Pediatric and Fetal MRI

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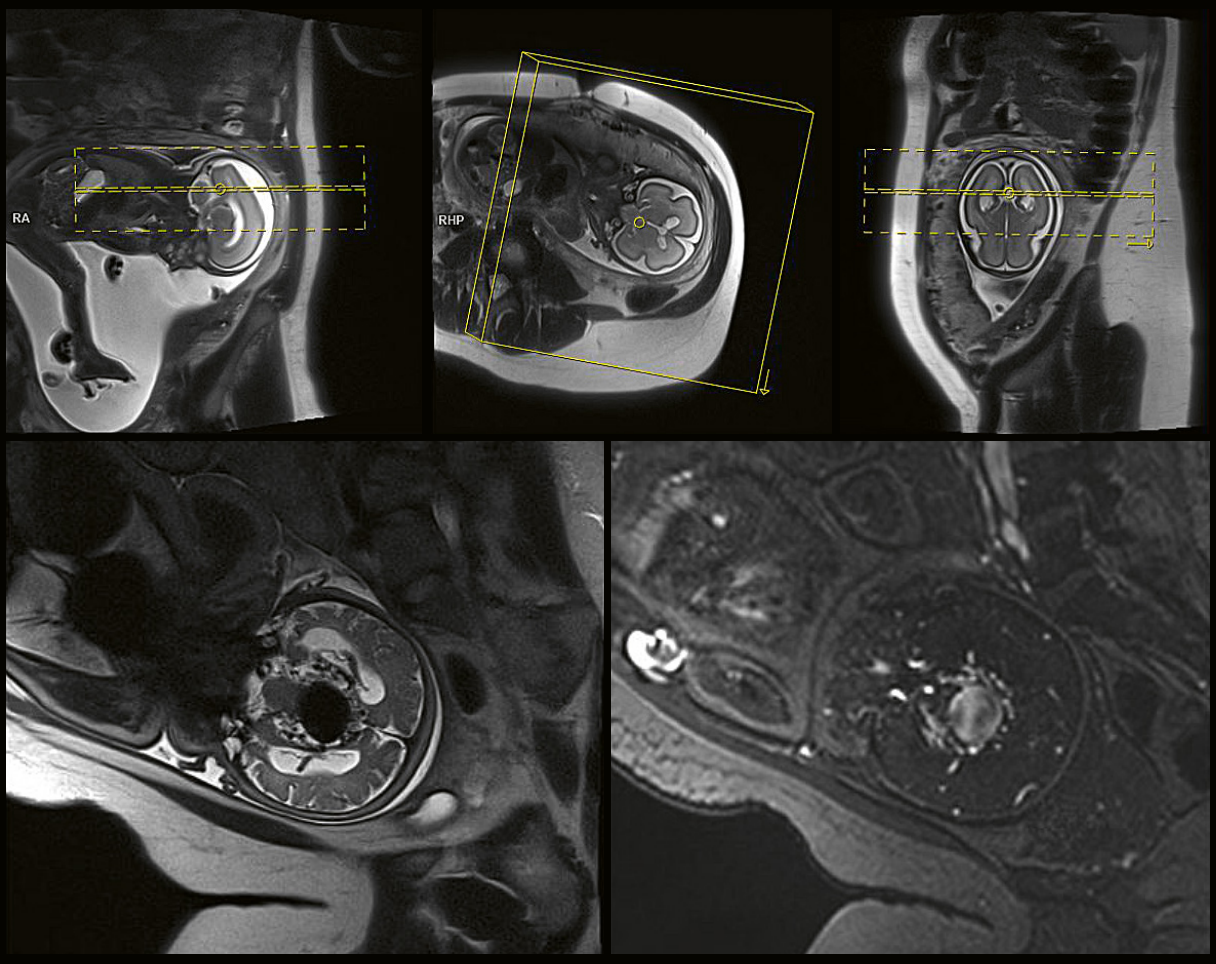

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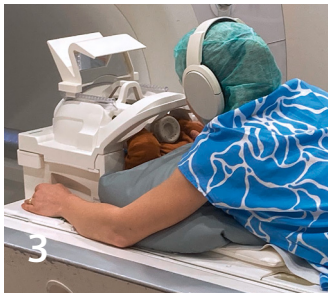
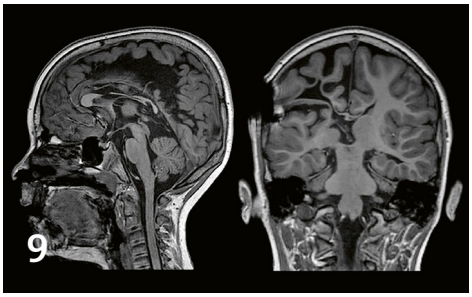
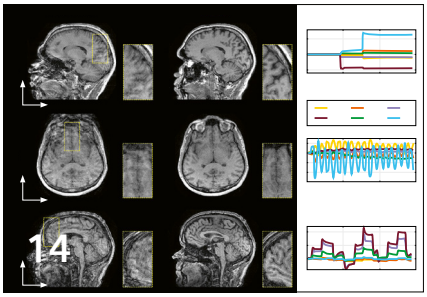


Deep learning acceleration for ultra-fast pediatric[1] brain MRI

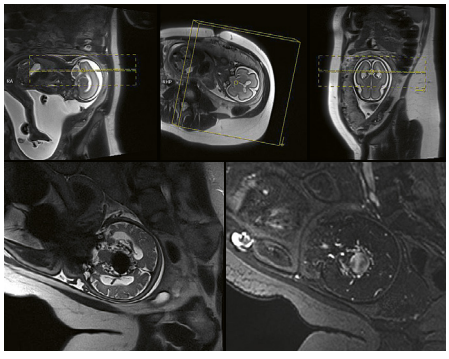


Sedation-free neuroimaging with Deep Resolve 3D[2]



BioMatrix Motion Sensor (SAMER)

Pediatric Imaging



Cover image
"Fetal Intracerebral Vascular MRI: How I Do It" by Matt Thomas, et al. (I-MED Radiology Fortitude Valley, Fortitude Valley, Queensland, Australia)

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

[2] Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.

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

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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.

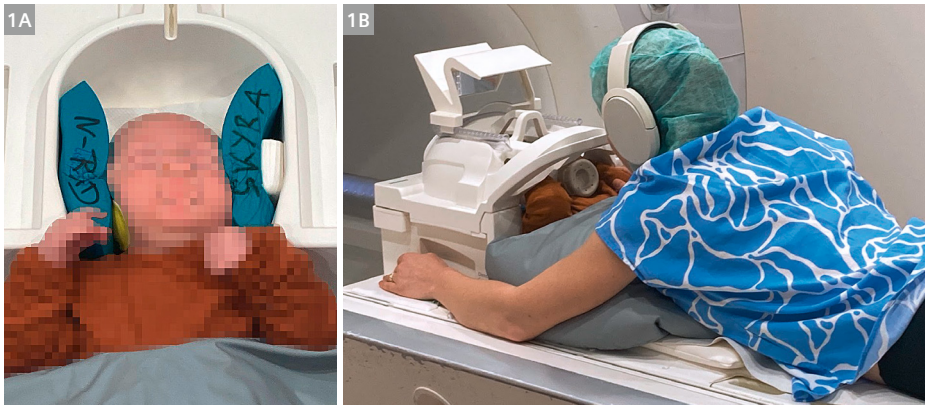
In neonates and infants[1] during the first months of life, the feed-and-wrap technique has proven to be highly effective. In this approach, the child is fed immediately before the MRI examination in an attempt to induce a natural sleep phase. This, combined with immobilization in a vacuum mattress, is usually sufficient for successful image acquisition [4].

However, for young children aged 6 months[1] 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 months[1] 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.

[1] *MR 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.

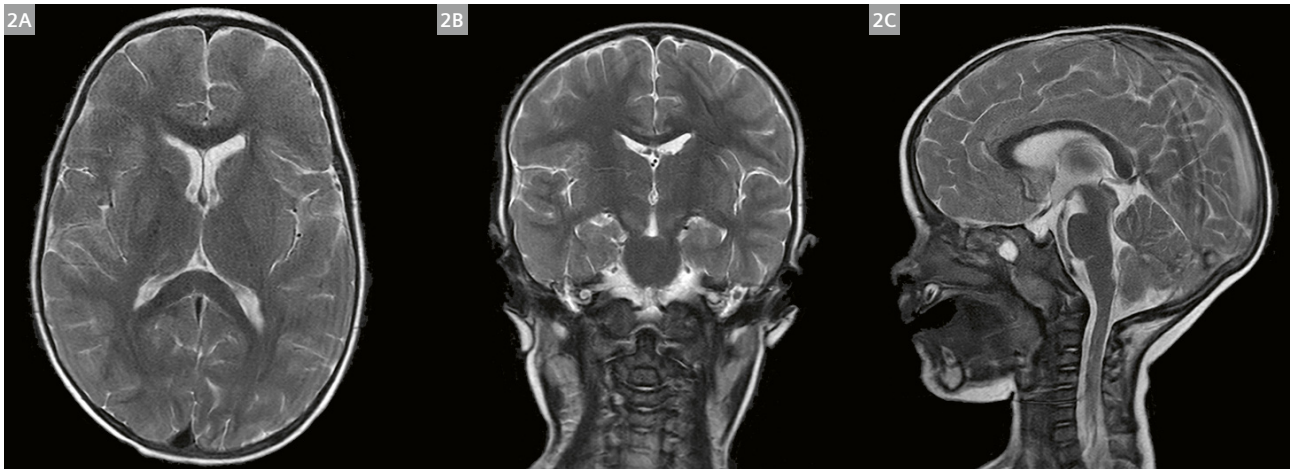
If in-bore positioning is refused or impractical, the caregiver remains at the entrance to the MRI tunnel. There, they can maintain reassuring tactile contact with the child's leg or abdomen. This form of support also has an anxiety-reducing effect, but is associated with an increased frequency of motion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

