Journal of the Pediatric Orthopaedic Society of North America 8 (2024) 100096

Contents lists available at ScienceDirect

Journal of the Pediatric Orthopaedic Society of North America

journal homepage: www.jposna.com

Original Research

Early Magnetic Resonance Imaging Use in Clinical Care Pathways for Musculoskeletal Infections in Pediatric Patients: A Systematic Review

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A R T I C L E I N F O

Keywords:
Magnetic resonance imaging (MRI)
Musculoskeletal infections (MSKI)
Pediatric musculoskeletal infections
Osteomyelitis
Septic arthritis
Diagnostic imaging

A B S T R A C T

Background: Magnetic resonance imaging (MRI) is often used in the work-up for pediatric patients with musculoskeletal infections (MSKIs). The timing of MRI has been shown to impact surgical accuracy and clinical outcomes for MSKI patients. However, its use in clinical care pathways (CCPs) for suspected cases of MSKI in this population has not been thoroughly reviewed. The objective of this literature review is to determine whether the use of MRI in CCPs for suspected cases of MSKI improves clinical outcomes.
Methods: A review was systematically conducted by 2 authors using studies from Ovid Embase, Ovid Medline, Scopus, Web of Science, and Google Scholar. Studies were screened for relevancy and inclusion criteria through the Covidence database. Retrospective cohort studies that discussed the use of MRI for MSKI in exclusively pediatric populations, published since 1990, and were written/translated to English were included. The quality of the included studies was assessed using tools for cohort studies from Cochrane and the National Center for Biotechnology Information. A qualitative summary of the results was used due to the small number of studies and variables reported in the included studies. A secondary search and review were conducted by the same 2 authors to identify more studies after the initial review.
Results: The first search across 5 databases yielded 1,857 studies. Of these, 3 retrospective cohort studies were relevant to the topic of the review and met the inclusion criteria. The second search yielded 120 studies, but none were applicable for inclusion. The 3 included studies showed that early MRI improves diagnostic accuracy and surgical timing. They reported on the ability of MRI to define the full extent of an MSKI and identify adjacent infections preoperatively, which improves surgical outcomes and decreases complication rates. The studies reported that early MRI use in CCPs decreases reoperation rates and unnecessary surgeries. The authors also discussed how early MRI use can indirectly decrease hospital costs.
Conclusions: Early use of MRI in suspected cases of MSKIs may allow for an accurate and timely diagnosis and may lead to early intervention and a decreased rate of complications. MRI can depict the full extent of infection and any adjacent infection(s), allowing for the correct intervention to be selected. This may decrease the number of unnecessary surgeries, thereby reducing reoperation rates, length of stay, and readmission rates.
Key Concepts:

(1) Magnetic resonance imaging (MRI) is a diagnostic tool for musculoskeletal infections (MSKIs).
(2) Prioritizing early MRI in clinical care pathways of suspected cases of MSKIs may improve patient outcomes.
(3) Benefits of early MRI for MSKI patients may include reducing unnecessary surgeries and reoperation rates.
Level of Evidence: II

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https://doi.org/10.1016/j.jposna.2024.100096
Received 9 July 2024; Accepted 11 July 2024
Available online 15 July 2024
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Introduction

The development of clinical care pathways (CCPs) for the treatment of musculoskeletal infections (MSKIs) in paediatric patients has demonstrated growing importance in patient outcomes [1–3]. A standardized clinical approach for the management of these patients limits inconsistent steps made on a case-to-case basis and improves patient care. The timing of magnetic resonance imaging (MRI) has become a focus for CCPs as it has shown to be crucial for a timely diagnosis, thereby optimizing the management of MSKIs [1–3]. MRI accurately depicts bone and soft tissue pathology as well as the accumulation of fluid, edema, sacroiliitis, discitis, and abscesses—important findings that other imaging techniques cannot detect to the same extent [4]. Despite these benefits, it has been challenging to regularly implement early MRI into CCPs due to difficulties in coordinating radiology, anesthesiology, and surgical departments; concerns include additional use of sedatives and/or delaying necessary surgery, as well as the additional use of resources and costs to perform the MRI [4–8]. The objective of this review was to identify the benefits that may result from prioritizing MRI use in CCPs. The impacts of early MRI use on hospital and treatment outcomes were analyzed to demonstrate the importance of prioritizing this imaging method in suspected cases of MSKI in pediatric patients.

