Sedation-Free Musculoskeletal MRI in Children Using Deep Resolve – How I do it

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Introduction

At Oslo University Hospital (OUS), we encounter a significant volume of pediatric cases, which present unique challenges due to the different needs of young patients[1]. In cases involving children aged four years and below, it is common to use sedation during MRI exams. This approach ensures the child remains still throughout the scan, enabling precise imaging without motion-related artifacts. Sedation also minimizes potential distress or discomfort for the child.

With older children (aged five years and above), using in-bore entertainment systems is an effective distraction technique. This method aims to keep the child relaxed and cooperative during the exam, thereby enhancing their tolerance and decreasing the need for sedation. In some more complex cases, neither sedation-free exams nor sedation may be possible and general anesthesia becomes necessary.

For infants[1], we often try to use the feed-and-wrap technique, which has shown success. This involves feeding the infant and then wrapping them snugly. This helps to keep them calm during the exam.

Cutting-edge techniques like Deep Resolve have significantly contributed to faster scans, which are crucial for every patient group. Faster scans have the added benefit of providing clearer and more detailed images, which can aid more accurate diagnoses [1]. By employing Deep Resolve when scanning younger children, we can lower the sedation rate, and the associated risks and costs, as well as minimize patient discomfort and potentially enhance the overall patient experience.

After upgrading our MAGNETOM Skyra scanner that ran *syngo* MR E11C software to a MAGNETOM Vida Fit scanner running *syngo* MR XA50, we have substantially streamlined our musculoskeletal (MSK) protocols. We have shortened the scan duration and enhanced our efficiency without compromising on diagnostic quality. Several MSK examinations are now around 50% faster.

Patient preparation

Along with robust protocols, patient preparation is another crucial factor in pediatric MRI. Last year, we made a preparation video, which is now on our hospital's YouTube channel (https://rb.gy/1wnxot) (Fig. 1) [2]. This video was made specifically for our department, so that parents and their children will recognize the facilities, the scanner, and the staff when they arrive. Before the video existed, they often visited us at the MRI lab for a demonstration, which usually happened the day before the exam. This took up time slots, which was problematic for a busy

1 Patient preparation video on YouTube (https://rb.gy/1wnxot).

[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. Note: This disclaimer does not represent the opinion of the author.*

department. The video now allows us to maximize the efficiency of our patient preparation, reduce unnecessary visits, and ensure a smoother MRI experience for parents and their children.

If the MRI exam involves a gadolinium injection, we use a tailored strategy that involves both the MRI lab and the pediatric department. The pediatric department places the cannula prior to the exam, which streamlines the process so the exam can start promptly. Children often feel anxious or fearful about medical procedures like a cannula insertion. Placing it at an early stage provides more time to address any fears or concerns the child might have, and reduces the likelihood of the child being upset or uncooperative during the scan. Collaborating with the pediatric department in this way has led to higher success rates in our MRI exams. In fact, it makes the whole hospital experience less intimidating for the children.

Equipment

Hardware

We installed our first 3T scanner, a MAGNETOM Skyra (Siemens Healthineers, Erlangen, Germany) in 2011. We upgraded in 2022 to a 3T MAGNETOM Vida Fit scanner with BioMatrix technology. The upgrade provided a substantial leap in capabilities. Improvements in both hardware and software facilitate sedation-free MRI for our MSK cases, providing high image quality in shorter scan times (Fig. 2). We have three 1.5T systems and one 3T system at our hospital. We prefer to perform MSK cases on the advanced 3T system, as it has the latest technology, which allows us to deliver high-quality care and precise diagnostics for MSK conditions. The availability of dedicated MSK coils (such as those for the knee, ankle, hand/wrist, and shoulder) and the additional UltraFlex Large and Small coils enhances our versatility and adaptability when imaging different anatomical regions. The UltraFlex coils enable improved coverage and imaging in cases when the dedicated coils either do not fit or provide insufficient coverage, showcasing the flexibility of the equipment.

Software

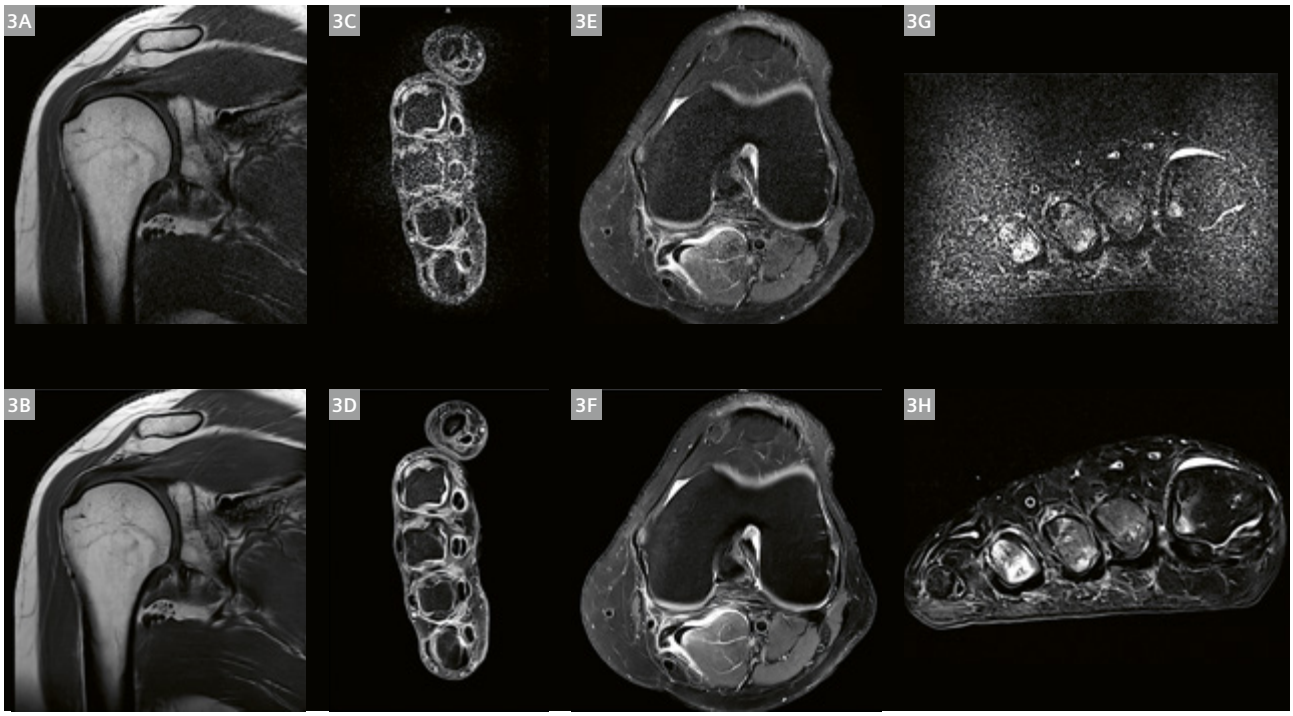
Our 3T MAGNETOM Vida Fit runs *syngo* XA50 software, which enables Deep Resolve (Sharp, Gain, and Boost) for our 2D TSE sequences (Fig. 3). Deep Resolve is an advanced image reconstruction technology that enhances image quality for 2D TSE sequences. It uses sophisticated algorithms and deep learning techniques to significantly improve image sharpness, clarity, and signal-to-noise ratio. The aim is to elevate overall diagnostic precision by reconstructing exceptionally high-quality images derived from the initially acquired raw data. Moreover, Deep Resolve is progressively extending its field of application to include other sequences, such as HASTE, DWI, and even 3D sequences like SPACE and VIBE[2]. This will benefit diagnostic accuracy and clinical insights across a broader range of MRI sequences.

