

Pediatric whole-body magnetic resonance imaging: Intra-individual comparison of technical quality, artifacts, and fixed structure visibility at 1.5 and 3 T

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Abstract

Purpose: To compare whole-body magnetic resonance imaging (WBMRI) performed at 1.5 and 3 T for technical quality, artifacts, and visibility of selected fixed structures. **Patients and Methods:** 21 children who had WBMRI at both 1.5 and 3 T scanners within a relatively short interval (3-13 months; average-8.6 months) were included. The images were objectively compared with scores from 4 to 1 for five parameters including severity of artifacts; visibility of liver, vertebral column, and marrow in legs; and overall image quality. Inter-observer agreement was calculated using Kendall's coefficient of Concordance (W) and scores were compared using Signed Rank test. **Results:** There was substantial inter-observer agreement for all five categories at both field strengths. The difference between averages of mean scores of all five parameters for two field strengths was statistically significant ($P < 0.05$), indicating less artifact, better fixed structure visibility, and overall image quality at 1.5 T as compared to 3 T. However, scores at 3 T were also rated within a good range (around 3) indicating its feasibility for WBMRI in children. **Conclusion:** WBMRI at 1.5 T has significantly better image quality, fixed structure visibility, and fewer artifacts, as compared to WBMRI at 3 T in children. This difference is unlikely to significantly affect detection of pathology on 3 T WBMRI as the image quality score at 3 T was also within good range.

Key words: 1.5 T; 3 T; artifacts; children; image quality; whole-body magnetic resonance imaging

Introduction

Whole-body magnetic resonance imaging (WBMRI) is now recognized as an important tool in both diagnosis and follow-up of various oncologic and non-oncologic

conditions in children.^[1-8] WBMRI can be performed at both 1.5 and 3 T magnetic field strengths. There are a few studies comparing these two field strengths in adults for whole-body MR angiography,^[9] oxygen-enhanced MRI of

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lungs,^[10] cardiac and coronary imaging,^[11,12] and abdominal diffusion-weighted imaging (DWI).^[13] Comparison of image quality and artifacts of WBMRI performed at 1.5 and 3 T has also been performed in adults.^[14] However, to the best of our knowledge, there has been no study comparing the image quality of WBMRI at these two magnetic strengths in children. It would be ideal to compare studies performed on the same patient analyzing the same pathology simultaneously at these two magnetic field strengths in order to avoid bias secondary to the temporal variation in imaged pathology. However, this would not be feasible, especially in children. We attempted to compare the technical quality at the two magnetic field strengths in the same patients performed at different times but at a time interval.

The aim of our study was to retrospectively perform intra-subject comparison of technical quality, artifacts, and the visibility of selected fixed structures between WBMRI coronal short tau inversion recovery (STIR) sequences performed at 1.5 and 3 T.

Patients and Methods

Institutional Research Ethics Board approval and waiver for consent were obtained for this study.

Patients

A list of children who had undergone MRI studies on both 1.5 and 3 T at our institution, a tertiary pediatric referral center, for various indications was obtained from a database that keeps record of all MRI exams. Children who had WBMRI at least once each on our 1.5 and 3 T Philips (Achieva; Philips Medical system, Best, the Netherlands) MRI scanners from January 2008 to April 2011 were included in this study. Selection of 1.5 T versus 3 T scanner for WBMRI is done clinically based on 3 T compatibility (based on certain devices and prosthesis in the body) and availability of the scanner. Of 22 children who fulfilled these criteria, one child with a gap of 22 months between two WBMRI exams was excluded, as this was deemed to be a long time interval which could potentially cause significant changes in the body physique, physiology, and ability of the child to stay still during the exam. Remaining 21 (6 boys, 15 girls; age between 4.6 and 17 years with average age of 12.03 years at the time of first WBMRI) children who formed the final study group had a maximum gap of 13 months between the WBMRI exams. The minimum interval between WBMRI exams was 3 months, with an average interval of 8.6 months. This interval was thought to be not long enough to change significantly physical characteristics of the body in a child, thus allowing fair comparison of WBMRI technical quality at two field strengths.