Materials and methods

Search strategy

A search of medical literature pertaining to the discussion of MRI use for MSKIs was done with the assistance of a librarian at BC Children's Hospital. An initial, limited literature search was conducted on PubMed and National Center for Biotechnology Information (NCBI) to determine keywords and Medical Subject Headings terms used in relevant sources that could be applied to the search strategy for this review.

The search strategy was constructed and edited in Ovid MEDLINE and then translated to 4 other databases using the established keywords and Medical Subject Headings terms. The following terms were used in the search: "magnetic resonance imaging," "MRI," "musculoskeletal infection," "septic arthritis," "osteomyelitis," "diagnostic imaging," "early diagnosis," "time factors," "preoperative," and other search terms as detailed under Supplementary Material. A search term developed at the University of Alberta was also used to limit the search to studies on pediatric populations [9]. These terms were applied to Ovid Embase, Web of Science, Scopus, and Google Scholar to expand the scope of our review. All searches were conducted on May 12, 2023.

Search results from all 5 databases were then uploaded to the online tool, Covidence, for review (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia, www.covidence.org). All duplicates obtained from the different searches were removed by the database. Two reviewers (MK and MH) then screened the remaining studies. The titles and abstracts were reviewed first to determine the potential relevance of the sources. Those that cleared this screening then underwent a full-text review by the same 2 reviewers to confirm that the focus of the sources was relevant, and to determine if the article followed the established inclusion criteria. The inclusion criteria selected for studies that: (1) discussed the use of MRI for MSKI, (2) looked at only a pediatric population, (3) were written in or translated to English, (4) were published after 1990, and (5) were a retrospective cohort study or randomized control trial.

On August 14, 2023, this review was registered to the International Prospective Register of Systematic Reviews. The protocol's registration number is CRD42023453532. Quality assessment of each included study was then done using the "Tool to Assess Risk of Bias in Cohort Studies" from Cochrane as well as the "Quality assessment tool for cohort studies" from NCBI. Data were then extracted and analyzed from the included studies. A qualitative summary of study results was used due to the small number of studies and variable reporting of results. In addition, only retrospective cohort studies resulting from the search were found to be relevant and meet the inclusion criteria.

Due to a low yield of studies that followed the established inclusion criteria, an updated literature search was conducted on March 1, 2024. The same search strategy was used, and it was conducted across the same databases; however, the search results were limited to studies published since May 12, 2023. All additional studies were imported into Covidence to be reviewed by the same 2 reviewers (MK and MH).

Results

Literature search

The initial literature search applied across 5 different databases yielded 1,857 studies. Of those, 559 were duplicates, leaving 1,298 studies for screening. From the title and abstract screening, 1,062 studies were excluded due to a lack of relevance. The full-text screening found 233 studies did not meet the inclusion criteria, resulting in 3 papers being selected for data extraction and analysis (see Fig. 1).

All 3 studies included were found to have an unclear risk of bias using the "Tool to Assess Risk of Bias in Cohort Studies" from Cochrane in combination with the "Quality Assessment Tool for Cohort Studies" from NCBI.

The secondary search yielded 120 studies; 31 duplicates were removed leaving 89 additional studies for review. The reviewers found 52 of those studies to be irrelevant from title and abstract screening, and the remaining 37 were found to not meet the inclusion criteria during full-text screening.

Primary benefits of early MRI use

Three retrospective cohort studies conducted in tertiary care children's hospitals assessed clinical outcomes that were influenced by the timing of MRI in the workup of MSKIs in pediatric patients (see Table 1). Each study retrospectively reviewed patients' hospital charts to compare the results from before and after the implementation of early MRI. Corin et al. conducted their study at a pediatric referral center in the United Kingdom, where they assessed the outcomes in 51 patients; of those, 27 received a pre-emptive MRI, and 24 patients only received an MRI postoperatively. Similarly, Griswold et al. examined and compared these outcomes in 93 patients, 40 of whom did not receive preoperative MRI, and 53 who did. This study was conducted at a tertiary children's hospital in the United States [7]. Gottschalk et al. also analyzed the consequences of early MRI in 130 patients who received care at a children's hospital in the United States; 77 received an early MRI for diagnosis compared to 53 patients that underwent primary hip aspirations [8].

