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Magnetic Resonance Imaging After Total Hip Arthroplasty: Evaluation of Periprosthetic Soft Tissue

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Background: The evaluation of periprosthetic osteolysis in patients who have had a total hip arthroplasty is challenging, and traditional imaging techniques, including magnetic resonance imaging and computerized tomography, are limited by metallic artifact. The purpose of the present study was to investigate the use of modified magnetic resonance imaging techniques involving commercially available software to visualize periprosthetic soft tissues, to define the bone-implant interface, and to detect the location and extent of osteolysis.

Methods: Twenty-eight hips in twenty-seven patients were examined to assess the extent of osteolysis (nineteen hips), enigmatic pain (five), heterotopic ossification (two), suspected tumor (one), or femoral nerve palsy (one). The results were correlated with conventional radiographic findings as well as with intraoperative findings (when available).

Results: Magnetic resonance imaging demonstrated the bone-implant interface and the surrounding soft-tissue envelope in all hips. Radiographs consistently underestimated the extent and location of acetabular osteolysis when compared with magnetic resonance imaging. Magnetic resonance imaging also disclosed radiographically occult extraosseous soft-tissue deposits that were similar in signal intensity to areas of osteolysis, demonstrated the relationship of these deposits to adjacent neurovascular structures, and allowed further visualization of hypertrophic synovial deposits that accompanied the bone resorption in twenty-five of the twenty-eight hips.

Conclusions: Magnetic resonance imaging is effective for the assessment of the periprosthetic soft tissues in patients who have had a total hip arthroplasty. While not indicated for every patient who has pain at the site of an arthroplasty, these techniques can be effective for the evaluation of the surrounding soft-tissue envelope as well as intracapsular synovial deposits and are more effective than radiographs for the detection and evaluation of osteolysis, thus aiding in clinical management.

Level of Evidence: Diagnostic study, <u>Level III-1</u> (study of nonconsecutive patients [no consistently applied reference "gold" standard]). See Instructions to Authors for a complete description of levels of evidence.

Periprosthetic osteolysis resulting from wear-generated debris frequently leads to implant loosening and has become the leading problem associated with total hip replacement¹. Despite severe bone loss, many patients remain asymptomatic². The recognition and assessment of osteolysis has relied on the use of routine serial radiographs that are made as part of the follow-up evaluation³⁻⁶. It is generally recognized, however, that radiographs either fail to detect lesions or grossly underestimate the extent of bone loss that is observed intraoperatively⁷⁻⁹. The use of additional oblique radiographs has been reported to increase the recognition of osteolysis¹⁰. Conventional radiographs, however, only provide a two-dimensional analysis of a three-dimensional process¹¹.

More recently, computerized tomography involving the use of software designed to reduce beam-hardening artifact has been shown to more accurately measure periprosthetic osteolysis in a three-dimensional manner¹². While more precise quantification of osteolysis is possible with computerized tomography, one disadvantage of that technique is the exposure of the patient to ionizing radiation. In addition, computerized tomography is primarily used to evaluate bone and is of limited value for the visualization of surrounding soft tissues and neurovascular structures.

Although magnetic resonance imaging has proved to be

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useful for the evaluation of the native hip, it has not been widely used following total hip arthroplasty, largely because of signal loss adjacent to the metallic components. Preliminary studies have addressed the use of magnetic resonance imaging to evaluate various complications following total hip arthroplasty¹³⁻¹⁵. White et al.¹⁴ evaluated twelve patients (fourteen total hip replacements) with use of magnetic resonance imaging before and after the administration of intravenous gadolinium contrast medium and noted periprosthetic abnormalities (including loosening, granulomatosis, and infection) in eleven hips. Tissue depiction around the femoral component was deemed to be of diagnostic quality in all eleven patients, but tissue depiction around the acetabular component was determined to be of diagnostic quality in only five. Similarly, previous authors have used modified commercially available pulse-sequence parameters to assess various complications of hip arthroplasty, including deep venous thrombosis and the integrity of the soft-tissue envelope in cases of instability and loosening^{13,16}.

