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MUSCULOSKELETAL

Evaluation of suspected musculoskeletal infection in children over 2 years of age using only fluid-sensitive sequences at MRI

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Abstract

Purpose This study was conducted in order to evaluate whether an MRI protocol with only fluid-sensitive sequences can be used to evaluate for musculoskeletal (MSK) infection of the pelvis and limbs in children.

Materials and methods This retrospective study analyzed 90 contrast-enhanced (CE) MRI studies from 88 consecutive patients (52 boys and 36 girls; mean age 9 ± 4.3 years; range 2–17) that were performed for the clinical suspicion of MSK infection. Two radiologists reviewed each study twice. The initial study review included only the fluid-sensitive sequences (fluid-sensitive study); the second review, performed at least 1 month later, included all sequences of the contrast-enhanced study (CE study). At each review, anatomic sites of abnormal signal and overall suspicion for infection were recorded. Cohen's kappa and percent agreement were performed to compare agreement between readers, types of studies, and clinical diagnoses.

Results Interreader agreement for both types of studies had kappa values between 0.86 and 1. For the assessment of MSK infection, the fluid-sensitive study had 100% sensitivity and 61.3% specificity, with 84.8% interreader agreement; and the CE study had 100% sensitivity and 71.0% specificity, with 88.6% interreader agreement. All cases of septic arthritis (13 cases) and osteomyelitis (25 cases) were identified as possible infection or infection until proven otherwise (negative predictive value 100%) with 100% interreader agreement on fluid-sensitive sequences.

Conclusion An abbreviated MRI study using only fluid-sensitive sequences has the same high degree of sensitivity as a CE study to identify MSK infection in children and could be used to exclude septic arthritis and osteomyelitis.

Key Points

• *MRI with only fluid-sensitive sequences can be used to evaluate for musculoskeletal infection in children.*

Keywords Infection · Arthritis · Osteomyelitis · Children · MRI

Abbreviations

κ	Cohen's kappa
CE	Contrast-enhanced
CRMO	Chronic recurrent multifocal osteomyelitis
CRP	C-reactive protein
ESR	Erythrocyte sedimentation rate
MRI	Magnetic resonance imaging
MSK	Musculoskeletal
NPV	Negative predictive values
OAI	Osteoarticular infection
OM	Osteomyelitis
PACS	Picture archiving and communication system
SA	Septic arthritis
STIR	Short tau inversion recovery
WBC	White blood cell count

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Introduction

In children, musculoskeletal (MSK) complaints are often nonspecific with different etiologies producing similar symptoms. Physical examination and history are often more limited in children than adults, leading to a reliance on imaging to determine the next step in patient management. Osteoarticular infection (OAI) describes deep MSK infections that can involve the bone (osteomyelitis) and joint (septic arthritis). Delay in the initiation of treatment for OAI in children, particularly those who are skeletally immature, can produce severe long-term sequelae, including premature physeal closure, limb length discrepancy, and angulation deformity [1–3]. The diagnosis of OAI is made more challenging because blunt trauma is the main risk factor and OAI may occasionally present without a fever or elevated serologic markers [4–7]. Conversely, while fever typically raises clinical concern for infection, fever can be the presenting symptom for inflammatory myositis, inflammatory arthritis, and neoplasm. Magnetic resonance imaging (MRI) is highly sensitive and specific for the evaluation of musculoskeletal infection and is the "gold standard" modality for the concurrent evaluation of bone, cartilage, and soft tissues [8–15]. Therefore, MRI is increasingly used for the initial evaluation of deep MSK infection, and the results can positively impact patient care [12–14, 16, 17].

Routine MRI evaluation for suspected MSK infection typically includes imaging sequences acquired before and after administration of intravenous contrast. These contrast-enhanced (CE) studies require more imaging sequences, lengthening overall scan times, and peripheral intravenous access, which, in children, often necessitates the use of anesthesia [18–22]. Intravenous contrast agents can cause adverse reactions, including a rare chance of severe anaphylactoid reaction [23], and anesthesia has a rare risk of hypoxia, apnea, and vomiting [24–26] and might have long-term effects on the developing brain, including disruption of synapse formation [27]. Therefore, attempts have been made to validate abbreviated noncontrast MRI protocols that reduce the number of necessary imaging sequences while maintaining diagnostic accuracy to reduce the need for anesthesia and contrast administration [14, 28–31].