The primary beneficial outcomes observed from early MRI use across the studies included early diagnosis, early intervention, decreased rates of complications, improved surgical planning, decreased reoperation rates, reduced rates of unnecessary surgeries, and shorter length of stays (LOSs) (see Table 1) [6–8].

Accurate diagnosis

All 3 studies discussed the ability of MRI to provide a complete and accurate diagnosis of MSKIs. Griswold et al. observed a 40% increase in the identification of adjacent infections when preoperative MRI was used. Specifically, they reported that when pre-emptive MRI was used, they identified 71.87% of infections, compared to 35.29% ($P = .0003$) of adjacent infections that were identified when MRI was not done pre-emptively [7]. Similarly, Gottschalk et al. stated that 42% of adjacent

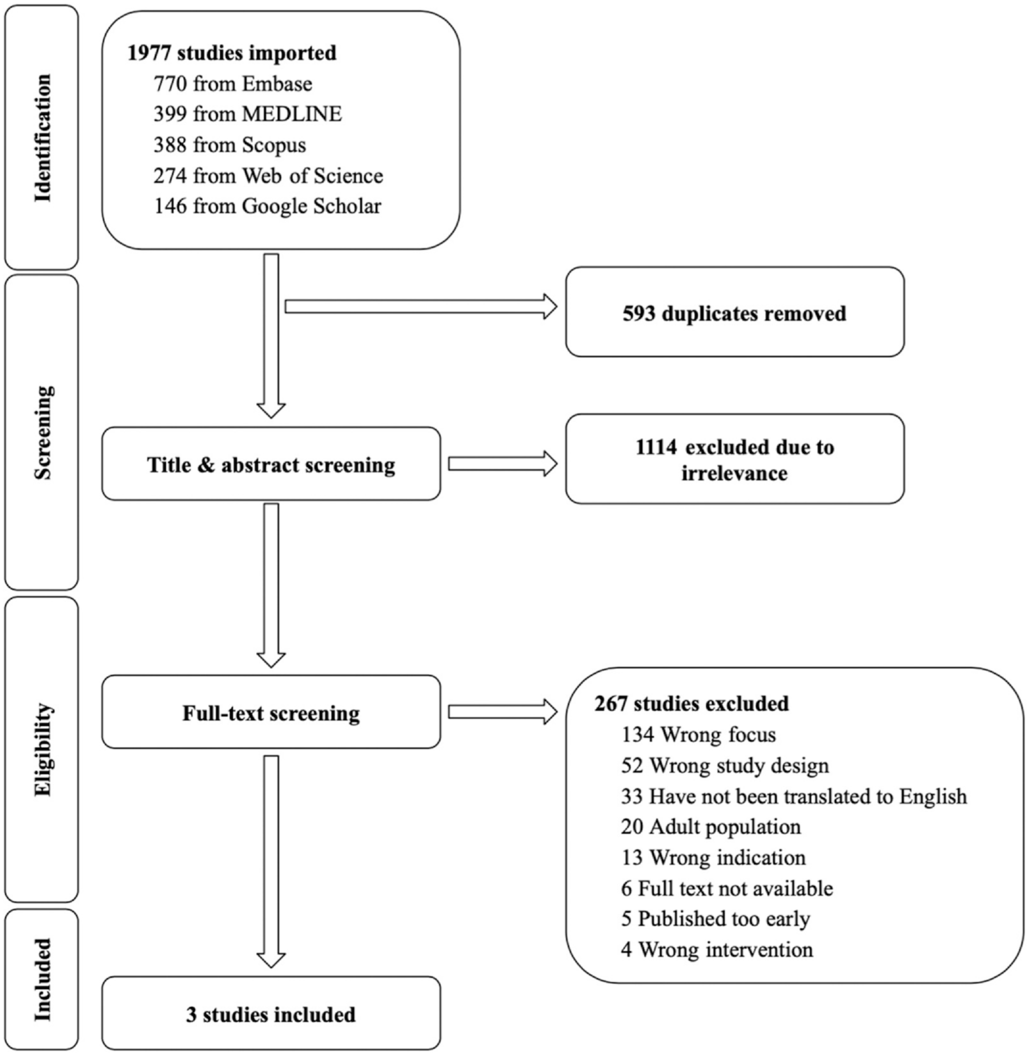

Figure 1. Flow chart depicting the process of selection for relevant studies that satisfied the inclusion criteria.

