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Whole-body MRI in children and adolescents: Can T2-weighted Dixon fat-only images replace standard T1-weighted images in the assessment of bone marrow?

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ABSTRACT

Objective: When performing whole-body MRI for bone marrow assessment in children, optimizing scan time is crucial.
The aim was to compare T2 Dixon fat-only and TSE T1-weighted sequences in the assessment of bone marrow high signal areas seen on T2 Dixon water-only in healthy children and adolescents.
Materials and methods: Whole-body MRIs from 196 healthy children and adolescents aged 6 to 19 years (mean 12.0) were obtained including T2 TSE Dixon and T1 TSE-weighted images. Areas with increased signal on T2 Dixon water-only images were scored using a novel, validated scoring system and classified into "minor" or "major" findings according to size and intensity, where "major" referred to changes easily being misdiagnosed as pathology in a clinical setting. Areas were assessed for low signal on T2 Dixon fat-only images and, after at least three weeks to avoid recall bias, on the T1-weighted sequence by two experienced pediatric radiologists.
Results: 1250 high signal areas were evaluated on T2 Dixon water-only images. In 1159/1250 (92.7%) low signal was seen on both T2 Dixon fat-only and T1-weighted sequences while in 24 (1.9%) it was not present on either sequence, with an absolute agreement of 94.6%. Discordant findings were found in 67 areas, of which in 18 (1.5%) low signal was visible on T1-weighted images alone and in 49 (3.9%) on T2 Dixon fat-only alone. The overall kappa value between the two sequences was 0.39. The agreement was higher for major as compared to minor findings (kappa values of 0.69 and 0.29, respectively) and higher for the older age groups.
Conclusion: T2 Dixon fat-only can replace T1-weighted sequence on whole-body MRI for bone marrow assessment in children over the age of nine, thus reducing scan time.

1. Introduction

Whole-body MRI has become an important imaging method for the evaluation of bone marrow, enabling detection and in part characterization of a variety of both malignant and non-malignant diseases in adults as well as in children [1–5]. The examination is relatively time consuming, depending on the number and type of sequences performed, and by the anatomy included. Since some children, particularly the youngest, struggle to lie still for the entire exam duration, either because of their age or their medical condition or both, optimizing scan time is important to reduce anxiety in the child and achieve examination of good quality, less affected by motion artifacts. This is especially true for children who undergo frequent follow-ups to monitor the disease progression.

To date, standardized and validated whole-body MRI protocols in children and adolescents are lacking. In a recent systematic review, a significant variation as to body coverage, sequences and technical settings used was found [6]; among the fat-suppressed fluid-sensitive

Abbreviations: **STIR**, short inversion time inversion recovery; **CHESS**, chemical shift-selective fat saturation; **SNR**, signal-to-noise ratio; **TSE**, Turbo Spin Echo.

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sequences, the majority used a short time inversion recovery (STIR) often followed by a coronal T1-weighted sequence. Only one study [7] mentioned the T2-weighted Dixon. This sequence, as opposed to STIR, generates a set of four image reconstructions in a single acquisition: in-phase (equivalent to standard non-fat-suppressed images) and out-of-phase, fat-only (for fat quantification) and water-only (equivalent to fat-suppressed) (Fig. 1) [8].

In adult musculoskeletal imaging, Dixon T2-weighted water-only images are increasingly being used to provide fat-suppressed, fluid sensitive images [8–10]. The chemical shift based, water-fat separation is a robust fat suppression technique compared to alternative fat-suppression such as chemical shift-selective fat saturation (CHESS) and has a relatively higher signal-to-noise ratio (SNR) compared to STIR [11]. Further, the generation of fat-only images in the same acquisition has fueled an interest in the potential of T2 Dixon to replace T1-weighted Turbo Spin Echo (TSE) images for the assessment of bone marrow involvement in adults [12–16].

As for children and adolescents, to the best of our knowledge, no study exists comparing T2 Dixon fat-only and T1-weighted TSE images. The two sequences are fundamentally different. While T1-weighted TSE images are composed of signals from fat due to its low T1-value, the images also contain some signal from water-containing tissues. Conversely, fat-only Dixon images are reconstructed from the T2-weighted out-of-phase and in-phase images, without residual water signal. In theory, this might influence the appearance of water containing red bone marrow compared to yellow bone marrow across age groups.

In two previous studies we have demonstrated that healthy children have a wide range of signal intensity in the bone marrow on whole-body MRI [17,18]. In the present study we aimed to compare the signal on T2 Dixon fat-only and T1-weighted TSE sequences in areas where high signal was seen on T2 Dixon water-only in a cohort of healthy children and adolescents undergoing whole-body MRI. This will indicate if the use of T2 Dixon sequence can replace T1-weighted TSE images in a whole-body protocol, hence reduce scan time.