The purpose of the present study was to investigate the use of modified magnetic resonance imaging techniques involving commercially available software to visualize periprosthetic soft tissues, to define the bone-implant interface, and to detect the location and extent of osteolysis. Our hypothesis was that magnetic resonance imaging would be superior to conventional radiographs for the detection of both acetabular and proximal femoral osteolysis.

Materials and Methods

Clinical Data

T wenty-eight hips in twenty-seven patients were examined; one patient with bilateral replacement had imaging of both hips. The inclusion criteria were the presence of a primary total hip replacement and evidence of osteolysis on magnetic resonance images. The study group included nine men and eighteen women who had a mean age of sixty-two years (range, thirty-five to eighty-four years) at the time of imaging. The mean interval between the index arthroplasty and the initial magnetic resonance imaging examination was 12.9 years (range, three to thirty-one years). The indications for hip arthroplasty included osteoarthritis (seventeen hips), osteonecrosis (six), fracture (three), inflammatory arthritis (one), and tumor resection (one).

The components that had been used for the twentyeight arthroplasties included an uncemented titanium acetabular component with a cemented cobalt-chromium femoral stem and a modular cobalt-chromium head in fifteen hips, an uncemented titanium acetabular component with an uncemented titanium femoral stem and a modular cobaltchromium head in five, a cemented polyethylene acetabular component and a cemented nonmodular cobalt-chromium stem in three, an uncemented titanium acetabular component with a cemented nonmodular stainless steel stem in two, an uncemented titanium acetabular component with an



Axial fast-spin-echo magnetic resonance image of the hip of a seventy-one-year-old woman, obtained fourteen years after total hip arthroplasty, showing well-defined foci of marrow replacement in the medial wall (thick arrow), and in the anterior column (thin arrow). For orientation purposes, the greater trochanter is shown on the right (asterisk). Note the sharp contrast between the intermediate signal intensity of the osteolysis (similar to that of skeletal muscle) and the adjacent higher signal intensity of the fatty marrow. The pseudocapsule is distended anteriorly by material with the same signal characteristics.

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uncemented cobalt-chromium stem and a modular cobaltchromium head in two, and a cemented titanium acetabular component with an uncemented titanium femoral stem and a modular cobalt-chromium head in one.

All patients who had been referred for magnetic resonance imaging were evaluated with conventional anteroposterior and frog-leg lateral radiographs and a comprehensive physical examination. In eighteen patients (nineteen hips), magnetic resonance imaging was performed specifically for the evaluation of osteolysis. In the remaining nine patients (nine hips), osteolysis had been noted on radiographs and magnetic resonance imaging was performed for other reasons. Specifically, five patients had been referred for the evaluation of severe, enigmatic pain that was not thought to be related to the osteolysis seen on radiographs; two, for the preoperative assessment of heterotopic ossification; one, for the evaluation of a suspected tumor; and one, for the evaltion of a femoral nerve palsy.

Plain Radiographic Assessment

Anteroposterior and frog-leg lateral radiographs were made for all patients, and any areas of periprosthetic radiolucency were noted. All radiographic measurements were made by means of a consensus review by two experienced attending orthopaedic surgeons (L.E.P. and E.A.S.) who were blinded to the magnetic resonance imaging findings. When osteolysis was seen on plain radiographs before magnetic resonance images were obtained, an assessment of the areas of femoral and acetabular osteolysis was performed.

Osteolysis on the acetabular side was measured on the anteroposterior radiograph of the pelvis with use of the ruler (magnification, 120%) on a standard transparent template. Measurements were made to the nearest millimeter. The dimensions of a radiolucent lesion were determined by measuring the greatest diameter of the lesion and then measuring a second diameter perpendicular to the first, similar to the technique described by Maloney et al.¹⁷. The total area of a lesion was calculated (in square millimeters) by multiplying the two diameters (length \times width)¹⁷. The location of the acetabular lesions was classified as zone I, II, or III, according to the system described by DeLee and Charnley¹⁸. If a lesion spanned two zones, it was classified as a combined zone (e.g., zone I/II or zone II/III).

