Pediatric Whole-Body MRI: How I Do It

Bac Nguyen, BSc; Lil-Sofie Muller, M.D., Ph.D.

Oslo University Hospital, Rikshospitalet, Oslo, Norway

Introduction

At Oslo University Hospital we have a high rate of pediatric patients, which can often pose a technical and diagnostic challenge. Indications for MRI in children at our institution include brain, spine, heart, abdomen, pelvis, MSK, and whole body. In non-cooperative children or children under 5 or 6 years of age[1], the examinations are most often performed under general anesthesia. For the older children, entertainment on a TV screen is offered and the examination is then generally well tolerated. In infants under 3 months of age, the feed and wrap technique is used, sometimes in combination with light sedation.

As the name indicates, whole-body MRI (WB-MRI) can image the entire body in one scan. It gives a full overview of multifocality, and favors detection of disease over characterization, sometimes even before symptoms develop. Although the entire body is not always imaged, the term whole-body MRI is normally used when three or more anatomical areas are included in one scan. There are numerous indications for WB-MRI [1]. In our institution, it is most often used for cancer staging, for early detection of cancer in children with genetic predisposition syndromes, or in cases of relapse in children with treated malignancy. It is also widely used in inflammatory disorders like chronic non-bacterial osteomyelitis and in children with juvenile idiopathic arthritis (JIA). Sometimes WB-MRI is used in children with non-specific symptoms and unknown underlying pathology.

[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.*

Equipment

Modern high-end systems like the 3T MAGNETOM Vida and 1.5T MAGNETOM Sola (Siemens Healthcare, Erlangen, Germany) are equipped with BioMatrix technology, which facilitates WB-MRI with exquisit image quality within a short scan time. At our hospital, we mostly perform WB-MRI on our 1.5T systems. We currently only have one 3T scanner, which is prioritized for other uses. Our 1.5T scanners are a MAGNETOM Aera and a MAGNETOM Avanto[fit] (Siemens Healthcare, Erlangen, Germany). The protocols are highly optimized regarding image quality and total scan time. The coils available for these scanners are designed for WB-MRI and consist of a Head/Neck 20, a Spine 32, two Body 18, and a peripheral angiography coil

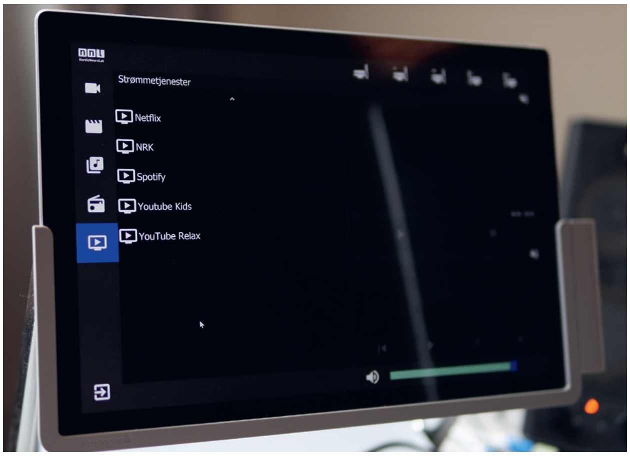
1 The TV screen is behind the bore. A mirror (not shown here) allows the patient to see the screen while lying in the bore.

with 36 channels. These coils make our workflow faster, and we use the time saved to invest in the image quality.

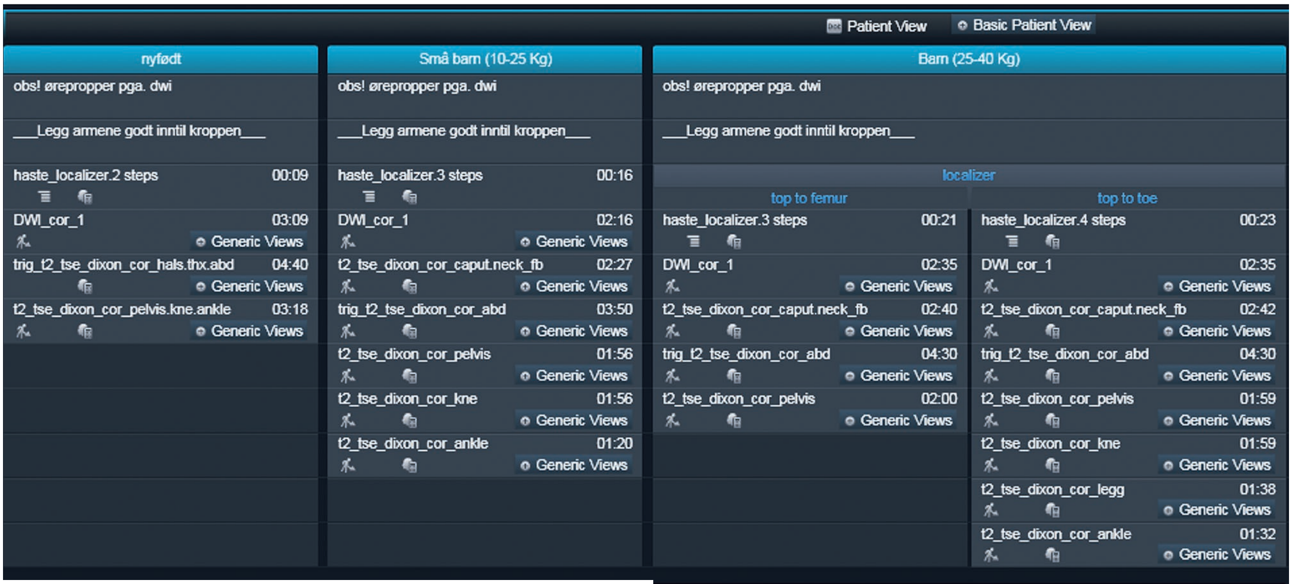
TV entertainment is offered through our NordicNeuroLab solution (Fig. 1). The child can choose to watch a movie, YouTube, Netflix, etc. (Fig. 2). In our experience, being able to watch TV drastically reduces the need for sedation or anesthesia, and most patients manage to complete a WB-MRI examination with sufficient image quality.

