A Rapid MRI Protocol for the Evaluation of Acute Pediatric Musculoskeletal Infections

Eliminating Contrast and Decreasing Anesthesia, Scan Time, and Hospital Length of Stay and Charges

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Background: Acute musculoskeletal infection affects >1 in 6,000 children in the United States annually. Magnetic resonance imaging (MRI) is the gold standard for the diagnosis of musculoskeletal infection, but it traditionally requires contrast and anesthesia for children, delaying management. A rapid MRI protocol involves MRI without anesthesia and with limited non-contrast sequences optimized for fluid detection and diffusion-weighted images to identify abscesses. We hypothesized that a rapid MRI protocol would improve imaging and treatment efficiency for pediatric patients undergoing musculoskeletal infection evaluation without substantially affecting accuracy.

Methods: This was a single-center, retrospective study of patients undergoing evaluation for musculoskeletal infection before (60 patients in the traditional cohort [TC]) and after (68 patients in the rapid cohort [RC]) implementation of the rapid MRI protocol. Sociodemographic and clinical variables were extracted from electronic health records, and statistical comparisons were performed.

Results: The anesthesia rates were 53% for the TC and 4% for the RC, and the contrast administration rates were 88% for the TC and 0% for the RC. The median time to MRI after ordering was 6.5 hours (95% confidence interval [CI], 5.0 to 8.6 hours) for the TC and 2.2 hours (95% CI, 1.4 to 3.6 hours) for the RC ($p < 0.01$). The median duration of MRI was 63.2 minutes (95% CI, 56.8 to 69.6 minutes) for the TC and 24.0 minutes (95% CI, 21.1 to 29.5 minutes) for the RC ($p < 0.01$). The median hospital length of stay was 5.3 days (95% CI, 3.7 to 6.9 days) for the TC and 3.7 days (95% CI, 1.9 to 4.1 days) for the RC ($p < 0.01$). The median hospital charges were $47,309 (95% CI, $39,137 to $58,769) for the TC and $32,824 (95% CI, $22,865 to $45,339) for the RC ($p < 0.01$). Only 2 positive cases of musculoskeletal infection in the RC were missed on the initial imaging, but these instances were not attributable to the rapid protocol itself. Although 10 of 68 rapid MRI scans resulted in nondiagnostic outcomes due to patient motion, only 6 of 68 required repeat MRI with anesthesia.

Conclusions: In patients evaluated for musculoskeletal infection, the rapid MRI protocol eliminated contrast and minimized anesthesia while improving MRI access and decreased scan and interpretation times, hospital length of stay, and hospital charges. The rapid MRI protocol had high sensitivity for diagnosing musculoskeletal infection and a low rate of imaging failure.

Level of Evidence: Diagnostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Acute musculoskeletal infection affects >1 in 6,000 children in the United States annually and represents nearly 10% of orthopaedic consultations at tertiary pediatric centers, with most cases comprising osteomyelitis, septic arthritis, and/or pyomyositis[1-3]. Delays in treatment increase the risk of complications, joint damage, and prolonged hospital stays[4-6]. Therefore, expedited management is essential to improving outcomes of acute pediatric musculoskeletal infection. The diagnostic test of choice is magnetic resonance imaging (MRI), given its high sensitivity and specificity for detecting changes suggestive of infection[7-9]. Unfortunately, multiple challenges exist to efficient MRI acquisition in children, including the time needed for intravenous access, anesthesia, contrast, and the duration of the imaging itself. Thus, the process of acquiring the MRI can delay treatment. As MRI scans become ubiquitous for decision-making, clinicians must

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consider the treatment delays incurred and the level of imaging detail needed to identify infections and guide clinical decision-making.

MRI acquisition can be accelerated with specific strategies. Although non-contrast images are generally sufficient for musculoskeletal infection diagnosis, gadolinium contrast adds considerable time for administration and additional sequences to improve detail[10-12]. In patients with adult foot osteomyelitis or pediatric knee pain, limiting MRI sequence selection resulted in reduced examination duration with non-inferior accuracy[13,14]. A recent study implementing changes in MRI acquisition for pediatric musculoskeletal infection concluded that limited sequences were sufficient for diagnosis[15]. Rapid MRI protocols that include workflow optimization, elimination of contrast and anesthesia administration, and minimization of sequence number and length are a promising solution. Rapid protocols have been adopted for evaluation of acute abdominal pain, head trauma, cerebral dysfunction, and nontraumatic neurologic symptoms[16-19]. A limited MRI protocol has been described for pediatric musculoskeletal infection[20]; however, the results have yet to be reported. Therefore, this retrospective study investigated whether implementation of a rapid MRI protocol for pediatric musculoskeletal infection evaluation at a major tertiary pediatric hospital could decrease anesthesia and contrast administration, enhance imaging efficiency, and reduce length of stay and hospital charges without affecting diagnostic accuracy.