The indications in 21 children included 4 cases of Li-Fraumeni syndrome, 5 neuroblastoma, 2 retinoblastoma,

3 rhabdomyosarcoma, and 1 each of acinic cell carcinoma, epithelioid hemangioendothelioma, tuberous sclerosis with epithelioid angiomyolipoma, nasopharyngeal undifferentiated sarcoma, Ewing sarcoma, desmoplastic round cell tumor, and metastatic adenocarcinoma of colon. Nineteen children had WBMRI on both 1.5 and 3 T without sedation or anesthesia; remaining two were under general anesthesia for both 1.5 and 3 T scans.

Magnetic resonance imaging technique

WBMRI was performed using 1.5 and 3 T Philips (Achieva; Philips Medical system) MRI scanners equipped with high-performance gradient systems, sliding table platform, and quadrature body coil integrated in the magnet bore obviating the need to reposition the patient with each station. The exam included single STIR coronal sequence at multiple stations covering the entire body from vertex to toes at multiple stations. The images from multiple stations were retrospectively stitched using software (Mobiview) provided by the vendor to obtain whole-body images. There was some overlap between the stations and stitching was done based on table position. The coronal STIR sequence at 1.5 T was performed with the following parameters: Time to repeat (TR) 3000 ms, echo time (TE) 60 ms, inversion time (TI) 165 ms, field of view (FOV) 400–500 mm, matrix 380 × 290, slice thickness of 5 mm with 1 mm gap, number of signal averages 6, echo train length (ETL) 26, and pixel bandwidth 446 Hz. STIR parameters at 3 T included TR 9126 ms, TE 70 ms, TI 230 ms, FOV 400–500 mm, matrix 460 × 360, slice thickness of 6 mm with 1 mm gap, number of signal averages 2, ETL 27, and pixel bandwidth 256 Hz. Approximate time for each station at 1.5 T was 5 min and at 3 T was 4 min. The total scan time varied from 20 to 35 min depending on the height of the child. The acquisition was free breathing, no sagittal images of the spine were acquired, and no contrast or bowel paralysis was used.

Image analysis

WBMRI images were reviewed by a pediatric radiologist (8 years of experience in reading pediatric body MRI) and a pediatric radiology fellow (A year of experience in reading pediatric body MRI) independently on picture archival and communication system (PACS). Images at 1.5 and 3 T were reviewed by both at separate occasions with a gap of at least 4 weeks. Individual station images as well as whole-body stitched images of each WBMRI exam were reviewed to assess five aspects/categories: Vertebral column visibility, liver visibility, visibility of distal tibia/fibula, artifact grading, and overall image quality. These five aspects were analyzed using the grading system summarized in Tables 1 and 2 and some are illustrated in Figures 1 and 2. Two regions of bone marrow space were selected – one that may be affected by breathing movement (vertebral column) and another that is unlikely to be affected by movement (distal tibia/fibula). For soft tissue visibility, the liver was selected, as it is a common site of metastases. This scoring system

Table 1: Grading for fixed structure visibility

Grade	Spinal column visibility	Liver visibility	Marrow visibility in distal tibia/fibula
4	Clear visibility of disc structures and bone marrow	No significant motion artifact, clear visualization of the portal vein bifurcation, good visualization of left lobe	Good visibility of cortex and metaphyseal margins, fibula clearly seen
3	Minor artifacts with no significant implication on diagnostic quality	Mild motion artifacts, portal bifurcation visualization, left lobe visualization limited	Reduced corticomedullary differentiation, fibula and metaphyseal margins seen
2	Artifacts or poor SNR causing some limitation of spinal column visibility	Moderate motion artifacts, portal bifurcation visualization poor, and left lobe visualization poor. Small lesions (<1 cm) would be missed	Marrow visibility affected by darkening from poor SNR, chemical shift, and susceptibility; metaphyseal margin poorly visualized or fibula not clearly visualized
1	Poor visibility of spinal column	Poor visibility, even large lesions would be missed	Overall poor visibility of both bones and marrow

SNR: Signal-to-noise ratio

Table 2: Grading for severity of artifacts and overall image quality

Grade	Artifacts severity	Overall image quality
4	No significant artifacts	Best image quality, no artifacts, good SNR, good fixed structure visibility
3	Minor artifacts with no significant implication on diagnostic quality	Image quality minimally affected by one or more factors including artifact, slightly reduced SNR, reduced fixed structure visibility
2	Moderate artifact with some limitation of diagnostic quality	Image quality affected by significant artifacts, poor SNR, low fixed structure visibility, but some diagnostic information still available
1	Severe artifacts making the exam nondiagnostic	Nondiagnostic study

SNR: Signal-to-noise ratio

was developed by us. Before reviewing the actual images of the study group, both reviewers together reviewed 10 WBMRI exams (5 at 1.5 T and 5 at 3 T) outside the study group to ensure consensus regarding the scoring system used in this study. Both reviewers also listed the known artifacts for each exam. The pathologic findings were not analyzed in this study.