Entertainment system

Our entertainment system is produced by NordicNeuroLab AS (NNL, Bergen, Norway) [3]. The TV screen is located behind the scanner bore, and a tablet is kept in the control room (Fig. 4). The equipment was originally meant for fMRI examinations, but we saw great potential in using it elsewhere. Children can watch a movie, stream from providers such as Netflix, or listen to the radio. Most children between the ages of 5 and 15 prefer to watch a movie. Using an entertainment system to create a positive atmosphere is a strategic way of enabling a smoother and more successful scanning experience for children in this age group, and helps make them cooperative and comfortable during the examination.

2 Upgrading from a 3T MAGNETOM Skyra to a 3T MAGNETOM Vida Fit.

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



3 This illustration of the Deep Resolve technique emphasizes its benefit across different MSK regions. A comparative display shows the difference between conventional imaging and imaging with Deep Resolve. All images were acquired using a 3T MAGNETOM Vida Fit.
Shoulder: (3A) T1w TSE cor, 0.2 × 0.2 × 3.0 mm³ (interpolated), conventional imaging. **(3B)** Same parameters as in **(3A)**, but with Deep Resolve Boost and Sharp. TA 46 seconds.
Hand: (3C) T1w TSE fatsat tra post-Gd, 0.2 × 0.2 × 2.0 mm³ (interpolated), conventional imaging. **(3D)** Same parameters as in **(3C)**, but with Deep Resolve Boost and Sharp. TA 1:15 minute.
Knee: (3E) PDw TSE fatsat tra, 0.2 × 0.2 × 3.0 mm³ (interpolated), conventional imaging. **(3F)** Same parameters as in **(3E)**, but with Deep Resolve Boost and Sharp. TA 55 seconds.
Forefoot: (3G) T2w STIR cor, 0.2 × 0.2 × 2.0 mm³ (interpolated), conventional imaging. **(3H)** Same parameters as in **(3G)**, but with Deep Resolve Boost and Sharp. TA 2:00 minutes.

4 TV screen from NordicNeuroLab with a Microsoft Surface tablet. Patients can view the TV screen, which is positioned behind the bore. Depending on how a patient is positioned, they might require a mirror to see the screen. The tablet gives patients various entertainment options.

Fixation equipment

Fixation equipment is crucial for ensuring patients remain still and comfortable during examinations, especially considering the variation in understanding and cooperation among different patients, particularly children. Our equipment is provided by Pearl Technology AG (Schlieren, Switzerland). We have different pads and positioning aids to suit every anatomy (Fig. 5) [4]. The equipment is easy to attach, ensuring a consistent approach across radiographers. Having equipment that does not require improvisation and can be quickly placed reduces variability and the reliance on individual radiographer's techniques. This makes the process more standardized and reliable.

Lab schedule

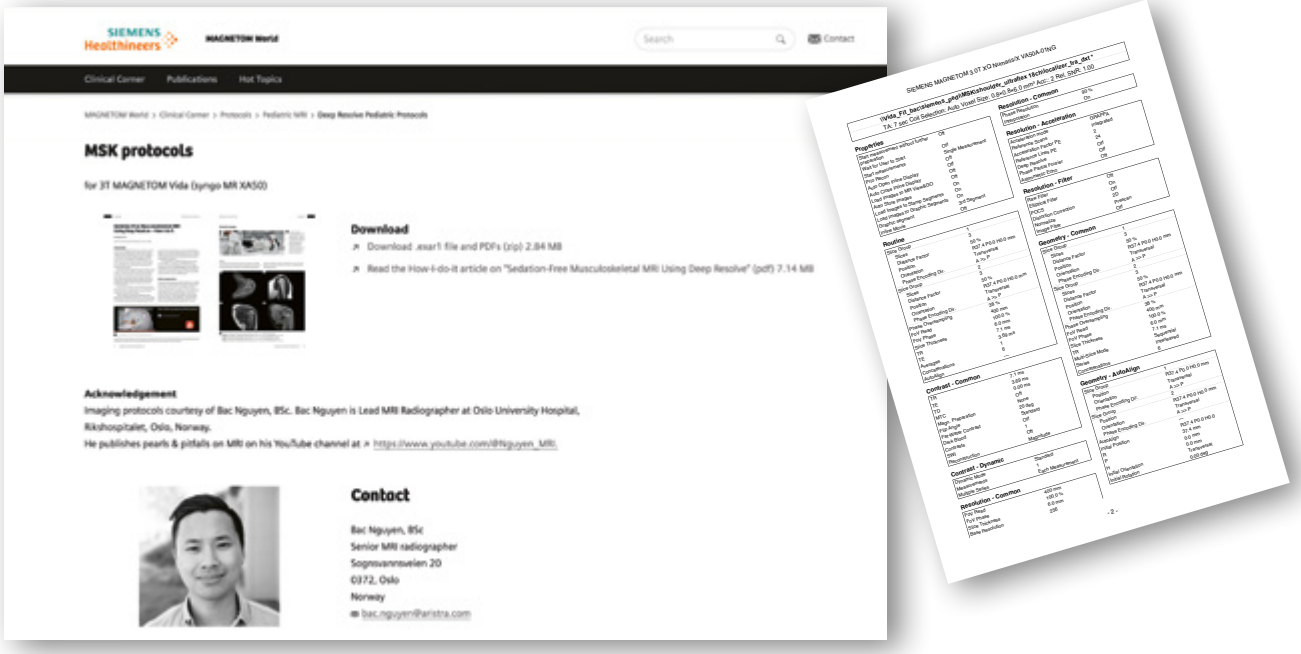
The ability to conduct faster scans opens up a number of opportunities for our lab. Firstly, the time gained gives us the flexibility to scan emergency patients who come during the day. Secondly, we can perform multiple examinations for the same patient in a single visit. We are constantly optimizing our lab to increase efficiency.