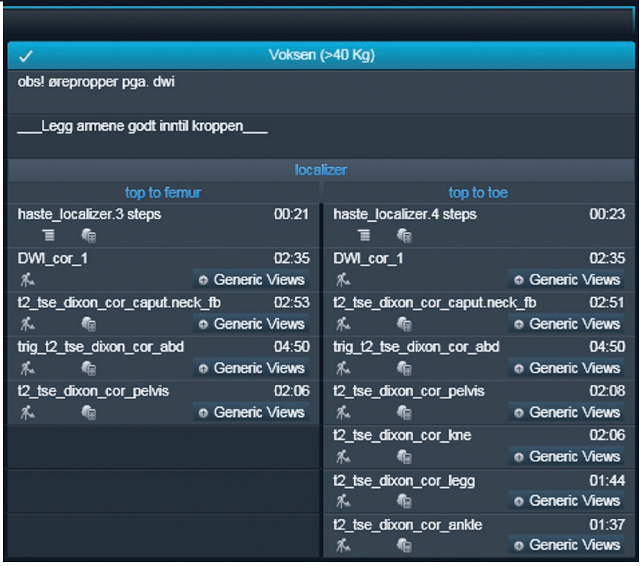
Protocols

With a team of 26 MRI radiographers, it is important to have robust protocols that are easy to set up and have minimal need for adjustment. For optimal and consistent image quality, we decided to make the protocols according to weight rather than age (Fig. 3). It is easier to tailor each



2 Children can choose from various entertainment options.





3 Screenshots showing how our WB-MRI are set up. We sometimes perform head-to-femur scans, and sometimes head-to-toe. The protocols are optimized according to weight rather than age.

protocol according to weight, because children with the same age can vary considerably in size.

There is no unifying protocol for WB-MRI in children. The sequences and planes are chosen according to the clinical question. However, WB-MRI is most often used as a screening tool for detecting pathology or identifying multifocality. This means that almost all protocols include a water-sensitive sequence with fat suppression, most often performed in the coronal plane. Historically, the STIR sequence was used most frequently due to its homogenous fat suppression [1]. In recent years, the Dixon fat-suppression technique has become readily available and

	0–10 kg		10–25 kg		25–40 kg		> 40 kg	
	T2w TSE Dixon	DWI	T2w TSE Dixon	DWI	T2w TSE Dixon	DWI	T2w TSE Dixon	DWI
Orientation	coronal	coronal	coronal	coronal	coronal	coronal	coronal	coronal
FOV read (mm)	350	300	350	400	450	450	450	450
FOV Phase (%)	90.6	98.5	112.5	74.6	131.3	69.3	140.6	69.3
FOV Phase Oversampling (%)	0	50	0	50	0	50	0	50
Phase direction	R-L	F-H	R-L	F-H	R-L	F-H	R-L	F-H
Base resolution	384	130	384	134	384	150	384	150
Phase resolution (%)	100	100	100	100	100	100	100	100
Slice thickness (mm)	3	3.5	3.5	3.5	4	4	4	4
Slices	30*	28*	38*	38*	46*	46*	46*	46*
Voxel size, interpolated (mm)	0.5 × 0.5	1.2 × 1.2	0.5 × 0.5	1.5 × 1.5	0.5 × 0.5	1.5 × 1.5	0.5 × 0.5	1.5 × 1.5
Scantime	2.5 min – 3 min	2.5 min – 3 min	2 min – 2.5 min	2 min – 2.5 min	2 min – 2.5 min	2.5 min – 3 min	2 min – 2.5 min	2.5 min – 3 min
TR (ms)	3540*	4560*	4470*	5320*	5400*	7290*	5200*	7290*
TE (ms)	109*	96*	109*	78*	109*	78*	109*	78*
Concatenations	2	1	2	1	2	1	2	1
Averages	3	10 (b50) / 30 (b1000)	1	2 (b50) / 15 (b1000)	1	4 (b50) / 15 (b1000)	1	4 (b50) / 15 (b1000)
Flip Angle (degree)	150		150		150		150	
Restore magnetization	yes	no	yes	no	yes	no	yes	no
PAT (GRAPPA)	2	2	2	2	2	2	2	2
Bandwidth (Hz/Px)	521	2024	512	2488	512	2380	512	2380
Turbo Factor	20		20		20		20	
b-values		b50 / b1000		b50 / b1000		b50 / b1000		b50 / b1000
TI		180		180		180		180
DWI mode		3D diagonal		3D diagonal		3D diagonal		3D diagonal
Diffusion scheme		monopolar		monopolar		monopolar		monopolar