Statistical analysis

Inter-observer agreement between the two reviewers was calculated for all five categories of image analysis using Kendall’s coefficient of Concordance (W). W-values less than 0.20 were considered as poor agreement, 0.21–0.40 as fair agreement, 0.41–0.60 as moderate agreement, 0.61–0.80 as substantial agreement, and greater than 0.81 as almost perfect agreement. Average of the mean scores given by the two readers for each category was used to compare 1.5 and 3 T using non-parametric Signed Rank test. Data analysis was performed using SAS 9.3. In all analyses, P values <0.05 were considered statistically significant.

Results

There was substantial agreement between the two reviewers for all five categories and both field strengths. W-values of marrow visibility, liver visibility, and overall image quality were higher for 3 T as compared to 1.5 T. W-values are summarized in Table 3.

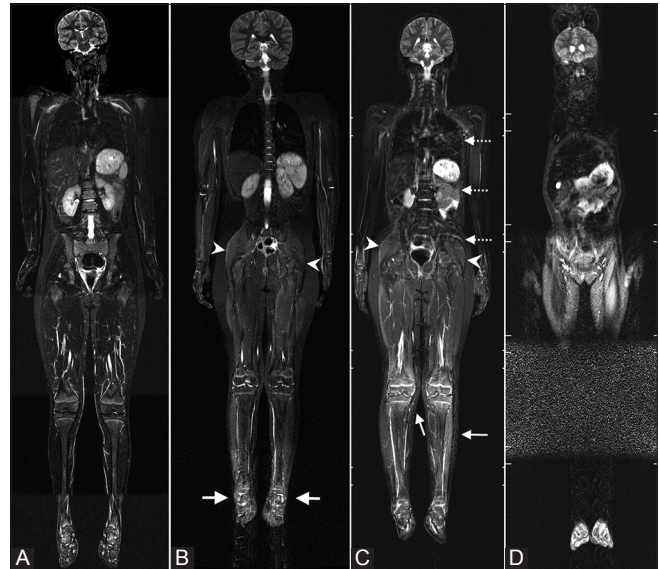


Figure 1(A-D): (A-D) Overall image quality comparison. (A) WBMRI image at 1.5 T shows excellent image quality rated as grade 4. (B) WBMRI image at 3 T shows good image quality rated as grade 3 that shows some movement artifacts affecting the lower legs and feet (arrows) and prominent chemical shift artifacts (arrowheads). (C) WBMRI image at 3 T shows fair image quality rated as grade 2 because of artifacts like ghosting (broken arrows), chemical shift (arrowheads), Moire fringe-like artifacts (arrows), and reduced visibility of liver and marrow in legs. (D) WBMRI image at 3 T shows poor image quality rated as grade 1/non-diagnostic because of extensive movement artifacts

The mean scores for all five categories by both readers were higher for 1.5 T images [Table 4]. Comparison was done between the mean scores at 1.5 and 3 T averaged between the two readers. The difference between the averages of mean scores of the two field strengths was statistically significant [Table 5], indicating less artifact, better fixed structure visibility and overall image quality at 1.5 T as compared to 3 T.

Artifacts listed by both readers were summarized and compared for two field strengths. Motion-related artifacts were seen to be the most common on both sets of images, including patient movement, motion due to pulsation, and bowel peristalsis. One form or the other of motion-related

