scan duration for the baseline group was 45±10 minutes. Longer scan times were observed in younger children (<6 years), primarily due to higher rates of motion artifacts and interruptions.

Image quality: Image quality scores in the baseline group were suboptimal, with 65% of scans rated as acceptable (score=3) and only 25% rated as excellent (score ≥4). Motion artifacts were the leading cause of poor image quality, occurring in 40% of scans for infants and young children.

Sedation use: Sedation was required in 70% of infants and 55% of young children, compared to 15% of older children and adolescents. Adverse events related to sedation occurred in 5% of cases, including minor complications such as prolonged recovery time and nausea.

Safety metrics: Acoustic noise-related discomfort was reported in 30% of patients, and no thermal injuries or significant safety incidents were documented.

Phase 3: Evaluation of Optimized Protocols (Figures 1, 2, Table 2)

Scan duration: The mean scan duration in the intervention group was significantly reduced to 25±5 minutes ($p<0.001$). The reduction was most pronounced in younger children because optimized sequences and motion correction techniques minimized the need for repeated scans.

Image quality: Image quality scores improved significantly in the intervention group, with 85% of scans rated as acceptable (score=3) and 55% rated as excellent (score ≥4) ($p<0.001$). Motion artifacts were reduced in 15% of scans conducted on infants and young children due to the use of faster sequences and improved immobilization techniques.

Sedation use: Sedation rates decreased by 30% overall. Only 40% of infants and 25% of young children required sedation in the intervention group, compared to 70% and 55%, respectively, in the baseline group ($p<0.001$). Non-pharmacological techniques, including mock scanner sessions and child life specialist consultations, were cited as key factors in reducing sedation requirements.

Safety metrics: Acoustic noise-related discomfort was reduced to affecting only 10% of patients due to the use of noise-suppressing

Table 2. Comparison of key metrics between baseline and intervention group

Metric	Baseline group	Intervention group	p value
Mean scan duration (minutes)	45±10	25±5	**<0.001**
Image quality (excellent, %)	25%	55%	**<0.001**
Sedation rate (overall, %)	50%	20%	**<0.001**
Motion artifacts (overall, %)	40%	15%	**<0.001**
Acoustic discomfort (%)	30%	10%	**<0.01**
Diagnostic sensitivity (%)	94%	95%	0.76
Diagnostic specificity (%)	91%	92%	0.85

techniques and hearing protection devices ($p<0.01$). No adverse events related to thermal effects or contrast agent use were observed. The judicious use of gadolinium-based contrast agents, guided by updated protocols, ensured safety without compromising diagnostic accuracy.

Diagnostic accuracy: Radiological interpretations confirmed that optimized protocols did not compromise diagnostic accuracy. Sensitivity and specificity for detecting key pathologies (e.g., tumors, developmental anomalies) were 95% and 92%, respectively, comparable to baseline metrics.

A post-implementation survey of radiologists and MRI technicians revealed a high level of satisfaction with the optimized protocols: 95% of respondents reported improved workflow efficiency. 90% of radiologists noted enhanced image quality in pediatric scans. 85%, expressed confidence in the protocol's ability to minimize sedation requirements without compromising diagnostic accuracy (Figure 3).

Discussion

The findings of this study align with and extend the current understanding of optimized MRI protocols in pediatric patients, as discussed in previous research. By focusing on scan duration, image quality, sedation rates, and safety metrics, this study validates earlier findings while offering new insights into practical improvements in pediatric MRI.