2. Methods

2.1. Study population

The present study is part of a prospective study performed during 2018–2020, including 196 healthy children and adolescents aged 6–19 years [17–20]. All had a whole-body 1.5 T MRI performed for research purposes only, at the Department of Radiology of Oslo University Hospital or University Hospital Northern-Norway. The participants were recruited via mail, announcements on social media or direct invitation, and included if there were no contraindications to MRI, a history of cancer, current infection, chronic or systemic disease, metabolic or musculoskeletal disorder, or a symptomatic trauma within the past four weeks. None of the participating individuals reported disease or symptoms from the musculoskeletal system when contacted within 18 months after the first examination.

For this sub-study we included baseline whole-body MRIs from all 196 individuals. The demographic details on the healthy pediatric cohort compared to the general population are reported in Table 1.

The study was approved by the Regional Ethics Committee (REK; no 2016/1696), and written informed consent was obtained from each participant and/or a caregiver according to national guidelines.

2.2. Whole-body MRI acquisition

The whole-body MRIs were performed during free breathing, using phased array surface coils and a 1.5 T MRI scanner (Philips medical systems, Best the Netherlands, Intera model release 2.3 (n = 118) or Magnetom Siemens Aera, software e11c (n = 78)). Coronal T2-weighted Dixon and T1-weighted sequences were acquired from the skull-base to toes in 3–5 steps. In 77/118 children and adolescents studied with the Philips scanner the STIR sequence was also performed. The scan parameters including scan time are shown in Table 2.

During the examination the child could either listen to music or watch a movie, and total scan time was approximately 30–45 min.

Table 1
Demographic details on the healthy pediatric cohort compared to the general population.

Variables	Study subjects, n = 196	Data from Statistics Norway*
Oslo University Hospital / University Hospital North Norway, n (%)	78 (39.8%) / 118 (60.2%)	–
Female, n (%)	101 (51.5%)	374,152 (48.8%)**
Age, years (range)Group 1 (n = 47)Group 2 (n = 52)Group 3 (n = 47)Group 4 (n = 50)	12.0 (6.0 – 18.9) **< 9** **9–11** **12–14** **15–19**	(6.0–15.0)
Median BMI, kg/m2 (range)	18 (13–30)	18 (-)
Sports-activity at least once a week, n (%)	167 (85%)	(84% – 89%)

* Statistics Norway, Helseforhold, levekårsundersøkelsen. Statistisk Sentralbyrå, statistikkbanken. https://www.ssb.no/statbank/table/06658. Accessed 24. May 2021.
** https://www.ssb.no/a/barnogunge/2020/tabeller/befolkning/bef0000.html. Age 6–17. Accessed 01. May 2022.

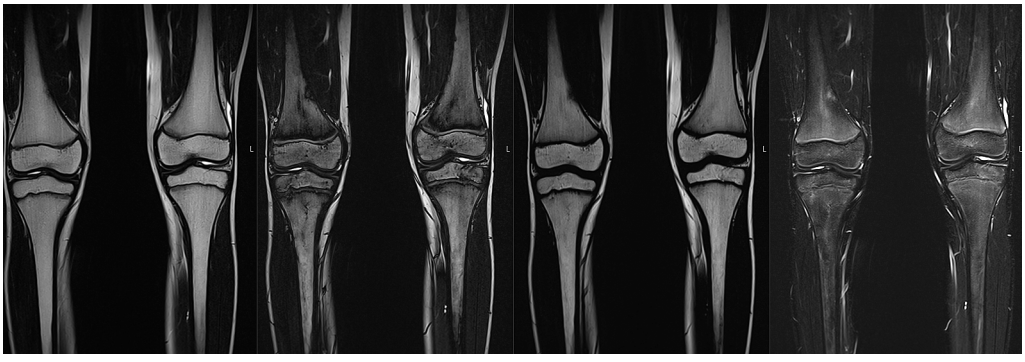

Fig. 1. Knee MRI of a healthy 12 year-old boy. T2 Dixon sequence with all four image reconstructions (a. in phase, b. out of phase, c. fat-only, d. water-only).

Table 2
Basic MRI parameters for the whole-body 1.5 T MRI. T2-weighted Dixon, T1-weighted TSE and STIR sequences (for Philips scanner in the upper table, for Siemens in the lower). TSE = Turbo Spin Echo, TR = Repetition Time, TE = Time to Echo, NSA = Number of Signal Averages.