5 Inflatable pads from Pearl Technology that we use to achieve proper fixation during the scans.

Visit us at

https://www.magnetomworld.siemens-healthineers.com/clinical-corner/protocols/pediatric-mri-protocols/deep-resolve-pediatric

to download 3T MAGNETOM Vida (*syngo* MR XA50) protocols (.exar1 & PDF).



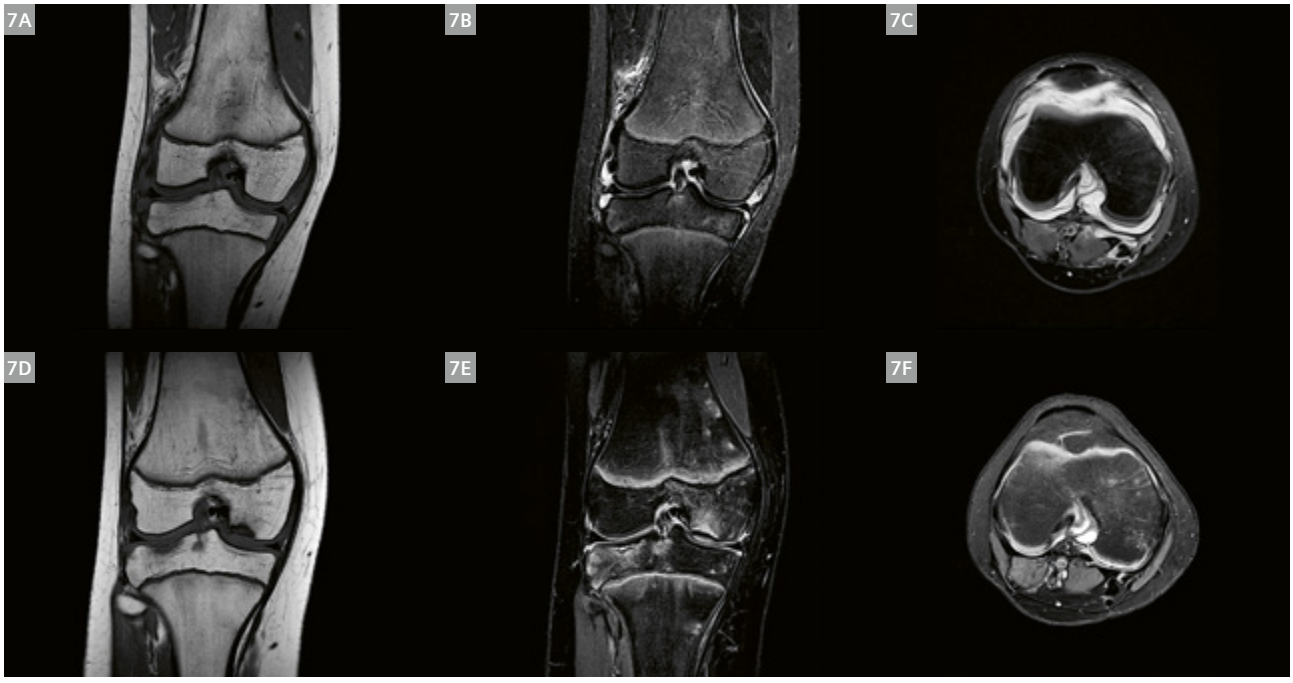
Protocols and cases

Knee imaging

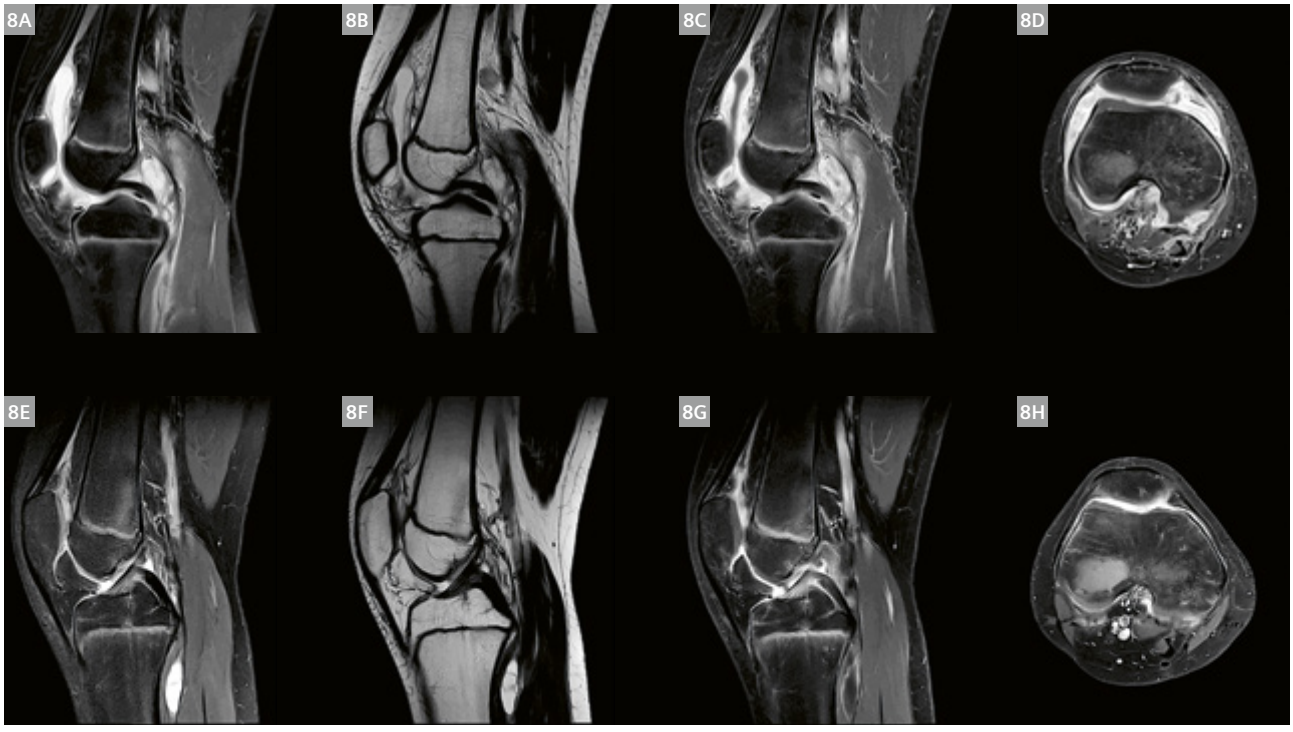
6 A healthy volunteer demonstrating how we set up a knee exam using inflatable pads. Proper fixation is crucial. Coil: Tx-Rx Knee 18.

