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The Utility of MRI With Multiacquisition Variable-Resonance Image Combination (MAVRIC) in Diagnosing Deep Total Hip Arthroplasty Infection

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Abstract

Background: The 2010 American Academy of Orthopaedic Surgeons Clinical Practice Guidelines report insufficient evidence to address the diagnostic efficacy of magnetic resonance imaging (MRI) for periprosthetic joint infection (PJI). *Questions/Purposes*: The purpose of this study was to determine the utility of MRI with multiacquisition variable-resonance image combination (MAVRIC) metal artifact suppression techniques in diagnosing PJI in the setting of total hip arthroplasty (THA). *Methods*: Multiacquisition variable-resonance image combination MRIs obtained of THAs between November 2012 and November 2016 were queried. Radiology reports were classified as positive (suspicious for infection), negative (no features of infection), or inconclusive (infection cannot be excluded or correlation with aspiration suggested if clinically concerned). Chart review identified cases of deep PJI according to the modified Musculoskeletal Infection Society criteria. *Results*: Of 2156 MRIs of THAs included, MRI was concerning for infection in 1.8% (n = 39), inconclusive in 1.2% (n = 26), and negative in 97.0% (n = 2091). Deep PJI was identified in 53 (2.5%) patients, 30 of whom (56.6%) had conclusively positive finding on MRI (false-negative rate: 43.4%, sensitivity: 56.6%). Of 2103 aseptic THAs, only 9 (0.4%) MRIs were read as suspicious for infection (false-positive rate: 0.4%; specificity: 99.6%). *Conclusion*: Magnetic resonance imaging with MAVRIC is a highly specific test for PJI with a low false-positive rate. This indicates that when clinicians are provided with an MRI that unexpectedly suggests infection, a formal evaluation for infection is indicated. In patients with otherwise equivocal diagnostic findings, MRI may help confirm, but not refute, a diagnosis of PJI. Prospective study with more experienced image reviewers may further support the use of MRI in PJI.

Keywords

prosthetic joint infection, Musculoskeletal Infection Society criteria, MAVRIC, MRI, total hip arthroplasty

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Introduction

Periprosthetic joint infection (PJI) is aclinically devastating complication of total hip arthroplasty (THA), resulting in substantial morbidity, mortality, and cost. Periprosthetic joint infection occurs in 1% to 2% of primary THAs [22,24] and 1.5% to 4% of revision THAs [2,25]. Infection remains a major cause of failure for THA, comprising up to 30% of all THA revision surgeries [5,12,13,25]. Early diagnosis and treatment are essential to preserving bony integrity and achieving favorable long-term outcomes. Although diagnostic criteria were standardized with the publication of the Musculoskeletal Infection Society (MSIS) criteria for PJI in 2011 [19], the definition has undergone modifications over time and the accurate diagnosis of PJI remains challenging [17,18].

While serum laboratory values, joint aspiration, intraoperative cultures, and histopathology are the mainstay for diagnosis of PJI, controversy exists regarding the utility of magnetic resonance imaging (MRI) in the diagnostic algorithm when evaluating for PJI. Magnetic resonance imaging is widely accepted as a useful imaging modality for the evaluation of a painful THA, as it has demonstrated

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excellent reliability in identifying osteolysis and wear-induced synovitis [11]. However, susceptibility artifact has traditionally remained a limitation of this modality, and the most recent American Academy of Orthopaedic Surgeons (AAOS) Clinical Practice Guidelines report the use of MRI as "inconclusive" in diagnosing PJI [16].

Since the publication of those guidelines, optimized conventional pulse sequences and novel metal artifact reduction techniques have increased in clinical practice [6,8,14,26,27]. Multiacquisition variable-resonance image combination (MAVRIC) is a technology that enables superior visualization of periprosthetic joint tissue [4]. Magnetic resonance imaging with MAVRIC has been shown to be superior to traditional fast-spin echo in enabling radiologists to visualize the synovium, tendon tears, and the prosthesis-bone interface in hip, knee, and shoulder arthroplasties [11].