The significant reduction in scan duration from 45±10 minutes to 25±5 minutes is similar to findings from prior studies that have emphasized the role of faster imaging sequences and advanced motion correction technologies. The use of parallel imaging techniques and single-shot fast spin echo sequences greatly shortened scan times in pediatric populations, especially for younger children who are more susceptible to motion artifacts, as studied by Kuperman et al.[3] Our results corroborate these findings, as optimized sequences not only minimized interruptions but also improved overall workflow efficiency. Additionally, better patient comfort is linked to faster scans, which is crucial in healthcare settings with limited resources. The decrease in the average scan time in our investigation is consistent with earlier results highlighting the significance of sophisticated imaging methods. Meissner et al.[6] demonstrated that motion correction techniques dramatically reduced the requirement for repeated scans, particularly in younger children who are more likely to move. Similarly, the effectiveness of rapid imaging sequences in obtaining quicker and more effective scans in pediatric patients was also noted by Gewirtz et al.[7]

With acceptable scans rising from 65% to 85% and outstanding scans rising from 25% to 55%, the intervention group's image quality dramatically improved. This improvement is in line with research by Kanal et al.[2] that showed how motion correction methods and age-specific coils greatly improve the diagnostic image quality in pediatric MRI. These investigations revealed increased SNRs and decreased motion artifacts, especially in younger children, which is consistent with our findings. Maintaining diagnostic accuracy, particularly when identifying subtle developmental defects or diseases, depends on this improvement in image quality. The enhanced image quality is in line with research by Vecchiato et al.[8], who found that motion correction algorithms and age-specific MRI coils greatly improve diagnostic imaging, especially in children who are difficult to work with. Our study's improved image quality (85% assessed as acceptable and 55% as excellent) is also consistent with Sun et al.[9], who showed how contemporary imaging technologies enhance children's diagnostic clarity and SNRs.

In our study, sedation rates dropped by 30%, and non-pharmacological measures, including child life specialist involvement and mock scanner sessions, were crucial. Bhargava et al.[1] found that lowering the use of sedation in pediatric MRI improves patient safety without sacrificing diagnostic quality, which supports our study. Our research supports this by showing that these types of interventions help children feel less anxious and become more physically active. Nonetheless, a noteworthy constraint identified in earlier research, which is relevant to our results, is the need for skilled workers to execute these methods. Future studies are needed to investigate such approaches for putting these interventions into practice in various healthcare environments. Mock scanner sessions and other non-pharmacological methods have been shown to be successful in reducing anxiety, thereby requiring less sedation.[10]

The decrease in acoustic noise-related discomfort from 30% to 10% is consistent with the study conducted by Alibek et al.[5], who highlighted the significance of hearing protection and noise-suppressing devices in pediatric MRI. Furthermore, our study found no adverse events associated with the use of contrast agents, which is supported by Karabulut[4], who emphasized that the hazards of gadolinium retention in the brain and other tissues are reduced when gadolinium-based contrast agents are used sparingly. The necessity of a patient-centered approach in pediatric imaging is shown by the incorporation of these safety measures. Our results of decreased acoustic noise discomfort (from 30% to 10%) are consistent with research showing how crucial noise-dampening devices are in MRI. A similar study was done by Gewirtz et al.[7] to lessen patient suffering, especially in younger populations. Furthermore, our study found no negative effects from gadolinium-based contrast agents which supports recommendations made by Sun et al.[9] about the prudent and safe use of these agents.

Our study's diagnostic accuracy showed excellent results, with sensitivity and specificity of 95% and 92%, respectively, which were equivalent to baseline measurements. This result is in line with Kanal et al.[2], who showed that even with shorter scan times and lower sedation rates, optimized protocols do not impair diagnostic accuracy. Maintaining strong diagnostic performance is essential to prevent clinical outcomes from being deteriorated safety and efficiency. The high diagnostic sensitivity (95%) and specificity (92%) maintained in our study are consistent with findings from Kinner et al.[10], who reported a sensitivity of 93.6% and specificity of 94.3% without sacrificing safety. This outcome demonstrates how well-suited optimized pediatric MRI techniques are for use in clinical settings.