The key to shortening MRI protocols is to limit the study to only the essential sequences that have proven to change management and influence outcomes [32]. For the evaluation of infection in children, MRI without contrast using a combination of fluid-sensitive and T1-weighted sequences has been found to be as sensitive as MRI with contrast [3, 15]. The use of fluid-sensitive sequences alone, such as short tau inversion recovery (STIR), has been found to be highly sensitive for the detection of infection in the hip joint [28, 29]. High sensitivity has been reported for the evaluation of septic arthritis (SA) and osteomyelitis (OM) with fluid-sensitive sequences in adults [33, 34]; however, outside of the hip joint, only one published study has investigated the use of fluid-sensitive sequences in children, and it did not specifically assess children with clinically suspected deep MSK infection [35]. Thus, the purpose of this study is to evaluate whether an MRI protocol with only fluid-sensitive sequences can be used to accurately evaluate for MSK infection of the pelvis and limbs in children.

Materials and methods

Study group

This retrospective study was compliant with the Health Insurance Portability and Accountability Act and received approval from our Institutional Review Board with a waiver of informed consent. The picture archiving and communication system (PACS) was used to identify consecutive patients between the ages of 2 and 18 years who underwent first-time routine CE MRI studies for the evaluation of deep MSK infection involving the pelvis and limbs at our institution, a regional tertiary children's hospital, between February 28, 2012, and March 20, 2017. Infants and young children under 2 years of age were excluded because they have an abundance of unossified cartilage and hematopoietic marrow that can obscure pathology [36]. Children with syndromic deformity, history of infectious or inflammatory arthritis, prior instrumentation, and incomplete imaging studies or medical records were excluded. Electronic medical records were reviewed to obtain history, results of other diagnostic imaging tests, use of anesthesia with MRI, procedures performed, microbiology results when available, and final clinical diagnosis. Results of the following serologic markers for inflammation were collected: white blood cell count (WBC), C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR).

MRI examination

Studies were performed using either a 1.5- or 3.0-T MRI scanner (General Electric Healthcare). Coil selection and imaging parameters varied slightly based on the size of the patient and region of interest imaged to optimize spatial resolution. The CE study contained the following sequences performed in three orthogonal planes: T1-weighted (TR/TE, 550/20), fluid-sensitive (T2-weighted fat-suppressed: TR/TE, 4000/20; or STIR: TR/TE, 3000/40), and post-contrast fat-suppressed T1-weighted (TR/TE, 550/20) sequences. Gadobenate dimeglumine contrast (MultiHance®, Bracco Diagnostics Inc.) was given at a dose of 0.1 mmol/kg for up to a maximum volume of 20 mL. The injection volume was diluted with normal saline to a minimum volume of 3 mL and injected via a peripheral intravenous line at a rate of 0.5 mL/s. Postcontrast images were acquired without delay.

MRI study review

Each MRI study was independently retrospectively reviewed by two board-certified and fellowship-trained radiologists (BKM with 7 years of experience in general MSK MRI interpretation and JCN with 4 years of experience in pediatric MSK MRI interpretation), both of whom were blinded to all clinical information other than the indication of infection. The initial study review included only the fluid-sensitive sequences; the second review, performed at least 1 month later, included the whole CE study, including fluid-sensitive, T1-weighted, and contrast-enhanced sequences. At both reviews, the presence or absence of pathology and the overall suspicion for infection were recorded. An additional consensus review was performed for each type of study to create a data set to use for evaluation of MRI diagnostic performance. The MRI scan time, use of anesthesia, total imaging time, and number of sequences for each examination were also recorded. MRI scan time was calculated from the start and stop times entered by the technologist. Total imaging time was the MRI scan time or, when anesthesia was given, the anesthesia time, which included MRI scan time.

Pathology was cataloged for seven anatomic spaces: skin, subcutaneous fat, myofascial plane, muscle, bone marrow, bone periosteum, and joint. The presence of pathology using fluid-sensitive sequences was defined as signal abnormality, architectural change, or both and defined as abnormal enhancement after contrast administration. Fluid collections suspicious for abscess were documented and were defined on fluid-sensitive sequences as areas of homogeneous fluid-signal intensity demonstrating mass effect and were defined on contrast-enhanced imaging as collections demonstrating peripheral rim enhancement. The overall suspicion for infection was determined using previously described MRI criteria for diagnosing musculoskeletal infections in children [3, 15], and the level of suspicion was graded by using a novel 4-point scale: level 0 for no infection, level 1 for unlikely infection, level 2 for possible infection, and level 3 for infection until proven otherwise.