infections would have gone unnoticed without the use of pre-emptive MRI. In the group of patients that were diagnosed via primary aspiration (and not early MRI), 37.5% of patients who required multiple surgeries were found to have received an incomplete initial diagnosis and, thus, inadequate surgical treatment. Here, postsurgical advanced imaging showed additional pathology that was not known of before surgery [8]. Corin et al. noted that the ability of MRI to identify adjacent infections and make an early diagnosis was critical in limiting complications. They found that determining the true extent of the primary infection and any adjacent infections allows surgeons to determine if surgical intervention is needed [6].

Prevention of unnecessary surgeries

In the study conducted by Corin et al., 37% of patients in the group who did not receive an MRI preoperatively had undergone an unnecessary washout procedure [6]. In the group of patients that received preoperative MRI, they reported that no unnecessary surgeries occurred [6]. They explained that overall if pre-emptive MRI was done in all cases, it would have prevented unnecessary hip washouts in 10/51 (~20%) cases. In addition, they stated that if pre-emptive MRI was not done in any of the cases reviewed, it could have resulted in up to 33 (65%) more unnecessary procedures [6].

Rates of additional operations

Two of the reviewed studies reported a change in rates of additional operations due to the prioritized use of MRI because of its utility in surgical planning. Gottschalk et al. reported that 30% of patients in the group who did not receive a preoperative MRI required an additional procedure, whereas only 17% of surgical patients who received an early MRI required reoperation (P = .03) [8]. Overall, Gottschalk et al. have reported that reoperation rates were 2.8 times greater when pre-emptive MRI was not done. Similarly, Griswold et al. reported a statistically significant decrease in unplanned repeat surgeries when early MRI was performed. Prior to protocol implementation, 50% of MSKI patients required repeat surgeries, of those, 85% were unplanned [7]. When the early MRI protocol was implicated, only 28% of patients required more than one surgery (P = .0487), with 60% of them being unplanned [7]. Corin et al. showed that pre-emptive MRI has the ability to define whether a muscle or subperiosteal abscess requires drainage, allowing for a specifically targeted approach. In this study, 26% of the patients who did not receive a preoperative MRI were found to require additional surgery upon the completion of postoperative imaging [6]. In comparison, they did not report any additional operations in the pre-emptive MRI group [6].

Table 1
Summary of the parameters in each included study.

Author and year	Early MRI (w/ or w/o)	Reoperation rates	% of unnecessary procedure	# of anesthetics used	% of adjacent infections identified pre-op	Time to surgery (days)	% of patients who required additional procedures	Length of stay (days)
Corin et al., 2022	w/	Not reported	0%	Not reported	Not reported	Not reported	0%	Not reported
	w/o	26%	37%	Not reported	Not reported	Not reported	26%	Not reported
Gottschalk et al., 2014	w/	17%	Not reported	1.5 ± 0.7	Not reported	1.30 ± 1.60	17%	7.3 ± 6.0
	w/o	30%	Not reported	1.7 ± 1.0	Not reported	1.03 ± 1.82	30%	7.5 ± 3.5
Griswold et al., 2020	w/	28%	Not reported	Not reported	71.87%	Not reported	28%	10.74 ± 11.5
	w/o	50%	Not reported	Not reported	35.29%	Not reported	50%	13.92 ± 12.83

MRI, magnetic resonance imaging.

Number of anesthetics

Gottschalk et al. reported an average of 1.5 ± 0.7 anesthetics used in patients who received early MRI and an average of 1.7 ± 1.0 used in the group that did not receive pre-emptive MRI (P = .16) [8]. This was not a statistically significant finding. In addition, Corin et al. and Griswold et al. recorded a fewer number of additional surgical procedures when early MRI was done, resulting in fewer anesthetics being used.