Case 1: Idiopathic arthritis

A 12-year-old girl with known juvenile idiopathic arthritis affecting the right knee and left ankle: A knee exam conducted in 2020 (when the patient was 10 years old) revealed findings of hydrops and synovitis. This exam was performed without sedation on our 3T MAGNETOM Skyra scanner. The patient received treatment and has now returned for another knee exam. It was performed on our newly upgraded 3T MAGNETOM Vida Fit using Deep Resolve technology (without sedation). The images show arthritis, a Baker's cyst, and three osteochondral lesions that appear stable (Figs. 7 and 8).



7 **(7A–7C)** First examination with conventional imaging acquired on a 3T MAGNETOM Skyra.
(7A) T1w TSE cor, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 2:57 min.
(7B) T2w TSE STIR cor, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 3:27 min.
(7C) PDw TSE fatsat tra, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 4:50 min.
(7D–7F) Second examination with Deep Resolve Boost and Sharp acquired on a 3T MAGNETOM Vida Fit.
(7D) T1w TSE cor, Deep Resolve Boost and Sharp, 0.1 × 0.1 × 3.0 mm^3 (interpolated), TA 1:01 min.
(7E) T2w TSE STIR cor, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:09 min.
(7F) PDw TSE fatsat tra, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 54 sec.



8 **(8A–7D)** First examination with conventional imaging acquired on a 3T MAGNETOM Skyra.
(8A) PDw TSE sag, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 3:31 min.
(8B) T2w TSE sag, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 3:16 min.
(8C) T1w TSE fatsat sag post-Gd, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 4:48 min.
(8D) T1w TSE fatsat tra post-Gd, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 5:10 min.
(8E–8H) Second examination with Deep Resolve Boost and Sharp acquired on a 3T MAGNETOM Vida Fit.
(8E) PDw TSE sag, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 55 sec.
(8F) T2w TSE sag, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 56 sec.
(8G) T1w TSE fatsat sag post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 2:00 min.
(8H) T1w TSE fatsat tra post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 2:00 min.

Ankle/foot imaging

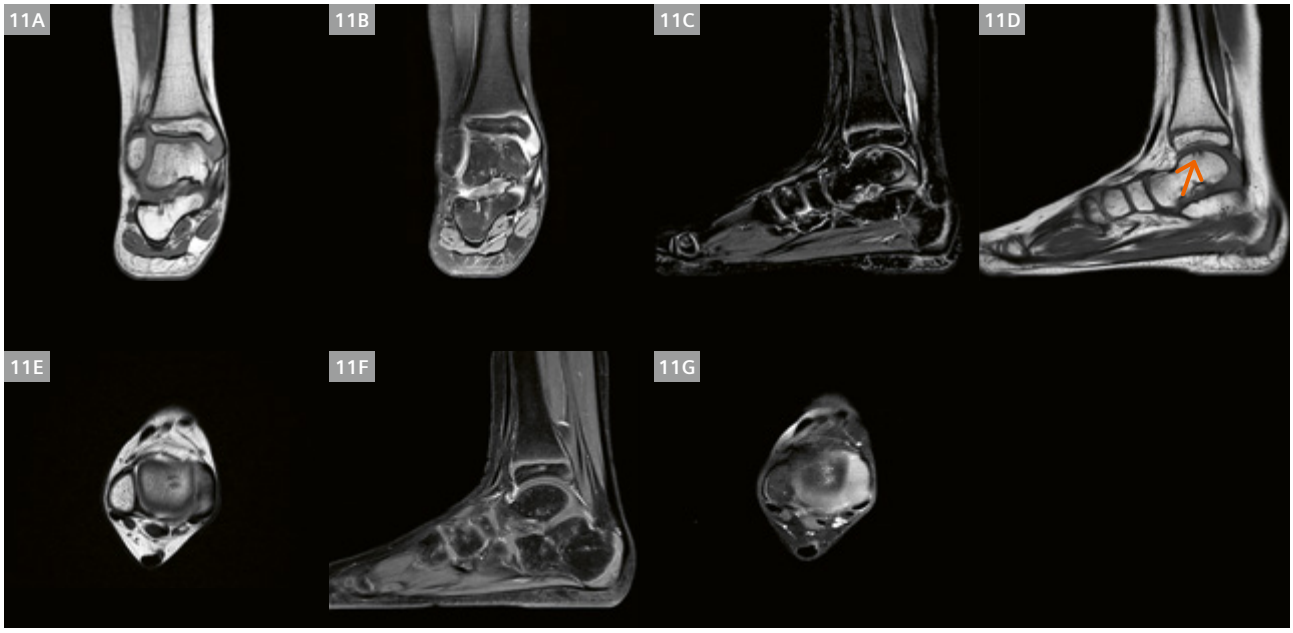
9 A healthy volunteer demonstrating how we set up an ankle/foot exam using inflatable pads. One pro tip is to slide the coil all the way to the side, and the healthy foot as far as possible to the opposite side. Place the feet as close as possible to the end of the table. Don't let the feet be positioned close together. With this setup, you can reduce phase oversampling and save scan time. Coil: Foot/Ankle 16.