Sequence	TR (ms)	TE (ms)	NSA	Slice thickness (mm)	Readout band width (Hz per pixel)	Acquired voxel size (mm)	Scan time (min)
Coronal T1-w TSE	450	5.1	1	3.5	391	0.9x0.9x3.5	1:48
Coronal T2-w Dixon fat-only	5156	100	1	3.5	293	0.9x0.9x3.5	3:16
STIR	3500	80	1	3.5	312	0.9x0.9x3.5	3:16
Sequence	TR (ms)	TE (ms)	NSA	Slice thickness (mm)	Readout band width (Hz per pixel)	Acquired voxel size (mm)	Scan time (min)
Coronal T1-w TSE	467	7.6	1	3.5	303	0.9x0.9x3.5	1:30–2:00
Coronal T2-w Dixon fat-only	5640	109	1	3.5	521	0.9x0.9x3.5	2:30–3:00

2.3. Image analysis

For the current study we employed a whole-body MRI child-specific scoring system for bone marrow assessment recently devised and validated using coronal T2 Dixon water-only images [20]. According to this scoring system, signal intensity was graded on a 0–2 scale, where 0 = absent, 1 = mildly increased, and 2 = moderate increased up to fluid-like signal and extension on a 1–4 scale, where 1 = very small lesion (<5%), 2 = involvement of up to 1/3 of the entire bone length, 3 = involvement of up to 2/3 of the entire bone length, 4 = involvement of up to the entire bone length. Based on intensity and extension, all the focal high signal intensity areas were scored and classified as "major" or "minor" findings, except for the hands, where only intensity was recorded (Table 3) [17,18]. High signal intensity areas with a speckled appearance (defined as two or more roundish/punctuated high signals, size 2–5 mm) in the epi-, meta-, or diaphysis of the long tubular bones were excluded from the analysis.

For the present study the whole body was arbitrarily divided into 117 anatomical areas.

Bone marrow high signal areas on T2 Dixon water-only were identified and scored in consensus by two radiologists with 20 and 6 years of experience in pediatric musculoskeletal imaging respectively, according to the abovementioned scoring system. In the event of discrepancies, the consensus was achieved by discussion.

The presence of corresponding low-signal was then assessed (absent/present) on T2 Dixon fat-only images and, in a blinded fashion after at least 3 weeks to avoid recall bias, on T1-weighted TSE images by the same radiologists. All readings were performed on a high-resolution Sectra viewing system (IDS7 PACS) and optimized room-light settings.

When high signal areas on T2-Dixon water-only images were not visible as low signal areas on either T1-weighted or T2 Dixon fat-only sequences, the images were also evaluated on T2 Dixon out-of-phase as visible or not for confirmation of T2-Dixon water-only signal as a true finding. Areas flawed by image artifacts or by too low SNR for image analysis were registered and excluded from further analysis.

2.4. Statistical analysis

Descriptive statistics were reported as numbers with percentages, means with standard deviations or medians with IQRs, where appropriate. To examine for differences according to age using Chi-Square tests, subjects were divided into four age groups (1 = < 9 years, 2 = 9–11 years, 3 = 12–14 years, 4 = 15–19). The agreement between T2 Dixon fat-only and T1 in the detection of low-signal areas was analyzed using kappa statistics (with 95% CI) and percentage absolute agreement. A kappa score of < 0.2 is considered poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good and 0.81–1.00 very good [21]. All statistical analyses were performed using Predictive Analytics Software (SPSS) version 28 (IBM, Armonk, NY), and a p-value < 0.05 was considered statistically significant.

Table 3
Subclassification of MRI-findings into minor or major on T2 Dixon water-only images, based on signal intensity on a 0–2 scale and signal extension on a 0–4 scale.

Signal intensity on a 0–2 scale/extension on a 0–4 scale	
Major MRI findings	Signal intensity 1 and extension 3–4 or Signal intensity 2 and extension 2–4
Minor MRI findings	Signal intensity 1 and extension < 3 or Signal intensity 2 and extension < 2

3. Results

196 whole-body examinations from healthy children and adolescents (95 males) from 6 to 19 years of age with a mean of 12.0 years (SD 3.6 years) were included. Each group by age consisted of 47–52 individuals (Table 1). A total of 22.932 body-regions (117 anatomical areas for each patient) were evaluated on T2-Dixon water-only images. 1290 high signal areas were identified, of which 20 were excluded due to suboptimal T2 Dixon fat-only images and 20 due to suboptimal T1-w images, leaving a total of 1250 high signal areas (642 male, 608 female, p=<0.001, Fisher's exact) for the present study.

Among these 1250 high signal areas, 730 were of mildly increased signal intensity while 520 were moderately increased. The majority of high signal areas were seen in the lower limbs (n = 564), pelvis (n = 269) or upper limbs (n = 287). 48 areas were found in the mandibles/spine and 82 in the thoracic cage. The overall kappa value was 0.39 (0.28–0.51) (Table 4).

1191/1250 high signal areas could be classified according to intensity/extension as major or minor findings (355 and 836 respectively). 59 areas were located in the hands.

Of the 1250 high signal areas identified on T2-Dixon water-only, 1159 (92.7%) had corresponding low signal on both the T2 Dixon fat-only and T1 images (Figs. 2 and 3) while 24 (12 major) (1.9%) showed no low-signal on either of the sequences with an absolute agreement of 94.6% (Table 5).