Materials and Methods

Rapid MRI Protocol

A new rapid MRI protocol prioritizing the timely acquisition of limited fluid-sensitive sequences and diffusion-weighted imaging (DWI) with avoidance of anesthesia and contrast was developed by the departments of orthopaedic surgery and radiology of a tertiary pediatric medical center. The protocol comprised inclusion criteria, a clinical workflow (Fig. 1), and

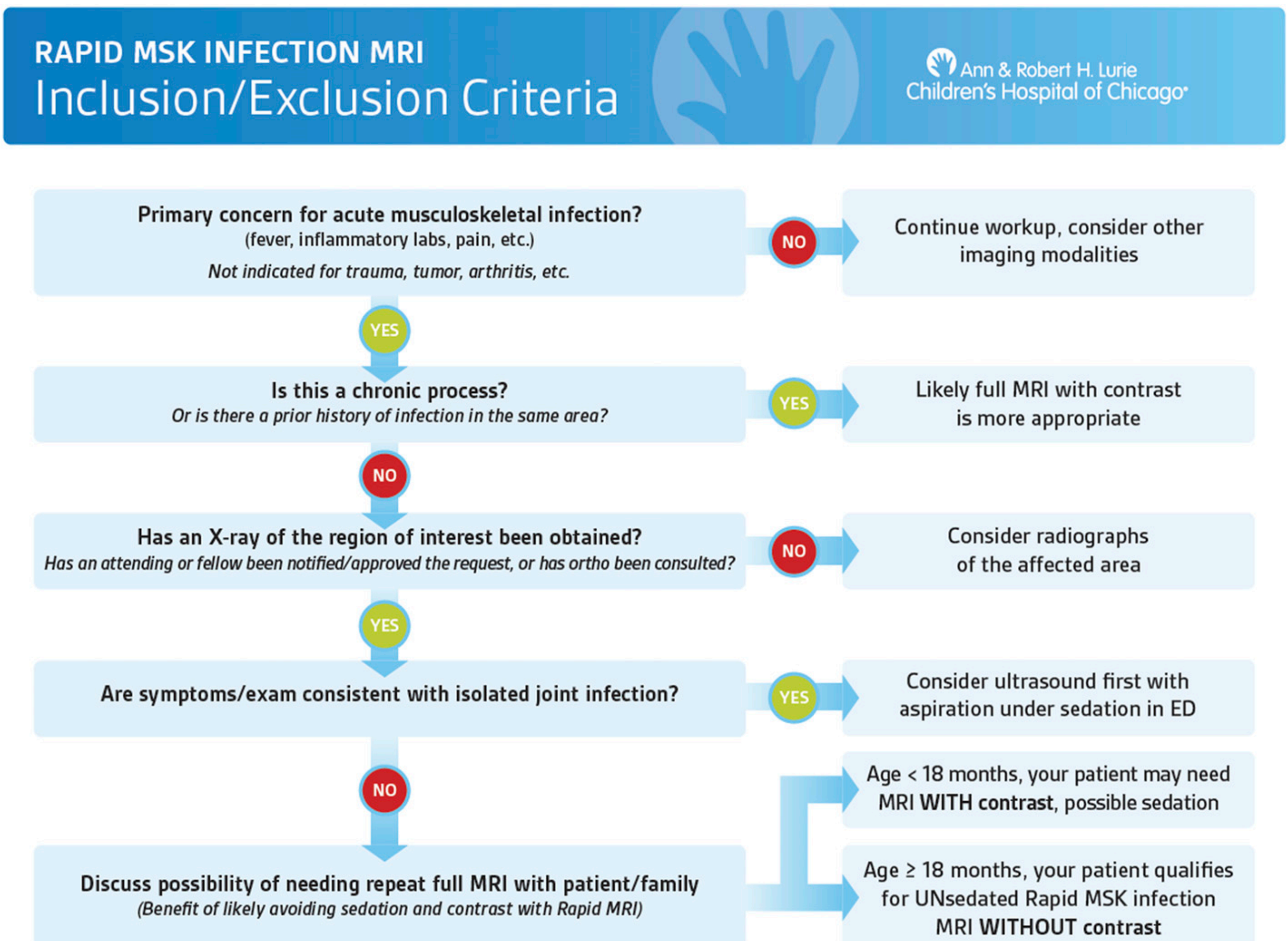

Fig. 1

Example of a rapid MRI protocol patient algorithm that helps to guide providers on appropriate imaging utilization. MSK = musculoskeletal, and ED = emergency department.