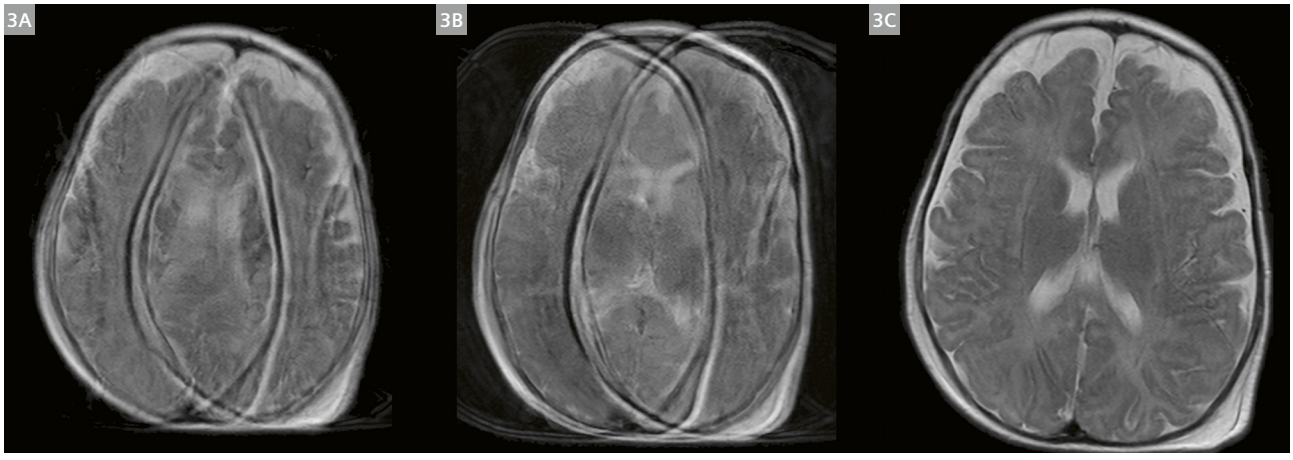
To increase motion robustness, our examination protocol specifically uses fast T2-weighted 2D sequences in three orthogonal planes (axial, coronal, sagittal). Longer 3D sequences with isotropic resolution are deliberately avoided, as they are significantly more susceptible to motion artifacts. The use 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 coronal 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 midline 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 infant[1]. **(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 infant[1] 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.

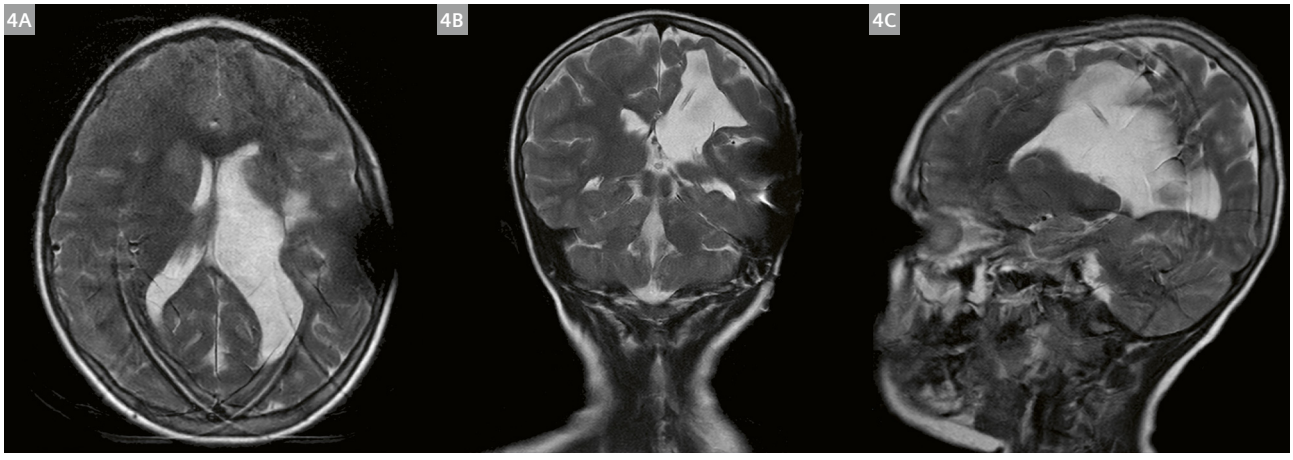
This setup offers several advantages: First, it reduces stress for staff, as it takes place outside of regular clinical operations and does not interfere with the ongoing examination schedule. Second, it allows radiology technologists to assess in advance whether a child might be too agitated for this 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 months[1] 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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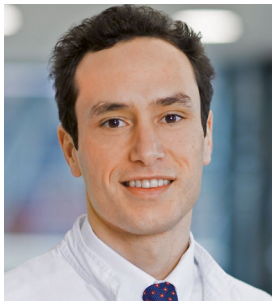

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Sedation-Free Pediatric Neuroimaging with Deep Learning-Reconstructed Deep Resolve 3D MR Sequences

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Introduction

In this article, we evaluate whether 3D sequences with deep learning (DL)-based image reconstruction can replace 3D sequences without DL for pediatric[1] neuroimaging, and help achieve sedation-free MRI exams.

At Oslo University Hospital, we encounter a significant number of pediatric cases, which present unique challenges due to their specific needs. Sedation or general anesthesia are commonly used during MRI exams for younger patients to ensure they remain still throughout the scan.

Cutting-edge AI-based techniques like DL-based image reconstruction have significantly contributed to faster scans, which are crucial for every patient group [1–4]. Faster scans offer the advantage of producing clearer and more detailed images by reducing the occurrence of motion artifacts, leading to more accurate diagnoses and higher success rates of awake MRI scans [5]. Deep Resolve is a newly launched deep learning application that enables faster, more motion-robust scans. Deep Resolve Boost is a powerful denoising algorithm to mitigate noise enhancement due to higher acceleration factors. Deep Resolve Sharp is a DL-based interpolation to improve the image resolution by a factor of two along each spatial dimension.

When scanning younger children[1], this can help reduce sedation rates, along with the associated risks and costs [6]. It also minimizes patient discomfort and can potentially improve the overall patient experience.

Findings and procedure details

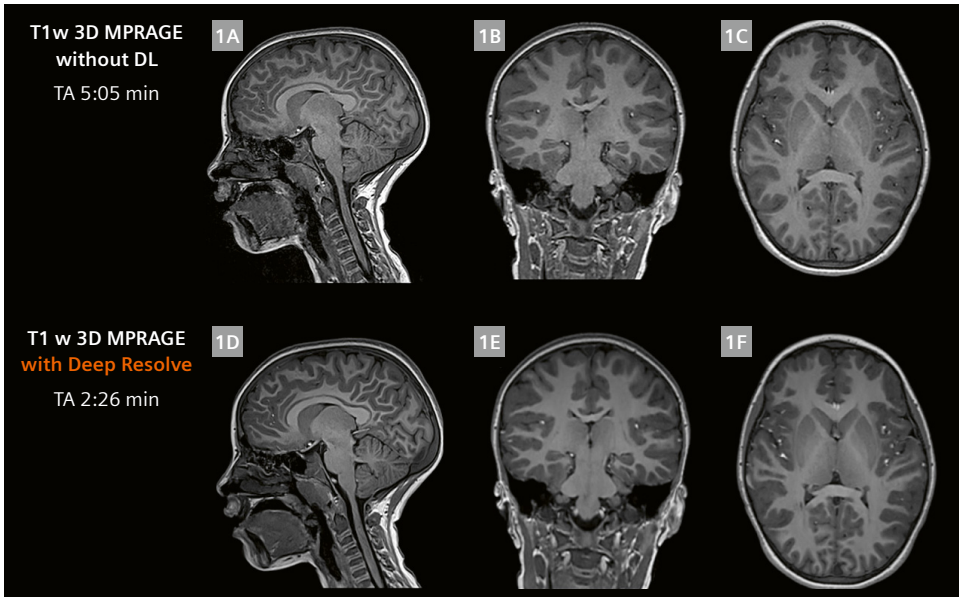
In addition to fast, motion-robust protocols such as Deep Resolve, proper patient preparation is a key element in enabling pediatric MRI without sedation or general anesthesia. Most of our neuro protocols include both 2D and 3D sequences. At our 3T MAGNETOM Skyra Fit (Siemens Healthineers, Erlangen, Germany), Deep Resolve is currently available for 2D sequences, and has been highly beneficial [7]. However, we are eager to have deep learning capabilities for 3D sequences. Currently, we are collaborating with Siemens Healthineers to implement work-in-progress (WIP) sequences[2] to use Deep Resolve in our 3D sequences. The two most commonly used and time-consuming 3D sequences are T1w 3D MPRAGE and T2w 3D SPACE FLAIR. Applying DL to these sequences would greatly assist in situations where patients struggle to remain in the scanner for extended periods.