All 24 high signal areas with no corresponding low signal on either of the sequences were visible on the out-of-phase images (Figs. 4 and 5). Their location is given in graphic e-only Table 6. The agreement between the two sequences differed between the age groups (p < 0.001) (Table 7). Excluding children under 9 years of age in the analysis gave a kappa value of 0.44 (0.31–0.56).

67 high signal areas (5.4%) showed no concordance between T1 weighted and T2 Dixon fat-only images. Of these, 49 returned low signal on T2 Dixon fat-only images alone, and 18 on T1-weighted images alone (3.9% and 1.5% of the total, respectively) (Table 5).

The agreement between T2 Dixon fat-only and T1-weighted images was better for "major" findings as compared to "minor" findings, with kappa values of 0.69 (0.51–0.87) and 0.29 (0.15–0.42), respectively. When evaluating intensity alone, the agreement between T2 Dixon fat-only and T1 was similar for both mildly and moderately increased signal intensity, with kappa values of 0.38 (0.25–0.51) and 0.39 (0.17–0.61), respectively.

As for locations, the agreement ranged between 0.51 (0.35–0.68) for lower limbs and −0.01 (-0.03–0.00) for the pelvis (Table 4). Discordance between the two sequences was frequently found in the humeri (12/67 cases, 18%) (Fig. 6) and in the ischiopubic/para-acetabular region (7/67

Table 4
The appearances of high signal areas in the bone marrow on whole-body MRI T2 Dixon fat-only and on T1-weighted TSE sequences, by localization.

		Visibility				Total	
		T1-w TSE only	T2 Dixon fat-only	Both	None		Kappa value (95%CI)
Localization							0.39
	-mandibles/spine	1	6	38	3	48	(0.04–0.74)
	-thoracic cage	1	1	79	1	82	0.49 (−0.12–1.0)
	-upper extremities	6	15	261	5	287	0.29 (0.06–0.51)
	-pelvis	2	9	258	0	269	−0.01 (-0.03–0.00)
	-lower extremities	8	18	523	15	564	0.51 (0.35–0.68)
Total		18	49	1159	24	1250	0.39 (0.28–0.51)

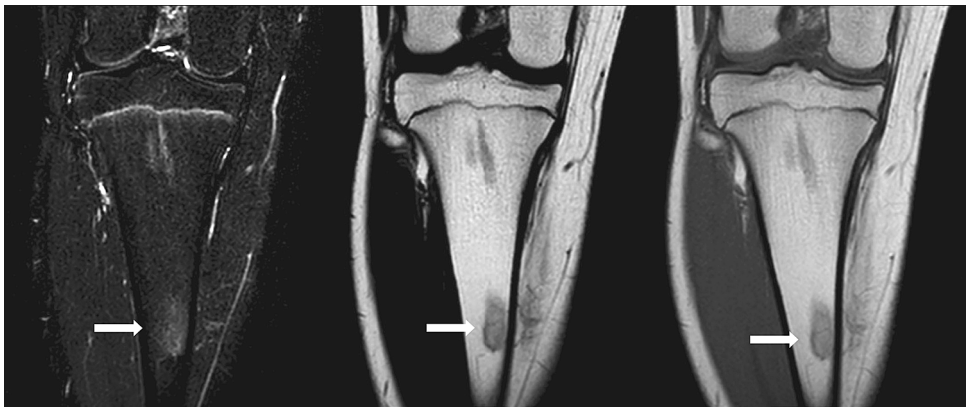

Fig. 2. 14-year-old girl with an oval, high intensity area in the tibia diaphysis as shown on a) T2 Dixon water-only image (arrow) b) T2 Dixon fat-only reconstruction, contrasted against yellow bone marrow (arrow) and c) T1-weighted image (arrow).

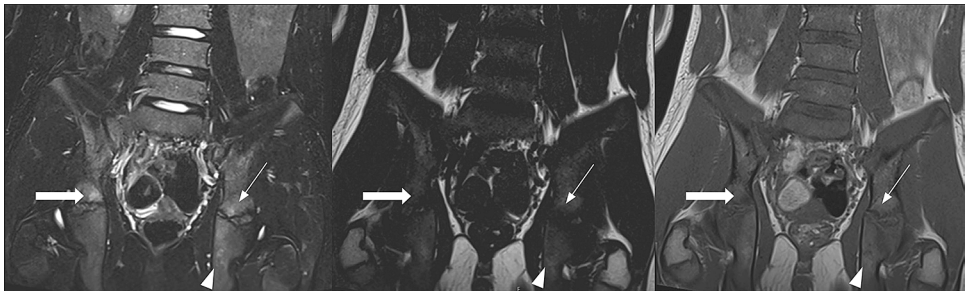

Fig. 3. Detail of the pelvis from a whole-body MRI in an 8-year-old girl, showing a) T2 Dixon water-only image with several high intensity areas in the right periacetabular region (arrow), and in the left periacetabular region (thin arrow, arrowhead). b) A T2 Dixon fat-only reconstruction illustrates the low signal intensity of red marrow in the axial skeleton, as compared to the appendicular skeleton. The high signal areas appear darker as well, albeit with little contrast to background (arrows and arrowhead). c) The axial skeleton on the corresponding T1-weighted image has more signal than the fat-only Dixon reconstruction; the detected areas have corresponding low signal (arrow and arrowhead), however the area in the left periacetabular region has only a slightly reduced signal (thin arrow).

