Magnetic resonance imaging of painful shoulder arthroplasty

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Specialized magnetic resonance imaging (MRI) was performed in 42 painful shoulder arthroplasties, 22 of which underwent subsequent revision surgery, allowing surgical confirmation of the pathology identified on MRI. One hemiarthroplasty was excluded because of motion artifact, leaving 21 studies (19 patients) to be correlated retrospectively to the surgical findings. At the time of revision surgery, there were full-thickness rotator cuff tears in 11 of 21 shoulders; MRI correctly predicted these in 10 of 11 shoulders. Full-thickness subscapularis tears were the most common finding (8/11 shoulders). Of the 21 shoulders, 10 did not have a rotator cuff tear, and MRI correctly predicted the absence of a tear in 8 of 10. MRI also correctly predicted glenoid cartilage wear in 8 of 9 shoulders. With limited pulse-sequence parameter modification, the data from this preliminary study suggest that MRI may be a useful technique with which to determine the integrity of the rotator cuff and residual cartilage and, thus, is potentially a tool in the management of painful shoulder arthroplasty. (J Shoulder Elbow Surg 2002; 11:315-21.)

INTRODUCTION

Evaluation of painful shoulder arthroplasty is one of the most challenging problems facing the shoulder surgeon, as rotator cuff tears, glenoid cartilage wear, and stiffness frequently coexist.[4] A patient may present with painful shoulder arthroplasty after having surgery performed at another institution, in which case the surgeon must determine the underlying cause of pain in a patient with limited motion and frequently distorted bony anatomy, without knowledge of the quality of the rotator cuff or glenoid articular cartilage. Currently, there is no information available concerning adjunctive imaging modalities to help evaluate the patient with painful shoulder arthroplasty.

Component position, periprosthetic lucency, and tuberosity position can be determined with conventional radiographs; however, the condition of the surrounding soft-tissue structures and articular cartilage cannot be determined with these studies. Arthrography can be used to assess for full-thickness rotator cuff tears; however, differentiating grades of partial-thickness rotator cuff tears and assessing muscle quality are limited. Arthrography does not allow for differentiation between tears of the subscapularis and the supraspinatus. Computed tomography potentially may be used to determine component position and to evaluate bone quality after arthroplasty. However, soft-tissue evaluation is limited because of the inherently poor tissue contrast and beam-hardening artifact from the metallic components. We are not aware of any reported series that have specifically examined the results of arthrography, computed tomography, or ultrasonography for imaging shoulder arthroplasty.

Magnetic resonance imaging (MRI) has not been widely used in patients who have undergone shoulder arthroplasty, largely because of the profound loss of signal adjacent to the metallic components, and in a general sense, it is ineffective and uninterpretable. The purpose of this study was to determine the utility of a modified magnetic resonance technique in identifying pathology after shoulder arthroplasty.

MATERIALS AND METHODS

This retrospective study included 42 painful shoulder arthroplasties, referred by 4 surgeons, that underwent specialized MRI from October 1996 to March 2000. There were 27 hemiarthroplasties and 15 total shoulder arthroplasties. Twenty-two shoulders underwent revision surgery after MRI, allowing surgical confirmation of pathology identified on preoperative MRI. One hemiarthroplasty, which was performed for the sequela of trauma, was excluded from the analysis of results because of inadequate imaging quality from severe patient motion artifact. Therefore, 21 shoulders (19 patients) were included in the analysis of results.

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Among the 21 shoulders, there were 12 hemiarthroplasties and 9 total shoulder arthroplasties. One patient underwent MRI and revision surgery on bilateral total shoulder arthroplasties. One patient underwent MRI and revision of a total shoulder arthroplasty and subsequently underwent repeat MRI and revision surgery. The analyses of MRI and revision surgeries in this patient were examined separately.

The mean age of patients who underwent MRI was 59 years (range, 35-81 years). There were 10 women and 9 men. The indications for the hemiarthroplasty were sequelae of trauma (11 shoulders) and arthritis associated with instability (1 shoulder). Of the 12 shoulders, 4 had undergone one surgical procedure before hemiarthroplasty: open reduction internal fixation of a fracture (2), anterior stabilization (1), and arthroscopic glenohumeral joint debridement with acromioplasty (1).

The indications for total shoulder arthroplasty were osteoarthrosis (6 shoulders), arthritis associated with instability (2 shoulders), and sequelae of trauma (1 shoulder). Of the 9 shoulders, 5 had undergone a procedure before total shoulder arthroplasty: 1 procedure (3 shoulders), 2 procedures (1 shoulder), and 3 procedures (1 shoulder). Previous surgical procedures included arthroscopic acromioplasty (3 shoulders), anterior stabilization (2 shoulders), rotator cuff repair (2 shoulders), coracoid resection (1 shoulder), stabilization procedure with a subscapularis repair (1 shoulder), and instrumentation removal (1 shoulder).

Among the total shoulder arthroplasties, 8 of 9 shoulders underwent the primary arthroplasty at the authors' institutions. Among the hemiarthroplasties, all 12 had undergone the primary arthroplasty at an outside institution.

MRI technique and evaluation

A previously undescribed technique was used to image the shoulder arthroplasties. Image parameters were manipulated to minimize interecho spacing and reduce the susceptibility artifact from the shoulder arthroplasties. All images were obtained on a 1.5-T superconducting magnet (Signa Horizon LX; General Electric Medical Systems, Milwaukee, Wis). All images were obtained with a send-receive phased-array shoulder coil (shoulder phased array; Medrad, Milwaukee, Wis). The shoulders were positioned in neutral rotation with the biceps tendon at the 12:00 axis, whenever possible. Patients were encouraged to breath using their abdominal muscles as much as possible, in order to minimize excessive chest wall excursion.