Case 2: Polyarticular juvenile idiopathic arthritis

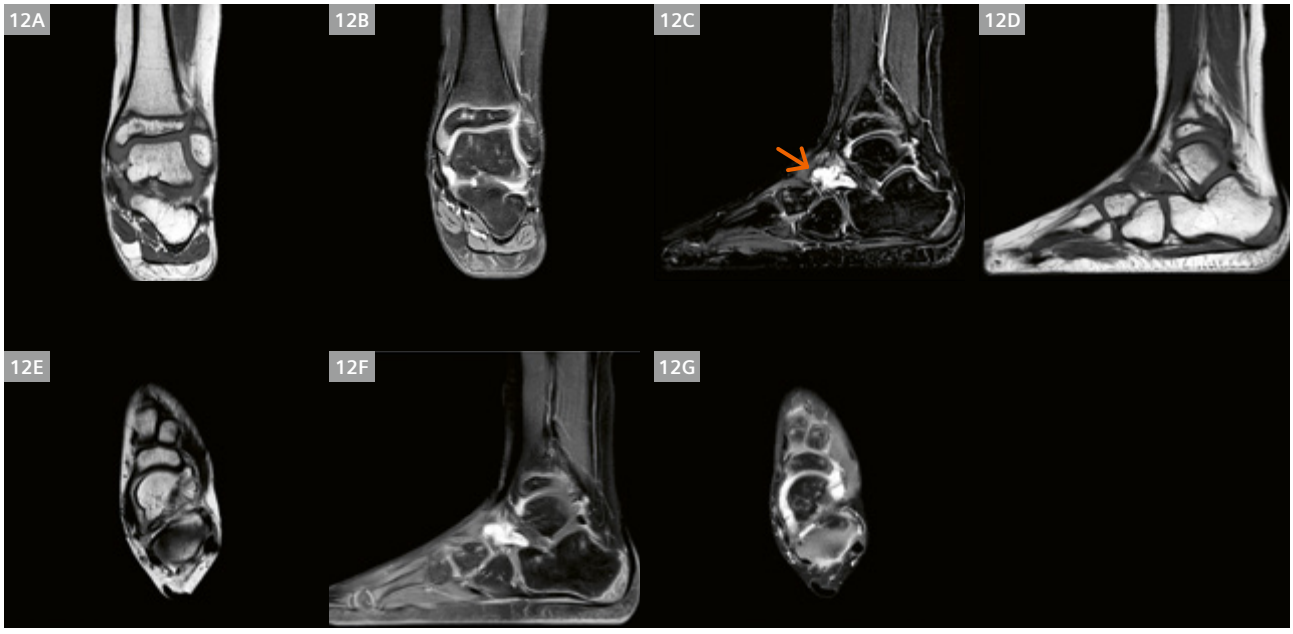
A 6-year-old girl with known polyarticular juvenile idiopathic arthritis in the right ankle: Her first MRI ankle exam was performed without sedation on our 3T MAGNETOM Skyra when she was 5 years old. She had an initial evaluation and treatment for the right ankle (Fig. 10) and is returning for re-evaluation of the same ankle. Additionally, there is a request to assess the left ankle during this visit.

With the latest techniques provided by our 3T MAGNETOM Vida Fit, we were able to examine both ankles with a gadolinium injection. The right ankle shows synovitis at the first metatarsophalangeal (MTP) joint, and osteochondral lesion at the talus (Fig. 11). Imaging of the left ankle indicates synovitis of the talonavicular joint (Fig. 12).

10 **(10A–10F)** First examination (right ankle) with conventional imaging acquired on a 3T MAGNETOM Skyra.
(10A) T1w TSE sag, 0.2 × 0.2 × 3.0 mm³ (interpolated), TA 2:22 min.
(10B) T2w TSE cor, 0.2 × 0.2 × 3.0 mm³ (interpolated), TA 4:05 min.
(10C) T2w TSE tra, 0.2 × 0.2 × 3.0 mm³ (interpolated), TA 2:18 min.
(10D) PDw 3D SPACE sag, 0.6 × 0.6 × 0.6 mm³, TA 5:00 min.
(10E) PDw 3D SPACE multiplanar reconstruction (MPR) cor.
(10F) PDw 3D SPACE MPR tra.