Signs of infection on MRI that favor a diagnosis of infection include synovitis, joint effusion, extracapsular enhancement or fluid collections, sinus tracts, bony destruction, reactive lymphadenopathy, and, in particular, layering of thickened hyperintense synovium [4,9,11]. However, the concomitant findings of wear-induced granulomatous reactions, adverse local tissue reaction (ALTR), and underlying rheumatologic conditions complicate the identification of classically infectious features [9]. To date, there is little published data regarding the utility of MRI using MAVRIC novel metal artifact suppression techniques for the diagnosis of PJI. The purpose of this study was to evaluate the sensitivity and specificity of MAVRIC MRI for diagnosing PJI in patients with THAs.

Methods

Montage radiologic database search software was used to retrospectively identify all hip MRIs performed with MAVRIC metal artifact suppression sequencing and ordered by 1 of 26 arthroplasty attendings at a single institution between November 1, 2012, and November 1, 2016. Additional search criteria included the presence of the words "replacement" and "arthroplasty" in the body of the report. Exclusion criteria were the presence of a hip resurfacing implant, hemiarthroplasty, cement spacer in place of definitive arthroplasty, MRI of a native hip in a patient with contralateral arthroplasty, and duplicate reports for the same MRI scan. In patients with multiple MRIs of the same THA, additional MRIs were included only if there was at least a 6-month interval between repeat scans.

All MRIs were performed using a standard imaging protocol on a 1.5 Tesla MRI machine. Images were interpreted by board-certified radiologists with a variable level of experience in the interpretation of MRI of arthroplasty, ranging between less than 1 year and more than 10 years. Magnetic resonance imaging reports were reviewed for patient age, sex, laterality, reason for obtaining the MRI, and to confirm the presence of a THA. The content of MRI reports was reviewed for specific mention of infection as well as imaging features commonly representative of infection (including hyperintense or lamellated synovitis, pericapsular edema, abscess formation or the presence of loculated fluid collections, evidence of a sinus tract, lymphadenopathy, and bony destruction). Reports were classified into 1 of 3 categories based on the radiologist's written report: positive (suspicious for or consistent with infection), negative (no signs or features consistent with infection), or inconclusive (infection cannot be ruled out, correlation with aspiration recommended). Magnetic resonance imaging reports lacking any of the above features of infection and also lacking mention of infection were categorized as negative for infection. Magnetic resonance imaging reports mentioning 1 or more of the features of infection listed above without a confirmatory statement regarding the likelihood of infection were recorded as "indeterminate." Adverse local tissue reaction was distinguished from infection generally based on the lack of surrounding soft tissue edema, as per the radiologist interpretation of these findings. The presence of ALTR was documented in a binary fashion.

Medical record chart review was performed on all included patients to identify clinical evidence of infection as per the 2016 modified MSIS criteria (Table 1) [17]. All available serum inflammatory markers, synovial fluid aspirates, and operative cultures and pathology were reviewed. Operative dictations were also reviewed for the presence of a sinus tract. Clinical data were limited to within 6 months of the associated MRI. In patients with repeat laboratory results within the 6-month time frame, the laboratory data in closest proximity to the date of MRI were recorded. The MSIS criterion was to define the presence or absence of PJI. In the primary analysis, patients without available laboratory or operative data within 6 months of the MRI were presumed to be aseptic. A subgroup analysis included only patients with laboratory data available within 6 months of the MRI to implement a stricter definition of aseptic cases.

The utility of MRI in diagnosing PJI was evaluated by calculating sensitivity, specificity, positive predictive value, and negative predictive value. Analyses were stratified by the concomitant presence of a metal-on-metal (MoM) implant, the presence of ALTR on MRI report, and the availability of laboratory data within 6 months of the MRI, the availability of laboratory data within the 6 months prior to MRI. The 3 most experienced and highest volume musculoskeletal radiologists at our institution read 86% of the included MRIs in this study; therefore, a subgroup analysis including reports from these 3 radiologists only was also performed to eliminate bias from radiologists less experienced in identifying this pathology. Univariate analysis evaluated baseline difference between stratified groups. Multivariable logistic regression was performed to identify

Table 1. Modified MSIS criteria for chronic PJI.

