ORIGINAL ARTICLE

What is the Role of Magnetic Resonance Imaging in the Evaluation of Total Hip Arthroplasty?

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Abstract MRI has been shown to be an extremely effective instrument in the management of painful hip arthroplasty. Its superior soft tissue contrast and direct multiplanar acquisition compared to computerized tomography (CT) and radiographs allows for reproducible visualization of periacetabular osteolysis, demonstrating compression of neurovascular bundles by extracapsular synovial deposits. In addition, MRI can often elucidate etiology of neuropathy in the perioperative period and is further helpful in evaluating the soft tissue envelope, including the attachment of the hip abductors, short external rotators and iliopsoas tendon. A further advantage of MRI over CT is its lack of ionizing radiation. Most importantly, MRI can disclose intracapsular synovial deposits that precede osteoclastic resorption of bone.

Key words MRI · osteolysis · neuropathy · hip arthroplasty

Introduction

Magnetic resonance imaging (MRI) is beginning to be recognized as an important adjunctive imaging modality available to the orthopedic surgeon in the evaluation of patients with painful total hip arthroplasties and has been shown to be the most sensitive method to quantify the extent of periprosthetic osteolysis [1–5]. Painful complications

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associated with total hip arthroplasty include osteolysis with or without implant loosening, infection, neural injury, heterotopic ossification and dislocation [6, 7]. Conventional radiography, aspiration arthrography, nuclear scintigraphy and computerized tomography are the traditional modalities used to evaluate total hip arthroplasty complications. Whereas they remain very useful, they can be limited by poor soft tissue contrast, spatial resolution and/or specificity [8]. Furthermore, the use of ionizing radiation poses a cumulative radiation burden in the setting of longitudinal study. We will review the current experience using MRI to evaluate the total hip arthroplasty complications of osteolysis, infection, neural injury, heterotopic ossification, dislocation, and the painful hip of indeterminate etiology.

The previous limitations of MRI in total hip arthroplasty are a result of the signal artifact generated by the metallic components [9]. The metallic components cause a regional degradation of signal due to rapid dephasing of the excited nuclei. In addition, the metallic components have a different magnetic susceptibility and are thus more easily magnetized than the diamagnetic surrounding soft tissue, creating regional frequency shifts with alternating areas of low- and high-signal artifact that obscure the anatomic boundaries of surrounding bone and soft tissue. The degree of artifact is a function of several factors. Three important factors are the shape of the components, their orientation, and the relative ferromagnetism. Titanium causes less artifact than cobalt chrome because it is less ferromagnetic [3, 10].

In addition, aligning the long axis of the metallic components parallel to the axis of the frequency-encoding gradient, which may be an option at the time of image acquisition, also helps in diminishing this artifact [1, 3, 9, 10]. This accounts for the characteristic improved depiction of the surrounding soft tissue structures around the stem of the femoral component, which is parallel to the external magnetic field, as opposed to the acetabular component, wherein the screw or the cement mantle is oriented obliquely relative to the external field [1]. In addition, the spherical femoral head causes considerable frequency shifts, creating the greatest degree of artifact, and most

likely accounting for the limited visualization of soft tissue structures around the acetabular component in previous studies, including evaluation of hip and shoulder arthroplasty [3, 9].

The technique used to perform MRI on total hip arthroplasties has been well described [1]. The pulse sequences used are all commercially available and may be duplicated on any closed, high field unit. The artifact reduction is achieved by the alteration of pulse sequence parameters to reduce the frequency shift that disturbs the MRI appearance of regional anatomic structures. These include the use of wider receiver bandwidths and/or commercially available modifications of the radio frequency profile. Fast spin-echo techniques use 180° refocusing "pulses", which act to limit signal loss secondary to diffusion and thereby increase overall signal-to-noise ratio [3]. Additional frequency-selective fat suppression techniques are not recommended because of the local field disturbance that occurs in the presence of the metal and because fast inversion recovery sequences are a suitable substitute [10]. The use of these modified pulse sequence parameters allows reliable, consistent depiction of the surrounding soft tissue envelope and aids in the clinical problem of determining the cause of painful total hip arthroplasty.