On the femoral side, radiolucent lesions were measured and their area was calculated in a similar manner on both anteroposterior and frog-leg lateral radiographs. With use of a technique similar to that described by Huddleston¹⁹, the location of the femoral lesions was classified on both anteroposterior radiographs (zones 1 through 7) and lateral radiographs (zones 8 through 14) according to the system described by Gruen et al.²⁰. Once again, if a lesion spanned two zones, then a hybrid zone (e.g., zone 2/3 or zone 8/9) was created. The total osteolysis load for each patient was calculated (in square millimeters) by adding the areas of all lesions on the acetabular and femoral sides.





Axial fast-spin-echo magnetic resonance image of the hip of a sixty-nine-year-old woman, showing a soft-tissue mass of intermediate signal intensity (thin arrow). The signal intensity of this soft-tissue mass is the same as that of the osteolysis replacing the posterior margin of the ischium (thick arrow). For orientation purposes, the greater trochanter is shown on the right (asterisk). Note the low-signal-intensity rim outlining the focus of marrow replacement.

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Fig. 3-A

Fig. 3-B

Fig. 3-A Plain radiograph of the hip of a seventy-two-year-old man, obtained 10.5 years after total joint arthroplasty, showing evidence of osteolysis. The prominent erosion of the medial portion of the femoral neck (arrow) raised the clinical concern of a superimposed tumor.
Fig. 3-B Subsequent coronal magnetic resonance image of the same hip shown in Figure 3-A, demonstrating massive osteolysis (thick arrow) replacing the normal high signal intensity of the marrow. For orientation purposes, the greater trochanter is shown on the left (asterisk). Note the additional involvement at the acetabular dome and the extension into the iliacus bursa (thin arrow). Also note that the osteolysis is well defined and is of intermediate signal intensity with a low-signal-intensity rim, indicating an indolent pattern of bone destruction that is atypical of tumors. The extent of osteolysis seen on radiographs did not reflect the severe degree of osteolysis seen on magnetic resonance imaging, which aided in the planning for revision arthroplasty and removed any concern regarding the presence of a neoplasm.

Magnetic Resonance Imaging Technique and Evaluation

All procedures were performed on a 1.5-T clinical superconducting magnet (Signa Horizon LX; General Electric Medical Systems, Milwaukee, Wisconsin) with use of a shoulder phased array (Med Rad, Indianola, Pennsylvania) centered over the proximal aspect of the femoral component. Initial images were obtained with a body coil utilizing an initial coronal fast inversion recovery sequence with a field of view of 35 cm, a repetition time of 4500 to 5000 msec, an effective-echo time of 17 msec, an inversion time of 150 msec, a receiver bandwidth of 31.2 to 62.5 kHz (over the entire frequency range), and a slice thickness of 5 mm with no interslice gap. Additional coronal, sagittal, and axial fast-spin-echo sequences (Fast Spin Echo XL; General Electric Medical Systems) were obtained with use of the surface shoulder coil with a repetition time of 3000 to 5000 msec, an echo time of 30 to 36 msec, and a wider receiver bandwidth of 62.5 to 83.5 kHz. The field of view ranged from 17 to 20 cm, the slice thickness ranged from 3 to 4 mm with no gap, and the matrix was 512 by 320 to 384 at six excitations, yielding a maximum in-plane resolution of 332 μ m. Tailored radiofrequency (Tailored RF; General Electric Medical Systems) was performed to further reduce interecho spacing. The total imaging time ranged from twenty-five to forty minutes, depending on the size of the patient and the need for repetition of pulse sequences due to involuntary motion.

The bone-cement or metal-bone interface was evaluated, without knowledge of the plain radiographic findings, for the presence of intermediate signal intensity (reflecting osteolysis) replacing the normally hyperintense fatty marrow; all findings were confirmed on at least two planes of imaging. The location of lesions in the femur was classified according to the zones of

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Fig. 4

Coronal fast-spin-echo magnetic resonance image of the hip of a sixty-seven-year-old woman who presented with pain twenty-four years after primary arthroplasty, demonstrating a large fluid collection (arrow) lined by metallic debris in the greater trochanteric bursa lateral to the site of the arthroplasty. For orientation purposes, the lesser trochanter is shown on the lower right (asterisk).