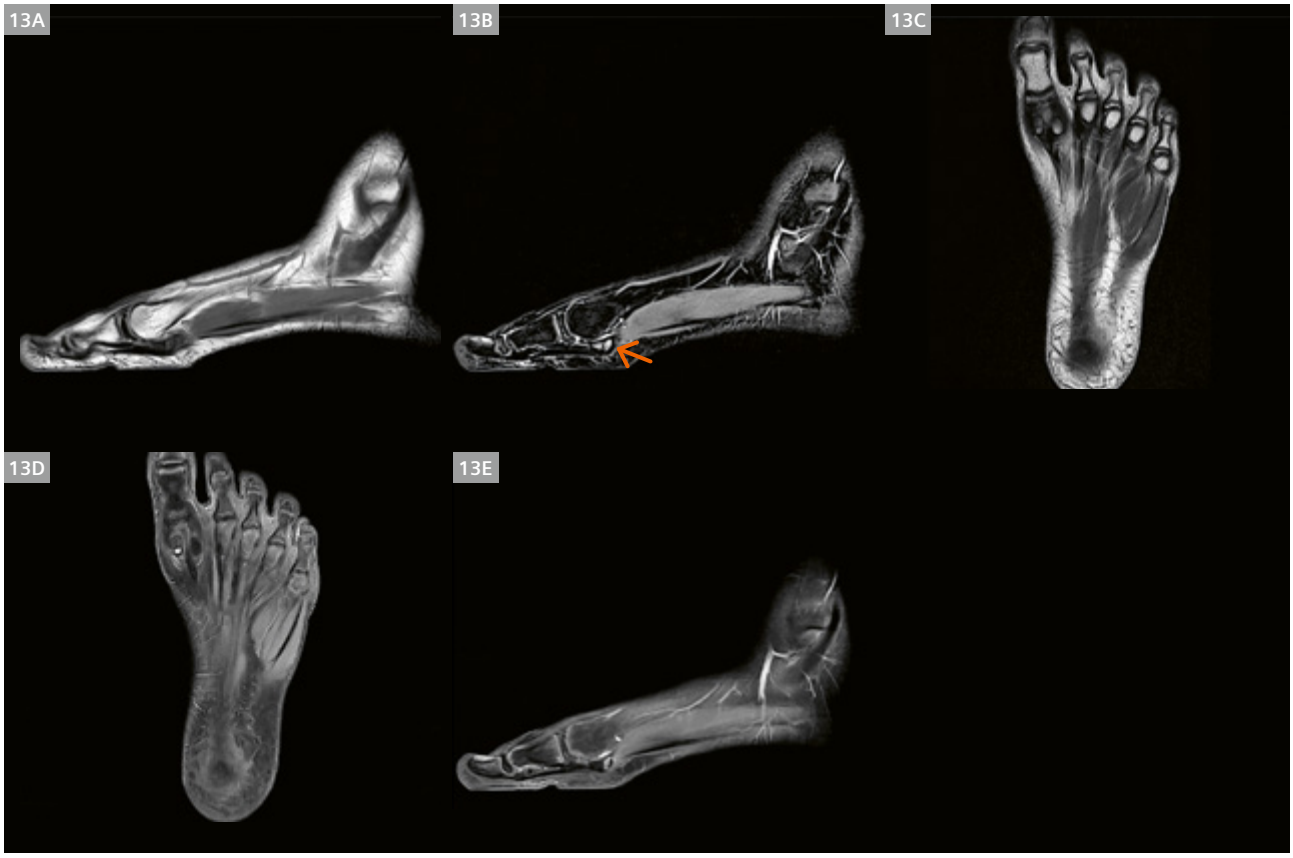
11 **(11A–11G)** Second examination (right ankle) with Deep Resolve Boost and Sharp acquired on a 3T MAGNETOM Vida Fit.
(11A) T1w TSE cor, Deep Resolve Boost and Sharp, 0.1 × 0.1 × 3.0 mm^3 (interpolated), TA 46 sec.
(11B) PDw TSE fatsat cor, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 43 sec.
(11C) T2w STIR TSE sag, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 56 sec.
(11D) T1w TSE sag, Deep Resolve Boost and Sharp, 0.1 × 0.1 × 3.0 mm^3 (interpolated), TA 52 sec.
(11E) T2w TSE tra, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 50 sec.
(11F) T1w TSE fatsat sag post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:38 min.
(11G) T1w TSE fatsat tra post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:30 min.



12 Second examination (left ankle) with Deep Resolve Boost and Sharp acquired on a 3T MAGNETOM Vida Fit. Same parameters as in Figure 11.

Case 3

A 9-year-old girl who underwent ultrasound imaging of the left ankle/foot without definite findings of arthritis, tenosynovitis, or enthesitis: Her first MRI exam was done without sedation. The imaging (Fig. 13) revealed signal changes in the bipartite sesamoid bone at the first MTP joint.

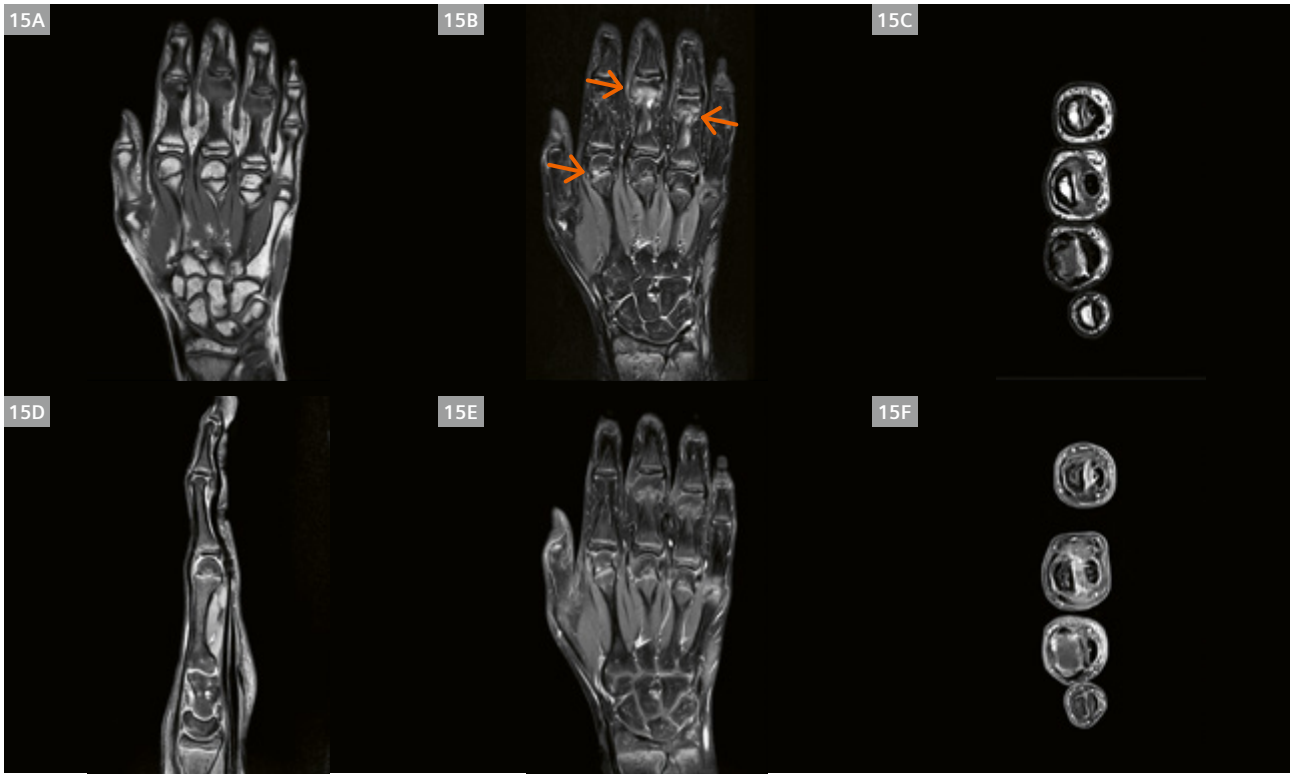


13 Images of the left ankle/foot acquired using Deep Resolve Boost and Sharp on a 3T MAGNETOM Vida Fit.
(13A) T1w TSE sag, Deep Resolve Boost and Sharp, 0.1 × 0.1 × 3.0 mm^3 (interpolated), TA 1:33 min.
(13B) T2w STIR TSE sag, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 1:09 min.
(13C) T2w TSE tra, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:00 min.
(13D) T1w TSE fatsat sag post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:08 min.
(13E) T1w TSE fatsat tra post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:30 min.