At the Hospital for Special Surgery, images are obtained by using a 1.5-T clinical superconducting magnet (Sigma Horizon LX; General Electric Medical Systems, Milwaukee, WI, USA) with a shoulder phased array (Med Rad, Indianola, PA, USA) centered over the proximal aspect of the femur. A body coil is used and the images begin with a coronal fast inversion recovery sequence, a field of view of 35 cm, a repetition time of 4,500 to 5,000 milliseconds, an effective echo time of 17 milliseconds, an inversion time of 150 milliseconds, a receiver bandwidth of 31.2 to 62.5 kHz, and a slice thickness of 5 mm with no interslice gap. Additional images are obtained using fast spin-echo sequences (Fast Spin Echo XL, General Electric Medical Systems, Milwaukee, WI, USA) with a surface shoulder coil in the coronal, sagittal and axial planes, with a repetition time of 3,000 to 5,000 milliseconds, an echo time of 30 to 36 milliseconds, a wider receiver bandwidth of 62.5 to 100 kHz (over the entire frequency range), with a field of view ranging from 17 to 20 cm, slice thickness from 3 to 4 mm without gap, and matrix 512 by 320 to 384 excitations, resulting in a maximum in-plane resolution of 332 μm. Interecho spacing is further reduced by performing tailored radio frequency (tailored RF, General Electric Medical Systems) [1].

Osteolysis

Periprosthetic osteolysis remains the number one problem in total hip arthroplasty, often resulting in surgery to debride and bone graft lesions in patients with stable implants before they loosen or for revision of components once loosening has occurred. Conventional radiography consisting of serial radiographs has been the standard method of evaluating patients for the development of osteolysis [11–13]. However, it is generally recognized that conventional radiographs greatly underestimate the amount of bone destruction [14–16]. The addition of oblique views increases the likelihood of detecting the presence of osteolysis but continues to greatly underestimate the amount of bone destruction [17, 18]. In addition, conventional radiography is limited in that it represents a 2-dimensional analysis of a 3-dimensional problem [18]. Improved accuracy in assessing periprosthetic bone loss would not only facilitate preoperative planning for revision arthroplasty, but also provide an accurate means for serial evaluation of nonoperative treatment modalities as they become available.

Computerized tomography has recently been used to evaluate periprosthetic osteolysis [19]. Modifications in the software have resulted in a decrease in beam-hardening artifact, allowing for a more accurate 3-dimensional assessment of the extent of osteolysis. Robertson et al [20] demonstrated that plain radiographs underestimated bone loss by 20% or more in a study using computed tomography (CT) for evaluation of 19 patients with total hip arthroplasty. Although a dramatic improvement over conventional radiography, computerized tomography has the disadvantage of exposure of the patient to ionizing radiation, and techniques to reduce the beam hardening ("streak") artifact require an increase in the dose applied. Another disadvantage of CT is the limitation in evaluating soft tissues and surrounding neurovascular structures.

In the past, MRI has been limited by the distortion resulting from signal loss around metallic implants. More recently, modifications in commercially available pulse-sequence parameters have allowed for accurate assessment of the bone and soft tissues about total hip arthroplasties [1, 2].

A recent study by Potter et al [1] demonstrated that MRI of 27 patients with 28 total hip arthroplasties allowed visualization of the bone/cement or bone/implant interface in all 28 hips. The appearance of osteolytic lesions with MRI was characterized by the presence of intraosseous intermediate to slightly increased signal intensity similar to skeletal muscle. There was also a characteristic line of low signal intensity surrounding the area of focal marrow replacement (Fig. 1). Extraosseous extension shared the same signal characteristics. The signal characteristics of infection and/or tumor are different, being less well defined and characteristically hyperintense and closer to that of fluid [1].

The correlation between MRI and radiographs in determining the location and presence of osteolysis was generally good [1]. There were 3 hips with discrepancies in location of lysis on the acetabular side. Plain radiographs failed to detect anterior column lesions in 2 hips, and motion artifact limited the MRI evaluation in one hip. Evaluation of the femoral side was a little more difficult. For one, the surface coil used did not extend to the tip of the femoral component, which severely limited the evaluation of Gruen zones 3, 4, 5, 10, 11, and 12. This resulted in a discrepancy in 3 hips where plain radiographs demonstrated osteolysis at the stem tip, which was not detected by MRI. In 5 hips, a lytic lesion was noted in Gruen zone 7 on radiographs but was not visualized on MRI. In 2 of these
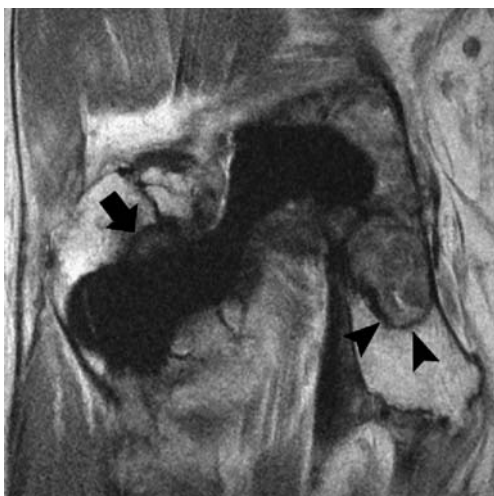
Fig. 1. Sagittal MR image of an 84-year-old patient status 13 years post right total hip arthroplasty with both periacetabular and femoral osteolysis. Well-defined foci of intermediate signal intensity replace the normally high signal intensity of the fatty marrow of the ischium (arrowheads) characteristic of osteolysis. Additional osteolysis is also seen in the proximal femur in Gruen zone 14 (arrow)

hips, osteolysis was recognized on MRI in Gruen zone 8, suggesting some variability in determining discrete zones on MRI compared with radiographs. In the other 3 hips, the marrow appeared normal in 2 and the MRI image was affected by motion in one. Although a direct comparison of osteolysis volume was not possible, the extent of osteolysis was grossly underestimated on the conventional radiographs. Subsequent revision of loosened components in 9 hips allowed for confirmation of the MRI lesions by both gross inspection and histopathology.

