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.

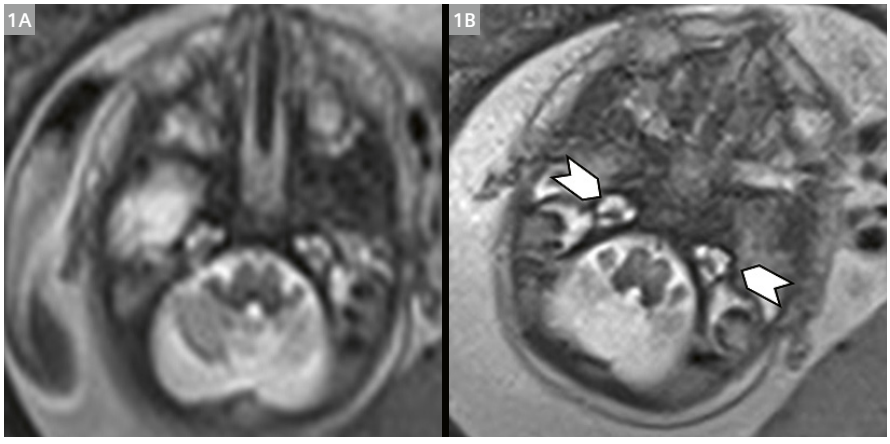
Deep Resolve operates when *k*-space undersampling is enabled, which explains why the GRAPPA acceleration factor shifts from "None" to "2" in the optimized protocol. This also suggests a potential further optimization strategy: increasing the parallel imaging factor from 2 to 3. Such an adjustment would 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.

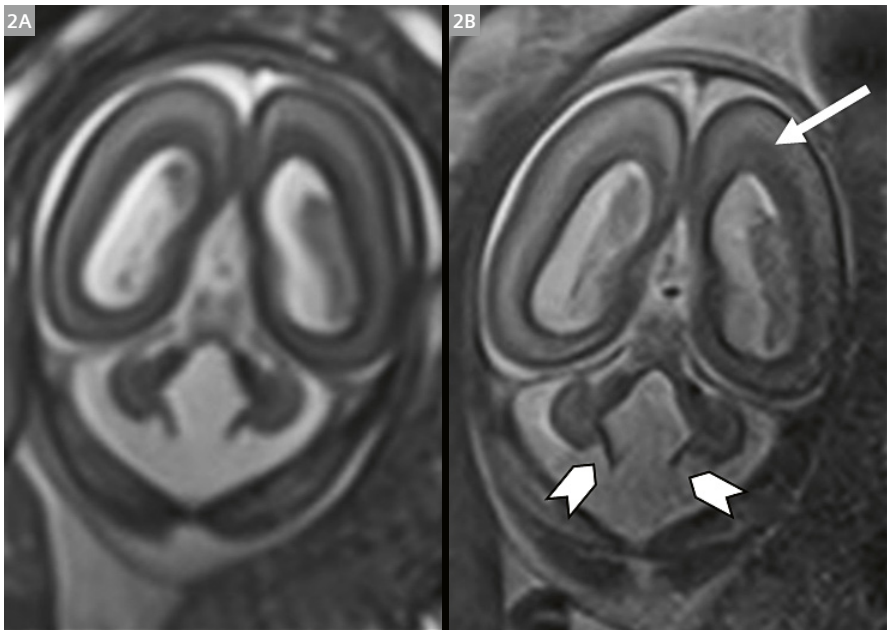
Results

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.

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