Length of stay

Two studies discussed the impact of early MRI on the average LOS. Gottschalk et al. reported an average LOS for the immediate MRI group to be 7.3 ± 6.0 days, whereas the immediate aspiration group was 7.5 ± 3.9 days (P = .83). Likewise, Griswold et al. reported that the average LOS was 3.8 days shorter (P = .22) after the implication of protocol. Note that both studies reported statistically insignificant decreases in LOS.

Hospital costs

Corin et al. explained that pre-emptive MRI could decrease hospital costs by preventing unnecessary surgeries through its ability to give accurate diagnoses. They reported that an MRI costs 16 euros (23.67 Canadian dollars) per minute less than an operating room; therefore, overall expenses would decrease if surgery is deemed unnecessary through early MRI [6]. Griswold et al. also explained that preoperative MRI could reduce hospital costs if the same anesthesia can be used for MRI and surgery.

Discussion

This review suggests that the early use of MRI for diagnosing the extent of MSKIs in pediatric patients before surgical treatment decisions improves clinical outcomes. MRI is emerging as the modality of choice for diagnosing MSKIs due to its ability to indicate the extent and severity of infection [10]. It has been reported to have a sensitivity and specificity ranging between 90% to 95.6% and 79% to 89%, respectively, in the identification of osteomyelitis and other MSKIs [10–13]. In a retrospective review conducted by Song et al., they observed no false-positive or false-negative findings when MRI was used. They also discussed that MRI was preferred by patients' parents over aspirations because it is not invasive [14]. Other authors have also reported MRI having a specificity between 77% and 80% and a sensitivity between 89% and 97% for the identification of soft tissue abscesses; therefore indicating that MRI can provide more information on the extent of the infection than other imaging modalities [10,12]. MRI can detect precise details in both soft tissues and bone, as well as in both superficial and deeper tissues [12]. It has also been used to distinguish viral and bacterial myositis and, therefore, may assist in pathogen identification. Moreover, MRI has also been recognized for its ability to detect infection earlier than other imaging modalities [10,12]. These are some of the reasons that may have contributed to MRI being considered the most informative, first-line, imaging modality in suspected cases of MSKI [14,15].

Early and accurate diagnosis through pre-emptive MRI use allows for the rapid commencement of treatment and a significant decrease in the rate of complications resulting from MSKIs [5–7,16,17]. Early intervention can also reduce the need for surgical debridement or drainage, thus limiting invasive procedures. This may improve patients' experiences and decrease hospital costs [1,6,17,18]. MRI has also been recognized for its ability to define the full extent of an infection, and adjacent infection(s) prior to surgery, allowing for accurate surgical planning and decreasing reoperation rates [2,4,6–8,10,19–21]. The preoperative knowledge of the extent of infection can also decrease operative time and surgical exposure, thereby reducing hospital costs and benefiting patient recovery [6,20]. Determining the full extent of an infection before surgical intervention can significantly reduce the rate of unnecessary surgeries. Many pediatric MSKI patients have undergone washouts and drainage procedures that upon review, were not required for a full recovery [6]. Early MRI may also prevent delays in the commencement of antibiotics or surgical interventions [1,22].

While there are many benefits of early MRI use reported in the literature, some authors have expressed concern about regularly incorporating pre-emptive MRI in CCPs for MSKI patients [4–6]. As MRI is sensitive to movement artifacts, young or uncomfortable pediatric patients require sedation for this imaging. This additional use of sedatives could increase the risk of complications in these patients due to the adverse events associated with anesthesia [4,5]. However, Griswold et al. reported that implementing a protocol that allows for immediate transfer from MRI to surgery (if necessary) can allow a patient to undergo these 2 interventions under a single anesthetic. Furthermore, performing an MRI and surgery continuously has been reported as a safe strategy to limit delays to surgical interventions as well as the number of anesthetics used [22]. In addition, Gottschalk et al. reported that fewer anesthetics were required in the group that underwent pre-emptive MRI compared to the group that did not. The number of anesthetics would decrease with preoperative MRI due to decreased reoperation rates.