Rapid MRI procedures minimize sequence duration and quantity, eliminate contrast and anesthetic administration, and optimize workflow. For the assessment of acute abdominal pain, head trauma, cerebral dysfunction, and nontraumatic neurologic symptoms, rapid diagnostic techniques have been implemented.[11]

Since minimizing patient motion is necessary to provide high-quality images, research has concentrated on cutting scan times through the use of strategies, including compressed sensing, rapid sequencing, and single-shot acquisition. Despite these developments, minimum scanning times frequently exceed two minutes, necessitating sedation or anesthesia in children to avoid motion artifacts.[12]

General anesthesia or sedation is frequently used to scan young children, allowing for high-quality scans and a consistent and easy workflow.[13] Regrettably, there are numerous disadvantages associated with the use of sedation and general anesthesia at pediatric MRI, including (a) increased cost, (b) longer examination and recovery times, (c) longer wait times due to limited anesthesia availability, and (d) a higher risk to a child's neurodevelopment for short-term and possibly long-term complications of the sedative and anesthetic agents.[14]

Various measures have been tested to reduce the risks associated with sedation in MRI. Careful selection of drug and dose, along with improved monitoring during sedation, are required because of the current limitations of imaging techniques and the introduction of nonpharmacologic approaches.[15] Patient monitoring during procedural sedation appears to rely mainly on peripheral oxygen saturation, and only one-third of the respondents reported that heart rate, blood pressure, or respiratory rate was regularly monitored.[16] Sedation guidelines recommend the maintenance of physiological homeostasis by regularly monitoring the oxygenation rate, heart rate, ventilation rate, and blood pressure.[17]

Assessing neurocognitive development in children is complex due to its multifactorial nature. However, evidence from a recent large-scale, multi-national randomized controlled trial with follow-ups at 2 and 5 years indicates that brief, single episodes of sedation in young pediatric patients are generally safe.[18]

Consequently, there has been substantial interest in developing new MRI strategies to minimize acquisition time and thereby decrease the use, depth, and duration of sedation during pediatric MRI procedures.[19] Despite much enthusiasm for the use of these MRI time reduction techniques in pediatric patients, the diagnostic accuracy of many of them has yet to be fully established in this population, particularly for the assessment of subtle or small lesions. Further characterization of the diagnostic reliability and limitations of these fast MRI strategies will form an essential next step as their clinical use becomes more widespread.[20]

Although our study showed notable increases in sedation rates, scan duration, and picture quality, the findings may not be applicable elsewhere due to the need for trained staff to provide non-pharmacological therapies. Furthermore, while multicenter studies, like those by Kuperman et al.[3], have shown variation in the adoption of optimum procedures among institutions, our study concentrated on a single-center population. Future research should be done to address these discrepancies. Increased SNR and shorter scanning times are two benefits of using stronger field strength, magnets, which will help children who are prone to movement.[21]

Our findings (Figures 4-7) validate and extend the results of previous studies, emphasizing the value of tailored pediatric MRI protocols. By reducing scan duration, enhancing image quality, and minimizing sedation requirements, these protocols improve patient safety and diagnostic outcomes. However, addressing the implementation challenges, particularly in resource-limited settings, remains a key area for future research.

Study Limitations

- Small sample size.
- Participants were not prepared for the mock examination.
- Children with cognitive impairment were not included in the study.