Table 1: An overview of our parameter settings on a 1.5T MAGNETOM Aera. Keep in mind these settings can be different depending on scanner model. Also, this table only shows one step, while WB-MRI uses multiple steps.
*varies due to coverage

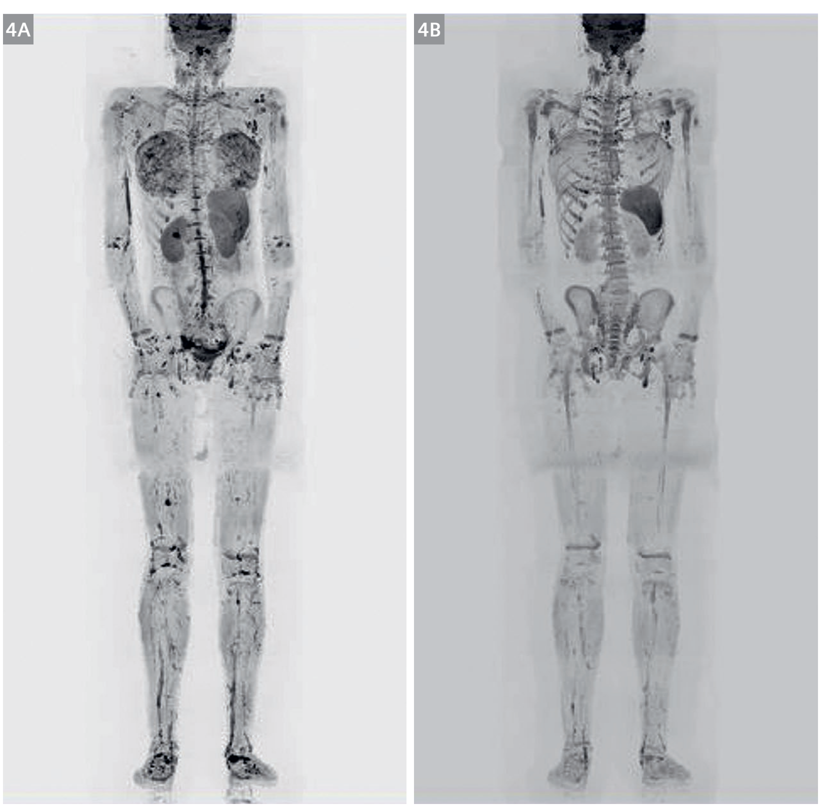
enables the combination of robust Dixon fat suppression with the image quality from the T2-weighted TSE sequence. In addition, this produces in-phase, out-of-phase, water-sensitive and fat-sensitive images in one acquisition. Our WB-MRI protocol now consists of T2w coronal TSE Dixon and coronal DWI (b-values 0 and 1000 s/mm^2, and ADC map) because we mainly use WB-MRI for detection rather than characterizing lesions. Previously, we included T1w coronal TSE in our WB-MRI protocol, mainly for bone-marrow pathology, but this is now no longer included in the standard protocol because we get all the information we need from T2w coronal TSE Dixon fat-only images [2].

Leaving out T1 sequences saves time that we can then invest in other dedicated sequences depending on the region of interest. For instance, we can add a T1-weighted sequence for T1 characterization. The setup for our protocol parameters can be seen in Table 1.

WB-DWI is often performed in transverse plane because it results in fewer distortion artifacts and better image quality. We later reconstruct and compose the images in the coronal plane, often in inverted scale to resemble PET images (Fig. 4). The big drawback of transverse acquisition is the long scan time, especially if two or more b-values with an ADC map are required. We have worked on optimizing the DWI in order to obtain the sequence directly in the coronal plane with two b-values and an ADC map. The main benefit is that this is time-efficient, but the coronal images are also better quality than the ones reconstructed from the transversal acquisition. We have protocols for both 3T and 1.5T systems, but we mainly use 1.5T scanners because it results in less distortion and inhomogeneity on the DWI sequence. Another important reason for using 1.5T is that it allows us to cover more of each step in the coronal plane than we can with 3T.