PJI must meet at least 1 of the following criteria:
1. Two positive periprosthetic (tissue or fluid) cultures demonstrating the same organism
2. A sinus tract communicating with the joint
3. At least 3 of the 5 below "minor" criteria
   - Increased serum CRP >10 mg/L and ESR > 30 mm/h
   - Increased synovial WBC > 3000 cells/μL
   - Increased synovial fluid polymorphonuclear neutrophil percentage >80%
   - Positive histologic analysis of periprosthetic tissue (>5 neutrophils per high-powered field)
   - Single positive periprosthetic fluid or tissue culture

Adapted from Parvizi et al [17].
MSIS Musculoskeletal Infection Society, *PJI* periprosthetic joint infection, *CRP* C-reactive protein, *ESR* erythrocyte sedimentation rate, *WBC* white blood cell.

Table 2. Exclusions.

Reason for exclusion	n
Hip resurfacing	287
Native hip	110
Repeat MRI of same hip within 6 months	46
Cement spacer	9
Duplicate MRI report	7
Hemiarthroplasty	6
Incomplete exam	1

MRI magnetic resonance imaging.

Table 3. Baseline demographics and outcomes.

	Entire cohort (n = 2156)
Demographics	
Age	Mean 62.2 (±11.9)
Female	1170 (54.3%)
Metal-on-metal implant	301 (14.0%)
Reason for MRI[a]	
Pain	629 (29.1%)
Evaluate for ALTR	524 (24.3%)
Evaluate for loosening/osteolysis	429 (19.9%)
Soft tissue evaluation[b]	422 (19.6%)
Rule out infection	273 (12.7%)
Other/unknown	218 (10.1%)
Research	190 (8.8%)
Clinical data	
Bloodwork	835 (38.8%)
Joint aspiration	339 (15.7%)
Operative cultures	184 (8.6%)
Clinical data within 6 months of MRI	957 (44.4%)
MRI findings of infection	
Positive	39 (1.8%)
Inconclusive	26 (1.2%)
Negative	2091 (97.0%)
Clinical PJI (as per modified MSIS criteria)	53 (2.5%)

MRI magnetic resonance imaging, *ALTR* adverse local tissue reaction, *PJI* periprosthetic joint infection, *MSIS* Musculoskeletal Infection Society.
[a]Primary or secondary indication; patients may have 2 indications represented here.
[b]Includes bursitis, psoas impingement, and sciatic nerve evaluation.

whether MRI with MAVRIC is predictive of PJI. All statistical analysis was performed using SPSS (version 22.0), with *P* values of less than .05 indicating statistical significance.

Results

The initial radiographic report query resulted in 2622 MRIs for review. After application of exclusion criteria, 2156 MRIs were included in the analysis (Table 2). The final cohort consisted of MRIs ordered by 26 fellowship-trained arthroplasty surgeons and read by 23 musculoskeletal radiology fellowship-trained radiologists. The primary or secondary reason for ordering the MRI was most commonly "pain" for the entire cohort (28.9%). However, in patients with diagnosed PJI, the MRI was most commonly ordered for "rule out infection" (45.3%), followed by "pain" in 24.5%. In the entire cohort, the MRI was read as concerning for infection in 1.8% (n = 39), inconclusive in 1.2% (n = 26), and negative in 97.0% (n = 2091). Of the 2103 aseptic THAs, only 9 MRIs were read as suspicious for infection (false-positive rate: 0.4%) and 21 additional MRIs were inconclusive (1.0%). Baseline demographics and outcomes are detailed in Table 3.

We identified a deep PJI after THA in 53 patients (2.5%), according to the modified MSIS criteria. Of the confirmed infected cases, 30 (56.6%) had a conclusively positive finding on MRI, 5 (9.4%) had indeterminate MRI findings, and 18 (34.0%) had no signs of infection on MRI. The overall false-negative rate of MRI in detecting clinical infection (negative and inconclusive findings combined) was 43.4%. Negative MRI reports in patients with PJI as diagnosed by MSIS criteria documented either no findings related to the synovium (n = 5), nonspecific mild synovitis (n = 8), nonspecific moderate to severe synovitis (n = 1), or polymeric-induced synovitis (n = 4). All 5 indeterminate MRI reports documented other features that compounded the clinical diagnosis (eg, prior history of infection without evidence of active infection or presumed insufficiency fractures causing bony edema). Although date of surgery was not available, 5 MRI reports indicated recent postsurgical changes (2 were classified as negative for infection, 2 as indeterminate for infection, and 1 as positive for infection).