Hand/wrist imaging

14 A healthy volunteer demonstrating how we set up a hand/wrist exam using inflatable pads. Coil: Hand/Wrist 16.

Case 4: Bone marrow edema
A 10-year-old girl with suspected arthritis of the left hand/wrist: Ultrasound imaging was initially performed with inconclusive findings for arthritis. The referring physician requested an MRI exam, which was performed without sedation. MRI findings indicated bone marrow edema at the second metacarpophalangeal (MCP) joint, and at the third and fourth proximal interphalangeal (PIP) joints, which is not typical arthritis. Post-traumatic injury might be a plausible reason for the observed symptoms and physical changes (Fig. 15).

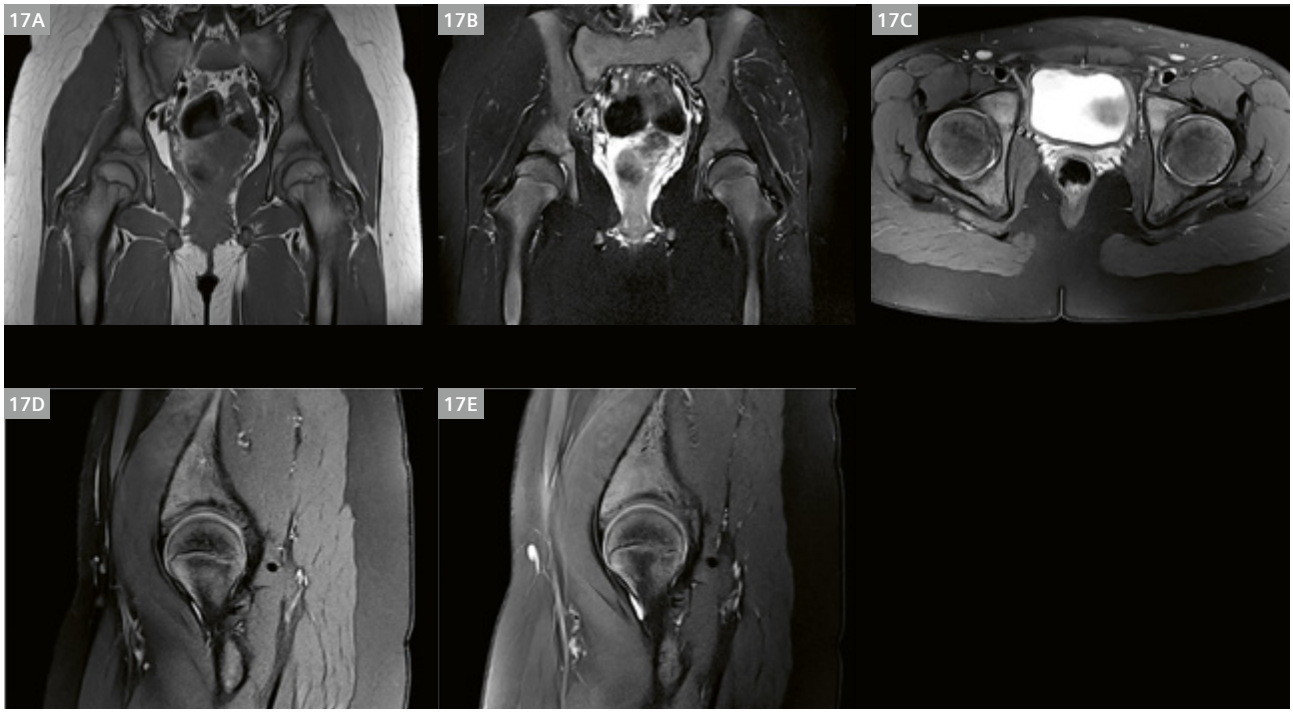


15 Images of the left hand acquired using Deep Resolve Boost and Sharp on a 3T MAGNETOM Vida Fit.
(15A) T1w TSE cor, Deep Resolve Boost and Sharp, 0.1 × 0.1 × 2.0 mm³ (interpolated), TA 1:17 min.
(15B) T2w STIR TSE cor, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 2.0 mm³ (interpolated), TA 2:00 min.
(15C) T2w TSE tra, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 2.0 mm³ (interpolated), TA 2:20 min.
(15D) PDw TSE fatsat sag, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 2.0 mm³ (interpolated), TA 1:10 min.
(15E) T1w TSE cor post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 2.0 mm³ (interpolated), TA 1:40 min.
(15F) T1w TSE tra post-Gd, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 2.0 mm³ (interpolated), TA 1:30 min.

Hip imaging

16 A healthy volunteer demonstrating how we set up a hip exam using inflatable pads. Try to have the end of the coil as near as possible to the body, and fixate the legs so they can't easily move during the exam. We used an UltraFlex Large 18 coil here, but depending on patient size, an UltraFlex Small 18 or Body 18 can also be used.

Case 5
A healthy 7-year-old female volunteer underwent an MRI exam for the first time (without sedation). She reported that the TV entertainment meant she felt no fear or anxiety about the loud noises and confined space inside the scanner (Fig. 17).