Table 5
Agreement between T2 Dixon fat-only and T1-weighted TSE sequences in 1250 high signal areas previously identified on T2 Dixon water-only images from 196 healthy children and adolescents.

		T1-weighted TSE		
		No low signal	Low signal	Total
T2 Dixon fat-only	No signal	24 (1.9%)	18 (1.5%)	42 (3.4%)
	Low signal	49 (3.9%)	1159 (92.7%)	1208 (96.6%)
Total		73 (5.8 %)	1177 (94.2 %)	1250

areas, 10%).

4. Discussion

In this cohort of healthy children and adolescents, nearly 93% of the bone marrow areas with high signal identified on T2 Dixon water-only images returned low-signal on both T2 Dixon fat-only and T1-weighted images. <2% did not return low signal on either of the two sequences, with an absolute agreement of 94.6%. The kappa was fair to good with an average of 0.39. This value was not unexpected and does not affect the reliability of the results. In fact kappa value may be unsatisfactory when there is a considerable imbalance in the class distribution and in our study the marginal distribution is highly unbalanced since most areas were hypointense in T2-DSE FO and T1-w TSE and only a few were not.

Kappa value was higher in older children and for “major findings”, i.e. areas which in a clinical setting might have been mistaken for pathology. Conversely, the majority of the discordant findings were classified as “minor”. These are important observations supporting the use of T2 Dixon fat-only images as an alternative to T1-weighted images for assessment of bone marrow lesions on whole-body MRI in children over the age of nine.

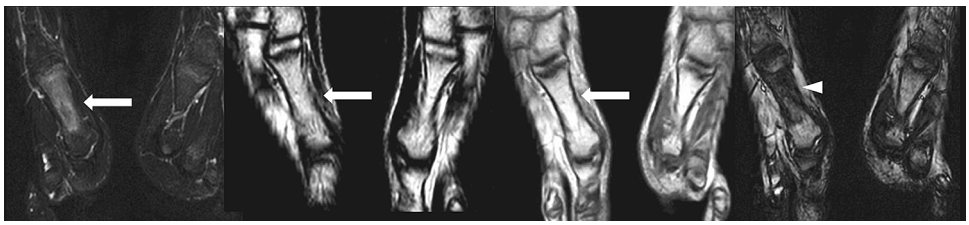

Fig. 4. MPR reconstructions of the right and left forefoot in a 13-year-old boy. a) Increased signal in the right first metatarsal on T2 Dixon water-only image (arrow). Neither T2 Dixon fat-only image (b) nor T1-weighted image (c) show corresponding low signal (arrows). d) The out-of-phase Dixon image depicts a reduction of signal in the right first metatarsal bone compared to the left side, confirming the increased water content (arrowhead).

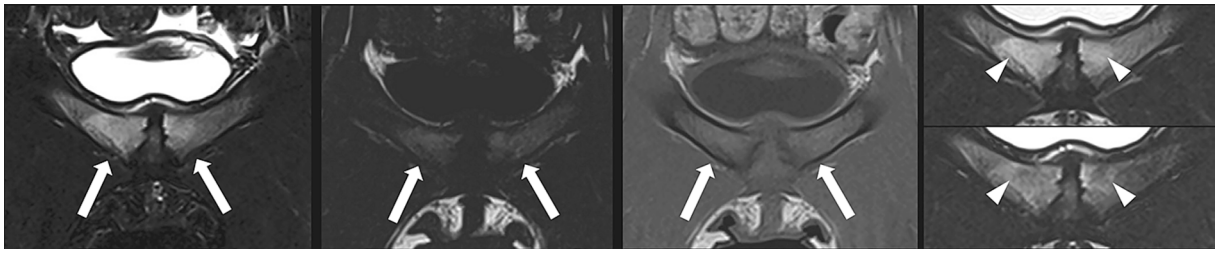

Fig. 5. Whole-body MRI in a 17-year-old adolescent. Details from the pubic bones, showing a) symmetrical high signal on T2 Dixon water-only images (arrows). b) On the T2 Dixon fat-only image the signal is difficult to evaluate and appears as not reduced (arrows). c) The pubic bones have homogeneous, not decreased signal on the T1 weighted image (arrows). d) On the in-phase (upper image) there is increased signal in the pubic bones (arrowheads), on the out-of-phase (lower image) there is patchy reduced signal in the same areas confirming the mixed water and fat content.