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

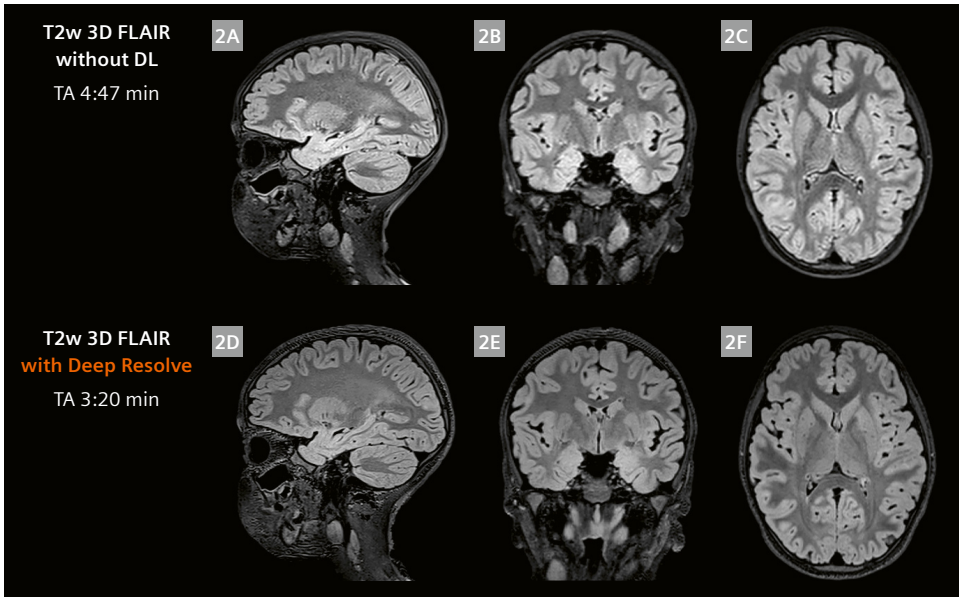
[2] *Work in progress. The applications are currently under development and are not for sale in the U.S. and in other countries. Their future availability cannot be ensured*

Case 1

A 6-year-old girl with sickle cell anemia underwent an MRI of the brain prior to stem cell transplantation.



1 T1w 3D MPRAGE
This figure illustrates the difference between T1w 3D MPRAGE images with and without Deep Resolve deep learning (DL) image reconstruction. The conventional protocol uses PAT 2 and an isotropic resolution of 1.0 × 1.0 × 1.0 mm^3 while the Deep Resolve protocol uses PAT 6 and an isotropic resolution of 0.8 × 0.8 × 0.8 mm^3. However, DL helps to reduce acquisition time by nearly 52%. **1A** and **1D** show the initial orientation, while **1B**, **1C**, **1E**, and **1F** are multiplanar reconstructions (MPR).

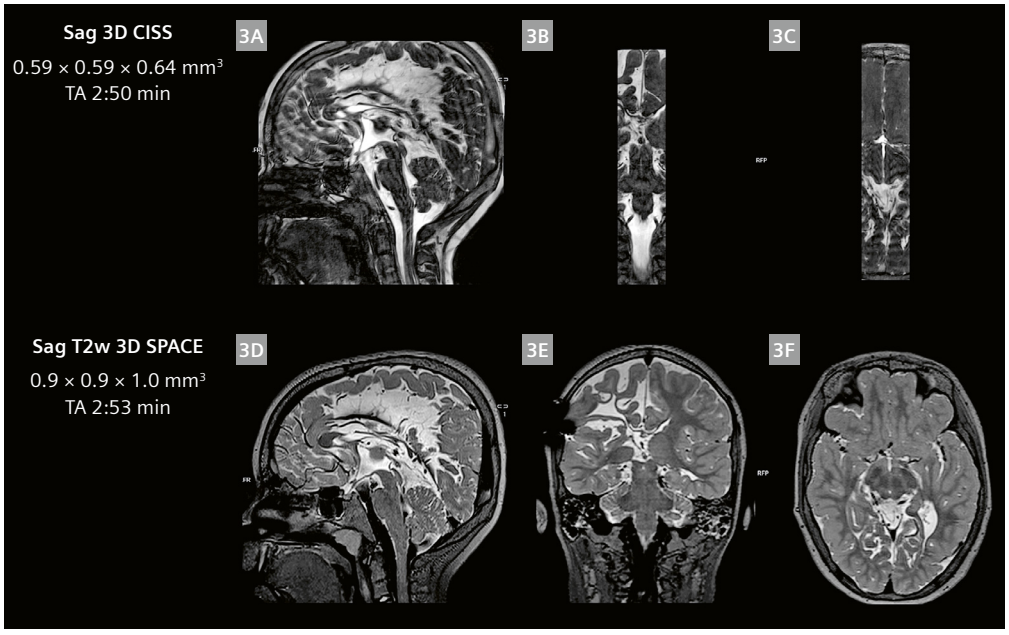


2 T2w 3D FLAIR
This figure demonstrates the difference between T2w 3D FLAIR images with and without Deep Resolve deep learning image reconstruction. The resolution and slice coverage are comparable in both sequences (0.9 × 0.9 × 0.9 mm^3). The conventional protocol uses PAT 4, while the Deep Resolve protocol uses PAT 6. With Deep Resolve, it was possible to reduce the acquisition time by approximately 30% for this sequence. **2A** and **2D** show the initial orientation; **2B**, **2C**, **2E**, and **2F** show the corresponding MPRs.

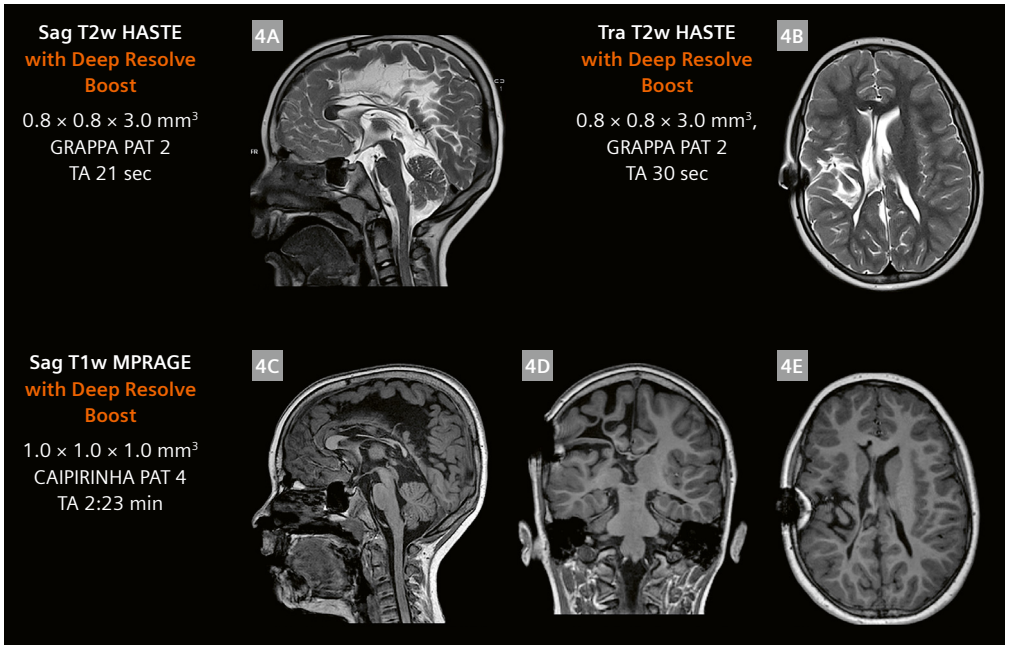
Using Deep Resolve, it was possible to reduce the scan time by 52% and 30% for MPRAGE and 3D FLAIR, respectively, while improving the apparent image quality. While Deep Resolve Boost helped maintain a great signal-to-noise ratio (SNR) despite the higher acceleration factor, Deep Resolve Sharp helped improve the image quality by reconstructing images with a super-resolution factor of 8. Since the resolution is improved in readout and phase-encoding direction by a factor of 2, we have a total factor of 4 in 2D imaging. In addition, with 3D Deep Resolve, you can add a factor of 2 in slice direction giving you an overall factor of 8.

Case 2

Awake MRI examination of a 7-year-old boy with a porencephalic cyst and difficulty remaining still. The patient is being monitored following a shunt placement.



3 The 3D CISS images **(3A–3C)** exhibit motion artifacts due to the patient's difficulty in remaining still. In contrast, the T2w 3D SPACE sequence **(3D–3F)** was successfully completed with good image quality. **3A**, **3D** initial sagittal orientation, **3B**, **3C**, **3E**, and **3F** corresponding coronal and transversal MPRs.