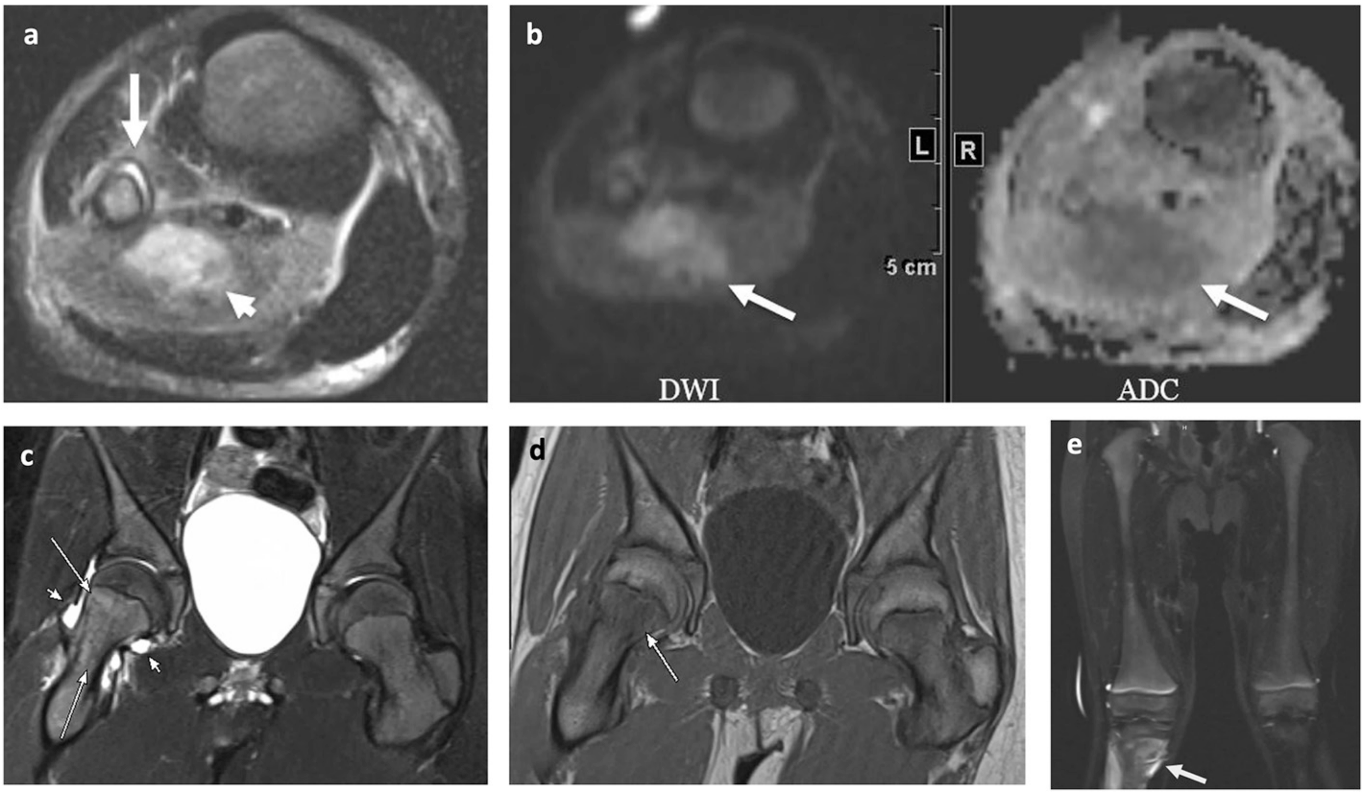

Fig. 2

Figs. 2-A through 2-E Examples of rapid MRI scans. **Figs. 2-A and 2-B** A 7-year-old boy with right calf pain. **Fig. 2-A** An axial, T2-weighted, fat-suppressed image from a rapid MRI protocol showing a small subperiosteal abscess of the fibula (arrow) and adjacent intramuscular abscess (small arrowhead). **Fig. 2-B** Axial DWI and corresponding ADC images demonstrating restricted diffusion (hyperintensity on DWI and hypointensity on ADC images) within an intramuscular fluid collection consistent with an abscess (arrow). **Figs. 2-C and 2-D** A 9-year-old girl with right hip pain. A septic joint and subtle osteomyelitis were detected with the rapid MRI protocol. **Fig. 2-C** Coronal T2-weighted, fat-suppressed image showing a moderate-sized right hip joint effusion (arrowheads), which proved to be a septic joint. **Figs. 2-C and 2-D** Imaging showing subtle asymmetrical bone marrow edema (arrows) of the right femoral neck compatible with osteomyelitis. **Fig. 2-E** A 3-year-old boy with fever and a limp. A large-field-of-view sequence demonstrating osteomyelitis (arrow) of the right proximal tibia.

specific MRI sequences sensitive to musculoskeletal infection. The protocol was implemented in concert with the emergency medicine, hospitalist, and infectious disease services. Usage was limited to suspected acute musculoskeletal infection in the extremities or pelvis. Our workflow (Fig. 1) recommends the rapid protocol for appropriate patients who are 18 months to 18 years of age. The protocol also can be and has been used in younger infants, but there exists a risk of missing infection in unossified cartilage, as described by Browne et al.[12]. If patients did not tolerate the rapid scan without anesthesia, they would be admitted for a traditional examination with anesthesia.

MRI Sequences

Initially, a large-field-of-view, single-shot, fast-spin-echo sequence identifies the anatomic area of concern, a feature that is especially useful in children for whom localization based on physical examination is difficult. The STIR HASTE (Short Tau Inversion Recovery Half-Fourier Acquired Single-shot Turbo spin Echo) sequence is