Table 6
Location of the 24 high signal areas on T2 Dixon water-only with no corresponding low signal on T2 Dixon fat-only and TSE T1.

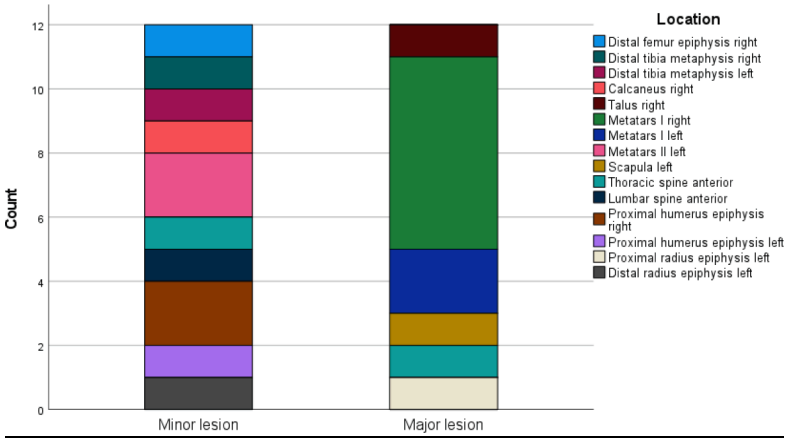

Table 7
Agreement between T1-weighted TSE and T2 Dixon fat-only sequence in areas with high signal on T2 Dixon water-only sequences according to different age groups.

		T1-weighted only	T2 Dixon fat-only	Both	None	Total	Kappa value (95%CI)
Age group, years	< 9	4	10	239	1	254	0.10 (-0.12–0.3)
	9–11	7	9	319	4	339	0.31 (0.06–0.56)
	12–14	2	20	295	13	330	0.51 (0.34–0.69)
	15–19	5	10	306	6	327	0.42 (0.18–0.66)
Total		18	49	1159	24	1250	0.39 (0.28–0.51)

When evaluating intensity alone, the agreement between the two sequences was quite similar for mild and moderately increased signal intensity, suggesting that the extension of a lesion is an important factor for the perception of findings.

In some of the cases showing low signal on both the T2 Dixon fat-only and the T1-weighted images, we experienced that the low signal was easier to recognize on the T2 Dixon fat-only images as compared to the T1-weighted images (Fig. 7). We speculate that this in part might be due to subtle movements of the child between T2 Dixon and T1-weighted scans, whilst water-only and fat-only images are acquired in the same sequence. Moreover, although fat-only images may occasionally lack the anatomical conspicuity of T1-weighted images, the poorer conspicuity might be overcome by the non-fat-suppressed in-phase images.

Regarding the 2% of high signal areas where low signal was absent

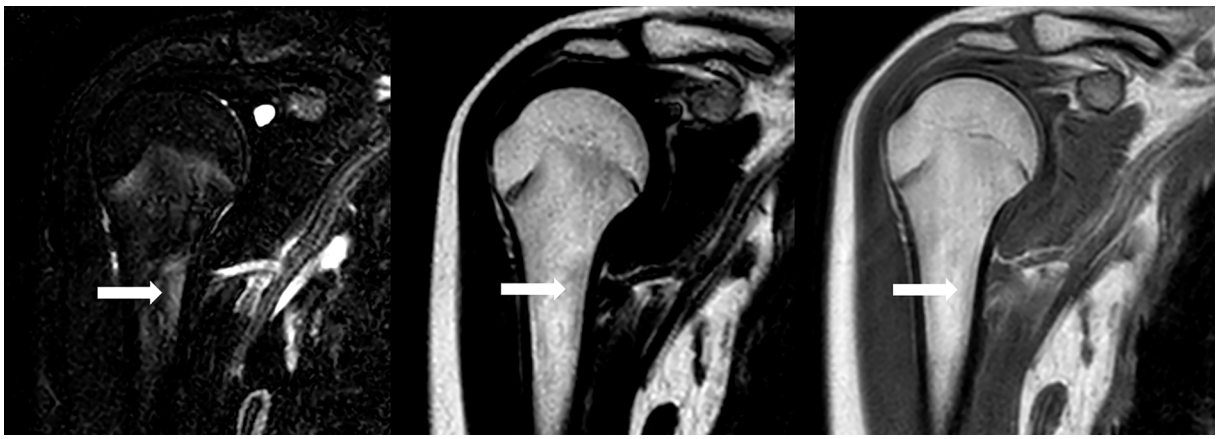

Fig. 6. Detail of the proximal humerus from a whole-body MRI in a 16 year-old girl. a) increased signal from the medial part of the proximal humerus diaphysis on the water-only Dixon reconstruction (arrow) b) low signal in the same location on the fat-only reconstruction (arrow) c) the T1 image does not show a decreased signal in the corresponding area (arrow).