Statistical analysis

Analyses were performed on the R 3.3.1 program environment including the "psy" and "boot" packages (R Foundation for Statistical Computing, Vienna, Austria). Interreader agreement on the presence or absence of pathology in each anatomic space was determined using Cohen's kappa (κ) with 95% confidence intervals (CI) generated from 1000 bootstrap replicates. A kappa value greater than 0.81 indicates almost perfect agreement, a value between 0.61 and 0.80 substantial agreement, and a value between 0.41 and 0.60 moderate agreement [37].

Percent agreement was used to compare the detection of pathology in each anatomic space and the interpretations of the fluid-sensitive and CE studies between the readers, and also to compare with the final clinical diagnosis. Sensitivity, specificity, positive predictive value (PPV), and negative predictive values (NPV) were calculated. Wilcoxon rank sum test was used to compare the number of anatomic spaces involved for MSK infection to noninfectious etiologies, and to compare age, MRI scan time, and total imaging time of patients that received anesthesia to patients that did not receive anesthesia. All statistical tests were two-sided and 5% ($p < 0.05$) was set as the level of significance.

Results

Cohort characteristics

The study group consisted of 88 patients (52 boys and 36 girls; mean age of 9 ± 4.3 years; range 2–17) who underwent a total of 90 MRI studies (two patients had bilateral thigh studies) to evaluate for clinically suspected MSK infection. The most common presenting symptom was fever ($n = 42$). Other common presenting symptoms included pain ($n = 36$), pain with limp or nonweight-bearing ($n = 10$), pain and swelling ($n = 10$), swelling ($n = 3$), and limp ($n = 2$). The distribution of anatomic regions imaged is detailed in Table 1. Moderate conscious sedation or general anesthesia was used in 35 studies (38.9%), which involved younger children ($p < 0.001$) and led to longer total imaging time ($p < 0.001$), but did not significantly change the MRI scan time ($p = 0.44$) (Table 2).

Forty-eight patients (54.5%) had a clinical diagnosis of an MSK infection in our cohort, which was established using a combination of clinical assessment, inflammatory markers, and imaging findings. Of these patients, 29 patients were culture-positive by blood, arthrocentesis, or biopsy, and 19 patients were culture-negative. The culture-positive organisms included *Staphylococcus aureus* (methicillin-sensitive, $n = 21$; methicillin-resistant, $n = 4$), *Streptococcus pyogenes* ($n = 3$), and *Borrelia burgdorferi* ($n = 1$). Patients diagnosed with MSK infection were significantly more likely to have fever (33 of 42 patients with fever; 79%; $p = 0.001$), compared to patients without fever (15 of 37 patients without fever; 41%). On average, patients diagnosed with infection had a normal WBC (mean 11.8 ± 6.1 10^9/L; normal range 4.0–12.0 k/μL), an elevated CRP (mean 31.1 ± 163 mg/dL; normal range 0–2.9 mg/dL in this age group), and an elevated ESR (mean 39.7 ± 27.1 mm/h; normal range 0–15 mm/h). There was a statistical correlation between presence of infection and elevated CRP levels ($p = 0.007$), and no statistical correlation between presence of infection and elevated WBC ($p = 0.20$) or ESR levels ($p = 0.19$).

Table 1 Summary of cases with diagnoses sorted by MRI region

MR exam type	Exams	Diagnosis					
		SA	OM	SA + OM	Other infection	Noninfectious process	Indeterminant
Pelvis*	16	3	1	1	4	7	
Hip	1					1	
Thigh	19	1	2	2		11	3
Knee	17	3	5		1	6	2
Calf	2		1			1	
Ankle	8		3	2	1	2	
Foot	13	1	5		3	4	
Shoulder	4				3	1	
Elbow	1		1				
Forearm	3				1		2
Wrist	3		2		1		
Hand	3				1	2	
Total	90	8	20	5	15	35	7

SA = septic arthritis; *OM* = osteomyelitis; *Other infections* = cellulitis, fasciitis, myositis, or thrombophlebitis without OM or SA; *Noninfectious processes* = three cases of juvenile idiopathic arthritis, eight cases of juvenile dermatomyositis, one case of chronic recurrent multifocal osteomyelitis (CRMO), two cases of acute lymphocytic leukemia, and 17 cases of musculoskeletal processes, such as hematoma, muscle strain, ligament sprain, fracture, apophysitis, and Osgood–Schlatter syndrome; *Indeterminant* = noninfectious cases where the final diagnosis was unclear, and the patient recovered