a proprietary Siemens sequence that can often be replicated on other scanners. It is a faster version of the STIR sequence that scans only half of the k-space but remains highly sensitive for fluid detection. Then, focused small-field-of-view sequences of the affected area are acquired, including axial, sagittal, and coronal T2-weighted, fat-suppressed sequences, a coronal T1-weighted sequence, and axial DWI with an accompanying apparent-diffusion-coefficient (ADC) map. The T2 sequences are excellent for diagnosing fluid collections, joint effusions, and bone marrow edema. T1 sequences are fundamental for marrow assessment, as osteomyelitis will typically have a hypointense signal. DWI sequences are helpful to diagnose abscesses, as purulent material may have restricted water motion (resulting in hyperintensity on DWI and hypointensity on the ADC map), whereas confluent edema or seroma may not (resulting in hyperintensity on both DWI and ADC maps). All imaging was interpreted by pediatric board-certified radiologists. Examples of images made with the rapid MRI protocol are presented in Figure 2. A comparison of the traditional and rapid MRI protocols in our institution is highlighted in Table I.

Study Design and Study Population

This retrospective study was approved by our institutional review board. All patients ≤18 years old who had signs and

TABLE I Comparison of Sequences Acquired in the Traditional and Rapid MRI Protocols

	Rapid	
Traditional, with Contrast*	Localized or Focal Examination†	Non-Focal Examination
Axial T1-weighted Coronal T1-weighted Sagittal T1-weighted Axial T1-weighted fat-suppressed Axial T2-weighted fat-suppressed Coronal T2-weighted fat-suppressed Sagittal T2-weighted fat-suppressed (Contrast administration time§) Axial T1-weighted post-contrast Coronal T1-weighted post-contrast Sagittal T1-weighted post-contrast	Axial T2-weighted fat-suppressed Coronal T2-weighted fat-suppressed Sagittal T2-weighted fat-suppressed Coronal T1-weighted Axial DWI and ADC map	Coronal STIR HASTE, large field of view‡ Axial T2-weighted fat-suppressed Coronal T2-weighted fat-suppressed Sagittal T2-weighted fat-suppressed Coronal T1-weighted Axial DWI and ADC map