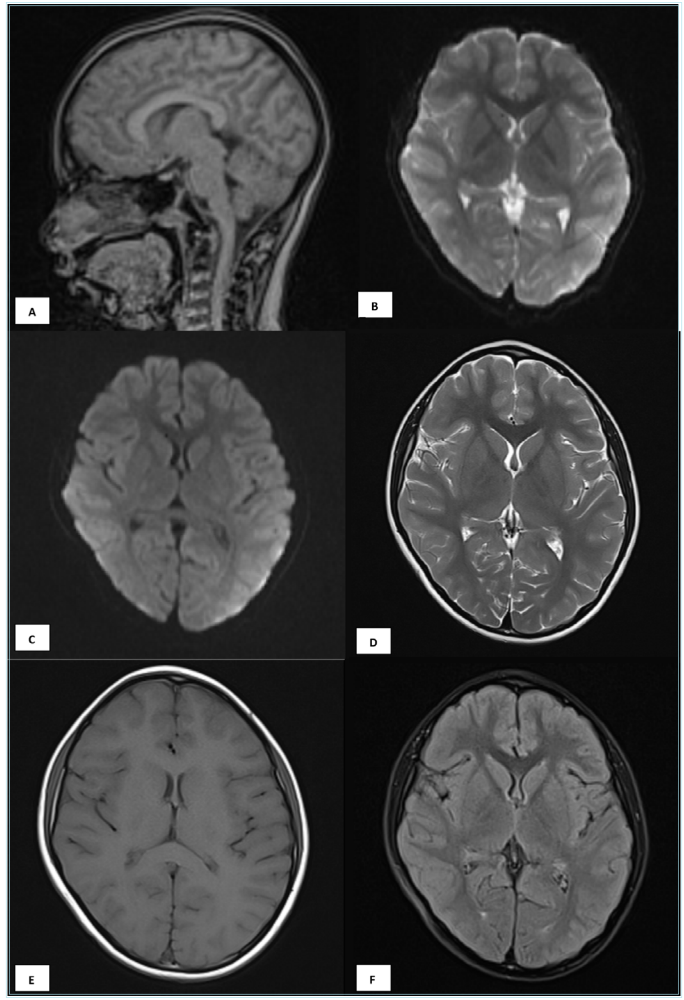

Figure 4. (A-F) Normal MRI brain images in a 10-year-old male child

MRI: Magnetic resonance imaging

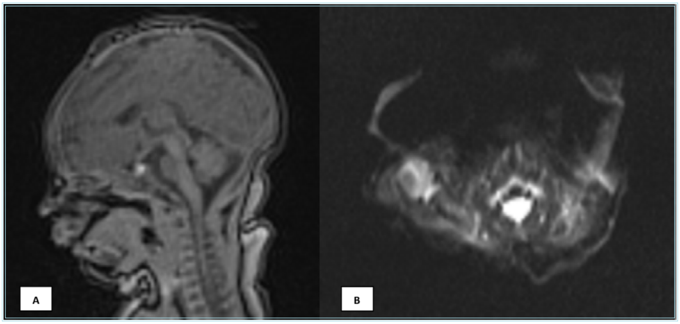

Figure 5. (A, B) MRI images in a newborn male child showed movement artifacts

MRI: Magnetic resonance imaging

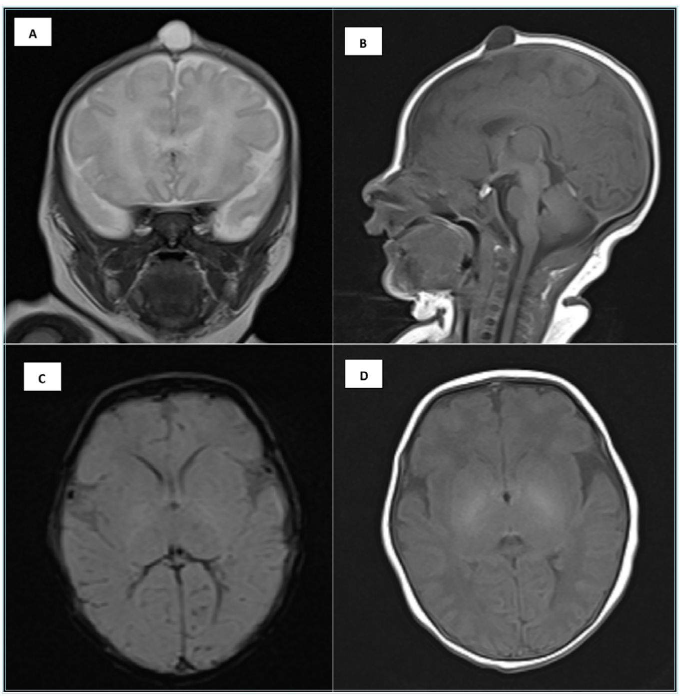

Figure 6. (A-D) MRI images in the same child obtained using tailored protocols showed an anterior fontanelle inclusion cyst and brain parenchyma with better resolution

