

Ultra-Fast Pediatric Brain MRI for Toddlers and Young Children Using Deep Learning Acceleration

Sebastian Altmann, M.D.; Vanessa Schöffling, M.A.; Ahmed Othman, M.D., MHBA

Johannes Gutenberg University (JGU) Medical Center Mainz, Department of Neuroradiology, Center for Imaging, Minimally Invasive and Molecular Therapy, Mainz, Germany

Introduction

The rapid advancement of deep learning-based reconstruction techniques has led to significant changes in medical imaging, most notably in magnetic resonance imaging (MRI). These developments, which currently focus primarily on the acquisition of 2D datasets, have enabled substantial reductions in scan time [1–3]. This opens up new possibilities, especially in the fields of pediatric radiology and neuroradiology.

In neonates and infants¹ during the first months of life, the feed-and-wrap technique has proven to be highly effective. In this approach, the child is fed immediately before the MRI examination in an attempt to induce a natural sleep phase. This, combined with immobilization in a vacuum mattress, is usually sufficient for successful image acquisition [4].

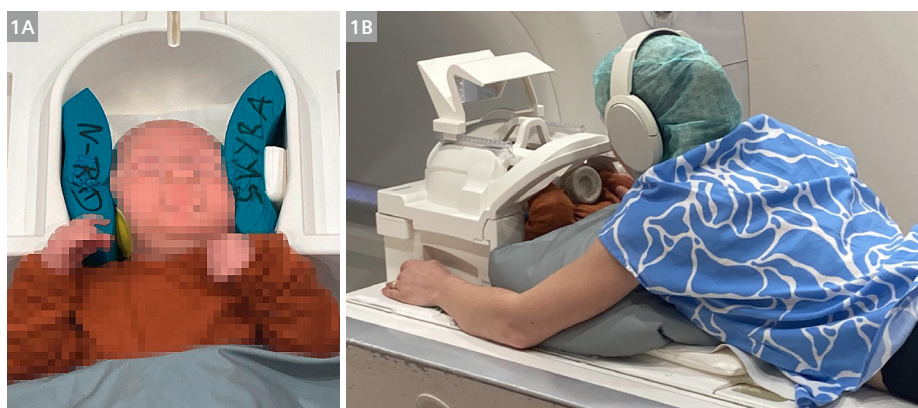
However, for young children aged 6 months¹ to about 6 years, sedation or general anesthesia remain the most reliable options for acquiring diagnostic MRI datasets. This necessity presents multiple challenges, particularly in emergency settings or during recurrent follow-up examinations (e.g., in patients with ventriculoperitoneal shunts). In addition to the significant healthcare costs, sedation carries a low but not negligible risk for pediatric patients.

Furthermore, the logistical and staffing requirements for anesthesia often limit its availability, especially in acute care scenarios, where trained anesthesiology personnel may not be immediately accessible [5, 6].

These limitations can, in extreme cases, result in delayed or insufficient MRI diagnostics, forcing clinicians to rely on computed tomography (CT) instead. While CT offers speed and accessibility, it also involves ionizing radiation exposure, which is particularly undesirable for this vulnerable patient population [7].

Until recently, the technical capacity to significantly accelerate MRI acquisition was limited. However, emerging technologies, including real-time imaging and deep learning-based reconstruction algorithms, are now providing viable solutions to these challenges [8].

In this article, we describe the successful clinical implementation of an ultra-fast, T2-weighted, deep learning-enhanced MRI protocol tailored to pediatric patients, especially to those aged from 6 months¹ to 6 years. We provide a detailed overview of our workflow, with practical recommendations for patient preparation, positioning, and scan execution aimed at optimizing outcomes in both routine follow-ups and emergency pediatric imaging scenarios.



1 (1A) Positioning of an infant in the head coil for MRI examination: The infant wears adequate hearing protection. The head is securely stabilized within the coil using soft padding, and the body is additionally supported with a vacuum cushion. (1B) The mother lies in a prone position with forearms propped up to soothe the infant, maintains eye contact via a mirror, and can also hold the bottle. Both wear adequate hearing protection.