Gruen et al.²⁰. Because of the extension of osteolysis between regions without a discernible interface, the location of lesions in the acetabulum was classified according to anatomic regions rather than according to the zones of DeLee and Charnley¹⁸. To determine osteolysis volume, image files were transferred onto a standard personal computer and a manual outline of the affected areas was made. Subsequent conversion of pixels to cubic millimeters was performed with use of a software conversion program developed on Mat Lab 6.2 software according to the formula Volume = Σ (Ar \times ST), where Ar is the area of osteolysis in the slice and ST is the slice thickness (Applied Science Laboratory, General Electric Medical Systems). No additional correction for field disturbance was made during post-processing. The osteolysis volume (in cubic millimeters) that was determined on magnetic resonance images was compared with the total osteolysis load (in square millimeters) that was measured on radiographs. The results of the magnetic resonance imaging evaluation were then correlated with the findings on preoperative conventional radiographs as well as with the subjective findings noted at the time of subsequent surgery (when performed).

Results

Delineation of Osteolysis

T n all twenty-eight hips, magnetic resonance imaging consis-L tently allowed visualization of the bone-implant interface and the surrounding soft tissues. The areas of periprosthetic osteolysis in all hips were characterized by intermediate to slightly increased intraosseous signal intensity (similar to that of skeletal muscle) with an additional line of low signal intensity surrounding the focal marrow replacement (Fig. 1). In three hips, extraosseous deposits of material sharing the same signal characteristics were noted (Fig. 2). The signal characteristics of osteolysis were distinctly different from those of infection or tumor (Fig. 3-B) in that the signal intensity was intermediate (closer to that of skeletal muscle) and the lesion was well defined, whereas the signal intensity at the site of infection typically is hyperintense (closer to that of fluid) and poorly defined because of the more aggressive pattern of bone destruction. Conversely, extravasated cement is markedly hypointense, with a signal intensity that is closer to that of cortical bone (Table I).

The mean area of acetabular osteolysis on conventional radiographs was 740.58 mm² (range, 126 to 1380 mm²), and the mean volume on magnetic resonance images was 43,976.30 mm³ (range, 738 to 436,688 mm³). The mean area of femoral osteolysis on conventional radiographs was 426.68 mm² (range, 60 to 2035 mm²), and the mean volume on magnetic resonance images was 7569.95 mm³ (range, 180 to 33,733 mm³).

In general, there was good association between the presence and location of osteolytic lesions as observed on conventional radiographs and magnetic resonance images. Discrepancies in the location of acetabular osteolysis were noted in three hips. In two of these hips, plain radiographs failed to detect anterior column lesions, one of which had an extraosseous extension. In the third hip, magnetic resonance imaging was degraded because of motion, which limited the diagnostic ability.

The proximal-medial margin of the femoral boneprosthesis interface was slightly more difficult to discern on magnetic resonance images, likely because of the relative paucity of high-signal-intensity fatty marrow. In addition, the fact that the shoulder surface coil that was utilized did not extend to the tip of the femoral stem precluded the ability to visualize Gruen zones 3, 4, 5, 10, 11, and 12 on magnetic resonance images. This latter limitation was noted in three hips, in which plain radiographs demonstrated lesions at the tip of the stem that were not seen on magnetic resonance images. In five hips, osteolytic lesions that were noted in Gruen zone 7 on radiographs were not seen on prospective interpretation of magnetic resonance images. In two of these hips, osteolysis was noted in an adjacent zone (zone 8), suggesting some variability in the determination of discrete zones between the tomographic magnetic resonance images and the two-dimensional radiographs. In the remaining three hips, involvement of Gruen zone 7 was not seen on magnetic resonance images, even at the time of a retrospective review. In one hip there was severe degradation of image quality due to motion, and in the other two hips the marrow appeared normal.