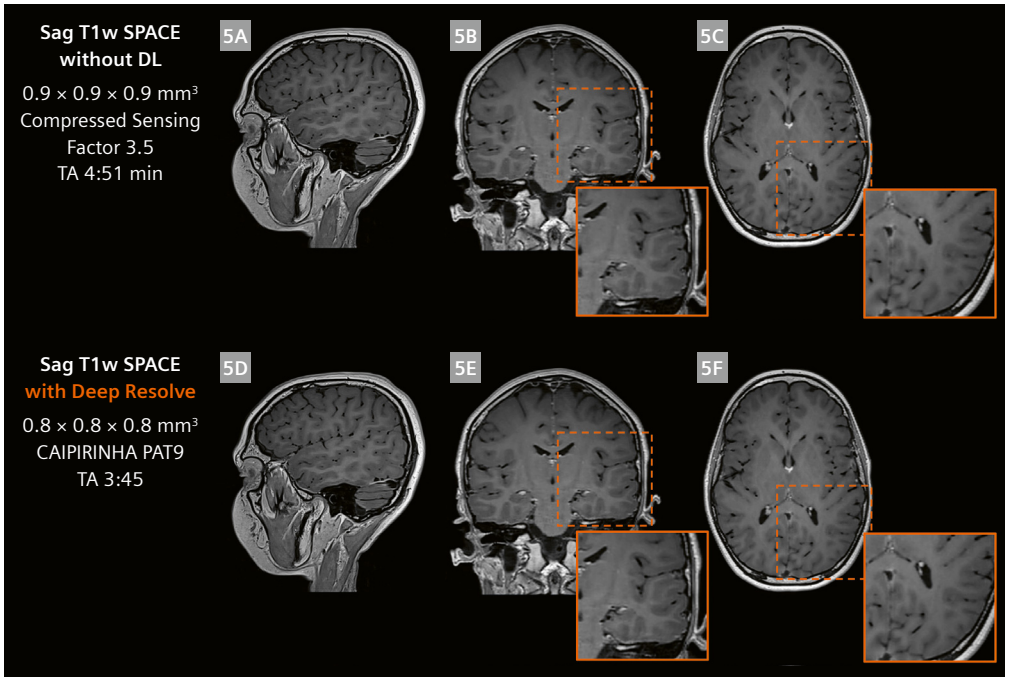


4 Continued from Figure 3. The boy expressed a desire to leave after the previous scan, but agreed to stay a few more minutes. We then performed a T2w HASTE sequence with Deep Resolve (**4A** and **4B**), which allowed us to obtain sharp images in just a few seconds. Finally, we conducted the T1w MPRAGE sequence with Deep Resolve **(4C)** as he reached his limit of tolerance. Figures **4D** and **4E** are MPR of 4C.

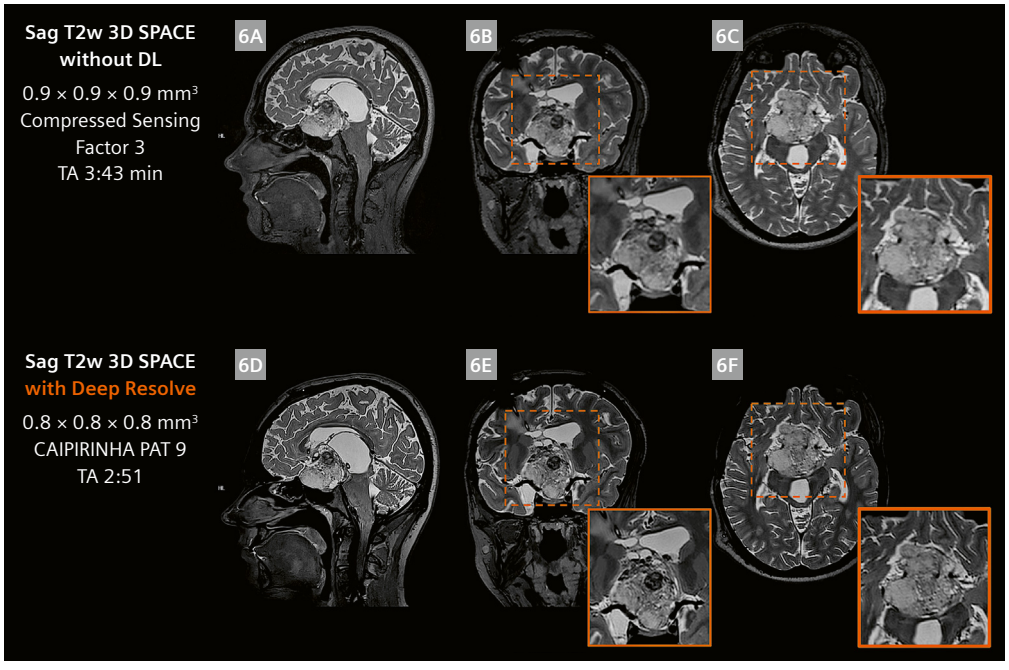
In this patient with limited cooperation, Deep Resolve was essential to performing a successful non-sedated MRI examination. Notably, without Deep Resolve, the routine T1w MPRAGE sequence, which typically requires approximately 5 minutes, would likely have been unfeasible in this case.

Case 3

A 10-year-old boy underwent MRI without sedation for a known pilomyxoid astrocytoma in the suprasellar region.



5 This figure highlights a key challenge of 3D volumetric imaging: The MPR views often appear less sharp than the initial imaging orientations, which in this case is the sagittal orientation. Using the T1w 3D SPACE sequence, we compared routine acquisitions **(5A–5C)** with images acquired using Deep Resolve **(5D–5F)**. The results clearly demonstrate improved sharpness and clarity of the MPR view with Deep Resolve. 5A and 5D initial sagittal orientation, 5B, 5C, 5E, and 5F coronal and transverse MPRs respectively.



6 Continued from Figure 5, we observe a similar effect with the T2w 3D SPACE sequence. The comparison between images without deep learning **(6A–6C)** and with Deep Resolve **(6D–6F)** reveals the same outcome: significantly sharper and clearer MPR views, without any signs of blurriness when applying Deep Resolve.

Here again, Deep Resolve allowed faster scans for both T1w and T2w SPACE while improving the image quality, especially when performing 3D reformatting.

Conclusion

The use of Deep Resolve 3D for pediatric neuro imaging shows great potential to further reduce the overall exam time beyond what was possible with Deep Resolve 2D. It furthermore contributes to improving image quality and the apparent resolution of the images. This may contribute to avoiding sedation or general anesthesia in some pediatric patients, while contributing to improve the diagnostic accuracy.

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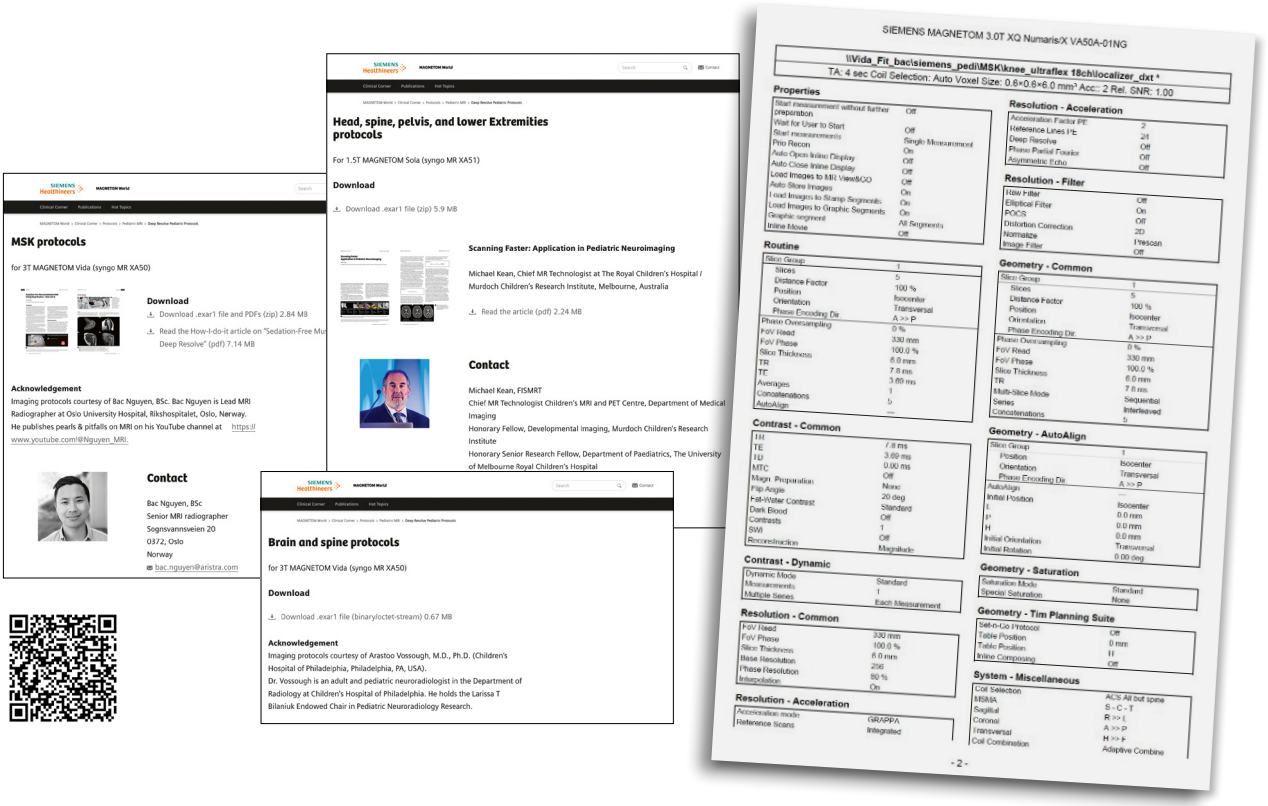

Scout-Accelerated Motion Estimation and Reduction (SAMER) for Pediatric Brain MRI