¹MR scanning has not been established as safe for imaging fetuses and infants less than 2 years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.

Weighting	T2	T2	T2
Orientation	Transversal	Coronal	Sagittal
Averages	1	1	1
Total time (sec)	17	15	15
Time of acquisition (sec)	5	5	5
FOV (mm ²)	240	240	240
Matrix size	384 × 384	384 × 384	384 × 384
Phase resolution	80%	80%	80%
TE (ms)	97	97	97
TR (ms)	3850	3470	3470
Reconstructed voxel size (mm ³)	0.3 × 0.3 × 5 (i)	0.3 × 0.3 × 5 (i)	0.3 × 0.3 × 5 (i)
Parallel imaging acceleration	4	4	4
SMS factor	2	2	2
Slice thickness (mm)	5	5	5
Slice distance factor	10%	10%	10%

Table 1: Sequence parameters for the ultra-fast deep learning-based protocol. Interpolation = i; time to echo = TE; repetition time = TR; Simultaneous Multi-Slice = SMS

Technical aspects

Sequences are accelerated using the CE-certified Deep Resolve techniques (Siemens Healthineers, Erlangen, Germany) and acquired in all three planes: axial, sagittal, and coronal, with a slice thickness of 5 mm using a 1.5T clinical scanner (MAGNETOM Sola; Siemens Healthineers, Erlangen, Germany) with a 20-channel head-neck coil. The total acquisition time for all three planes was less than one minute. The parameters for the sequences are provided in Table 1.

Patient preparation, positioning, and scan execution

Thorough preparation of both the child and the accompanying caregiver is crucial for successfully performing MRI examinations without sedation in children. In our clinical setting, parents receive detailed written information about the examination procedure at an early stage. Additionally, a standardized MRI safety questionnaire is provided to and discussed with the parents. The MRI compatibility of the accompanying person is systematically checked using a structured checklist to reliably rule out ferromagnetic implants or other contraindications.

A central element of the information provided is specific information about potential dangers in the MR tunnel, especially regarding the presence of a caregiver. These include restricted movement, emergency procedures, and the increased risk of RF-induced heating due to close

physical contact. Parents are informed in detail about these aspects to set realistic expectations and actively define their role.

Once safety clearance has been obtained and written consent has been given, the child is placed in a supine position directly on the scanner table. A vacuum-fixable mattress is then placed over the child to reduce involuntary movements during the examination and ensure stable positioning. In our setting, this positioning primarily serves to secure the infant or toddler during imaging. Additionally, soft positioning aids such as pillows and foam wedges are used to stabilize the position further and enhance comfort.

This form of positioning significantly optimizes image quality by minimizing motion artifacts. At the same time, however, wrapping the child in the vacuum mattress can impair heat dissipation and lead to increased thermal stress due to restricted ventilation. This effect is particularly noteworthy in very young patients. Due to the very short total duration of the examination in our protocol – typically only a few minutes – this risk is considered acceptable. For more protracted examinations, however, targeted monitoring of heat regulation would be necessary to prevent overheating.

The child's head is carefully positioned in the head coil and fixed in place with cushions inserted at the sides to severely restrict head movement.

To promote compliance and reduce anxiety, a child-friendly mirror is mounted inside the MRI tunnel. This allows the child to maintain constant visual contact with the accompanying caregiver. This measure has proven

particularly effective in younger children to minimize restlessness and movement. However, it is essential to ensure that the caregiver only looks at the child through the mirror. Lifting the head or looking directly down can lead to motion artifacts. The caregiver is therefore specifically instructed to maintain constant eye contact from a fixed position and not to change it during the examination.

A key feature of our protocol is the option of positioning a parent inside the MRI tunnel. Provided that safety clearance has been obtained and risk-specific consent has been given, the parent is positioned in a prone position inside the tube. The caregiver supports themselves on their elbows, gently embraces the child's upper body with their arms, and places their hands on either side of the child's head. This position allows for reassuring physical closeness and can, if necessary, contribute to additional manual stabilization of the head.