Shorter scan times in coronal acquisition are possible due to less coverage in the A-P direction, which means fewer slices and shorter TR. Due to inhomogeneity and distortion when acquiring images in the coronal plane, you need to use a FOV phase of around 60–70% (scanner dependent). If you choose a larger FOV phase, it will cause distortion in the periphery of the images. Phase direction is F-H to cope with distortion, and a phase oversampling of up to 50% helps to avoid aliasing artifacts (Fig. 5).

A good tip is to start the protocol with coronal DWI. However, this comes with advantages and disadvantages. One advantage is that you get a fast overview with the help of DWI to draw your attention to the area of pathology. Then, subsequent sequences can be focused on the area of interest. Another point is that coronal DWI requires more post-processing time compared to other sequences in the protocol. This includes composing, multiplanar reconstruction, and maximum intensity projection. The post-processing can be performed during the acquisition of the morphological sequences to save time.

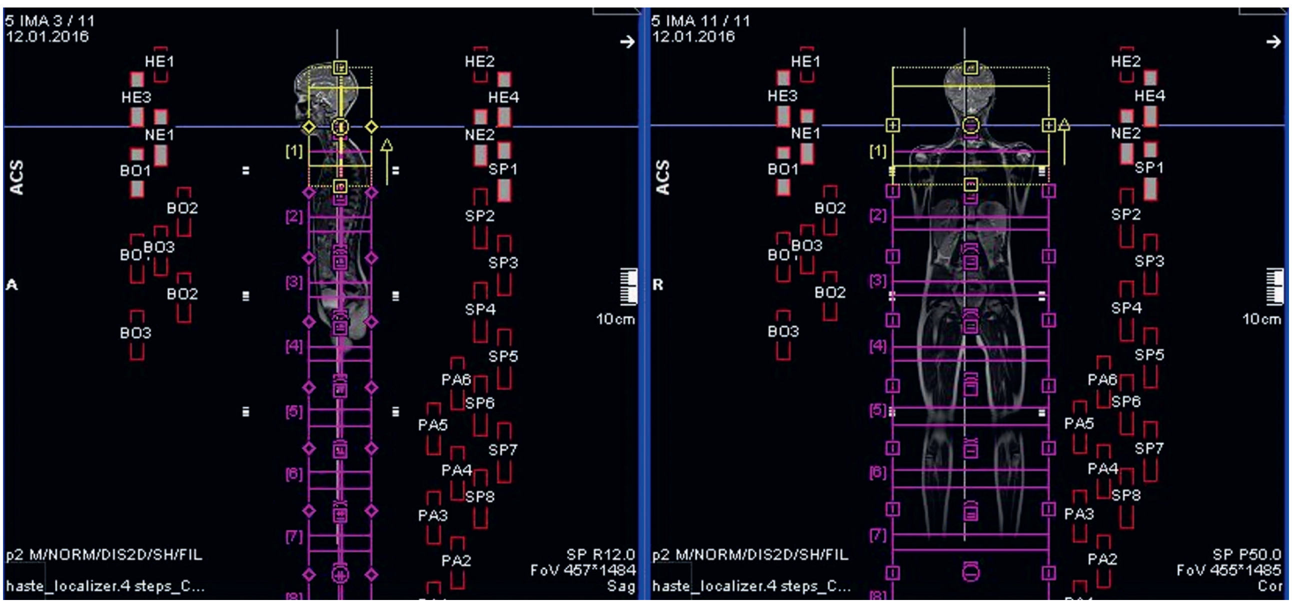


4 WB-DWI with inverted scale to resemble PET images. **(4A)** b-value 50 s/mm^2 and **(4B)** b-value 1000 s/mm^2. Performed directly in the coronal plane with multiple steps and then composed.

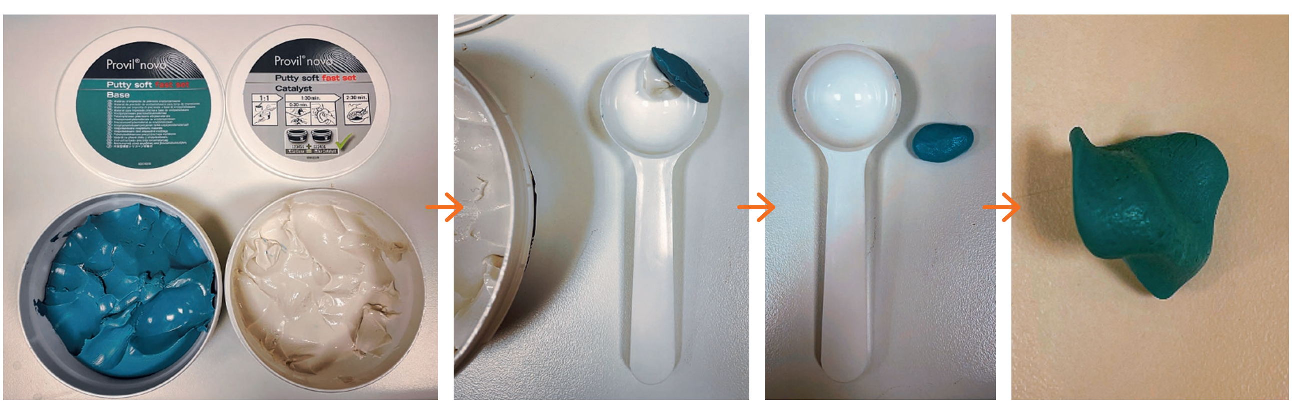
The disadvantage of starting with DWI is that the intense noise from the sequence at the very beginning of the protocol can scare children. Therefore, we always talk to the children to prepare them for the noise and also stay open to the option of starting with morphological sequences such as T2w coronal TSE Dixon if needed. We give the children headphones and earplugs. For younger children, earplugs can be fitted by cutting them in half, but this is not something we do at our institution. Instead, we use "Putty Soft", which can be sized to fit any ear (Fig. 6).