*If the examination was non-focal, often 2 separate traditional MRI scans would be ordered (e.g., femur and pelvis, or upper and lower leg), resulting in twice as many sequences. †Sequences have been optimized for each instrument with the goal of a total scan time of <10 minutes. ‡For example, if a non-focal, lower-extremity examination is performed, it typically images bilateral thighs and lower legs. The technologist will then call the radiologist to ask on which area to focus the remainder of the examination. §Contrast administration time is not a sequence but is a time-consuming step.

symptoms concerning for acute musculoskeletal infection, including fever, bone or joint pain, limp, inability to bear weight, and swelling, and who were admitted to the emergency department or inpatient service and evaluated with MRI were included. Acute musculoskeletal infection was defined as an infection involving muscle, bone, or joint structures. The traditional MRI cohort (TC) comprised all patients evaluated with MRI prior to implementation of the rapid protocol (January to December 2019). The rapid MRI cohort (RC) comprised all patients evaluated for acute musculoskeletal infection after implementation (June 2021 to June 2022). Inclusion into either cohort solely depended on the dates of presentation. Following a 6-month trial period in which the rapid protocol was developed and optimized, there was an official institutional launch, after which the rapid protocol became the standard for musculoskeletal infection evaluation. The RC represents the first 12 months after the official launch. Patients evaluated in the outpatient setting and those assessed for spine or chronic infection or for non-infectious indications were excluded. Sociodemographic, clinical, imaging, and hospital charge variables corresponding to the initial hospital encounter and the patient's first attempted MRI were extracted from the electronic health record and recorded.

TABLE II Demographic and Clinical Characteristics of the Traditional and Rapid MRI Cohorts*

	Traditional MRI (N = 60)	Rapid MRI (N = 68)	P Value†
Age‡ *(yr)*	7.2 ± 5.5	6.8 ± 5.2	0.73
Sex§			0.65
Male	32 (53.3%)	39 (57.4%)	
Female	28 (46.7%)	29 (42.6%)	
Final diagnosis§			
Acute musculoskeletal infection	32 (53.3%)	30 (44.1%)	0.30
Osteomyelitis	28 (46.7%)	27 (39.7%)	0.43
Septic arthritis	10 (16.7%)	10 (14.7%)	0.76
Pyomyositis	3 (5.0%)	1 (1.5%)	0.34
Treatment for musculoskeletal infection§			
Surgery	18 (30.0%)	14 (20.6%)	0.22
Interventional radiology	13 (21.7%)	3 (4.4%)	**<0.01**
Antibiotics	31 (51.7%)	28 (41.2%)	0.23
Anesthesia§	32 (53.3%)	3 (4.4%)	**<0.01**
Contrast§	53 (88.3%)	0 (0.0%)	—

*Comparison between cohorts were performed using Student t and chi-square tests. †Significant values are shown in bold. ‡The values are given as the mean and the standard deviation. §The values are given as the number of patients, with the percentage in parentheses.

Statistical Analysis

Demographic and clinical data were summarized and reported using descriptive statistics. The Student t test and chi-square analysis were used to compare demographic and clinical variables between cohorts. Distribution analyses, including normality tests, were conducted for time to imaging and to treatment, hospital length of stay, and hospital charges. Because those variables were non-normally distributed, Mann-Whitney U tests were used to compare the variables between the cohorts. The time to treatment was only calculated for patients who had not begun treatment prior to MRI order placement. We excluded a patient from a specific subanalysis if the corresponding variable could not be collected. Significance was set at $p < 0.05$. Data storage and management were

TABLE III Timing Related to Imaging Acquisition*

	Traditional MRI		Rapid MRI		
Time	No. of Patients	Median†	No. of Patients	Median†	P Value‡
From imaging order to imaging acquisition	60	6.5 (5.0 to 8.6)	62	2.2 (1.4 to 3.6)	**<0.01**
Duration of imaging	60	63.2 (56.8 to 69.6)	62	24.0 (21.1 to 29.5)	**<0.01**
From hospital arrival to imaging order	58	6.9 (4.1 to 9.8)	66	5.2 (4.0 to 6.1)	0.18
From imaging order to final interpretation	60	9.9 (7.6 to 13.3)	62	4.1 (3.1 to 5.5)	**<0.01**

*Comparison between cohorts were performed using Mann-Whitney U tests. †The values are given as the median in hours (except for the duration of imaging, which is given in minutes), with the 95% confidence interval in parentheses. ‡Significant values are shown in bold.

conducted with Microsoft Excel (version 2102). Statistical analysis was performed using SAS 9.4 (SAS Institute).