If in-bore positioning is refused or impractical, the caregiver remains at the entrance to the MRI tunnel. There, they can maintain reassuring tactile contact with the child's leg or abdomen. This form of support also has an anxiety-reducing effect, but is associated with an increased frequency of motion artifacts in children under three years of age.

In our institutional setting, we use the 1.5T MAGNETOM Sola scanner, because the examination room provided more space and a child-friendly environment, and the 70 cm bore diameter facilitated greater comfort for both child and caregiver. These infrastructural aspects, however, may vary between institutions.

The examination protocol was kept as short as possible. To this end, state-of-the-art AI-supported image reconstruction methods, the Simultaneous Multi-Slice technique, and targeted sequence optimizations such as increasing the turbo factor (echo train length) were employed. These measures significantly reduced acquisi-

tion time while maintaining diagnostic accuracy. Shortened protocols are particularly advantageous in pediatric imaging, as they minimize motion-related artifacts, improve patient comfort, and facilitate the feasibility of performing scans without sedation or anesthesia.

Our standardized methodology consistently enables the acquisition of high-resolution T2-weighted images in all three spatial planes, ensuring comprehensive representation of the child's neurocranial anatomy. Figure 2 illustrates the image quality achieved in a 2-year-old boy who was successfully examined without sedation following a fall against a door frame.

Direct skin-to-skin contact between the child and the caregiver may be necessary in exceptional cases, for instance when the child needs to be calmed or repositioned at short notice. Such contact should be limited to a few seconds and avoided whenever possible. As a rule, non-conductive, MRI-compatible materials such as thick foam layers or metal-free blankets are placed between the child and the caregiver to prevent RF loop formation and local overheating [9]. In our setting, standard metal-free positioning aids are routinely used, including two flat wedges, small triangular wedges, small wedge fillers, and two universal insert cushions (Siemens Healthineers, Erlangen, Germany). In addition, MRI-compatible pediatric thermal blankets may be employed, for example the ConRad™ MRI Safe Thermal Blanket (Patterson Veterinary, Loveland, CO, USA) or the MRI-Safe Pediatric Thermal Blanket (MRI Equip, Nisswa, MN, USA). These aids contribute to patient comfort and safety while minimizing the risk of RF loops and local heating during MRI examinations. In addition, a clear signal is agreed upon with the caregiver before the examination begins, which they can use to request a brief interruption of image acquisition – for example, by wiggling or lifting their foot. This arrangement allows the caregiver to calm or reposition the child



2 Images of a 2-year-old boy with head trauma. **(2A)** Axial T2 TSE with Deep Resolve, **(2B)** coronal T2 TSE with Deep Resolve, **(2C)** sagittal T2 TSE with Deep Resolve.

in a targeted manner while no image sequence is running that would be affected by movement.

To protect against acoustic stress, all pediatric patients receive combined hearing protection. Our facility uses individually adapted OHROPAX® Classic wax earplugs (OHROPAX GmbH, Wehrheim, Germany), which provide a particularly effective seal. In addition, child-friendly Natus MiniMuffs® ear muffs (Ewimed Switzerland AG, Bern, Switzerland) are applied to further reduce noise exposure from loud MRI sequences. For additional relief, sequences that are particularly low noise (e.g., single-shot T2) are placed at the beginning of the examination protocol, while louder gradient sequences are moved to the end of the examination whenever medically justifiable [10]. However, diagnostically necessary sequences always take priority, and repeat sequences are only performed if absolutely necessary after all essential acquisitions have been completed.

Infants and toddlers can also be calmed with a pacifier or a small bottle of familiar liquid (breast milk, infant formula, or mild tea), provided they tolerate this well. Slight motion artifacts caused by swallowing are acceptable as long as they do not significantly impair image quality. All drinking aids used must be completely metal-free and made of MRI-compatible plastic.