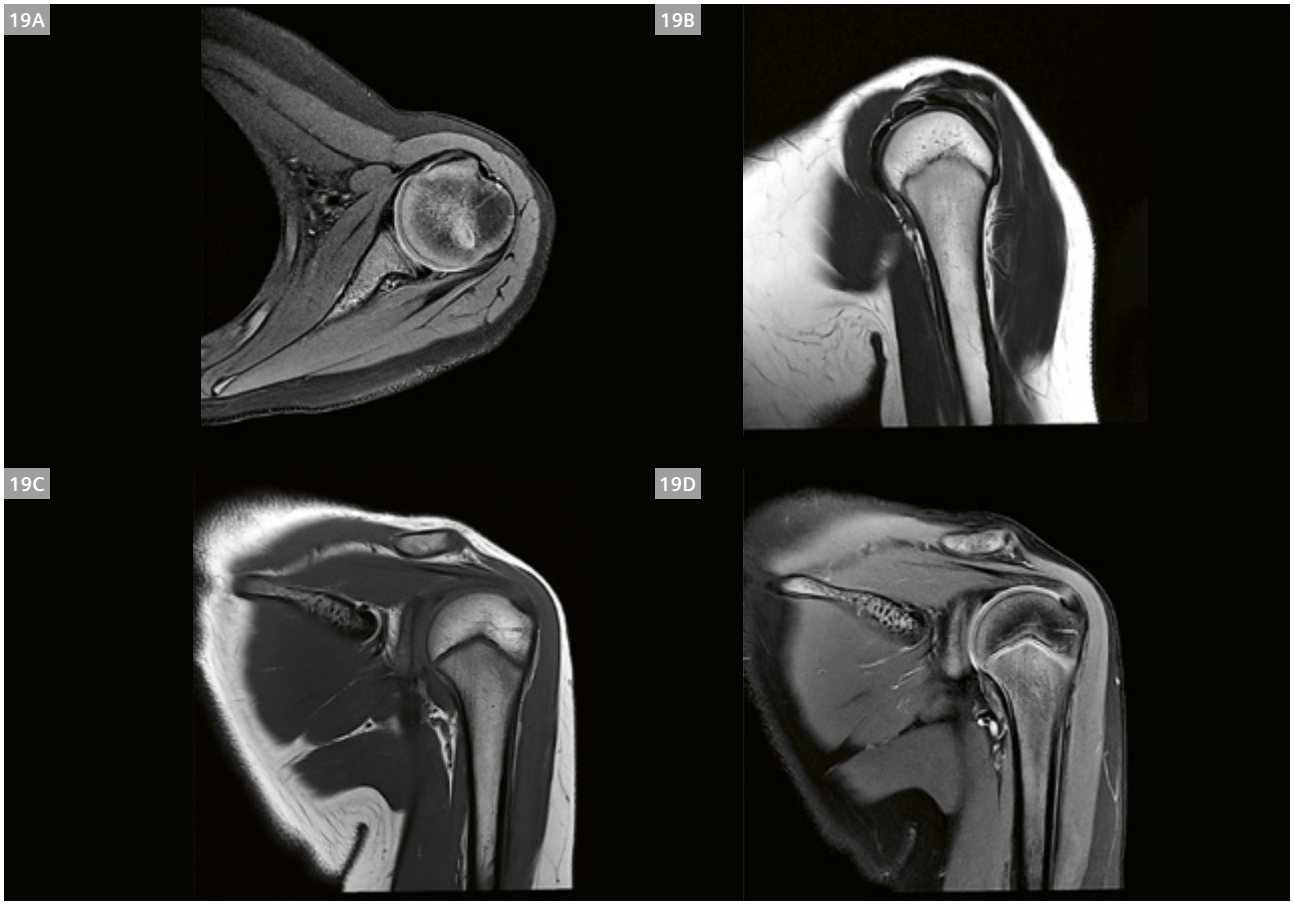
17 Hip images acquired using Deep Resolve Boost and Sharp on a 3T MAGNETOM Vida Fit.
(17A) T1w TSE cor, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 1:02 min.
(17B) T2w STIR TSE cor, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 1:12 min.
(17C) T2w PD TSE fatsat tra, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 1:20 min.
(17D, 17E) T2w PD TSE fatsat sag, Deep Resolve Boost and Sharp, 0.3 × 0.3 × 3.0 mm^3 (interpolated), TA 1:19 min.

Shoulder imaging

18 A healthy volunteer demonstrating how we set up a shoulder exam using inflatable pads. Try and use an oblique pad at the back of the other shoulder. This creates a slope so the patient will slide easily toward the coil. Also remember to fill the empty space in the front of the coil, so the shoulder is fixed. Coil: Shoulder 16.

Case 6

A healthy 9-year-old female volunteer underwent an MRI exam for the second time (without sedation). Even with no TV entertainment, she had no issues because she had undergone an MRI scan before. Nonetheless, she said it was easier to lie still and that she was more comfortable with TV entertainment.



19 Shoulder images acquired using Deep Resolve Boost and Sharp on a 3T MAGNETOM Vida Fit.
(19A) PDw TSE fatsat tra, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:21 min.
(19B) T2w TSE sag, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:26 min.
(19C) T1w TSE cor, Deep Resolve Boost and Sharp, 0.2 × 0.2 × 3.0 mm^3 (interpolated), TA 1:04 min.
(19D) PDw TSE fatsat cor, Deep Resolve Boost and Sharp, 0.2 × 0.2 x 3.0 mm^3 (interpolated), TA 1:18 min.

Conclusion

In this article, I aimed to highlight the remarkable impact of using the latest Deep Resolve technology and higher acceleration possibilities. As well as reducing scan times and improving image quality, the applications have also given us greater flexibility in scheduling lab appointments. Notably, we were also able to increase the success rate of our exams, especially for non-sedated children, as we could provide them with a more comfortable experience during their MRI visits. I am eagerly anticipating the expansion of Deep Resolve technology to cover other sequences[2], such as BLADE TSE, CINE, CE MRA, GRASP-VIBE, and an extended version of 2D TSE Dixon.

Acknowledgements

I am extremely grateful to the remarkable team at Rikshospitalet, and for having the opportunity to work alongside such talented individuals. I would also like to express my sincere thanks to Siemens Healthineers for their collaboration, which significantly enhanced our collective efforts. The dedication and support were invaluable in helping us achieve our shared goals.

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3 NordicNeuroLab: https://www.nordicneurolab.com
4 Pearl Technology: https://www.pearl-technology.ch/en/