Results

The TC and the RC were similar in demographic characteristics, including age, sex, and final diagnoses (Table II). There were no differences in the rates of surgical procedures or systemic antibiotic administration. There was a drop in interventional radiology procedure rates between the TC and the RC ($p < 0.01$). The rate of anesthesia significantly decreased from 53.3% to 4.4% ($p < 0.01$), and the rate of contrast administration decreased from 88.3% in the TC to 0.0% in the RC.

Timing related to MRI acquisition improved significantly in multiple areas (Table III). After implementation of the rapid protocol, there were significant decreases in the median time from the imaging order to acquisition (see Appendix Supplemental Fig. 1-A), median duration of the MRI examination (see Appendix Supplemental Fig. 1-B), and median time between the imaging order and receipt of the final MRI interpretation (see Appendix Supplemental Fig. 1-C). There was a nonsignificant trend toward earlier MRI ordering (see Appendix Supplementary Fig. 1-D), but we noted that 2 patients in each cohort were excluded from that subanalysis because their initial presentation was not for acute musculoskeletal infection. With most patients with musculoskeletal infection presenting to the hospital between 12 P.M. and 12 A.M. (72.4% in the TC and 66.7% in the RC), a significantly higher percentage ($p < 0.01$) of patients with MRI orders placed between 12 P.M. and 12 A.M. received imaging results prior to 6 A.M. service and operating room start times in the RC (76.7%) compared with the TC (45.2%). There were no significant differences in the time from the imaging order to a procedure or to antibiotic initiation (Table IV).

There was a significant decrease ($p < 0.01$) in median hospital length of stay, from 5.3 days (TC) to 3.7 days (RC) (Table V; see also Appendix Supplemental Fig. 1-E). This held true regardless of whether patients had an acute musculoskeletal infection ($p = 0.04$) or not ($p = 0.02$). There was also a significant decrease ($p < 0.01$) in median total hospital charges for the hospital stay for all patients, from $47,309 (TC) to $32,824 (RC) (Table VI; see also Appendix Supplemental Fig. 1-F). For patients without musculoskeletal infection, total hospital charges decreased from $30,713 (TC) to $16,692 (RC) ($p < 0.01$), and we found a nonsignificant reduction in hospital charges for those with acute musculoskeletal infection. Of note, the same 2 patients from each cohort who were previously excluded from the analysis in Table III (time from hospital arrival to imaging order) were also excluded from the analyses in Tables V and VI because their length of stay and hospital charges were significant outliers complicated by issues beyond acute musculoskeletal infection.

With regard to the rate of false-negative results and imaging failures, 2 patients were diagnosed incorrectly on the initial rapid MRI scan, with a correct diagnosis being made upon a repeated traditional MRI scan administered due to persistent symptoms. The first patient (see Appendix Supplemental Fig. 2) was 11 years old and

TABLE IV Time to Treatment for Patients with Acute Musculoskeletal Infection*

	Traditional MRI		Rapid MRI		
Time	No. of Patients	Median† *(hr)*	No. of Patients	Median† *(hr)*	P Value
From imaging order to procedure (interventional radiology or surgery)†	23	23.7 (14.8 to 33.0)	15	24.0 (12.5 to 52.3)	0.90
From imaging order to antibiotic initiation‡	21	15.4 (8.9 to 21.2)	23	16.3 (5.4 to 30.1)	>0.99

*Comparison between cohorts were performed using Mann-Whitney U tests. †The values are given as the median, with the 95% confidence interval in parentheses. ‡Excluded any patients in whom a procedure or antibiotics were started before the MRI examination.