Conclusion

It is feasible to perform WB-MRI in children of all ages. The protocol must be robust and adjusted to patient weight. For specific indications, WB-MRI may give a good overview of disease burden in multifocal disease. It can also be useful in follow-ups for disease recurrence, and is occasionally used to look for disease focus in non-specific findings or symptoms.



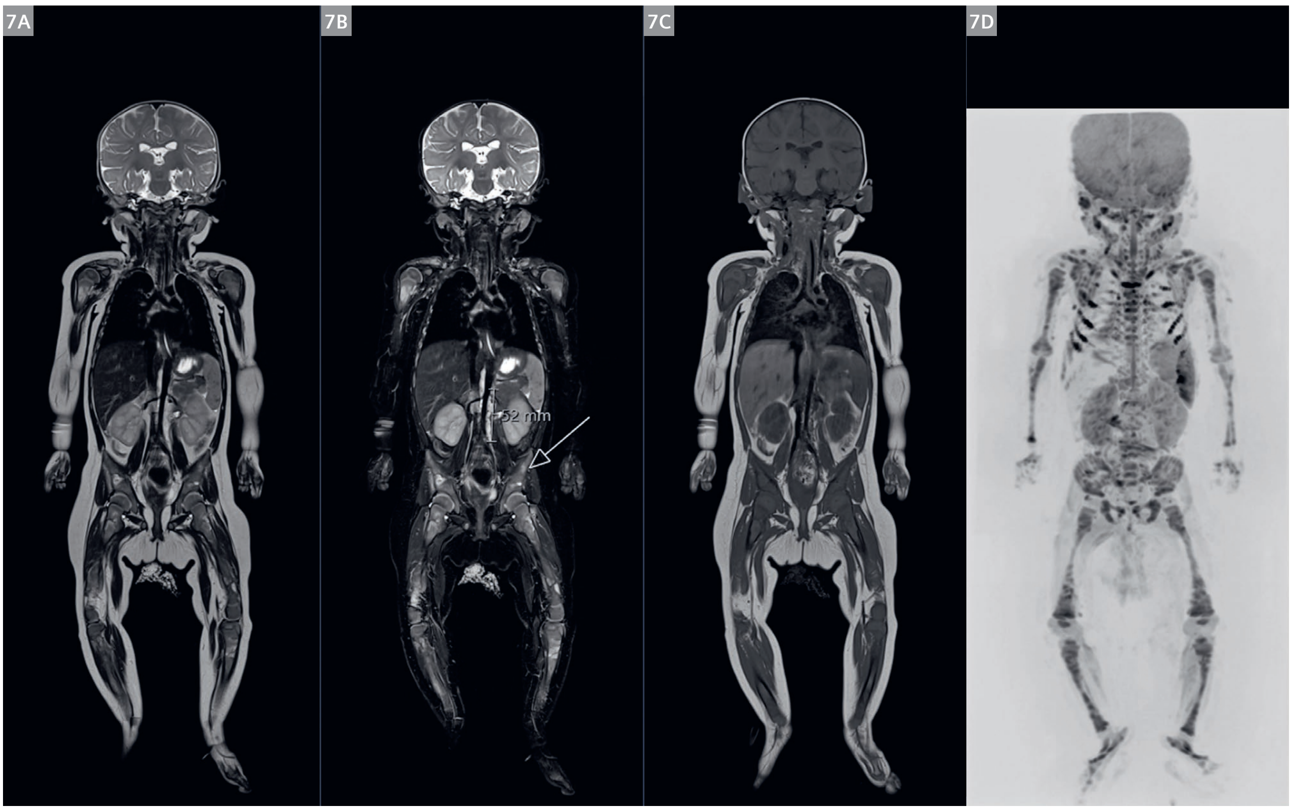
5 Our setup of WB-DWI for direct coronal imaging. In this case, we had eight multiple steps and then composed later.



6 We mix the Putty Soft to shape earplugs that fit any patient perfectly. It is easy and fast to use, and reduces noise in combination with the headphones.

Case 1

A 5-month-old baby[1] with suspected multifocal Langerhans cells (LCH). WB-MRI was performed for disease staging with general anesthesia on a 1.5T MAGNETOM Avanto[Fit]. The examination showed multiple lesions throughout the skeleton and lesions in the spleen, skin, and retroperitoneum.