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TABLE I Spectrum of Magnetic Resonance Imaging Findings at the Site of Total Hip Arthroplasty		
Pathologic Condition	Soft Tissue	Surrounding Bone
Osteolysis	Discrete intermediate signal intensity deposits, close to skeletal muscle	Typically hypointense rim, well demarcated from surrounding fatty marrow
Infection	High signal intensity, close to fluid	Hyperintense surrounding marrow edema replacing normal fat
Extruded cement	Low signal intensity, close to cortical bone	No reaction: normal fatty signal of marrow
Heterotopic ossification	Discrete high signal intensity, fatty marrow deposits when mature	No reaction: normal fatty signal of marrow when mature

Twenty-five of the twenty-eight hips had distention of the normally thin, hypointense pseudocapsule by particulate synovitis. The intracapsular debris typically had signal characteristics that were similar to those of the material replacing the bone; the only exception was noted in one hip, in which metallic debris was seen. The implant in that hip had a titanium stem and a titanium acetabular component that articulated with a cobalt-chromium head (Fig. 4).

Intraoperative Correlation and Implant Loosening

Fifteen of the twenty-eight hips underwent subsequent revision arthroplasty. In this subset, all cases of osteolysis that had been noted on magnetic resonance images were confirmed intraoperatively by gross inspection and histopathological analysis. Histopathological analysis demonstrated granulomatous reactions, metal and polyethylene debris, and an absence of inflammatory infiltrates or positive cultures that were indicative of infection. Nine of the fifteen revisions were performed for the treatment of loosening, including loosening of the acetabular component (seven hips), the femoral component (one), or both components (one), and the remaining six revisions were performed for the treatment of osteolysis without overt evidence of loosening. The subjective assessment of the location and extent of osteolysis correlated with the findings on magnetic resonance images in all nine hips that were revised because of loosening. In the six hips without loosening, the limitations of operative exposure precluded a direct correlation between the actual size and extent of the pelvic osteolytic lesions as seen on magnetic resonance images and those observed intraoperatively.

Additional Magnetic Resonance Imaging Findings

Two patients had been referred for the preoperative evaluation of the location and extent of heterotopic ossification relative





Axial fast-spin-echo magnetic resonance image of the hip of a forty-five-year-old man who presented, one year after total hip arthroplasty, with posterior dislocation despite acceptable component alignment on plain radiographs. For orientation purposes, the greater trochanter is shown on the left (asterisk). The image demonstrates marked distention of the pseudocapsule, which is filled with diminished-signal-intensity debris (arrows), that was attributed to particle reaction, without concomitant osteolysis. These findings were confirmed at the time of revision arthroplasty.

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to the neurovascular bundles and joint. Foci of mature heterotopic ossification are denoted as foci of discrete fatty marrow signal intensity in the adjacent soft tissues, often with no discernible tissue plane adjacent to the implant²¹. Two patients demonstrated an insufficiency fracture of the hemisacrum and pubic ramus (one patient) or the sacral ala (one patient). Two hips demonstrated moderate greater trochanteric bursitis as evidenced by the presence of a discrete, characteristic fluid collection at that site²². One examination demonstrated osteolysis and diminished signal intensity throughout the synovial lining and adjacent bursae, indicating an extensive debris load (Fig. 4).

Discussion

r onventional radiography has been the standard method of imaging for the detection of periprosthetic osteolysis³⁻⁶. However, the quantification of related bone loss is underestimated by two-dimensional plain radiography, particularly when standardized views are used7-11. Additionally, Engh et al.23 reported poor interobserver reproducibility in a study on the assessment of osteolysis with use of plain radiographs. Saleh et al.²⁴ proposed a new classification system, based on an anteroposterior radiograph of the pelvis and frog-leg lateral radiographs of the hip, that demonstrated improved interobserver reliability for the assessment of the degree of bone loss and improved correlation with the intraoperative findings. However, intraoperative observation of bone loss, which frequently exceeds that observed on plain radiographs, typically confirms the limitation of radiographs in the assessment of osteolysis²⁵. While a more accurate assessment of osteolysis may facilitate better preoperative planning for revision arthroplasty, improved quantification of osteolysis also is needed for the serial evaluation of nonoperative treatment modalities, such as the use of oral bisphosphonates, which are currently being evaluated in clinical trials.