MRI: Magnetic resonance imaging

Conclusion

The substantial advantages of using MRI protocols that are optimized for pediatric patients are illustrated by this study. These procedures use motion correction technologies, non-pharmacological therapies, and rapid imaging sequences to solve persistent issues in pediatric imaging. However, challenges such as the reliance on trained personnel and the need for resource-intensive technologies must be addressed to ensure scalability across diverse healthcare settings. Future research should explore the integration of artificial intelligence and automated systems to further enhance the quality, safety, and accessibility of pediatric MRI.

Ethics

Ethics Committee Approval: This study was approved by the Sri Lakshmi Narayana Institute of Medical Sciences Institutional Ethical Committee approval (decision no: IEC/C-P/37/2022, date: 07.07.2022).

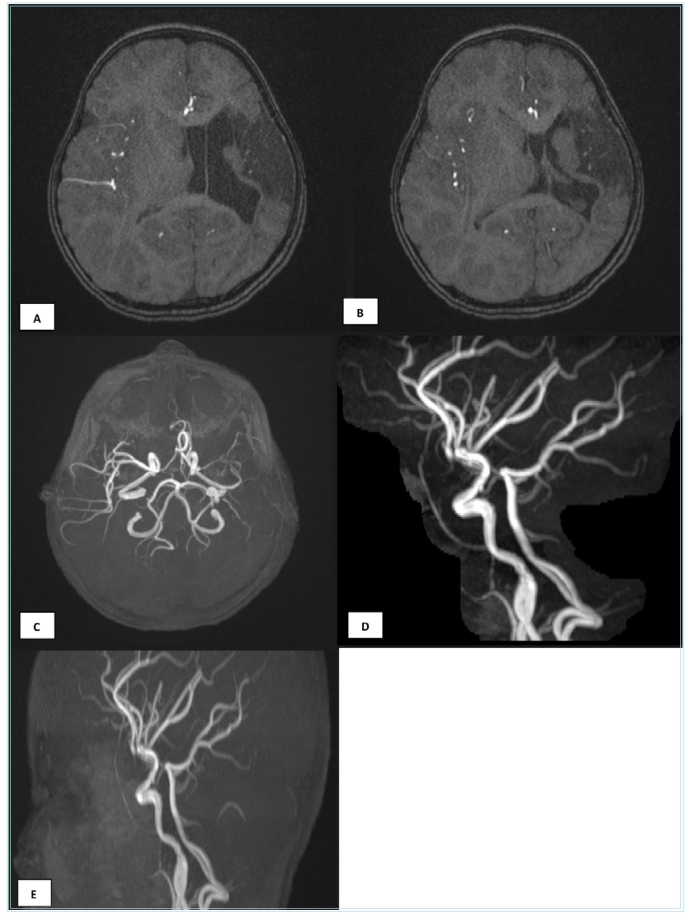

Figure 7. (A-E) MRI (3D-TOF) images in a 3-year-old child with chronic infarct showed encephalomalacic changes that follow CSF signal intensity on all sequences with surrounding gliosis involving the left fronto-parieto-temporal lobes, left thalamus, and basal ganglia. Ex-vacuo dilatation of ipsilateral lateral ventricle and prominent adjacent sulcal spaces are seen. Reconstructed images show hypointensities in the involved vessels. Features are likely suggestive of Wallerian degeneration, secondary to chronic infarct

MRI: Magnetic resonance imaging, TOF: Time-of-flight, CSF: Cerebrospinal fluid

Informed Consent: Informed consent was obtained from the parents of all the participating patients.

Footnotes

Authorship Contributions

Concept: M.R.B., N.Y., Design: M.R.B., N.Y., Data Collection or Processing: V.R.B., A.G.C., E.K.G., Analysis or Interpretation: V.R.B., A.G.C., Literature Search: V.R.B., Writing: V.R.B.

Conflict of Interest: No conflict of interest was declared by the authors.

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