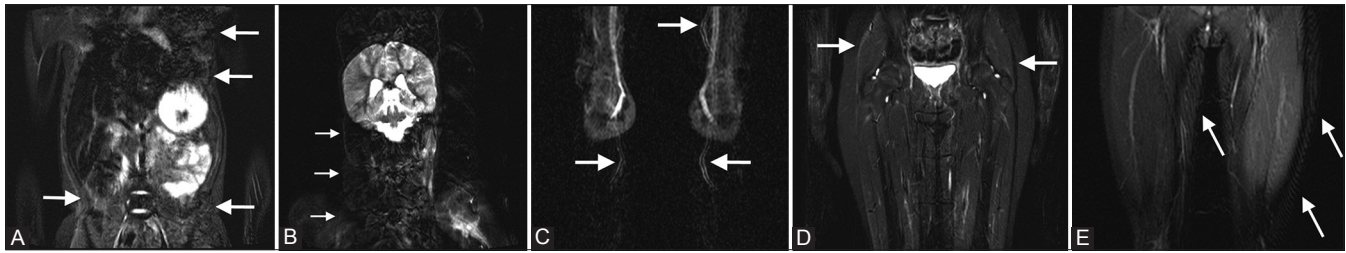


Figure 2(A-E): (A-E) Artifacts (arrows). (A) Breathing artifacts affecting the entire image. (B) Ghosting related to patient motion. (C) Pulsation artifacts in the feet from posterior tibial arteries. (D) Chemical shift at the interface of subcutaneous and muscle compartments in thighs. (E) Moire fringe-like artifacts at the body surface

Table 3: Inter-observer agreement

Category	Kendall's coefficient of concordance (W)	
	1.5 T (95% CI)	3 T (95% CI)
Artifact grading	0.64 (0.50-0.82)	0.66 (0.50-0.83)
Vertebral column visibility	0.74 (0.58-0.90)	0.62 (0.50-0.83)
Marrow visibility in distal tibia/fibula	0.80 (0.64-0.95)	0.88 (0.79-0.97)
Liver visibility	0.76 (0.61-0.90)	0.85 (0.72-0.99)
Overall image quality	0.70 (0.51-0.89)	0.78 (0.61-0.96)

CI: Confidence interval

Table 4: Mean scores for all categories

Categories	Reader 1		Reader 2	
	1.5 T	3 T	1.5 T	3 T
Artifact grading	3.3	2.8	3.2	2.6
Vertebral column visibility	3.5	2.6	3.9	3.4
Marrow visibility in distal tibia/fibula	2.9	2.5	2.8	2.4
Liver visibility	3.3	2.4	2.7	2.6
Overall image quality	3.2	2.8	3.0	2.7

Table 5: Comparison of average of mean scores by two readers between 1.5 and 3 T

Categories	Average of mean scores at 1.5 T	Average of mean scores at 3 T	Difference between average scores (1.5 T-3 T)	P value by signed rank test
Artifact grading	3.24	2.69	0.55	0.0007
Vertebral column visibility	3.67	3.00	0.67	<0.0001
Marrow visibility in distal tibia/fibula	2.98	2.52	0.45	0.0136
Liver visibility	2.83	2.48	0.36	0.0284
Overall image quality	3.10	2.74	0.36	0.0146

artifacts was seen in all the examinations (100%) on both 1.5 and 3 T. Ghosting was present in six cases on 1.5 T (28%) and nine cases on 3 T (42%). Pulsation artifacts from vessels were seen in three cases (14%) on 1.5 T images as compared

to those seen in nine cases (42%) on 3 T images. Chemical shift artifacts, predominantly affecting the interface between subcutaneous tissue and muscles in the extremities, were seen in 1 case (5%) on 1.5 T and in all 21 cases on 3 T (100%). Interference pattern seen as alternate curved bands of bright and dark signal at the periphery of the images, similar to Moire fringe artifacts resulting from field inhomogeneity, were seen in nine cases on 3 T (42%), but on none of the 1.5 T images. Susceptibility artifacts related to bowel and marrow were seen in six cases on 3 T (28%), but on none of the 1.5 T images.

Discussion

WBMRI is being used with increasing frequency in children for various oncologic and non-oncologic indications.^[1] It has been shown to be useful in the assessment of lymphoma.^[15] Even though this application, even in combination with DWI, is limited by its inability to differentiate between normal and abnormal lymph nodes, WBMRI has been shown to have high sensitivity and specificity for detection of malignant lymph nodes based on size criteria (short-axis diameter >1 cm).^[15] WBMRI is more sensitive than bone scan for detection of bone metastases in children.^[16-18] It is used for screening of children with cancer predisposition syndromes like Li-Fraumeni syndrome and in children with retinoblastoma for detection of metastases and osteosarcoma.^[2] Some non-oncologic applications of WBMRI in children include chronic recurrent multifocal osteomyelitis (CRMO), Langerhans cell histiocytosis, generalized osteonecrosis after cancer treatment, generalized vascular malformations like hemangiomas, lymphangiomas, and Klippel-Trenaunay syndrome, and fever of unknown origin.^[1] WBMRI in combination with DWI has the potential to replace PET/CT in the future.^[1] PET/MRI is likely to replace PET/CT in children because of lack of ionizing radiation from the CT component.