Validation data were performed in a cadaveric model in which simulated osteolytic defects of a known size were created in pelves implanted with standard cobalt chrome and titanium hip arthroplasties, followed by surrounding the model in an agarose medium to simulate the surrounding soft tissue [5, 21]. MRI analysis was compared to standardized radiographs (including bilateral oblique views) and CT with an optimized protocol to reduce the beam-hardening artifact. The sensitivity of MRI was 95% (83/87 possible lesions detected), whereas the sensitivity of CT was 75% (65/87 lesions detected) and the sensitivity of radiographs was 52% (45/87 lesions detected); MRI had consistently good lesion detection regardless of lesion location. Specificities for the 3 imaging modalities were similar, with radiographs at 96%, CT at 100%, and MRI at 98%. CT was more accurate in the measurement of larger lesion volumes [21]. Although the mean absolute error of lesion measured by MRI was greater than CT, the relative volumetric errors for MRI and CT were not significantly different [5].

Infection

Arthrography remains the diagnostic modality of choice to definitively diagnose an infection in total hip arthroplasty because it provides joint fluid for culture. Arthrography has been less useful in assessing implant loosening, limited by poor sensitivity particularly on the acetabular side [22, 23]. Results of nuclear scintigraphy, when normal, can aid in ruling out infection or loosening, but when positive lacks specificity and spatial resolution [24]. The use of radio-labeled white blood cells and colloid scans can improve the specificity of nuclear scintigraphy, the latter detecting postoperative alterations in marrow distribution [24]. However, they remain limited in providing anatomic images and evaluation of soft tissues, particularly as extraosseous sources of pain.

Although MRI cannot provide a definitive diagnosis of infection, it has been useful in helping to determine the extent of infection. In cases of superficial wound infection after total hip arthroplasty, MRI has been useful in
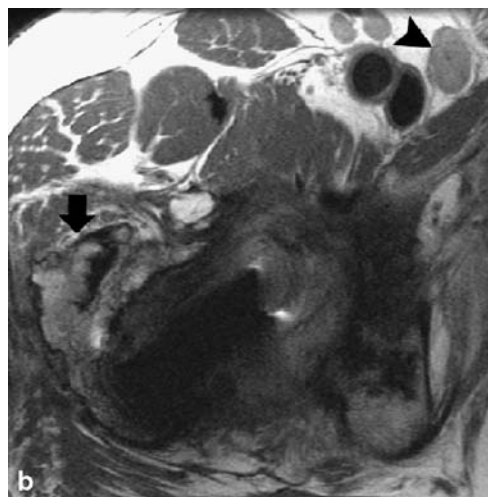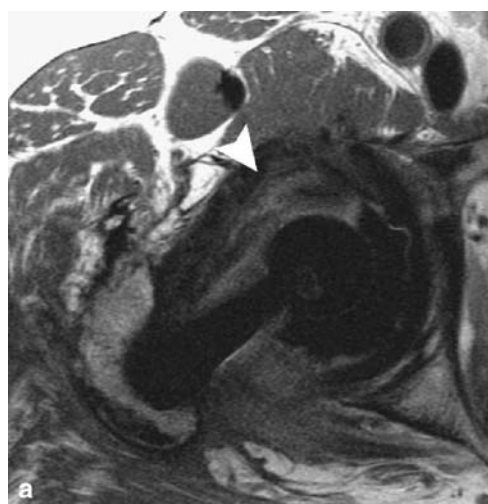

Fig. 2. **a** Axial MR image of a 62-year-old patient with an infected right hip arthroplasty. Laminated synovial reaction characteristic of infection is seen (white arrowhead). **b** An additional axial image demonstrates the presence of reactive enlarged regional lymph nodes (black arrowhead). Heterotopic bone formation confluent with the lateral margin of the proximal femur is also noted (arrow). MRI confirms that the infection has not spread into the adjacent soft tissue and is confined to the capsule

confirming the superficial nature of the infection and resolution of the infection with antibiotic treatment (H.G. Potter, personal communication) (Fig. 2). In selected cases, MRI has also been useful in determining the extent of infection in patients with known deep infection of total hip arthroplasties. This is particularly useful if a psoas abscess is suspected, as these can be missed at the time of surgical extirpation and debridement and result in persistence of infection.