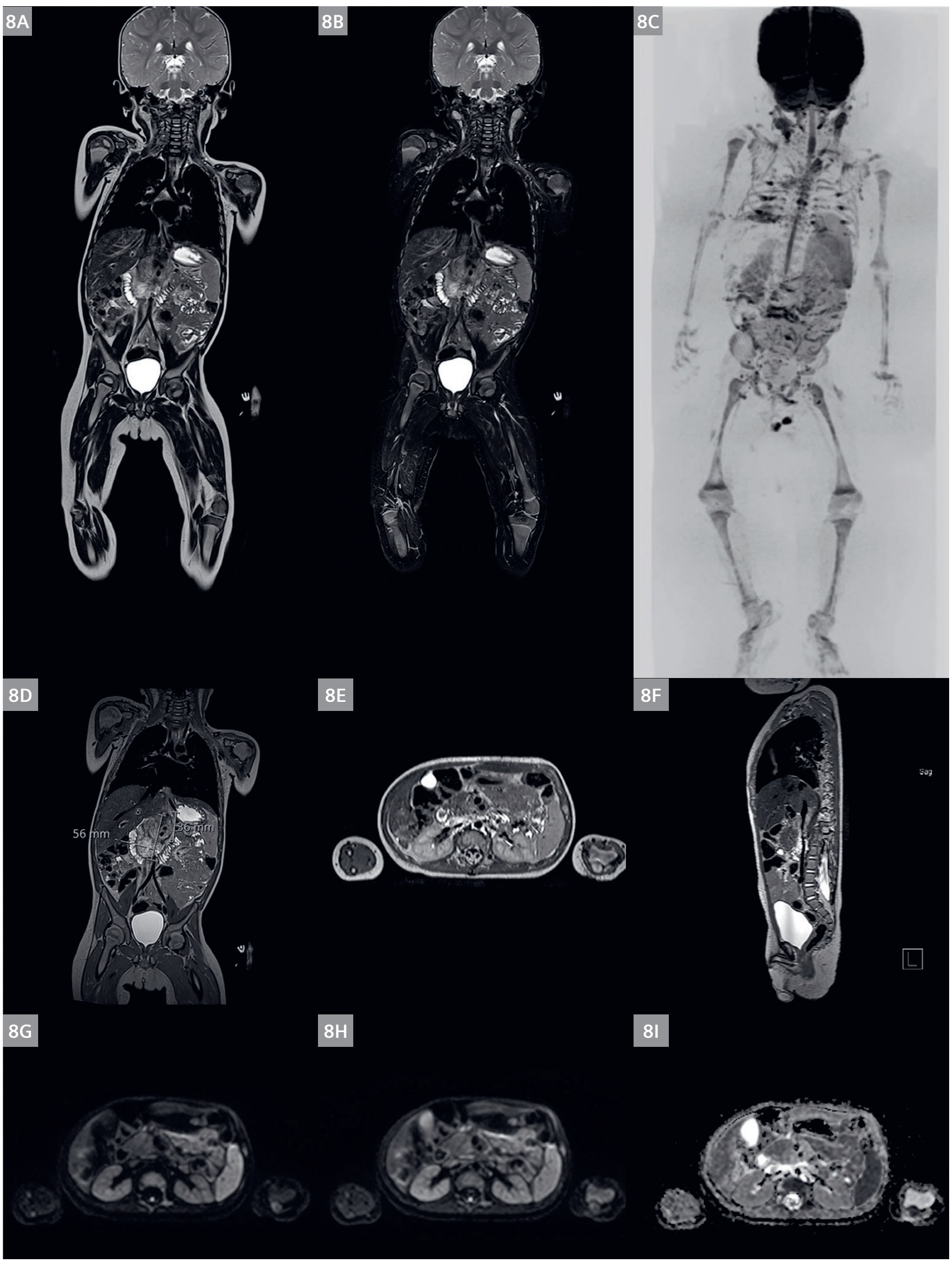
7 **(7A)** T2w TSE Dixon in-phase coronal, 0.45 × 0.45 × 3.5 mm, TA 2–2.5 min. Multiple steps, composed.
(7B) T2w TSE Dixon water-only coronal.
(7C) T1w TSE coronal, 0.45 × 0.45 × 3.5 mm, TA 2–2.5 min. Multiple steps, composed.
(7D) EPI DWI STIR coronal, 1 × 1 × 3 mm, b-value 1000 s/mm², TA 3–3.5 min. Multiple steps, composed.

[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.*

Case 2

A 10-month-old baby[1] treated for neuroblastoma with an intra-abdominal tumor, and lymph-node and liver metastases. WB-MRI was performed three months post-treatment under general anesthesia on a 1.5T MAGNETOM AvantoFit.