*Pelvis MRI identified three cases of sacroiliac joint SA and one case of hip joint SA

Agreement between readers and types of MRI studies

For the fluid-sensitive MRI study, kappa coefficients for the detection of pathology in all seven anatomic spaces ranged between 0.93 and 1; for the detection of abscess, the kappa coefficient was 0.86 (95% CI 0.62–0.97); and for the overall probability of infection (level 0–1 vs. 2–3), it was 0.94 (95% CI 0.72–0.97). For the CE study, kappa coefficients for the detection of pathology in all seven anatomic spaces ranged between 0.94 and 1; for the detection of abscess, the kappa coefficient was level 1; and for the probability of infection, it was 0.97 (95% CI 0.76–0.99). Percent agreement between the fluid-sensitive and CE studies was 100% across all seven anatomic spaces, and the percent agreement for the presence of a soft tissue abscess was 96.7%.

Diagnostic performance of fluid-sensitive and CE MRI

The diagnostic performance of the fluid-sensitive and CE studies compared to the clinical diagnoses of MSK infection was excellent. For the identification of MSK infection, the fluid-sensitive study had 100% sensitivity, 61.3% specificity, 80.0% PPV, and 100% NPV, with 84.8% interreader agreement; and the CE study had 100% sensitivity, 71.0% specificity, 84.2% PPV, and 100% NPV, with 88.6% interreader agreement. Table 1 summarizes the locations of SA, OM, and other MSK infections identified in our study. All cases of SA and OM were identified with a confidence level of 2 (possible infection) or 3 (infection until proven otherwise) with 100% interreader agreement on the fluid-sensitive study. There were three cases where confidence in the diagnosis for

Table 2 Mean patient age, total imaging time, MRI scan time, and numbers of imaging sequences

	Patient	Total imaging time	MR imaging		
	Age ± SD (range), years	Time (range), min	Time (range), min	Number of fluid-sensitive sequences (range)	Total number of sequences (range)
Anesthesia ($n = 35$)	5.9 ± 3.7 (2–17)*	139.2 (84–280)*	54.8 (30–93)	3.5 (3–6)	12.1 (10–17)
No anesthesia ($n = 55$)	11.4 ± 3.4 (3–17)*	65.2 (9–184)*	65.2 (9–184)	4.1 (3–9)	12.9 (7–23)

Total imaging time = MRI scan time and anesthesia time, if performed; *Total number of sequences* = all sequences in the CE MRI study

*Statistically significant difference ($p < 0.001$)

infection increased from a level 2 using the fluid-sensitive study to a level 3 using the CE study, namely: a case of thrombophlebitis in the wrist in a patient with Burkitt's lymphoma and neutropenia from induction chemotherapy where the presence of surrounding soft tissue enhancement favored the diagnosis of infection; a case of SA of the knee joint where only a joint effusion was noted on the fluid-sensitive sequences, but on contrast-enhanced images prominent rim-enhancing synovitis favored infection (Fig. 1); and a case of cellulitis of the foot where the enhancement pattern narrowed MRI diagnosis to infection. Finally, Fig. 2 depicts a case where confidence in the diagnosis for superinfection of a fracture increased from a level 2 using the fluid-sensitive study alone to a level 3 based on the precontrast T1-weighted and postcontrast imaging.

There were four cases where confidence in the diagnosis for infection decreased from a level 2 (possible) using the fluid-sensitive study to a level 1 (unlikely) using the CE study, namely: a case of ankle sprain where the lack of substantial synovial enhancement associated with the joint effusion argued against a superimposed septic arthritis (Fig. 3); a case of a finger fracture where the possibility of superimposed infection was less likely on the CE study because there was minimal to absent enhancement of the surrounding soft tissues; a case of a secondary ossification center of the right sacral ala where minimal enhancement made infection unlikely; and a case of juvenile dermatomyositis with bilateral relatively symmetric nonspecific muscle changes where the absence of myofascial enhancement made infection unlikely.

Regarding abscess, 13 abscesses were detected on the fluid-sensitive sequences and 16 abscesses were detected on the CE study. Ten abscesses were seen in cases of OAI, four in cases of cellulitis, and two in cases of myositis. Figures 2 and 4 illustrate cases where identification of abscess was not made by fluid-sensitive sequences.