Some authors have raised concerns that the delay in surgery resulting from preoperative MRI may result in increased complications [5,6]. However, Griswold et al. did not observe a statistically significant delay in surgery when the preoperative MRI protocol was in place ($P = .1224$). Other authors have reported that MRI is a costly intervention, which has also led to difficulties in regularly incorporating early MRI in CCPs for MSKI [4,5,23,24]. Nonetheless, as early MRI can decrease rates of unnecessary surgeries, reoperations, and complications, and may decrease LOSs and number of sedations, other hospital expenses would decrease. This benefit may outweigh the additional upfront costs associated with performing an MRI, leading to an overall decrease in hospital expenses [6,7].

Limitations of our review include limiting the search to studies written in English, the small number of studies selected, and the absence of published randomized controlled trials or prospective cohort studies included. To address these weaknesses, an additional literature search was conducted approximately 10 months after our initial search but no additional studies were found that met our inclusion criteria, demonstrating a gap in the current literature. However, this search also led to the discovery of an upcoming retrospective cohort study in the United Kingdom that aims to investigate the role of MRI and ultrasound in diagnosing MSKI [13]. The ongoing research on the benefits of using MRI for the management of MSKIs indicates that this strategy is of interest in a clinical setting. Moreover, this shows the promising significance of early MRI for pediatric MSKI patients, as well as a need for further research on this clinical approach.

Authors' preferred CCP (adapted from Provenzano et al. [25])

The importance of prioritizing an MRI is highlighted in this review and should be strongly considered when constructing a CCP for pediatric MSKI patients. However, before conducting an MRI, initial diagnostic evaluation, including complete blood count (CBC) with differential, C-reactive protein (CRP) (± erythrocyte sedementation rate (ESR)), blood cultures, and plain X-ray of the affected area, should be conducted when a pediatric patient presents with signs and symptoms suggestive of an MSKI. If a patient exhibits signs of sepsis, they should then be immediately started on intravenous (IV) antibiotics. A consultation with orthopedics, general pediatrics, and an infectious disease team should occur. In addition, as highlighted in this review, an MRI should be obtained as soon as possible—ideally within 24 hours of presentation. Performing an MRI before carrying out further interventions helps physicians to determine: if the patient requires surgical intervention, when the surgery is required, and the extent of surgery required. Furthermore, having a multidisciplinary approach in which anesthesia, radiology, and surgical teams coordinate together to conduct an MRI immediately before a scheduled surgery would help to limit the number of anesthetics used in pediatric MSKI patients. A multidisciplinary approach allows for patients to be immediately transferred from the MRI to the operation room under the same anesthetics (if surgery is deemed necessary). There are risks associated with sedating young patients multiple times within a short period, therefore achieving this coordination would be beneficial in multiple ways. Overall, an ideal CCP for suspected cases of MSKI in pediatric patients should involve a collaborative effort between orthopedics, general pediatrics, radiology, emergency medicine, anesthesiology, and infectious diseases. Although a coordinated effort can be a challenge, this review demonstrates that prioritizing MRI in a CCP has the potential to improve outcomes and patient care.

Conclusion

Our review suggests that MRI is excellent at identifying MSKIs early in the disease process and can accurately depict the extent of the infection. This may allow for appropriate and timely treatment and a reduced number of unnecessary invasive procedures, reoperations, and complications. There is a gap in the current literature focusing on the optimal timing of an MRI in suspected cases of MSKI in pediatric patients, however, there is evidence that this strategy is beneficial—demonstrating the importance of investigating this further.

Funding

No external funding was received for this study.

Ethics approval and consent

The author(s) declare that no patient consent was necessary as no images or identifying information are included in the article.

Author contributions

Marie Keenan: Writing – original draft, Formal analysis, Writing – review & editing, Data curation, Investigation, Methodology, Resources, Visualization. **Marianna Hsu:** Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – review & editing. **Lise Leveille:** Writing – review & editing. **Christine Alvarez:** Writing – review & editing. **Andrea Simmonds:** Conceptualization, Writing – review & editing, Data curation, Project administration, Supervision, Validation.

Declarations of competing interests

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.

Appendix A. Supplementary material

Supplementary material related to this article can be found at doi:10.1016/j.jposna.2024.100096.

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