TABLE V Hospital Length of Stay*

Patients	Traditional MRI		Rapid MRI		P Value‡
	No. of Patients	Median† *(days)*	No. of Patients	Median† *(days)*	
All	58	5.3 (3.7 to 6.9)	66	3.7 (1.9 to 4.1)	**<0.01**
Those who underwent procedure (interventional radiology or surgery)	25	7.9 (6.1 to 12.2)	16	7.6 (4.7 to 12.0)	0.37
Those who received antibiotics but did not undergo a procedure	7	4.5 (2.2 to 9.0)	13	4.1 (3.6 to 6.2)	0.81
Those with acute musculoskeletal infection	32	7.8 (6.1 to 10.1)	30	5.6 (4.0 to 7.3)	**0.04**
Those without acute musculoskeletal infection	26	2.5 (1.5 to 4.8)	36	1.2 (0.8 to 1.9)	**0.02**

*Comparison between cohorts were performed using Mann-Whitney U tests. †The values are given as the median, with the 95% confidence interval in parentheses. ‡Significant values are shown in bold.

had acetabular osteomyelitis, which presented as a subtle marrow signal abnormality on the initial rapid MRI and was not reported by the radiologist. There was subtle soft-tissue edema in the pelvis medial to the acetabulum, which was also not reported. In this case, the more apparent osteomyelitis and subperiosteal abscess on follow-up traditional MRI 2 days later were likely due to natural progression of disease. This patient was not counted in the antibiotic treatment group because antibiotics were not initiated at the first admission. The second patient (see Appendix Supplemental Fig. 3) was only 6 months old, below the typical age window for the rapid MRI protocol, and for unclear reasons, did not undergo MRI using our standard sequences. The field of view was too large, and focused fields of view were not obtained. These factors likely contributed to the omission of the subtle osteomyelitis and fluid collection from the diagnosis, although, in review, the areas of concern were subtly apparent on the initial rapid protocol images. With regard to rates of aborted imaging, zero patients in the TC (with an anesthesia rate of 53%) were not able to complete an MRI examination due to motion. Ten patients (15%) in the RC were not able to tolerate an MRI without anesthesia, leading to nondiagnostic images. However, only 6 of these 10 patients (9% of the RC) underwent a repeat MRI examination with anesthesia, at an average of <2 days after the initial MRI, whereas the other 4 patients had clinical improvement prior to availability of traditional MRI with anesthesia.

Discussion

To our knowledge, this is the first study to describe how the deployment of a rapid MRI protocol can improve the

TABLE VI Hospital Charges for the Entire Length of Stay*

Patients	Traditional MRI		Rapid MRI		P Value‡
	No. of Patients	Median†	No. of Patients	Median†	
All	58	$47,309 ($39,137 to $58,769)	66	$32,824 ($22,865 to $45,339)	**<0.01**
Those who underwent a procedure (interventional radiology or surgery)	25	$81,048 ($64,408 to $113,677)	16	$77,193 ($50,501 to $121,424)	0.50
Those who received antibiotics but did not undergo a procedure	7	$36,385 ($19,141 to $58,769)	13	$38,888 ($26,355 to $55,496)	0.63
Those with acute musculoskeletal infection	32	$71,277 ($51,232 to $109,736)	30	$49,668 ($43,693 to $61,936)	0.11
Those without acute musculoskeletal infection	26	$30,713 ($23,067 to $44,049)	36	$16,692 ($12,519 to $22,865)	**<0.01**

*Comparison between cohorts were performed using Mann-Whitney U tests. †The values, in U.S. dollars, are given as the median, with the 95% confidence interval in parentheses. ‡Significant values are shown in bold.

evaluation of acute pediatric musculoskeletal infection across several domains. Implementation considerably shortened the time involved in preparing for, performing, and interpreting imaging, thus significantly improving patient access to efficient diagnosis. The improvements in time to imaging were attributable to the elimination of intravenous access, contrast administration, and anesthesia, as well as the convenience of fitting shorter examinations into an otherwise full MRI schedule.

We observed significant decreases in hospital length of stay for all patients, and especially for those who did not have a musculoskeletal infection. The improvements in length of stay were greater than the improvements in imaging time, likely due in large part to more efficient discharges for patients with negative results, as they were able to avoid the delays associated with MRI scheduling, anesthesia, and hospital admission. With the rapid protocol, most patients' results were available prior to the start of the clinical day, creating an additive effect by enabling earlier access to consulting services and to the operating room in case of positive results. As a result, implementation significantly reduced hospital charges, especially for those without musculoskeletal infection because many were able to be discharged without intravenous access; contrast administration; anesthesia availability, evaluation, and administration; or inpatient admission. However, the lack of improvement in the time to antibiotic initiation suggests that this protocol does not yet expedite the initiation of infection treatment.