Neuropathy

Magnetic resonance imaging is the optimal means by which to image nerves surrounding hip arthroplasty. The information provided is not only useful in the evaluation of patients with nerve palsies but particularly useful in evaluating the relationship of screws or extravasated cement to the surrounding neurovascular structures in patients in whom a revision surgery is planned. In the case of nerve palsy, MRI can determine the presence or absence of direct injury (Fig. 3), hematoma, and/or scar tissue in the case of chronic injury. The data provided by MRI of neural injury after total hip arthroplasty may help to further our understanding of the mechanisms of injury.

Heterotopic ossification

The development of symptomatic and motion-limiting heterotopic ossification is fortunately a rare occurrence. The diagnosis is readily made using plain radiography. Computerized tomography has been used to assess the extent, and nuclear scintigraphy, the maturity of heterotopic ossification [25]. However, the extent of muscle involvement and the proximity or involvement of neurovascular structures can

Fig. 4. Coronal MR image of a 70-year-old man with heterotopic ossification (white arrow) at the lateral margin of the sciatic nerve fascicles (black arrowheads)

only be inferred. MRI of mature heterotopic ossification demonstrates discrete areas of fatty marrow signal intensity in the surrounding soft tissues, frequently without a well-defined plane. The ability to demonstrate the anatomical structures involved, particularly the proximity to neurovascular structures, makes MRI a very useful tool in the preoperative evaluation of patients in whom excision of heterotopic ossification is planned (Fig. 4).

Dislocation

Magnetic resonance imaging has been used to evaluate the soft tissues of total hip arthroplasty performed via a posterior approach after dislocation. Disruption of the posterior capsule and, in most cases, the external rotators has been demonstrated. (H.G. Potter, personal communication) Although the routine use of MRI in evaluating
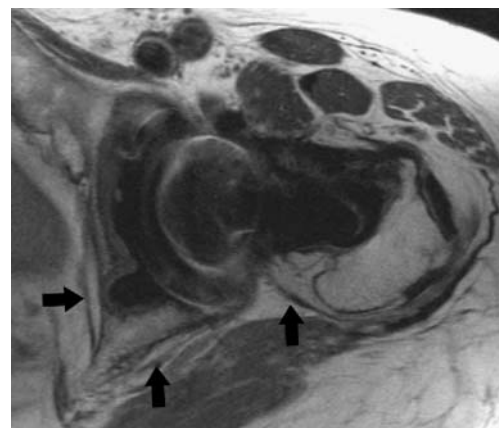

Fig. 3. Coronal MR image of a 40-year-old patient with immediate postoperative sciatic nerve dysfunction after left total hip arthroplasty. Susceptibility artifact in the lateral margin of the sciatic nerve (arrowhead) is due to metallic debris generated from retractor at the time of operative exposure. The remaining sciatic nerve is normal (arrows)

Fig. 5. Axial MR image of an 84-year-old patient with recurrent posterior left hip dislocation status 22 years post total hip arthroplasty. The short external rotators and pseudocapsule are severely attenuated (arrows). Also note the circumferential zone of intermediate signal intensity surrounding the acetabular component, characteristic of osteolysis and component loosening

recurrent instability is not indicated, MR imaging may be of particular benefit in ruling out abductor avulsion or dehiscence of the short external rotators in patients with recurrent dislocation and/or presence of a persistent limp (Fig. 5).

Pain of indeterminate origin

Patients presenting with painful total hip arthroplasty and normal radiographs, nuclear scans, and negative aspirations can present a diagnostic dilemma to the surgeon. Although some diagnoses are made on the basis of clinical examination, MRI is becoming an important and useful adjuvant study. Diagnoses that have been confirmed or made using MRI include iliopsoas tendonitis, trochanteric bursitis, sacral insufficiency fracture, abductor avulsion, and, in one case, fracture of a femoral stem [26]. In addition, debris-related synovitis has been noted in the absence of osteolysis.

Conclusion

Magnetic resonance imaging has become a very useful and important adjuvant imaging modality in the evaluation of patients with total hip arthroplasty at the Hospital for Special Surgery. Its role in the evaluation of osteolysis continues to be defined but will likely emerge as the most accurate method of quantifying the location and extent of osteolysis, particularly given its ability to detect intra-capsular burden of disease, which precedes osteoclastic resorption of bone. The spatial resolution and superior ability to image periarticular soft tissues including muscle, tendon, and neurovascular structures, combined with the ability to limit the prosthesis-induced artifact, has led to a significant increase in the utilization of MR imaging in the evaluation of postoperative complications related to total hip arthroplasty.

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