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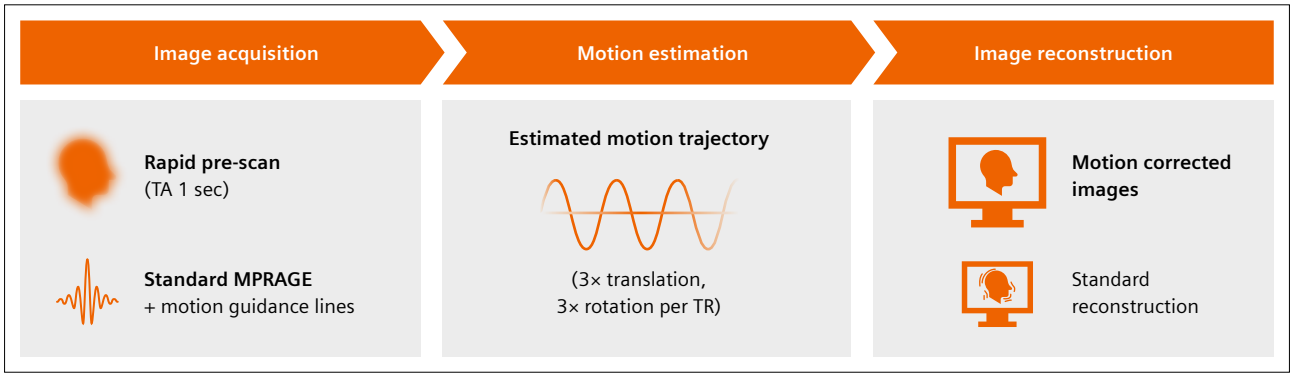
One of the biggest challenges in pediatric magnetic resonance imaging (MRI) is managing motion artifacts. Sedation or anesthesia is frequently used in pediatric[1] MRI, to minimize the motion artifacts. However, these approaches carry increased medical risks and additional costs [1]. Various strategies have been implemented to minimize motion in non-sedated pediatric MRI. These include patient preparation through educational videos, involvement with child life specialists, the use of MRI mock scanners and MRI-compatible audiovisual equipment [1, 2]. Additionally, modifications in MRI data acquisition can enhance motion robustness. Techniques like BLADE/PROPELLER [3] reduce susceptibility to motion by repeatedly traversing the center of *k*-space but often lead to increased scan time and altered image contrast and appearance compared to Cartesian acquisitions. Furthermore, reducing scan time has proven beneficial in non-sedated pediatric MRI. Emerging deep learning methods enable higher acceleration factors without compromising signal-to-noise ratio (SNR) or introducing reconstruction artifacts, making them increasingly common in clinical practice. However, while faster scanning may decrease the likelihood of motion, it cannot entirely eliminate patient motion [4, 5]. Moreover, highly accelerated acquisitions may exacerbate the appearance of motion artifacts compared to scans with moderate acceleration [6, 7].

Motion correction techniques offer a promising solution, however, no single method has yet gained widespread clinical acceptance due to the stringent requirements for robustness, reliability, and seamless integration into clinical workflows. Data-driven retrospective motion correction [8] offers a promising solution to these challenges. It derives the motion trajectory information from the acquired *k*-space data of the imaging sequence and produces the motion-corrected images without the need for additional tracking hardware or disruptive sequence modifications. Moreover, a significant advantage over prospective techniques is that radiologists can directly compare the motion-modeled reconstruction with the original, non-corrected images.



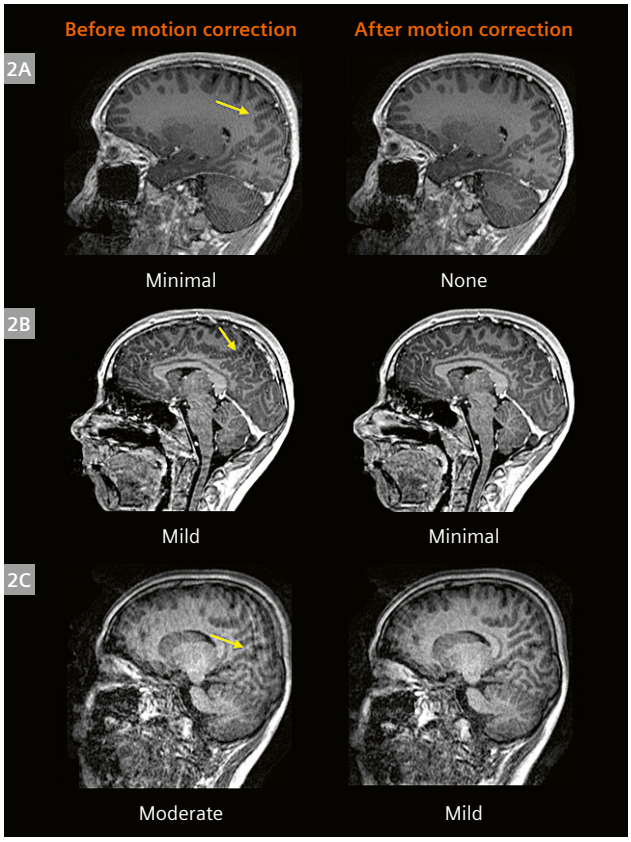
1 **Illustration of SAMER motion correction for MPRAGE.**
The rapid pre-scan (scout) and motion guidance lines acquired in every TR facilitate very rapid estimation of the six-degrees of rigid-body motion. Once all motion parameters across all TRs have been estimated, the motion-corrected images are computed by inverting a generalized forward model that takes into account the previously estimated motion trajectory. Moreover, the original, non-corrected images can be reconstructed.

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

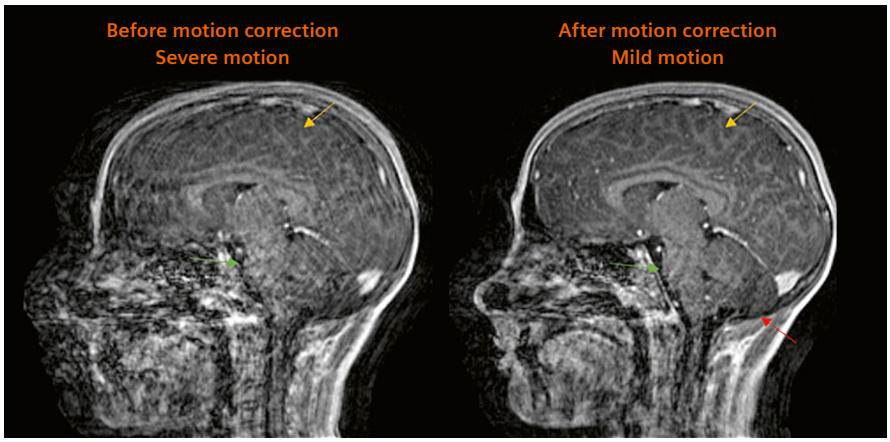
One such data-driven method is scout accelerated motion estimation and reduction (SAMER)[2] [6, 9, 10]. The SAMER technique is based on SENSE parallel imaging, utilizing a generalized forward model that accounts for motion effects. At the beginning of the SAMER scan, an ultra-fast, low-resolution scout image (TA ~1 second) is acquired, which is assumed to be motion-free (Fig. 1). The six degrees of rigid body motion (3× translation, 3× rotation) are estimated by comparing the scout image against a very small number of additional *k*-space encoding lines (motion guidance lines) acquired in every TR. Once all motion parameters from all TRs have been estimated, the motion-mitigated image is obtained by inverting a generalized forward model that incorporates the previously estimated motion trajectory. A key computational advantage of SAMER is its ability to estimate the subject's motion for each motion state independently, enabling very rapid computation times using standard scanner hardware.

We tested SAMER in non-sedated pediatric patients (<18 yrs old) undergoing outpatient clinical brain MRI examination on a 3T MRI system (MAGNETOM Prisma, Siemens Healthineers, Erlangen, Germany). The imaging protocols for all cases included the SAMER T1-weighted MPRAGE research sequence. The parameters for the MPRAGE sequence used for SAMER motion correction were: resolution = 1 × 1 × 1 mm^3, R = 2 × 2 and acquisition time 2:37 minutes. Since SAMER is a retrospective technique we can directly compare the motion corrected images against the original/standard reconstructed images.

Figure 2 presents T1 MPRAGE scans of awake pediatric patients imaged for various clinical indications, displaying motion artifacts from minimal to moderate. The SAMER method successfully reduced these artifacts, improving motion by one grade. In Figure 3, a case with severe motion is shown, where SAMER achieved a significant reduction in artifacts, improving motion by two grades.



2 **Representative cases:**
Sagittal T1 MPRAGE images in pediatric patients scanned for various clinical indications (top to bottom: adrenoleukodystrophy, seizure and headache) and had normal brain MRI.
(2A) Brain MRI in an 8-year-old boy with minimal motion artifact.
(2B) Brain MRI in a 9-year-old boy with mild motion artifact.
(2C) Brain MRI in a 9-year-old girl with moderate motion artifact.
Note that greater motion resulted in a greater degree of blurring of the gray/white matter junction. SAMER reconstruction improved motion by one grade, with motion grades following motion correction indicated on the right side of the figure.



3 Sagittal images of a 12-year-old boy show significantly improved motion artifacts by two grades on the motion-corrected SAMER (mild motion, grade 3) compared to the non-corrected (severe motion, grade 5) images. The brain cortex (yellow arrow), brainstem (green arrow), and posterior cranial fossa (red arrow) are better delineated and visualized on the SAMER images and are blurred and non-diagnostic on the non-corrected images.