The sensitivity and specificity of detecting clinical PJI in the cohort at large when the MRI findings were suspicious for infection were 56.6% and 99.6%, respectively. Subgroup analyses were then performed analyzing cohorts with MoM

Table 4. Sensitivity, specificity, and positive and negative predictive values for detecting clinical periprosthetic joint infection from MRI.

	Sensitivity	Specificity	Positive predictive value	Negative predictive value
Entire cohort (n = 2156)	56.6	99.6	76.9	98.9
MoM only (n = 301)	50.0	99.3	33.3	99.7
Non-MoM (n = 1845)	56.9	99.6	80.6	98.8
ALTR only (n = 271)	25.0	99.3	33.3	98.9
Non-ALTR (n = 1845)	62.2	99.6	80.0	99.1
Clinical data present (n = 957)	56.6	99.2	81.1	97.5
Clinical data prior to MRI (n = 702)	64.3	99.1	75.0	98.5
High-volume radiologist[a] (n = 1849)	57.5	99.6	74.2	99.1

Only definitively MRI positive results are included in these calculations.
MRI magnetic resonance imaging, *MoM* metal-on-metal, *ALTR* adverse local tissue reaction.
[a]High-volume radiologist defined as having 5 to 10 years or more of musculoskeletal radiology experience and having read a minimum of 200 MRIs in this cohort.

arthroplasty, MRI findings of ALTR, the presence of clinical data (within 6 months of the MRI), the presence of clinical data prior to the MRI, and MRIs read by the 3 most experienced and highest volume radiologists (Table 4). These 3 radiologists reviewed 86% of the MRIs in the cohort (874, 769, and 206 MRIs each). The fourth highest volume radiologist in this study interpreted more than 100 MRIs fewer. The specificity remained high for all subgroups (specificity: 97.6%–99.6%; negative predictive value: 97.5%–100%). Sensitivity was highest (67.9%) in the cohort with clinical data available prior to MRI. Positive predictive value was substantially lowered by the presence of an MoM implant (33%) and by evidence of ALTR on MRI (33%). In the absence of MoM implants or evidence of ALTR on MRI, the positive predictive value (PPV) ranged from 75% to 81% across the other sensitivity analyses (Table 4).

Multivariable logistic regression analysis (Table 5) revealed that when controlling for age, sex, the presence of MoM implant, findings of ALTR on MRI, erythrocyte sedimentation rate (ESR) >30 mm/h, and C-reactive protein (CRP) >10 mg/L, a positive MRI finding was a strong independent predictor of clinical infection (odds ratio: 262.75; 95% confidence interval [CI]: 94.07–733.88). This analysis was repeated, including only patients with clinical data available within 6 months of MRI (ie, excluding patients presumed to have aseptic THA without laboratory, aspiration, or operating room results; Table 6). In this subset, positive MRI findings were again independently predictive of clinical PJI when controlling for the above factors (odds ratio: 163.73; 95% CI, 46.59–575.42).

Discussion

The latest clinical practice guidelines published by the AAOS list the utility of MRI in diagnosing PJI as indeterminate due to the lack of current literature [16]. This retrospective study aimed to ascertain the sensitivity and specificity of MRI in diagnosing PJI after THA. In this cohort of THA patients undergoing MRI with MAVRIC metal artifact suppression sequencing, MRI was a highly specific test for clinical PJI. The presence of laboratory data within 6 months of MRI did not alter the sensitivity or specificity of MRI in this cohort. The presence of an MoM implant and evidence of ALTR on MRI did substantially lower the positive predictive value of MRI, while ALTR but not presence of MoM bearings decreased the sensitivity of MRI in diagnosing PJI. When controlling for ESR and CRP, MRI findings that were positive or inconclusive were each independently associated with the likelihood of clinical PJI.