Various combinations of sequences are used for WBMRI. Coronal STIR sequence alone or in combination with other sequences is the most commonly used one for WBMRI.^[1] Most pathologic tissues are proton rich and have prolonged T1 and T2 relaxation times resulting in high signal intensity on STIR images.^[7] Robust and homogeneous fat suppression

is another advantage of STIR sequence that is useful for evaluating bone marrow in children, most of whom have hypercellular marrow. The WBMRI at our institution includes only coronal STIR sequence covering the whole body. It is performed with a body coil integrated within the magnet bore, which in combination with sliding table platform obviates repositioning of patients at each station. Imaging with body coil has lower signal-to-noise ratio (SNR) as compared to phased-array coil. Despite this and other limitations like suboptimal depiction of sternum, ribs, scapula, and skull,^[19] and the lower sensitivity of coronal plane for detection of lymphadenopathy,^[20] coronal STIR serves the purpose well as a quick screening or “search” sequence for marrow and soft tissue abnormalities. With newer state-of-the-art systems with the capability to cover entire body with surface coil, potentially much better quality can be achieved.

MR signal improves with the magnetic field strength. MR imaging at 3 T provides high SNR, spatial resolution, and temporal resolution.^[21] Improved diagnostic accuracy and image quality has been reported with 3 T for imaging of brain, heart, vessels, musculoskeletal structures, and MR cholangiopancreatography.^[14,21] WBMRI at 3 T is expected to provide good-quality images in shorter time as compared to 1.5 T. However, these advantages are associated with increased motion- and pulsation-related artifacts, field inhomogeneity-related artifacts, increased susceptibility, increased chemical shift, and reduced T1 contrast due to longer T1 relaxation time at 3 T [Figure 3]. Increased chemical shift, increased susceptibility, and difficulty in achieving homogeneous magnetic field at 3 T as compared to 1.5 T result in greater artifacts at 3 T. Artifacts related to motion and susceptibility at 3 T can be minimized by use of parallel imaging where high signal at 3 T and parallel imaging act complementary to each other.

The previous comparison study between 1.5 and 3 T WBMRI in adults by Schmidt *et al.*^[14] involved multiple sequences including coronal STIR. Even though overall image quality at 1.5 T was significantly better than at 3 T, it was rated as “good” on both field strengths in their study, suggesting feasibility of 3 T for WBMRI.^[14] The difference in the image quality of STIR between 1.5 and 3 T was due to significantly more artifacts affecting STIR at 3 T, including dielectric effects, pulsation artifacts, and image inhomogeneity.^[14] Similar to that study, our results showed significantly better overall image quality at 1.5 T and also suggested feasibility of 3 T for performance of WBMRI, with overall image quality rated at 2.74 for 3 T versus 3.10 for 1.5 T, both of which are within a good range. Most artifacts were seen with greater frequency at 3 T in our study, with some like chemical shift, susceptibility, and Moire fringe-like artifacts seen almost exclusively at 3 T.

Abdominal DWI performed with free breathing has been shown to be of better quality with less artifacts at 1.5 T as