[2] *Work in progress. The application is currently under development and is not for sale in the U.S. and in other countries. Its future availability cannot be ensured.*

In conclusion, SAMER enhances the diagnostic image quality of clinical brain MR exams when motion is present, with the most notable improvements occurring in cases of moderate to mild motion. Future research will aim to expand SAMER to other sequences and image contrasts, allowing more children to undergo imaging without the need for anesthesia or repeated examinations.

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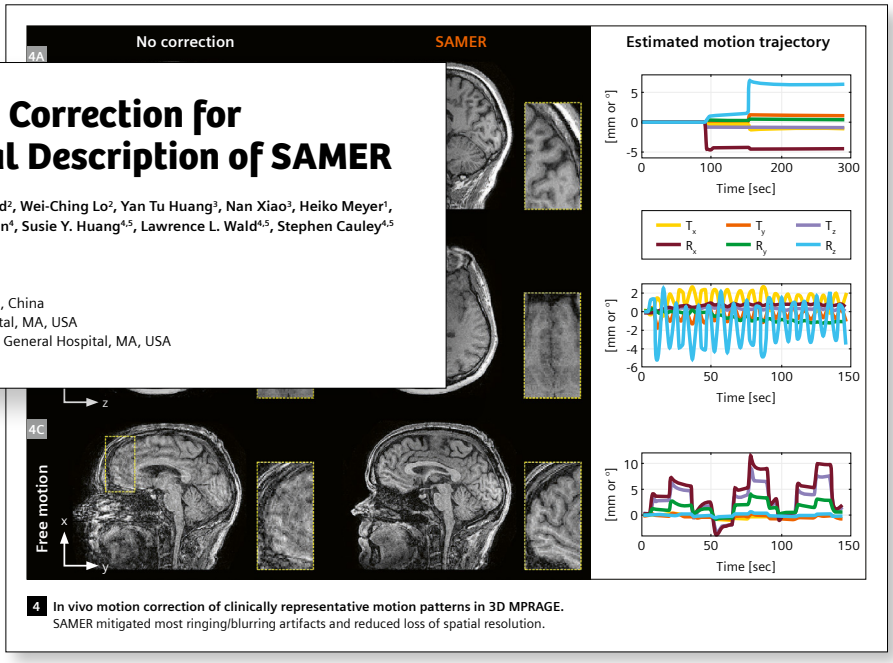

4 **In vivo motion correction of clinically representative motion patterns in 3D MPRAGE.** SAMER mitigated most ringing/blurring artifacts and reduced loss of spatial resolution.

Fetal Intracerebral Vascular MRI: How I Do It

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The goal of this article is to share how our site performs fetal[1] intracerebral vascular MRI. While ultrasound remains the primary modality for disorders related to pregnancy, MRI is increasingly used for problem solving and detailed visualization of the fetus. This information is valuable for better-informed prenatal counselling and guiding of treatment decisions, delivery, and post-natal care [1–3]. Furthermore, unlike ultrasound, MRI is not as limited by fetal position, maternal body habitus, overlying bone or gas, oligohydramnios, or ossification of the skull [1–3]. Vascular abnormalities that are suspected and/or not adequately assessed by ultrasound are one of many indications for fetal MRI [3].

In this article, we discuss how MRI of fetal intracerebral vasculature can be performed. We cover patient preparation, examination setup, practical scanning advice, protocol options, and post-processing.

Pre-appointment patient preparation

Patient preparation is an integral part of fetal MRI scanning [4, 5]. Good patient preparation contributes to the fetus being less active during the scan, which improves image quality and minimizes the need for patient recalls.

At the time of booking, patients are provided with a *Fetal MRI Patient Information Guide*. This details the procedure, MRI safety screening forms for the patient and their support person, equipment setup and expected scan time, breathhold techniques, and fasting and dietary instructions.

The patient is asked not to eat for four hours prior to their appointment. They are also asked to refrain from drinking cold, carbonated, or sugary drinks six hours prior to their appointment. We encourage them to drink room-temperature water. The patient is also instructed not to ingest any caffeine 24 hours prior to the appointment. These steps may reduce the likelihood of fetal motion during the scan [1].

The patient is also given the option of bringing a support person who can enter the MRI scan room with them. Additionally, they are informed that, although infrequent, recalls can occur due to inherent fetal movement. Relevant prior imaging should be requested and reviewed.

Examination setup

A clear explanation for the fetal MRI scan is given, along with instructions for the breathing techniques that the patient can use. A sensitive approach is important, as it is often a very stressful and emotionally charged time for the patient and their family [6]. Coil position is key, with the goal being to maximize signal in the region of interest. It is helpful to ask the patient if they know where the baby's head is located, what position they normally sleep in, or which position is most comfortable for them to lie in. We offer music to help calm the patient and provide some distraction, with relaxation music being preferable. The patient is informed that we may need to try different positions during the MRI examination if the images are affected by artifacts, fetal movement, or if the patient is becoming too uncomfortable. Always ask the patient to empty their bladder prior to starting the examination.

Our initial routine position when scanning fetal MRI is the supine left semi-lateral decubitus position, as the patient is uniformly surrounded by the spinal coils and the body array coil. Changing to the decubitus position, the patient's sleeping position, or their preferred position maybe helpful if there is continual fetal movement; artifacts due to bowel gas, the diaphragm, or amniotic fluid; susceptibility or dielectric effects; or if the patient is uncomfortable.

Scanning tips

The fetus is a moving target, and significant movement may result in fetal MRI yielding limited diagnostic information. This may be compounded in early gestation when the fetus is small and often exhibiting increased movement. MRI is therefore generally not performed at a gestational age of less than 18 weeks [1–3]. Fetal motion and size may remain difficult until a fetal age of 24 weeks.

Scanning a moving fetus presents many challenges, and an interactive scanning approach gives the best results [1]. Always plan from the most recent sequence and strive to be fast and efficient when making decisions while scanning. We optimized protocols to reduce SAR (Specific Absorption Rate) using the SAR assistant to improve workflow

[1]*Siemens Healthineers Disclaimer: MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures. Note: This disclaimer does not represent the opinion of the authors.*

	Localizer	t2_haste_p2	t2_haste_p2	t1_fl2d_p2	tof_fl2d_paracor	epi	ep2d_diff
Sequence	HASTE	HASTE	HASTE	FLASH	TOF	EPI	Diffusion
Imaging plane	3 planes	axial, sagittal, coronal	axial, coronal, sagittal	axial	paracoronal	axial	axial
FOV read	350 mm	300 mm	300 mm	300 mm	200 mm	300 mm	300 mm
FOV phase	100%	100%	100%	69.60%	100%	100%	100%
Slice thickness	7.0 mm	5 mm	3 mm	4 mm	2.5 mm	3 mm	3 mm
Slice gap	0	0	0	0	–33%	0	0

Table 1: Intracerebral vascular scanning protocol at 3T.

and reduce delays in imaging. While a free-breathing HASTE sequence is typically used to reduce acquisition time and improve patient comfort, we also use breathhold sequences in specific situations. This is particularly likely if the fetal head is near the diaphragm.

We run the diffusion sequence last, as the increased sequence volume can result in fetal motion following the sequence.

We start with 5 mm HASTE sequences and try to acquire one good scan in each plane: sagittal, axial, and coronal. These provide a quick global overview and allow for the patient to settle into the MRI environment. The radiographer can assess signal, artifacts, fetal position, coil selection, and position. Parameter changes and slice positioning decisions are made based on these sequences when planning the important 3 mm sequences.

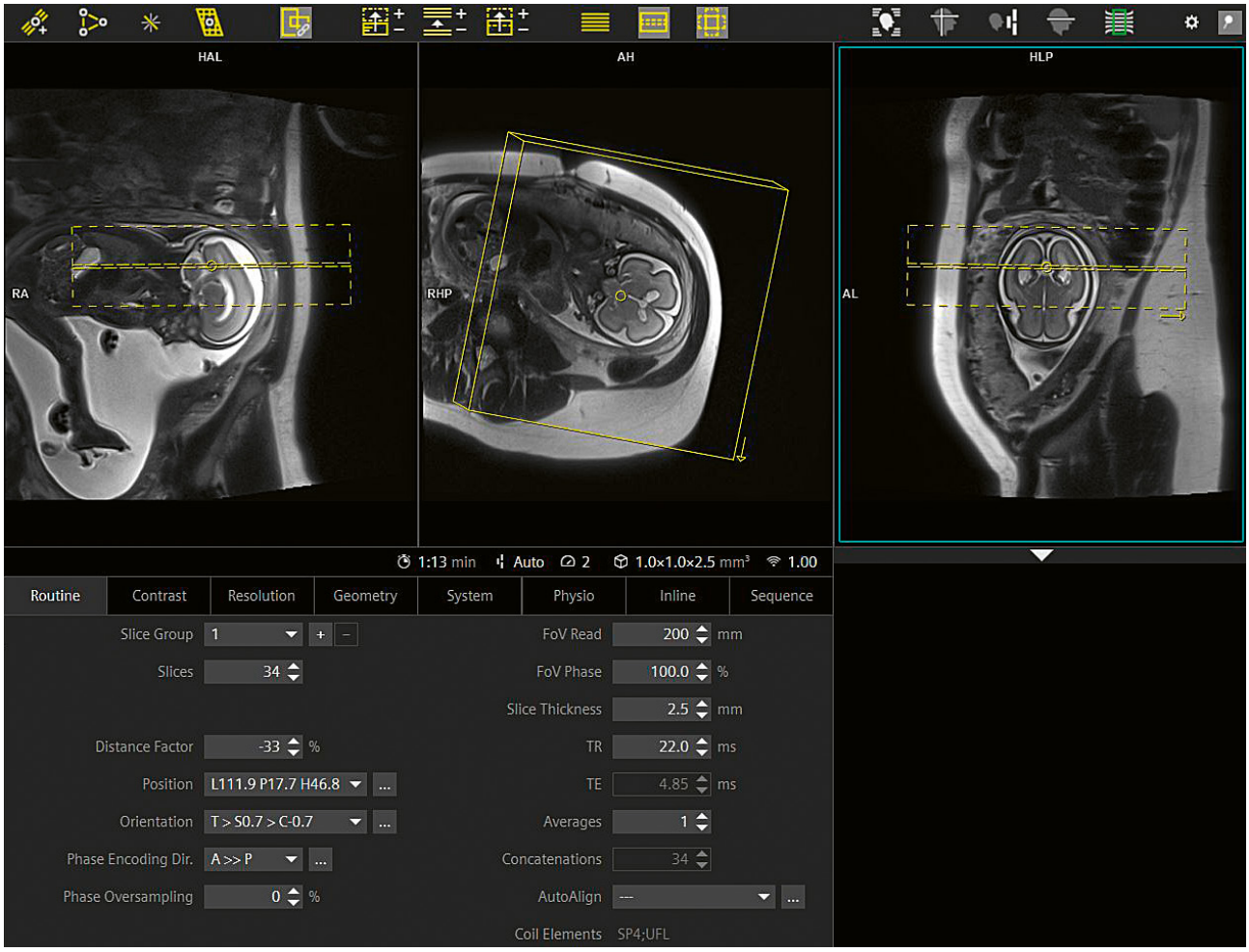
Next we perform 3 mm HASTE sequences in axial, coronal, and sagittal planes. HASTE sequences provide detailed anatomical information [3] and are motion-insensitive as *k*-space for each slice is acquired fully in one repetition time (TR). Furthermore, breathholds can be applied when the fetal head is close to the maternal diaphragm.