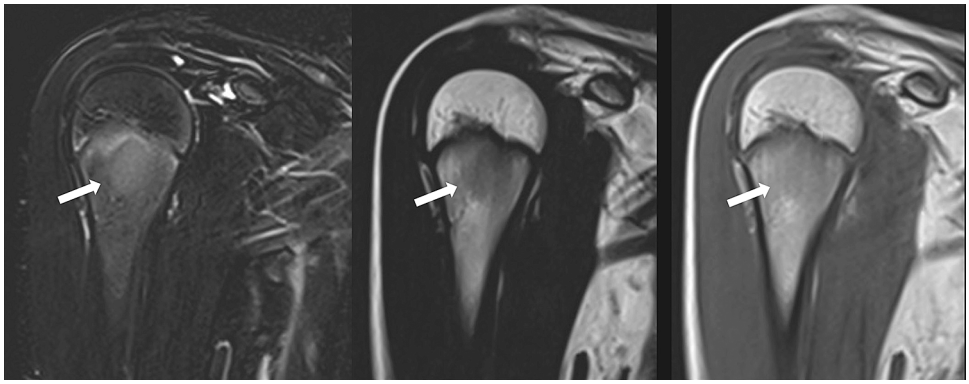

Fig. 7. Right proximal humerus in a 14-year-old boy, showing a) an area of increased signal on T2 Dixon water-only (arrow). b) T2 Dixon fat-only reconstruction shows a well delineated corresponding low signal area (arrow). c) The T1-weighted image displays a lower signal as well, but less well demarcated than the fat-only Dixon image (arrow).

on either of the two sequences, this might be due to residual amounts of fat signal in areas with increased water content as compared to the surrounding bone marrow. Interestingly, all these areas were visible on the out-of-phase images, confirming their true presence (Figs. 4 and 5). Out-of-phase images have proven helpful for the assessment of several musculoskeletal diseases, including neoplastic marrow lesions [22]. Two recent studies on patients with active and/or chronic sacroiliitis showed that the T2 Dixon out-of-phase images followed by the fat-only images were superior to the T1-weighted images in the detection of periarticular fat deposition [23,24].

As for locations, the best agreement between T2-Dixon fat-only and T1-weighted images was found for the lower extremities, which are most frequently affected in both inflammatory and infectious disorders in children and adolescents [25,26]. Discordance between the two sequences was most often seen in the proximal humeri and in the ischiopubic/para-acetabular regions. A possible explanation might be that the proximal humeri are more prone to movements from breathing, and are often further away from the coil, which can significantly degrade image quality. As for the pelvis, we hypothesize that areas close to the triradiate cartilage are challenging, as it can be difficult to define if the signal originates from the bone marrow or from the physiological cartilage. Both areas are known to contain a higher content of red bone marrow in the immature skeleton, resulting in lower signal on both sequences.

It must be remembered that the bone marrow is composed of a combination of hematopoietic red marrow and fatty yellow marrow, and that its composition changes throughout life in response to normal maturation (red to yellow conversion) and stress (yellow to red conversion) [4,27,28]. On T1-weighted imaging, increased signal reflects increased fat content and hence conversion from red marrow to yellow marrow. The overall T1 signal from red marrow is considerably lower as compared to fatty marrow, but typically higher than that from adjacent skeletal muscle [29]. Notably, in our cohort of healthy individuals we found several examples of areas with lower T1 signal compared to skeletal muscles (Fig. 8), a finding which has been previously reported to represent an infiltrative process in 35 out of 36 cases [30].

The agreement between the two sequences was higher amongst the older age groups as compared to children under 9 years of age. Amongst the cases with corresponding low signal on both sequences, we noticed that in several of our youngest children the signal intensity of the axial skeleton was in general lower on T2 Dixon fat-only than on T1 (Fig. 3). These findings are not unexpected as the amount of red marrow is higher in early childhood and marrow conversion in the appendicular skeleton occurs much more rapidly and to a greater degree than in the axial skeleton, challenging the interpretation of the T2 Dixon fat-only images in this age group.