With regard to the diagnostic outcomes with the rapid MRI protocol, although 2 cases of acute musculoskeletal infection were not initially reported as positive, we do not believe that this was due to fundamental flaws in the protocol. In the first patient, findings suggestive of musculoskeletal infection were present on the initial rapid MRI, but they were not noted by the radiologist, possibly because this area in the pelvis can be prone to poor fat suppression, producing artifacts (see Appendix Supplemental Fig. 2). In the second patient, the protocol was not completed correctly, and a definitive diagnosis of musculoskeletal infection was not conclusively made until follow-up imaging (see Appendix Supplemental Fig. 3). Therefore, despite these 2 false-negative results, we surmise that the rapid MRI protocol can accurately identify acute musculoskeletal infection with high sensitivity. This aligns with similar studies of the use of non-contrast images and minimized sequence numbers[10-12,15].

We observed what we consider an acceptably low rate (15%) of imaging failure or nondiagnostic studies due to patient motion, which was anticipated for a protocol without anesthesia. Although the actual rate of incomplete rapid MRI scans due to patient motion was slightly higher than 15%, several cases had sufficient meaningful data obtained despite ending prematurely. Although the lack of anesthesia can affect rapid MRI acquisition, enough clinically relevant information for treatment decision-making was obtained in the majority of cases, and the actual failure rate was low. In such cases, the consequence of an imaging failure is to simply acquire a traditional MRI scan with anesthesia. Only 6 of 10 patients with failed rapid MRI scans (<10% of the cohort) underwent repeat imaging with anesthesia, as the remainder improved clinically prior to the availability of traditional MRI and anesthesia. Overall, these results show that rapid MRI can offer the level of detail needed to guide management more efficiently, and without anesthesia or contrast, in the majority of pediatric patients with acute musculoskeletal infection.

There were several limitations to our study. Due to the retrospective collection of data from different years, there may have been unaccounted-for confounding variables (particularly because the TC was treated before the COVID-19 pandemic and the RC was treated in June 2021, during the pandemic, potentially resulting in differences in hospital workflow and other unanticipated changes in patient characteristics). The study size was somewhat limited, affecting statistical precision. The single-center nature of this study rendered our results subject to bias and the potential lack of generalizability due to geography and the specific patient population and management practices at our institution. Nonetheless, we present a meaningful investigation and analysis of the implementation of a rapid MRI protocol to evaluate acute pediatric musculoskeletal infection and have found significant benefits.

This protocol is now the standard of care for musculoskeletal infection evaluation at our institution. Although we occasionally encounter challenges with providers not knowing about the existence of and appropriate indications for the rapid MRI protocol, we have had no concerns about the protocol itself. We believe that it has great potential for expansion to other institutions. Critically, this protocol is not just a set of MRI settings, but requires a multidisciplinary commitment to its implementation and deployment. Radiologists may need reassurance that a lower level of detail is acceptable for making treatment decisions. Institutions seeking to implement this protocol should expect a low but nonzero need for repeat imaging. The protocol has a potential for misuse if ordered in inappropriate contexts (e.g., for trauma or a tumor). We encourage institutions to implement clinical workflows similar to that in Figure 1 and to identify representatives across departments to take leadership roles in its adoption and guiding its appropriate use. Additionally, electronic medical record "hard stops" can prompt ordering providers to confirm appropriateness. Future steps include ongoing quality control of the protocol, studying interobserver reliability between it and the traditional protocol, and expansion to other centers. Interested centers are encouraged to contact the corresponding author if they have a surgeon and radiologist team prepared to lead a deployment.

In conclusion, implementing a rapid MRI protocol for evaluating possible acute pediatric musculoskeletal infections eliminated contrast and significantly reduced anesthesia needs, while improving the time to imaging, duration of imaging, and interpretation time. There were significant decreases in hospital length of stay and hospital charges for all patients. The rapid MRI protocol had a very low likelihood of missing acute musculoskeletal infection on imaging. For a minority of patients, intolerance of the examination or motion led to imaging failure. Rapid MRI protocols can be utilized for the evaluation of acute pediatric musculoskeletal infection to decrease contrast and anesthesia usage, improve imaging access and utilization, shorten hospital stays, and reduce hospital charges, while resulting in an approximately 10% rescan rate. A multidisciplinary team was instrumental in successful deployment and adoption of the rapid protocol.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/H897). ■

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