Patient outcomes

Of the 48 patients diagnosed as having MSK infection with a confidence level of 2 or 3 on the fluid-sensitive study, 15 went straight to surgery, five had aspiration before surgery, and seven had aspiration without surgery. All of these patients received antibiotics and all had positive outcomes at subsequent outpatient follow-up. Within this group, 33 patients were diagnosed as having OAI with a confidence level of 2 or 3 on the fluid-sensitive study and 17 underwent joint washout or incision and drainage. As noted above, there were three cases where fluid-sensitive sequences had suggested a possible OAI, but confidence was decreased and an alternative diagnosis was favored on the CE study; none of these patients received treatment for infection.

Identification of noninfectious diagnoses

Regarding cases where confidence level for infection was 0 or 1 on the fluid-sensitive study MRI, alternative diagnoses were identified for 33 of the 40 patients with seven patients having an indeterminate diagnosis, as summarized in Table 1. The average number of anatomic spaces involved for MSK infection was greater than for noninfectious etiologies. SA without OM had significantly more anatomic spaces involved than

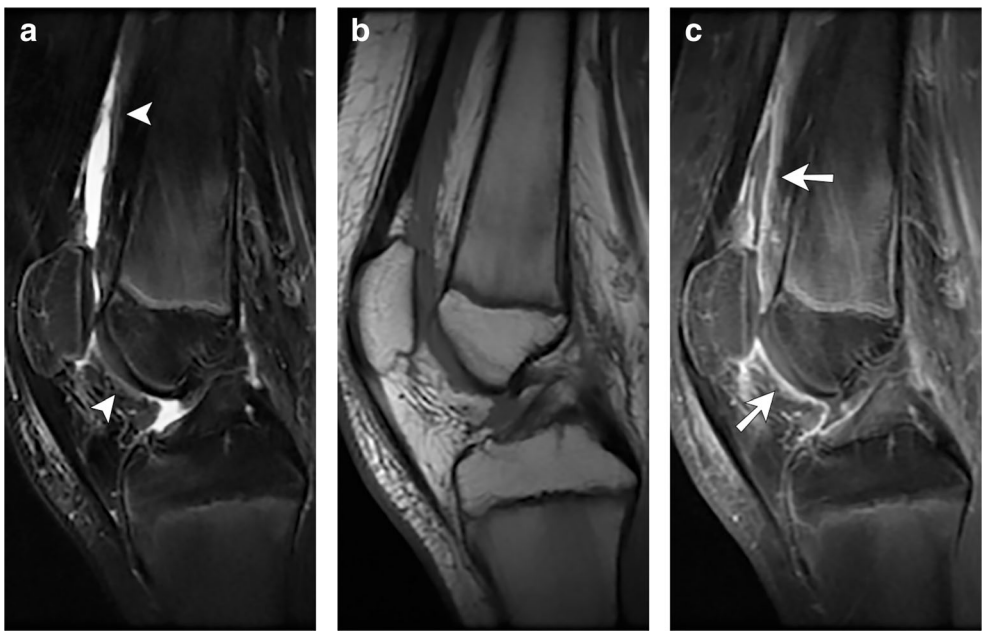

Fig. 1 A 13-year-old boy with knee swelling, fever, and rash, diagnosed with septic arthritis. **a** Sagittal fluid-sensitive (STIR) image of the knee showed a small joint effusion with possible mild synovitis (arrowheads) and was given a "possible infection" diagnosis. Corresponding T1-weighted (**b**) and contrast-enhanced (**c**) images revealed moderate synovitis (arrows), upgrading the level of suspicion to "infection until proven otherwise"