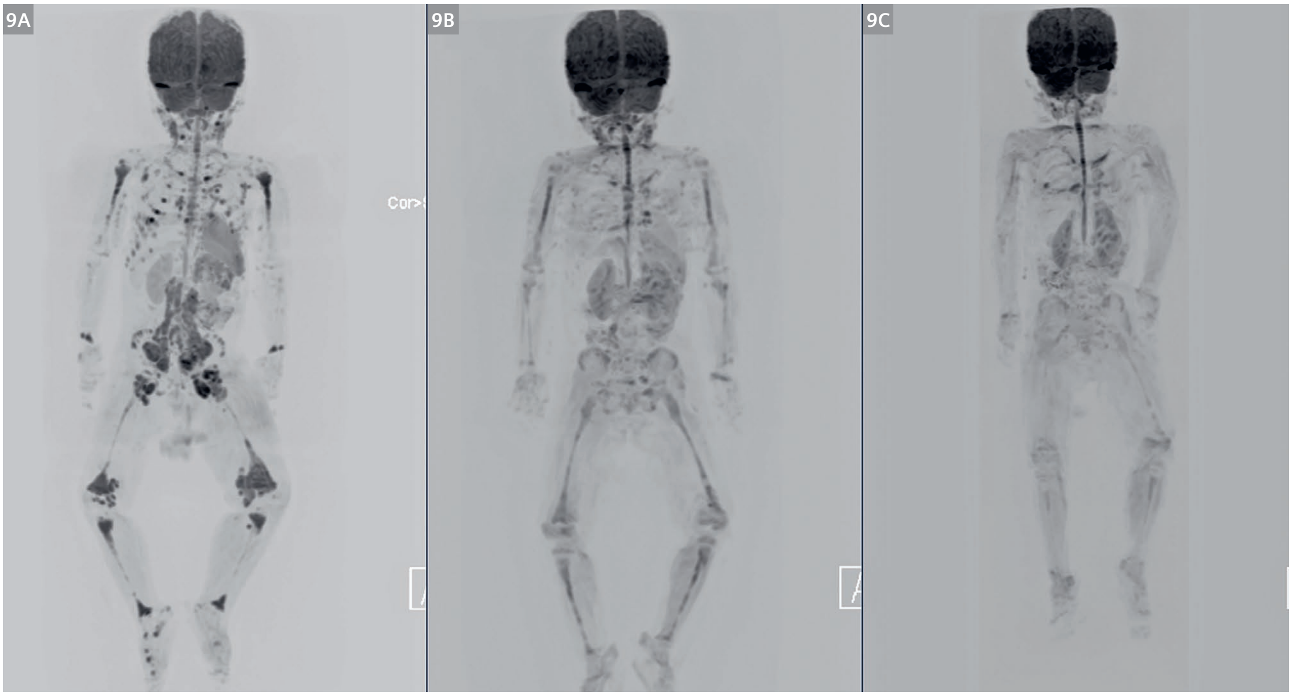
The coronal WB-MRI images provide an overview of the total disease burden, with both the primary tumor and the metastasis. Dedicated sequences of the abdomen were performed as part of the pre-operative assessment.



8 **(8A)** T2w TSE Dixon in-phase coronal, 0.45 × 0.45 × 3.5 mm, TA 2–2.5 min. Multiple steps, composed. **(8B)** T2w TSE Dixon water-only coronal. **(8C)** EPI DWI STIR coronal, 1 × 1 × 3 mm, b-value 1000 s/mm^2, TA 3–3.5 min. Multiple steps, composed. **(8D-F)** T2w 3D SPACE coronal with MPR of transversal and sagittal, 1 × 1 × 1 mm isotropic, TA 5 min. **(8G-I)** EPI DWI transversal, 1 × 1 × 4 mm, TA 3 min.

Case 3

A 2-year-old girl with neuroblastoma from the left adrenal gland with lymph-node and skeletal metastases. One initial and two follow-up WB-MRI scans were performed under general anesthesia on a 1.5T MAGNETOM Avanto^{Fit}. The scans were performed at approximately four-week intervals. The composed WB-DWI images give a good overview of the evolution of the primary tumor arising from the left adrenal gland, and of the lymph-node and skeletal metastases during the treatment course.



9 **(9A)** First WB-MRI. EPI DWI STIR coronal, 1 × 1 × 3 mm, b-value 1000 s/mm², TA 3–3.5 min. Multiple steps, composed.
(9B) First follow-up WB-MRI. EPI DWI STIR coronal, 1 × 1 × 3 mm, b-value 1000 s/mm², TA 3–3.5 min. Multiple steps, composed.
(9C) Second follow-up WB-MRI. EPI DWI STIR coronal, 1 × 1 × 3 mm, b-value 1000 s/mm², TA: 3–3.5 min. Multiple steps, composed.