In a previous paper we found a high agreement between STIR and T2 Dixon water-only sequences in the assessment of high signal marrow changes [19]. Based on this and present results, we would argue that STIR and anatomic T1-w sequences, often used for a whole-body MRI, might be both replaced by a single T2 Dixon sequence, reducing the total scan time, with a small caveat for those under the age of nine. The

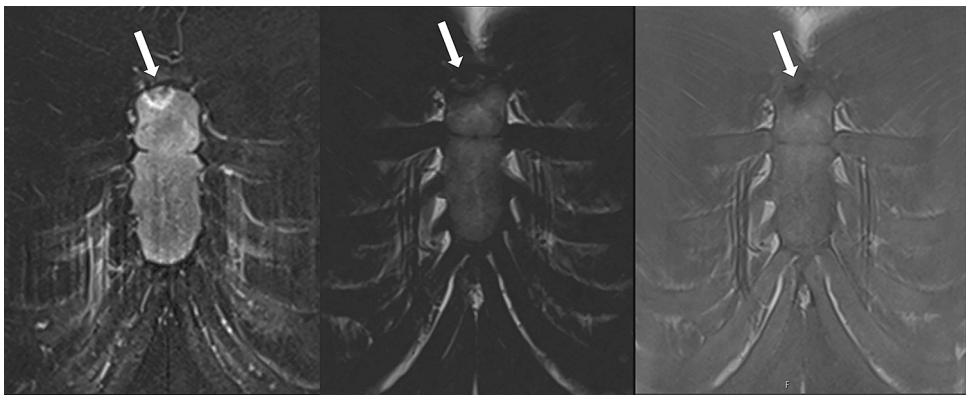

Fig. 8. 17-year-old adolescent with a) an area of irregularly increased signal on T2 Dixon water-only on the manubrium of the sternum (arrow) and corresponding low signal on both b) T2 Dixon fat-only (arrow) and c) T1-weighted image (arrow). The signal on the T1-weighted image is even lower than skeletal muscle.

effective time reduction could be of between 7 and 9 min depending on the number of stacks needed. This gain in time is not insignificant for a child since in paediatric patients the final minutes are less tolerated, thus the last sequences are those mostly affected by movement artefacts.

In recent years there has been a growing interest in the use of T2-Dixon fat-only in adult musculoskeletal imaging. Several studies have shown its potential to replace T1 images. In a retrospective study on 121 whole spine MRIs for suspected vertebral bone metastases, Maeder et al [12] concluded that T2-Dixon fat-only and water-only imaging provide diagnostic performance similar to that of the combination of morphologic sequences (T1 and T2 Dixon water-only). Evaluating the diagnostic performance of an MRI protocol including only sagittal T2-Dixon fat-only and water-only images as an alternative to a standard protocol in 114 adults with low back pain, Yang et al [13] reached the same conclusions. Thus, the authors suggest a shortened MRI protocol including a T2-Dixon sequence without an additional T1-weighted sequence, in this clinical setting. Also, Zanchi et al [14] retrospectively reviewing 50 lumbar spine MRI examinations, concluded that in subjects with non-specific low back pain and/or lumbar radiculopathy a simplified protocol of spine MRI in the sagittal plane with a T2-Dixon sequence provides the same information as a standard protocol including T1-weighted, T2-weighted, and fat-suppressed T2-weighted sequences.

To the best of our knowledge, this is the first paper examining the agreement between T2 Dixon fat-only and T1-weighted images as part of a whole-body MRI protocol in children and adolescents. The main strengths of our study are the high number of children and adolescents balanced by age, the high number of examined areas, the use of a validated scoring system for high signal areas, the wide range of signal intensity in the high signal lesions and the blinded design. The inclusion of two different centers using different vendors but similar MRI protocols and scan resolution strengthens the applicability of the results.

We acknowledge, however, some limitations. Firstly, the investigation was carried out on healthy children and adolescents only. However, the high proportion of "major findings" which, in a clinical setting could be mistaken for pathology, suggests that our results could be valid also for pathological processes. Secondly, the whole-body MRIs were performed on 1.5 T magnets. One might speculate that a 3 T magnet would provide higher agreement between the two sequences due to better image resolution. However, previous studies [13,14] have shown that the sequences perform equally well at 1.5 T and 3 T. Lastly, the results of this study are valid for the sequences used and could change if different resolutions or imaging parameters were applied.

In conclusion, the agreement between T2 Dixon fat-only and T1-weighted sequences in the assessment of bone marrow high signal areas in healthy children and adolescents indicates that a T1-weighted sequence can be replaced by T2 Dixon fat-only images in children older than 9 years. The scan time reduction resulting from the use of T2 Dixon sequence alone could have several advantages, in particular the reduction of exam-related stress in children and the achievement of good quality examinations, less affected by motion artefacts.

CRediT authorship contribution statement

Laura Tanturri de Horatio: Conceptualization, Data curation, Funding acquisition, Methodology, Validation, Writing – original draft. **Pia K. Zadig:** Resources, Investigation, Data curation. **Elisabeth von Brandis:** Resources, Investigation. **Lil-Sofie Ording Müller:** Resources, Writing – review & editing. **Karen Rosendahl:** Formal analysis, Methodology, Validation, Writing – review & editing. **Derk F.M. Avenarius:** Data curation, Methodology, Resources, Writing – review & editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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