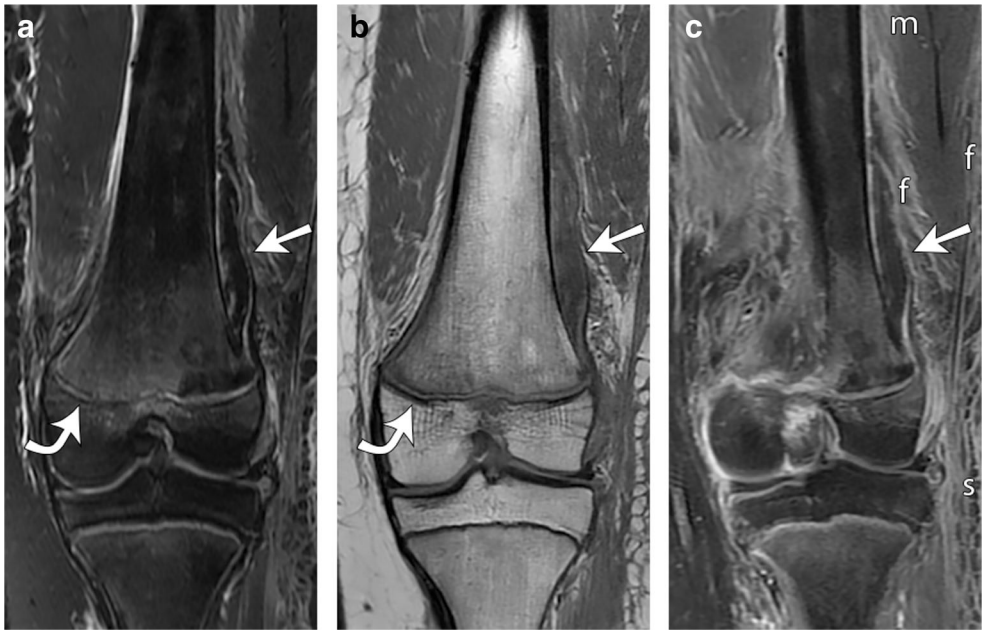

Fig. 2 An 11-year-old girl presents with fever 6 days after suffering a distal femoral Salter–Harris type IV fracture. **a** Coronal fluid-sensitive (T2-weighted fat-suppressed) image of the knee showed the distal femoral physeal injury (curved arrow) and a low-signal subperiosteal fluid collection (arrow). Because superinfection of a subperiosteal hematoma was a possibility and because there was increased signal in all anatomic spaces, the case was given a "possible infection" diagnosis, as infection could not be ruled out. Corresponding T1-weighted (**b**) image shows intermediate signal in the subperiosteal collection not typical for hematoma, upgrading the level of suspicion to "infection until proven otherwise." Contrast-enhanced image (**c**) is not helpful with regard to the subperiosteal fluid collection but does confirm abnormal enhancement of the reginal musculature (m), myofascial planes (f), and subcutaneous fat (s), compatible with myositis, fasciitis, and cellulitis, respectively

juvenile idiopathic arthritis (median 4 vs. 2 spaces, $p = 0.036$) and significantly more spaces involved than transient synovitis (median 0.5 spaces, $p = 0.013$).

Utility of radiographs and ultrasound performed before MRI

Prior to the clinical MRI, 59 patients had radiographic and 14 patients had ultrasound examinations, and based on these findings, five patients had arthrocentesis. On radiographic examination, 11 of 59 patients had findings supportive of the diagnosis of infection, such as joint effusion or cortical erosion, six of which were diagnosed with SA or OM, one with transient synovitis, and one with chronic recurrent multifocal osteomyelitis (CRMO). In this group of 59 patients, MRI was able to identify an additional 17 cases of SA and OM (73.9% of OAI cases in this group). On ultrasound examination, five of 14 patients had findings supportive of the diagnosis of infection, one of which was diagnosed with SA, two with transient synovitis, one with juvenile dermatomyositis, and one with infectious myositis. In this group of 14 patients, MRI was able to identify an additional case of OM (50% of OAI cases in this group). Of the five patients who received arthrocentesis, three were diagnosed with septic arthritis, one with transient synovitis, and one with cellulitis.

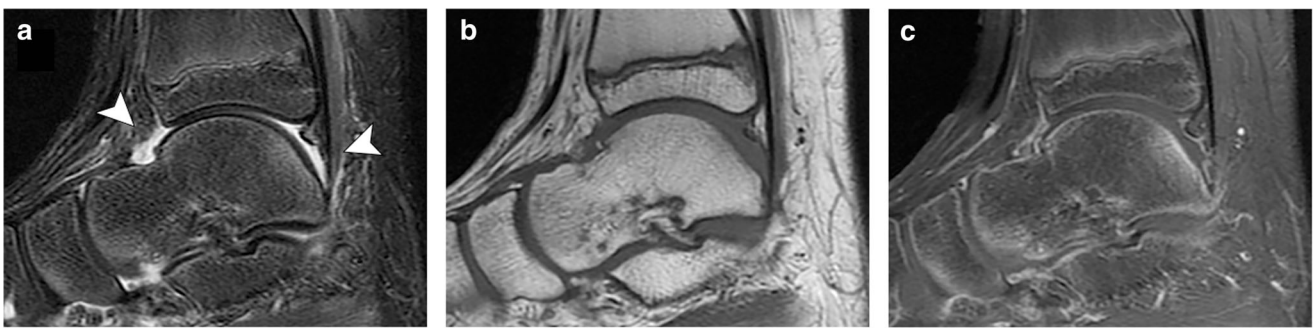

Fig. 3 A 12-year-old boy with ankle pain, unable to bear weight, diagnosed with ankle sprain. **a** Sagittal fluid-sensitive (STIR) image of the ankle showed a small joint effusion with possible mild synovitis (arrowheads) and was given a "possible infection" diagnosis. Corresponding T1-weighted (**b**) and contrast-enhanced (**c**) images revealed no synovitis (arrow), downgrading the level of suspicion to "unlikely." The patient improved on conservative management