To increase motion robustness, our examination protocol specifically uses fast T2-weighted 2D sequences in three orthogonal planes (axial, coronal, sagittal). Longer 3D sequences with isotropic resolution are deliberately avoided, as they are significantly more susceptible to motion artifacts. The use of short-cycled 2D sequences increases the likelihood of obtaining usable image data even with slight movement.

In our workflow, the total duration of image acquisition for all three planes is less than one minute. The coro-

nal plane provides an excellent representation of subdural fluid accumulations and the anterior skull base. The sagittal plane allows for a differentiated assessment of cerebrospinal fluid spaces, the ventricular system, and mid-line structures. The axial plane complements the dataset with a detailed image of cortical and subcortical structures. The total duration of the examination is therefore very short. By far the most time-consuming part is the careful preparation of the child and caregiver, and these efforts are directly related to image quality and the avoidance of repeat images.

Finally, it should be emphasized that non-sedation strategies do not necessarily reduce the overall examination time. While rapid acquisition techniques shorten scan duration, the time saved is largely invested in comprehensive preparation, including calming the child and positioning. Sedation-free strategies may allow some of this preparation to be performed outside the scanner room, potentially reducing the total time the patient spends in the scanner. The primary aim remains to avoid the risks associated with sedation – such as respiratory complications, circulatory instability, and post-anesthetic monitoring – while still obtaining high-quality diagnostic images.

Challenges in daily routine and limitations

These ultra-fast MRI sequences and the resulting significantly shortened scan times substantially reduce the risk of patient movement and associated motion artifacts. However, if movement occurs during this short scanning window, it can still result in pronounced artifacts. Therefore, despite all advancements in AI-assisted image reconstruction, this novel imaging protocol is not immune to motion-related artifacts.



3 Images from a 19-month-old male infant¹. **(3A)** and **(3B)** demonstrate impaired image quality of initial scans due to motion artifacts. As the acquisition time per sequence is less than 20 seconds, sequences can easily be repeated; **(3A, 3B)** axial T2 TSE with Deep Resolve, **(3C)** axial T2 TSE with Deep Resolve after calming the toddler.

However, due to the very short acquisition time of approximately 15–17 seconds per sequence, individual sequences can be easily repeated if temporary agitation results in relevant motion artifacts.

Figure 3 is an example of a 19-month-old male infant¹ who was accidentally dropped by his mother as she was going up the stairs. In this case, several brief repetitions of the scan were necessary, due to relevant motion artifacts. They resulted in significantly improved diagnostic quality. Nevertheless, some examinations cannot be completed entirely free of artifacts. While image quality may be compromised in such cases, it is often still sufficient for a confident diagnostic assessment. Figure 4 illustrates persistent motion artifacts in a 7-year-old boy, who underwent a regular control examination due to shunted congenital hydrocephalus.

Up to now, preparing children and their parents for the child's MRI examination has taken place in the anteroom of our MRI scanner. From there, the child can be introduced to the scanner and examination room through the open door. However, a significantly more effective approach – currently in planning – involves gradually and playfully familiarizing especially young children with the examination over multiple sessions. This includes a separate informational and preparation appointment using a pediatric MRI dummy, which allows for trial positioning.