A T1 sequence may be useful to demonstrate fat or hemorrhage and should be performed with a breathhold. Diffusion and EPI can be routinely included to further visualize hemorrhage and examine for metabolic or ischemic processes [3]. While these sequences are routinely acquired axially, other planes may be beneficial depending on the pathology.

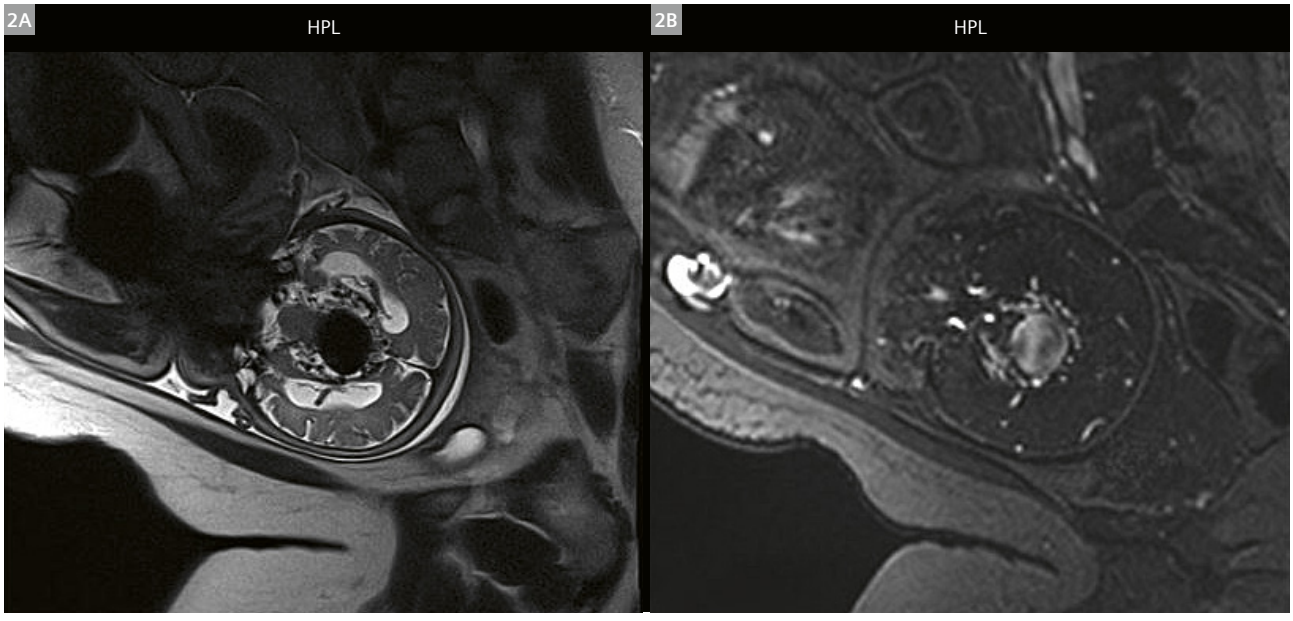
To acquire time-of-flight (TOF) for fetal cerebral vasculature, the tof_fl2d_paracor sequence from Siemens Healthineers may be used as a basis. Advantages of the 2D TOF sequence include a relatively short acquisition time and reduced sensitivity to patient motion. As the imaged slices are acquired sequentially, motion will only affect the slice being acquired at the time of motion. A 3D TOF sequence is not likely to succeed, as fetal motion will affect the entire volume. The main disadvantage of 2D TOF is a reduced sensitivity to in-plane flow, so the slice group should be placed perpendicular to the vessel of interest. This approach was adapted from a technique described by Neelavalli et al. [7].

Parameter	Value
TR	22 ms
TE	5.21 ms
FOV read	200 mm – 300 mm
FOV phase	100%
Base resolution	224
Phase resolution	85
Slices thickness	2.5 mm
Slices	23
Distance factor	–33%
Flip angle	60°
Bandwidth	240 Hz/s
GRAPPA	2
Scan time	56 s

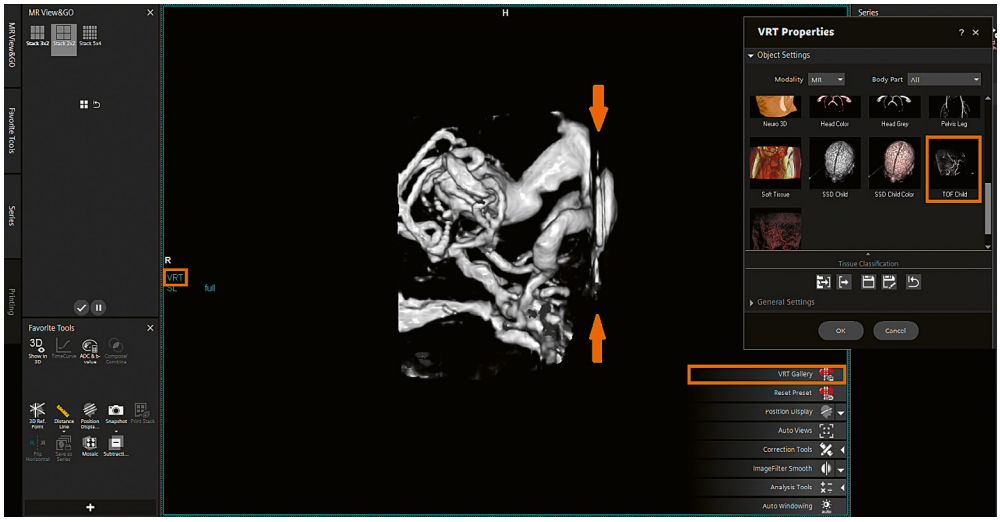
Table 2: Suggested parameters for fetal 2D TOF at 3T.



1 Example of planning for 2D TOF for the vein of Galen. The slice group is placed perpendicular to the vessel of interest.



2 Coronal HASTE **(2A)** and corresponding TOF **(2B)**. Example in a patient with vein of Galen malformation.



3 Sagittal view of the volume-rendered TOF on a vein of Galen malformation.

All images have been aquired on a 3T MAGNETOM Lumina.

The dataset is postprocessed with MR View&GO. The snip tool should be applied to remove signal from tissue outside the region of interest. The 2D TOF can be volume-rendered by cycling through the reconstruction types on the left side of the viewing segment until VRT is selected. Then we use the lower-right context menu to enter the VRT Gallery and change the cockpit setting to TOF Child. The orange arrows point to a slice disrupted by fetal movement. The advantage of the 2D TOF data acquisition is that only this slice is affected, rather than the entire volume as is the case in 3D TOF.

Conclusion

This article has discussed how we approach fetal intracerebral vascular MRI. Patient preparation and examination setup are important in achieving success, as is good scanning technique and protocol selection. TOF vascular imaging can be achieved with a 2D TOF sequence and post-processing using volume rendering. The information obtained from these examinations aids in patient decision-making and can impact clinical outcomes.

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Imaging the Early Fetal Brain Using Deep Resolve in 3T MRI

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Introduction

Fetal magnetic resonance imaging (MRI)[1] is contributing to progress on neurodevelopment within the clinical neurosciences [1]. While state-of-the-art ultrasound scanning produces images with excellent spatial resolution of the fetal brain even below a gestational age (GA) of 24 weeks, MRI based on T2-weighted single-shot sequences (e.g., HASTE) provides optimal contrast resolution of the various components of the brain mantle. However, despite making such progress, MRI has been affected in the last two decades by limited in-plane resolution (around 1 mm^2) [2]. This limitation impacts the diagnostic confidence of neuroradiologists when investigating small fetal brain structures, especially in countries where diagnostic efforts mostly focus on GAs in the range of 19 to 24 weeks due to legal constraints on pregnancy terminations. For these reasons, increasing spatial resolution is highly desirable.