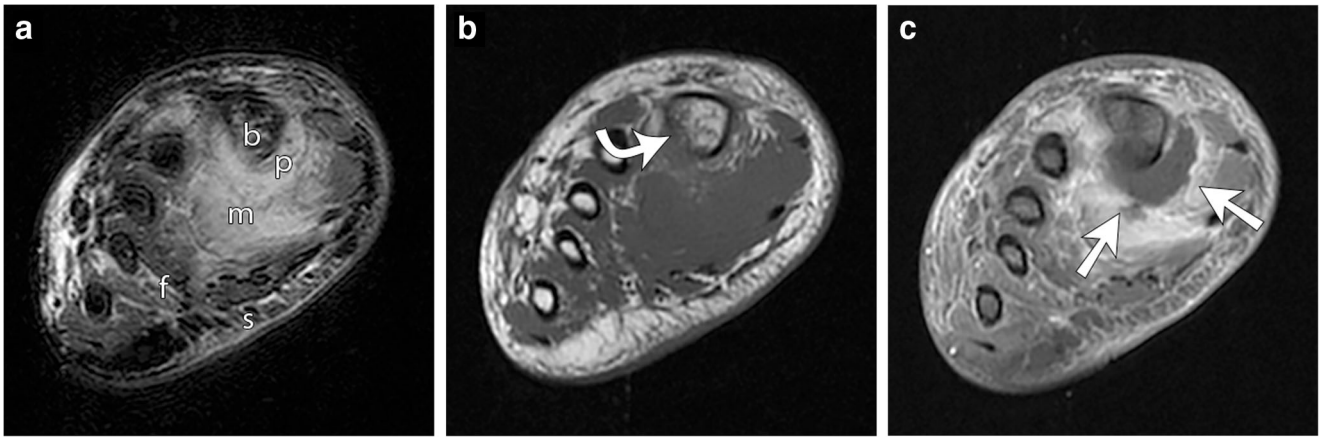

Fig. 4 An 11-year-old boy with foot swelling, pain, difficulty bearing weight, diagnosed with MSSA first metatarsal osteomyelitis and abscess. **a** Short-axis fluid-sensitive (STIR) image of the foot showed a phlegmon plantar to the first metatarsal, with abnormal signal in the metatarsal bone marrow (b) and periosteum (p), and regional musculature (m), myofascial planes (f), and subcutaneous fat (s). Corresponding T1-weighted image (**b**) confirms osteomyelitis of the first metatarsal (curved arrow) and contrast-enhanced (**c**) image defines an adjacent abscess (arrow)

MRI was performed subsequently in these cases to either evaluate for associated osteomyelitis or abscess prior to intervention or to increase confidence in a noninfectious diagnosis.

Discussion

Our study found that fluid-sensitive sequences can be used to identify OAI in children with clinical suspicion for infection with 100% sensitivity and 100% NPV. Regarding SA, these findings are consistent with prior studies of the hip joint that evaluated the diagnostic performance of a single coronal STIR sequence to study the nontraumatic hip joint in children [28] and adults [29], and an earlier study of the pelvis evaluating nontraumatic pain in children using a three-sequence protocol (axial STIR, coronal T2-weighted, and T1-weighted sequences) [14]. Each of these studies found that STIR sequences had high sensitivity for the detection of SA of the hip joint. We additionally found that fluid-sensitive sequences consistently detected SA of the sacroiliac joints and joints of the knee, ankle, and foot. Regarding OM, our findings are consistent with the investigations by Averill et al and Kan et al, who found noncontrast imaging (using a combination of fluid-sensitive and T1-weighted sequences) to have high sensitivity for OM in children [3, 15]. We additionally found that fluid-sensitive sequences alone consistently detected OM in children, including OM of the bones of the pelvis, tibia and femur, ankle, foot, and wrist, and that T1-weighted sequences were not required to achieve 100% sensitivity.