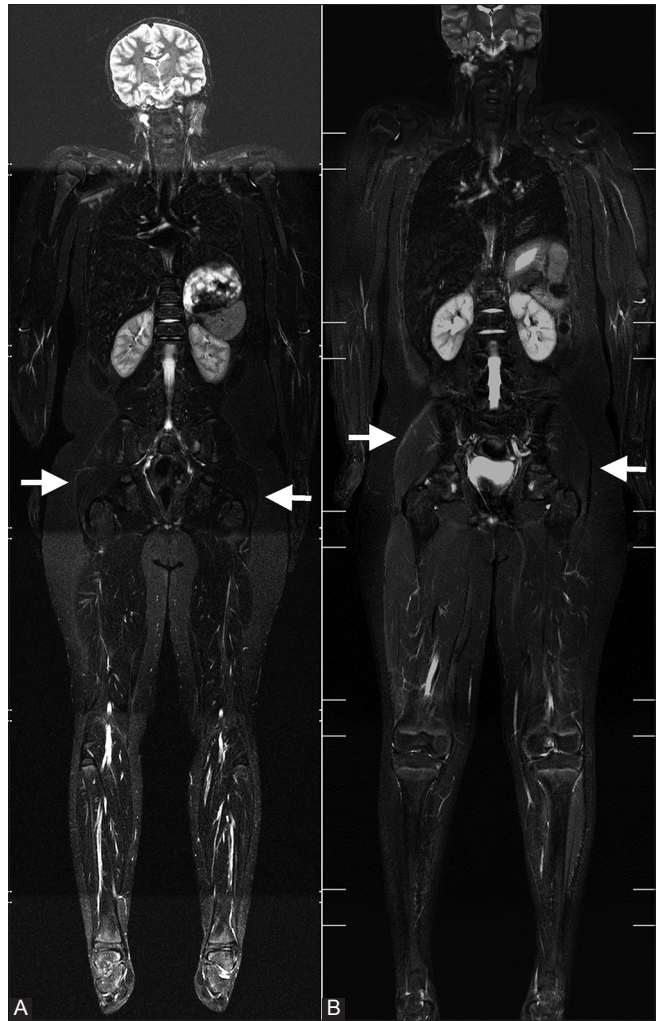


Figure 3(A and B): (A and B) Overall comparison of images at 1.5 and 3 T. WBMRI images at 1.5 T (A) and at 3 T (B) in a 10-year-old boy do not show any abnormality. The overall image quality was rated as 3 for both images. However, there are some inherent differences between the two images, including better lung visibility at 1.5 T, darker bones at 3 T (seen in proximal humeri, pelvic bones, and upper lumbar vertebrae), better signal in arms at 3 T, and greater chemical shift artifact at 3 T (arrows)

compared to 3 T.^[13] However, in the same study, image quality of DWI with breath hold and use of parallel imaging was better at 3 T as compared to 1.5 T, with similar artifact scores. Our WBMRI coronal STIR sequence is performed with free breathing even in stations involving the chest and abdomen. This was reflected in significantly more artifact in these regions on our images. Moreover, we could not use parallel imaging because our WBMRI is performed with the body coil.

Since we could not compare assessment of pathology in this study, we tried to evaluate fixed structure visibility, which in our opinion indirectly reflects diagnostic ability of WBMRI at 1.5 and 3 T. Two regions of bone marrow space were selected – one that may be affected by breathing movement (vertebral column) and another that is unlikely to be affected by movement (distal tibia/fibula). For soft tissue

visibility, the liver was selected, as it is a common site of metastases. Visibility of all three regions was significantly better at 1.5 T than at 3 T. However, similar to overall image quality, fixed structure visibility for both field strengths was within a good range [Table 5]. Higher visibility scores at 1.5 T for liver and vertebral column were mainly due to fewer artifacts related to breathing and other motion-related artifacts, while higher scores for marrow visibility in distal tibia and fibula at 1.5 T were due to less inhomogeneity and darkening as compared to 3 T. Higher inter-observer agreement (*W*-values) for scores at 3 T may be related to more severe degree of artifacts and relatively less visibility of fixed structures that are usually more obvious.

Our study has a few limitations. It is a retrospective study with a small sample size. The study period falls between 2008 and 2011. In the last few years since then, MRI technology has improved and some of the artifacts may have been reduced and image quality has improved. It does not directly compare assessment of pathology on two field strengths or impact of image quality and artifacts on lesion detection. Nonetheless, it provides comparative data on image quality and artifacts on the most commonly used sequence for WBMRI at two most commonly used field strengths in children.

Conclusion

Similar to previous studies in adults,^[14] WBMRI performed with coronal STIR sequence at 1.5 T has significantly better image quality, fixed structure visibility and fewer artifacts, as compared to WBMRI at 3 T in children. This difference is unlikely to significantly affect detection of pathology on 3 T WBMRI, as the image quality score at 3 T was also within a good range. Large studies comparing actual detection of pathology at two field strengths are required.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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