Robertson et al.²⁶, in a study of nineteen patients with a failed total hip arthroplasty, compared three-dimensional physical models based on computerized tomographic data with radiographic findings and noted that plain radiographs underestimated bone loss by at least 20% and resulted in selection of the correct type of prosthesis in only half of the patients who underwent revision. Such studies provide further support for the need to quantify osteolysis volume. While computerized tomography is more effective than conventional radiographs, it is still somewhat limited by the beam-hardening artifact at the metal-bone interface, particularly in cases of bilateral arthroplasty, and by exposure of the patient to the radiation required for serial studies. Moreover, computerized tomographic techniques that reduce the artifact typically require an increase in the energy dose and thus increase the exposure of the patient.

Magnetic resonance imaging does not expose the patient to ionizing radiation. Osteolysis is more conspicuous on magnetic resonance imaging, likely because of the superior soft-tissue contrast associated with this method, with segments of osteolysis having an intermediate signal intensity that contrasts with the high signal intensity of the medullary fat. This superior contrast allows for improved depiction of extraosseous soft-tissue deposits that may encroach on neurovascular structures and also allows for the detection of synovitis within the pseudocapsule, which may be present before there is evidence of osteoclastic bone resorption on radiographs or magnetic resonance images (Fig. 5). Finally, magnetic resonance imaging can disclose unsuspected findings that may contribute to morbidity, such as occult pelvic fractures, which were noted in three patients in this study.

The assessment of volume on the magnetic resonance images was based on a program that is available on many commercial workstations, and it does not provide any additional geometric calibration for the adjacent field distortion beyond that provided by the parameter modification. A direct correlation between the radiographic and magnetic resonance imaging findings regarding osteolysis was not possible in the present study because of the comparison of a two-dimensional, nondigitized radiographic technique with the volumetric (threedimensional) digital magnetic resonance imaging technique. The present study also was limited by the lack of a gross quantitative standard with which to judge the accuracy of magnetic resonance imaging in assessing the degree of osteolysis, as the limitations of standardized operative exposure may not allow for an accurate measurement of osteolysis volume. This is particularly true in cases of acetabular osteolysis in which the metallic shell is well fixed and bone loss can only be assessed through the holes of the cup. Additional in vitro studies are warranted to correlate the extent of bone loss observed at the time of surgery with that predicted preoperatively on magnetic resonance images. Nonetheless, we believe that magnetic resonance imaging is superior to conventional radiographs for detecting areas of bone resorption and for evaluating the periprosthetic soft tissues.

Compared with the surrounding soft tissue, metallic components at the site of an arthroplasty have a different magnetic susceptibility (i.e., ability to become magnetized) that distorts the regional magnetic field, creating large areas of signal void that obscure and distort the anatomic boundaries of the surrounding soft tissue, including neurovascular bundles and the pseudocapsule²⁷. The intensity of the artifact is a function of several factors, including the orientation of the components relative to the external magnetic field, the relative ferromagnetism, and the shape of the implant. Titanium is less ferromagnetic than cobalt-chromium alloy, and therefore it causes less artifact^{15,28}. In the present study, the majority of the implants were composed of cobalt-chromium heads and stems. This fact did not preclude diagnostic imaging with our protocol, thus demonstrating that imaging of nontitanium components is possible.

In the current study, the use of modified magnetic resonance imaging parameters, which may be duplicated on any closed, high-field unit, provided a useful adjunct to conventional radiographs for the evaluation of patients who had periprosthetic osteolysis. It is not our intention to suggest that such imaging is indicated or cost-effective for the evaluation of all patients who have had an arthroplasty, but rather that it may be appropriate for the evaluation of patients in

whom the precise location and extent of osteolysis cannot be discerned. Magnetic resonance imaging is justified if it can provide clinically important information that will affect patient management or if it is used as a research tool. Magnetic resonance imaging of total hip arthroplasty is an evolving technique, and further pulse-sequence refinement and clinical correlation will further elucidate the optimal applications of this technique.

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