Inclusion of the remainder of the CE study for interpretation improved specificity, interreader agreement, and abscess detection. Improved diagnostic accuracy was seen in the joints of three cases because of the presence or absence of synovial enhancement (Figs. 1 and 3), which is consistent with prior investigations [33, 38–41]. However, in our study, all cases of SA and OM were identified as "possible infection" or "infection until proven otherwise" with 100% interreader agreement on the fluid-sensitive study, and therefore, the findings of the CE study did not translate into improved performance to identify infection. This finding is consistent with investigations by Averill et al and Kan et al, who found no significant improvement in the diagnostic accuracy for SA and OM in children comparing non-CE and CE MRI studies [3, 15]. Finally, as seen in prior investigations, contrast-enhanced imaging did improve confidence in abscess identification, with three of 16 abscesses not appreciated on the fluid-sensitive sequences alone [3, 15, 33, 34].

Our success in the confident identification of infection may have been in part due to our organized documentation of each anatomic space, which influenced our level of suspicion for infection. Prior investigations have found that OAI more often demonstrates trans-spatial involvement, affecting multiple anatomic spaces [3, 14, 35, 42–46], and our findings support this observation. Regarding SA, we found more frequent changes in the surrounding fascia and muscle, and underlying bone in SA, than in juvenile idiopathic arthritis and transient synovitis. This pattern is consistent with prior investigations [14, 35, 42–46], and juxta-articular inflammatory changes about a joint effusion favor the diagnosis of septic arthritis.

Naturally, MRI is not required in all clinical situations. For example, when an effusion can be identified by radiographs or ultrasound, arthrocentesis can be diagnostic for septic arthritis. Laine et al investigated whether ultrasound evaluation is sufficient for suspected hip SA in children and found that once an effusion is confirmed, MRI is not required before treatment [47]. They concluded that comprehensive assessment by MRI could be reserved for those patients without joint effusion or who fail to clinically respond to hip arthrotomy and antibiotics treatment. In our cohort, MRI was performed after arthrocentesis in five cases to either evaluate the extent of infection prior to intervention or to increase clinical confidence in a noninfectious diagnosis.

Fever and CRP levels predicted the presence of infection in our cohort, while ESR and WBC levels did not. Children with infection were significantly more likely to have fever and often presented with localized pain, swelling, and a limp or nonweight-bearing status, which is consistent with prior studies [16]. A statistical correlation was seen between infection and CRP levels, which is a validated marker for OAI [16]. As seen in prior investigations, ESR levels could not predict patients with OAI apart from other diagnoses [48, 49]. We found no significant association of OAI to elevated WBC, which is not unexpected as WBC levels have been reported to be normal in as much as 80% of cases of OAI [50]. While a high WBC may indicate a need to look for sites of infection, studies have shown that the lack of an elevated WBC cannot reliably exclude septic joints [51].

Of the 48 patients diagnosed with a MSK infectious process in our cohort, 19 cases (39.6%) had no identifiable causative organism. Recent investigations have reported negative blood cultures in 33.3% [52] to 55.0% [53] of cases of OAI. One possible explanation is that some organisms require specific culture media or a longer growth period [54]. For example, we had no confirmed cases of the gram-negative bacteria *Kingella kingae*, which could be reflective of the difficulties detecting this organism using routine culture techniques [53, 54].

The present study had two major limitations. First, the retrospective design was a major limitation of this study because the MRI interpretation informed the final clinical diagnosis, creating a reference standard bias. Second, although our overall sample size was adequate, because of the heterogeneity of the study group, the sample size for each body region and patient age was small, and further validation with larger patient cohorts is needed.

In conclusion, an abbreviated MRI study using only fluid-sensitive sequences has the same high degree of sensitivity as a CE study to identify MSK infection in the pelvis and limbs of children over 2 years of age and could be used to exclude OAI. It is important to note that our findings and the findings of others demonstrate the advantages of CE imaging in some cases, especially for abscess detection and early septic arthritis, and a fast protocol is not meant to entirely replace the CE study. For patients younger than 18 months, with suspected MSK infection, a CE study is advised [36]. A future prospective investigation is required to see if the age of patients requiring anesthesia can be decreased by using a fast protocol employing fluid-sensitive sequences without contrast.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is B. Keegan Markhardt, M.D. (corresponding author).

Conflict of interest The authors declare that they have no conflict of interest.

Statistics and biometry One of the authors has significant statistical expertise and has a degree in statistics.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- case–control study
- performed at one institution

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