In the current study, the rate of clinical PJI (2.8% of non-MoM and 0.7% of MoM arthroplasties) was within the ranges previously reported in the literature [2,20,22,24,25]. The specificity of MRI for diagnosing PJI in patients with THA was above 99% for all cohorts when the MRI findings were suspicious for infection. This is higher than previously published reports of most other clinical tests. In the PJI literature, the specificity of an ESR >30 mm/h has been reported between 68% and 87%, while the specificity of having a CRP >10 mg/L ranges from 40% to 92% [21–26]. However, the sensitivity of positive MRI findings in this cohort (25%–64.3%) is lower than published reports of serum screening tests alone (64%–95% sensitivity of ESR >30 mm/h and 74%–96% sensitivity of CRP >10 mg/L) [1,3,7,10,15,23]. It is important to note that the negative predictive value remained high in all analyses in this study, despite low sensitivity. This is a result of the low prevalence of infection in this cohort and should not be independently used to evaluate the utility of this imaging modality. Therefore, MRI is best indicated as a second-line test with high specificity in patients with clinical concern for infection and/or positive serum screening test, rather than as an initial screening test in itself.

This study has several limitations. MRIs were performed for a variety of clinical reasons, often with more than 1 reason documented per patient. Due to its retrospective nature, we did not have data on the timing of index THA

Table 5. Multivariable logistic regression predicting clinical PJI (entire cohort).

	Odds ratio	SE	95% CI	*P* value
Age	1.00	0.02	0.97–1.04	.726
Sex (reference = male)	0.40	0.17	0.17–0.94	**.036**
MoM (reference = non-MoM)	0.27	0.30	0.03–2.32	.233
ALTR on MRI (reference = no ALTR seen)	0.59	0.47	0.13–2.77	.507
ESR >30 mm/h (reference = no)	6.79	3.83	2.25–20.53	**.001**
CRP >10 mg/L (reference = no)	21.54	23.80	2.47–187.78	**.005**
MRI suspicious for infection (reference = no signs of infection)	262.75	137.70	94.07–733.88	**<.001**
MRI indeterminate (reference = no signs of infection)	26.90	0.01	0.00–0.06	**<.001**

PJI periprosthetic joint infection, *CI* confidence interval, *MoM* metal-on-metal, *ALTR* adverse local tissue reaction, *MRI* magnetic resonance imaging, *ESR* erythrocyte sedimentation rate, *CRP* C-reactive protein.
Significant P values <0.05 bolded.

Table 6. Multivariable logistic regression predicting clinical PJI (subgroup with clinical data available within 6 months of MRI).

	Odds ratio	SE	95% CI	*P* value
Age	1.01	0.02	0.97–1.05	.750
Sex (reference = male)	0.34	0.18	0.12–0.96	**.042**
MoM (reference = non-MoM)	0.78	0.85	0.09–6.60	.822
ALTR on MRI (reference = no ALTR seen)	0.46	0.37	0.10–2.200	.330
ESR >30 mm/h (reference = no)	5.72	3.35	1.82–18.00	**.003**
CRP >10 mg/L (reference = no)	17.22	18.78	2.03–146.00	**.009**
MRI suspicious for infection (reference = no signs of infection)	163.73	105.00	46.59–575.42	**<.001**
MRI indeterminate (reference = no signs of infection)	37.81	27.42	9.13–156.62	**<.001**

PJI periprosthetic joint infection, *MRI* magnetic resonance imaging, *CI* confidence interval, *MoM* metal-on-metal, *ALTR* adverse local tissue reaction, *ESR* erythrocyte sedimentation rate, *CRP* C-reactive protein.
Significant P values <0.05 bolded.