Technique

In recent years, artificial-intelligence (AI) applications in MRI have made it possible to accelerate acquisitions and increase resolution using various image reconstruction and denoising algorithms [3].

In our department, we have started using Deep Resolve, an AI-driven image reconstruction technology, on our 3-Tesla MAGNETOM Vida scanner. Deep Resolve increases spatial resolution, and our aim is to acquire more-detailed T2-weighted HASTE images, which are the pillar of fetal neuro MRI.

	T2 HASTE	T2 HASTE with Deep Resolve
Acquisition time	20 s	13 s
TR/TE	2200 ms / 104 ms	1150 ms / 76 ms
Concatenations	1	1
FOV	260 mm	220 mm
Phase FOV	100%	100%
Base resolution	320	256
Phase resolution	65%	100%
In-plane res. acquisition	(1.25 × 0.81) mm^2	(0.86 × 0.86) mm^2
In-plane res. reconstructed	(0.81 × 0.81) mm^2	(0.43 × 0.43) mm^2
Slice thickness	3 mm	2.5 mm
Distance factor	20%	10%
Gap	0.6 mm	0.3 mm
Slices	9	11
Phase oversampling	60%	100%
GRAPPA	None	2
Gradient mode	Fast	Normal
Turbo factor	208	256
Echo spacing	6.50 ms	6.32 ms
Bandwidth	446 Hz/Px	630 Hz/Px

Table 1: Main parameters of the original HASTE protocol and the optimized version with Deep Resolve.

[1] *Siemens Healthineers disclaimer: MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures. Note: This disclaimer does not represent the opinion of the authors.*

Since our institution mostly deals with fetuses of an early GA (19–24 weeks), we used this approach with a higher in-plane resolution (about 0.5 mm^2). In what follows, we present some promising examples.

It is worth noting that, while applying AI-based technology to acquire higher-resolution images in small fetuses is challenging, these cases may benefit the most from strategies to improve spatial resolution.

The original HASTE sequence was designed with a specific combination of parameters to achieve an optimal balance between signal quality and spatial resolution. A reasonable compromise is typically obtained by disabling parallel imaging while increasing phase oversampling. This raises the signal-to-noise ratio (SNR) and minimizes wrap-around artifacts caused by the unpredictable orientation of the fetal brain.

However, increasing phase oversampling and reducing parallel imaging inherently introduces global blurring. This is due to the increase in echo spacing, an expected behavior in single-shot sequences. The implementation of Deep Resolve significantly mitigates this effect through two complementary mechanisms: a denoising boost and the enhancement of effective resolution provided by the sharpening model. Moreover, Deep Resolve enables the use of a higher receiver bandwidth. This helps reduce chemical-shift artifacts between adjacent tissues and thereby improves the delineation of anatomical boundaries.

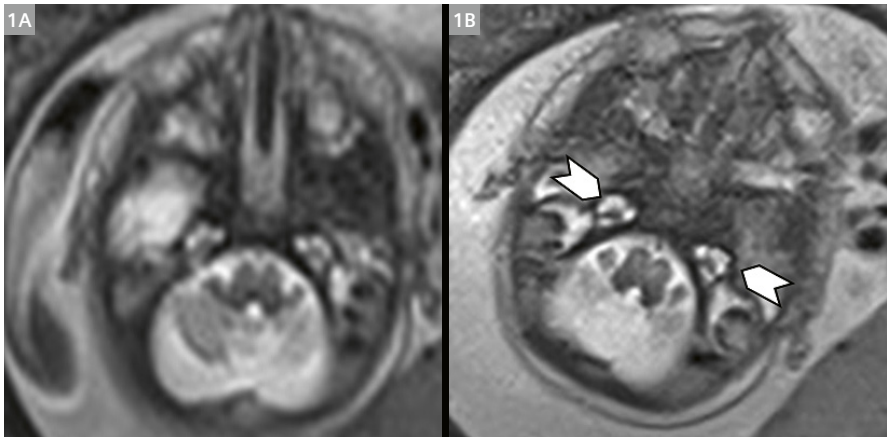
Deep Resolve operates when *k*-space undersampling is enabled, which explains why the GRAPPA acceleration factor shifts from "None" to "2" in the optimized protocol. This also suggests a potential further optimization strategy: increasing the parallel imaging factor from 2 to 3. Such an adjustment would improve image quality on two fronts by providing more effective denoising in undersampled regions and by further reducing echo spacing. These modifications, however, also require corresponding adaptation of the echo time, which declines as the echo train length becomes shorter.

In Table 1, we report the main parameters of our current T2-weighted HASTE protocol with the Deep Resolve algorithm.

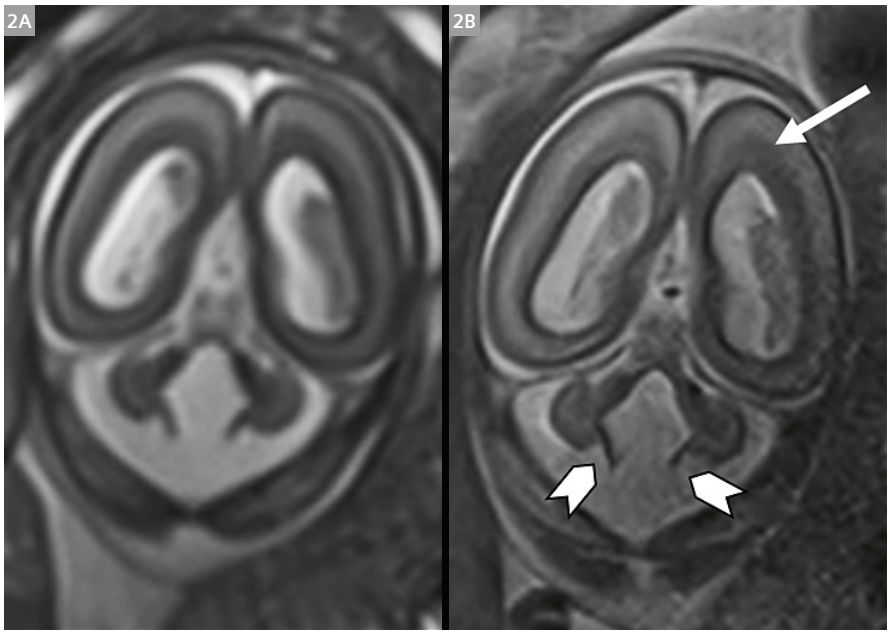
Results

In Figure 1, we report a case with mild undefined and borderline brain dysmorphism. Establishing the presence or absence of malformation of the inner ear may corroborate the suspicion of a genetic condition if the labyrinth also proves to be abnormal.

As an additional example of the use of Deep Resolve, the depiction of the structures of the posterior fossa also benefit from higher-resolution images (Fig. 2). The result is better visualization of cerebellar foliation and the ability to more confidently assess structures like the taenia-tela choroidea complex, which plays a pivotal role in the characterization of cystic malformations (e.g., differential diagnosis of Dandy-Walker spectrum versus Blake's pouch cyst, which is caused by failed perforation of the foramen of Magendie).



1 Axial T2-weighted HASTE of a fetus at 21 weeks gestational age, with 3 mm thick slices at 3 Tesla: **(1A)** 1 mm^2 in-plane resolution, **(1B)** corresponding slice acquired with Deep Resolve (0.86 × 0.86 mm^2 in-plane resolution, 2.5 mm slice thickness). The structures of the labyrinth of the inner ear are depicted with greater clarity and detail after Deep Resolve application (arrowheads).



2 Coronal T2-weighted HASTE with 3 mm thick slices at 3T from a fetus of 19 weeks gestational age with posterior fossa anomaly on ultrasonography: **(2A)** 1 mm^2 in-plane resolution, **(2B)** corresponding section acquired with Deep Resolve (0.86 × 0.86 mm^2 in-plane resolution, 2.5 mm slice thickness). The lateral and caudal dislocation of the tela choroidea in a Dandy-Walker spectrum case is better depicted with Deep Resolve (arrowheads). Note also the sharper appearance of the border between different layers of the brain mantle (arrow).

Discussion and conclusion

The preliminary cases presented here demonstrate how using deep learning in MR image reconstruction can benefit a complex field such as fetal neuro MRI. Extensive quantitative studies comparing images with and without AI techniques or with different AI grading now need to be performed.

Although Deep Resolve offers significant advantages in MR image reconstruction, it is important to also consider the possible drawbacks of this novel approach. For instance, exaggerated fetal motion may degrade the image quality, and image inhomogeneity may arise if the fetal head is not located in the best area for coil sensitivity.

Furthermore, signal inhomogeneity in the field of view can be an issue. However, since the abdomen is generally smaller when the fetus is younger, this kind of image degradation is less likely, especially if using high-density coils. This is the case at our institution, where we prefer the 18-channel UltraFlex coil, which adapts to the smaller dimension of the abdomen prior to the third trimester of pregnancy.

Other approaches to enhancing spatial resolution in fetal MRI may enter clinical practice in the near future. These include small-field-of-view techniques (e.g., multichannel RF transmission) once they have been adapted for T2-weighted acquisition rather than echo-planar acquisition. Adding AI methods to this approach may also further enhance image quality.

References

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