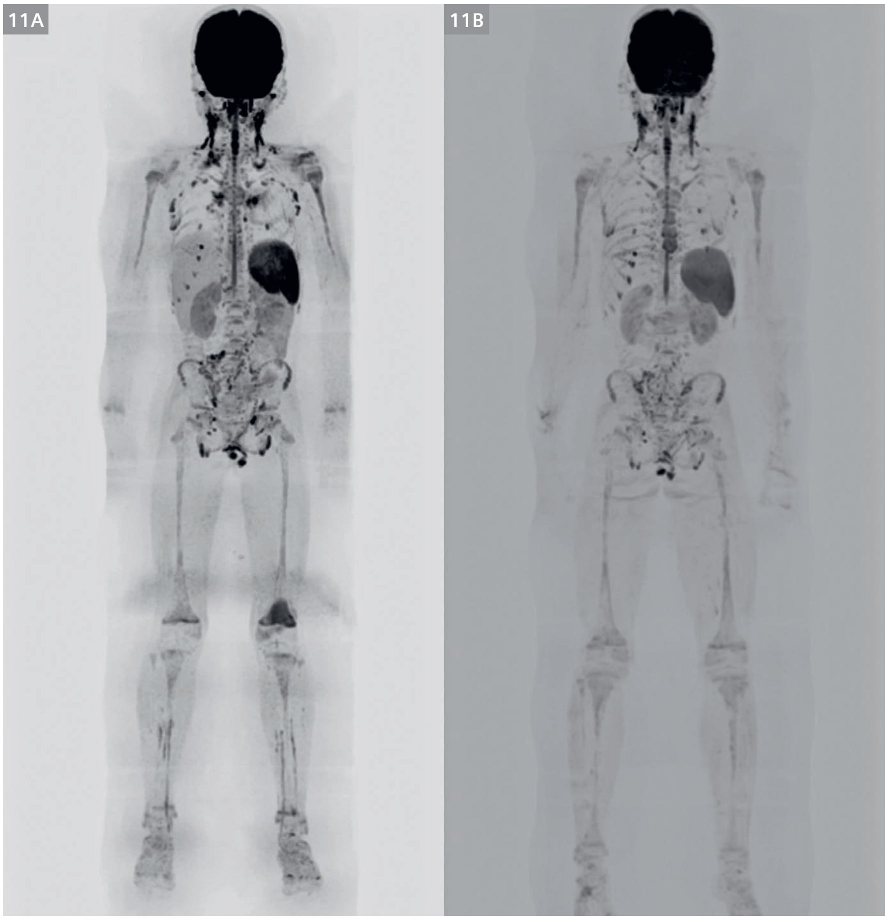
Case 4

A 12-year-old boy with relapse of neuroblastoma and progressive disease in his legs, pelvis, and abdominal lymph nodes. The patient was awake during WB-MRI, with the TV screen as entertainment, on a 1.5T MAGNETOM Aera. The examination was aborted due to patient discomfort and pain, so some images are distorted by motion artifacts. Nonetheless, the examination indicates progressive changes in the tibia, lymph-node metastasis, and multiple lesions in the spine.

10 **(10A)** T2w TSE Dixon water-only coronal, 0.45 × 0.45 × 4.5 mm, TA 2–2.5 min. Multiple steps, composed.
(10B) T2w TSE Dixon fat-only coronal.
(10C) EPI DWI STIR coronal, 1.5 × 1.5 × 4.5 mm, b-value 1000 s/mm^2, TA 2–2.5 min. Multiple steps, composed.

Case 5

A 10-year-old boy with shoulder pain. Prior CT examination showed mediastinal lymph nodes and a lesion in the spina scapula. WB-MRI was performed for screening of multifocal disease, malignancy, or other pathology. The patient was awake during WB-MRI, with the TV screen as entertainment, on a 1.5T MAGNETOM Aera. The initial WB-MRI shows additional pathological locations in the skeleton, such as in the left humerus, left tibia, and distal femur. The second WB-MRI was performed approximately 5 months post-treatment and indicates no residual disease and no new pathology.



11 **(11A)** First WB-MRI. EPI DWI STIR coronal, 1.5 × 1.5 × 4.5 mm, b-value 1000 s/mm², TA 2–2.5 min. Multiple steps, composed. **(11B)** Last WB-MRI. EPI DWI STIR coronal, 1.5 × 1.5 × 4.5 mm, b-value 1000 s/mm², TA 2–2.5 min. Multiple steps, composed.

References

1 Zadig P, von Brandis E, Lein RK, Rosendahl K, Avenarius D, Ording Müller LS. Whole-body magnetic resonance imaging in children – how and why? A systematic review. Pediatr Radiol. 2021;51(1):14–24.

2 Maeder Y, Dunet V, Richard R, Becce F, Omoumi P. Bone Marrow Metastases: T2-weighted Dixon Spin-Echo Fat Images Can Replace T1-weighted Spin-Echo Images. Radiology. 2018;286(3):948–959.

Contact

Bac Nguyen, BSc
Senior MRI Radiographer
Glenneveien 94
1476, Rasta
Norway
Tel.: +47 97702111
og_23@hotmail.com

Lil-Sofie Muller, M.D., Ph.D.
Consultant Paediatric Radiologist
Øvre Smestadvei 37 c
0378 Oslo
Norway
Tel.: +47 92828097
lilsofie.ording@gmail.com