implantation and thus were unable to determine whether the identified cases of PJI were diagnosed in the acute or chronic phase. Therefore, we are unable to determine whether MRI is more useful for acute or chronic infections. In addition, MSIS criteria were applied to all patients as the gold standard to determine the presence of clinical infection. We did not have data on the presence or absence of underlying inflammatory arthropathy in all patients, which may alter the accuracy of the MSIS criteria. We did not have laboratory data on all patients, and as such, patients without laboratory data and without evidence of revision arthroplasty were presumed to have an aseptic THA for the primary analysis. However, a subgroup analysis including only patients with available laboratory data within 6 months of MRI was performed to impose stricter criteria for the definition of aseptic cases. It is possible that some of these patients were clinically infected or received additional care at another institution, leading to misclassification bias. Finally, this study does not address recent developments in the diagnosis of PJI using additional serum and synovial markers highlighted in the most recent update to the MSIS criteria such as leukocyte esterase and serum D-dimer [18]. Further research should evaluate MRI in the context of these other promising noninvasive tests.

An additional limitation includes the retrospective MRI report review. The MRI diagnosis of infection is not made on 1 specific appearance but rather by the interpretation of the constellation of imaging findings and the likelihood of these findings being specific to infection. The presence of pericapsular edema carries the highest predictive value. Although edema can be seen in ALTR, the presence of surrounding soft tissue edema points more toward infection when present. Soft tissue edema is also present with implant loosening; however, the location and symmetry of the edema pattern can also help distinguish the source of this edema as infectious. Additional findings of laminar appearance and lymphadenopathy are more prevalent in infection compared with polymeric or ALTRs. Overt bony destruction with low signal intensity is more consistent with osteolysis compared with a higher signal intensity seen with osteomyelitis. As such, imaging for infection often has a spectrum of findings that are interpreted by the radiologist based on their experience. The MRI "indeterminate" category was created because of the nonbinary nature of many of these reports. However, MRIs were interpreted by board-certified radiologists with variable experience, some of whom had limited experience in evaluating MRI of arthroplasty. A previously reported MRI study of infection following total knee

arthroplasty was limited to more experienced reviewers and demonstrated that sensitivity of the MRI finding of lamellated, hyperintense synovitis for infection (based on culture positive for bacterial organisms at aspiration and/or histologic findings positive for bacterial infection at revision surgery) was 0.86 to 0.92 (95% CI, 0.75–0.97) and the specificity was 0.85 to 0.87 (95% CI, 0.74–0.94). There was almost perfect interobserver agreement ($\kappa = 0.82$, 95% CI, 0.72–0.93, $P < .001$) and intraobserver agreement ($\kappa = 0.89$, 95% CI, 0.78–1.00, $P < .001$) [21]. A subgroup analysis of the 3 most experienced and highest volume MRI radiologists in this cohort (accounting for 86% of all MRIs in this study) was performed revealing no difference in the sensitivity or specificity of this diagnostic test. Rather than concluding that experience does not impact the diagnostic accuracy of MRI, it is more likely that the results of these experienced radiologists have influenced the results of the cohort at large. It is also conceivable that a prospectively performed study with more expert MRI interpreters may have different results.

In conclusion, this retrospective review of a cohort of THA patients undergoing MRI with MAVRIC metal artifact suppression techniques for all indications revealed that MRI is a highly specific test when evaluating for PJI but is not sensitive enough to use in ruling out this diagnosis, especially in the presence of MoM bearings or when ALTR is present on MRI. The high 99% specificity and reasonably high 77% positive predictive value indicate that an unexpected suggestion of infection on MRI report in a patient with a painful THA warrants formal evaluation for infection even if clinical suspicion for infection was low prior to the MRI. In patients with otherwise equivocal diagnostic findings, MRI can help confirm, but not refute, the diagnosis of PJI. Furthermore, positive MRI findings were predictive of PJI after controlling for positive inflammatory markers, suggesting that MRI may be useful in the evaluation of the difficult and common clinical scenario of patients with elevated inflammatory markers and negative synovial fluid cultures. Further prospective study with more experienced image reviewers may further support the use of MRI in PJI.

Authors' Note

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

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Human/Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent

Informed consent was waived from all patients included in this study.

Level of Evidence

Level III: retrospective diagnostic study

Required Author Forms

Disclosure forms provided by the authors are available with the online version of this article as supplemental material.

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