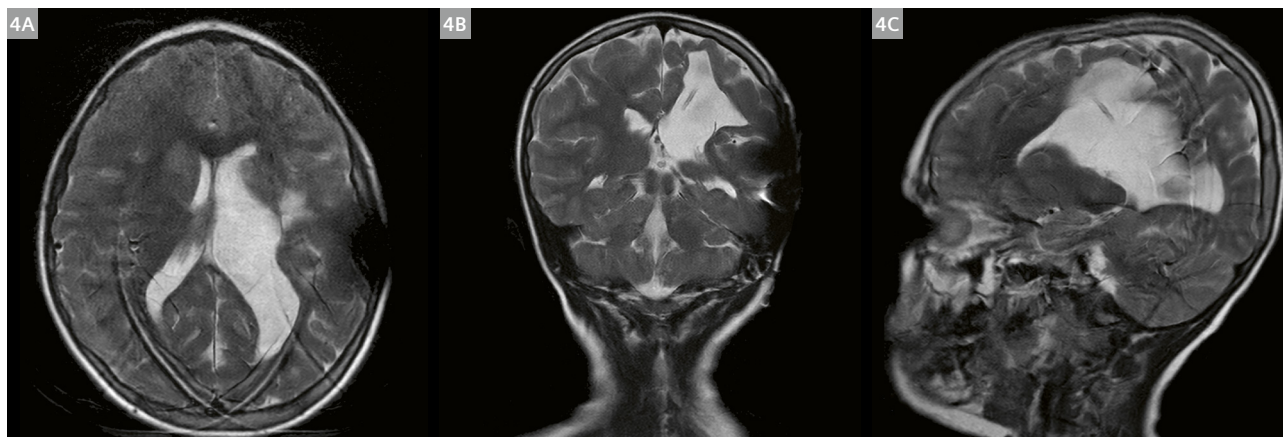
This setup offers several advantages: First, it reduces stress for staff, as it takes place outside of regular clinical operations and does not interfere with the ongoing examination schedule. Second, it allows radiology technologists to assess in advance whether a child might be too agitated for this examination technique.

For children, this stepwise process under protected conditions offers the opportunity to become gently accustomed to the procedure, helping to reduce the fear associated with an MRI scan. From our perspective, this type of preparation has the potential to improve image quality further, reduce the need for sequence repetition, and potentially lessen the emotional burden on parents, especially in cases where they may need to help stabilize their child's head during the scan.

Conclusion

Ultra-fast, non-sedated pediatric brain MRI using Simultaneous Multi-Slice (SMS) acquisition and deep learning-accelerated image reconstruction is feasible in children aged 6 months¹ to 6 years. Successful implementation requires meticulous preparation of both the child and the accompanying caregiver to ensure high-quality diagnostic images. In our protocol, rapid acquisition across three orthogonal planes, combined with AI-supported reconstruction, enables T2-weighted imaging, often within a total scan time of less than one minute.

These accelerated non-sedated protocols may, in selected cases, serve as a robust first-line imaging technique, potentially replacing CT in situations where radiation exposure is a concern, such as mild head trauma. By minimizing the need for sedation, this approach reduces periprocedural risks, enhances patient comfort, and may lower overall healthcare costs. The integration of structured pediatric preparation and gradual familiarization with the MRI environment further improves the likelihood of successful examinations and may decrease the need for repeat sequences.



4 Even after repetition due to severe artifacts, motion artifacts remain. Image quality is still impaired, but relevant intracranial pathology can be excluded. **(4A)** axial T2 TSE with Deep Resolve, **(4B)** coronal T2 TSE with Deep Resolve, **(4C)** sagittal T2 TSE with Deep Resolve.

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Contact

Sebastian Altmann, M.D.
Johannes Gutenberg University (JGU)
Medical Center Mainz
Department of Neuroradiology
Center for Imaging, Minimally Invasive
and Molecular Therapy
Langenbeckstr. 1
55131 Mainz
Germany
Tel.: +49 (0) 6131 17-6256
Sebastian.Altmann@unimedizin-mainz.de



Vanessa Schöffling, M.A.
Johannes Gutenberg University (JGU)
Medical Center Mainz
Department of Neuroradiology
Center for Imaging, Minimally Invasive
and Molecular Therapy
Langenbeckstr. 1
55131 Mainz
Germany
Vanessalnes.Schoeffling@unimedizin-mainz.de



Professor Ahmed Othman, M.D., EBIR
Johannes Gutenberg University (JGU)
Medical Center Mainz
Department of Neuroradiology
Center for Imaging, Minimally Invasive
and Molecular Therapy
Langenbeckstr. 1
55131 Mainz
Germany
Ahmed.Othman@unimedizin-mainz.de

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