Images were obtained through use of a fast spin-echo sequence with repetition time 4000 to 5300 ms/echo time 17 to 20 ms (effective). Field of view ranged between 18 and 20 cm. Slice thickness was between 2 and 3 mm with no interslice gap. Further interecho space reduction was afforded by a wider receiver bandwidth (31.2-83.5 kHz), as well as tailored radiofrequency (General Electric Medical Systems). Imaging matrix was 512×288 to 320 at 4 to 5 excitations. Total imaging time ranged between 25 and 35 minutes, depending on patient size and the need for repetition for motion-degraded sequences. Images were obtained in the oblique coronal and axial planes. Initial axial images were obtained from a true coronal localizer, and oblique coronal images were obtained parallel to the visualized long-axis of the rotator cuff tendons off the axial images rather than the spine of the scapula.

Images were analyzed for the integrity of the rotator cuff. Given the amount of degeneration in the majority of the tendons, assessment was limited to full-thickness tears, denoted by a measurable degree of retraction, rather than smaller partial-thickness tears. Muscle quality was also assessed for the presence of fatty infiltration and diminution of muscle bulk. The presence or absence of heterotopic ossification, as well as the integrity of the greater and lesser tuberosities, was assessed. The biceps tendon was also assessed throughout its visualized portion.

The presence of periprosthetic fracture, fluid collections, synovitis, or adjacent lymphadenopathy was noted. Periprosthetic intermediate signal intensity replacing normal marrow, indicative of loosening, when present, was noted. In addition, assessment of the glenoid cartilage was made on both the axial and oblique coronal images in the cases of hemiarthroplasty. Any associated thickening of the capsule or capsular distention was noted.

The results of the MRI evaluation were then correlated to the findings noted preoperatively on conventional radiographs, as well as the surgical findings.

RESULTS

At the time of revision surgery, there were full-thickness rotator cuff tears in 11 of 21 shoulders (Table). MRI correctly predicted full-thickness rotator cuff tears in 10 of 11 shoulders (Figure 1). Full-thickness subscapularis tears were most frequently present (8/11 shoulders). Of the 21 shoulders, 10 did not have a full-thickness rotator cuff tear at the time of revision surgery, and MRI correctly predicted the absence of a rotator cuff tear in 8 of these 10 shoulders (Figure 2). Although the sample size was relatively small, the sensitivity for detecting a full-thickness rotator cuff tear (with operative inspection used as the standard) was 91% (10/11), the specificity was 80% (8/10), the positive predictive value was 83% (10/12), and the negative predictive value was 89% (8/9).

Among the hemiarthroplasties, there was no mention of the glenoid articular cartilage in the operative reports of 2 shoulders and the glenoid could not be adequately visualized in 1 shoulder. Among the remaining 9 hemiarthroplasties, MRI correctly predicted glenoid cartilage wear in 8 (Figure 3).

MRI assisted in the evaluation of infection in 1 patient. A loculated fluid collection, as noted on MRI, underwent biopsy and was cultured (Figure 4). Infection was confirmed at the time of surgery with component removal and placement of an antibiotic spacer. In addition, MRI correctly predicted the presence of extruded cement adherent to the axillary nerve in another patient (Figure 5).

The lesser tuberosity, biceps tendon origin, and glenoid component were more difficult to visualize clearly on MRI, likely because of their close proximity to the spherical portion of the humeral component (Figure 6). The lesser tuberosity could be clearly iden-

Table Condition of the rotator cuff

Arthro-plasty	Diagnosis	Plain radiographs	Full-thickness rotator cuff tear on MRI	Full-thickness rotator cuff tear at revision surgery	MRI correlate	Revision surgery
TSA	Osteoarthritis	Superior subluxation	SSC tear	SSC tear	Yes	Open SSC repair, change humeral head
TSA	Osteoarthritis	No plain radiographs	SSC tear	SSC tear	Yes	Open SSC repair
TSA	Osteoarthritis	Superior subluxation	No	No	Yes	Arthroscopy, open bone grafting, new glenoid and humeral head
TSA	Osteoarthritis	Superior subluxation	SSC, SST, IST, tear	SSC, SST, IST tear	Yes	Removal loose glenoid and fixed humeral component, antibiotic spacer
TSA	Osteoarthritis	No subluxation	No	No	Yes	Open debridement
TSA	Osteoarthritis	Anterior-superior subluxation	SSC tear	SSC tear	Yes	Open SSC repair, change humeral head
TSA	Instability-associated arthritis	No subluxation	No	No	Yes	Arthroscopy, open removal of glenoid component
TSA	Instability-associated arthritis	Superior subluxation	Upper SSC tear	No	No	Arthroscopy, open removal of glenoid component
TSA	Sequelae of trauma	Posterior subluxation	SSC tear	SSC tear	Yes	Open SSC repair with achilles augmentation, biceps tenodesis
HHR	Sequelae of trauma	Superior subluxation, glenoid arthrosis	SSC, SST, IST, TM tear	SSC, SST, IST, TM tear	Yes	TSA with humeral allograft, rotator cuff repair, biceps tenodesis
HHR	Sequelae of trauma	Posterior-superior subluxation, glenoid arthrosis	No	No	Yes	Open posterior removal osteophytes, anteriorly new HHR
HHR	Sequelae of trauma	Superior subluxation	No	No	Yes	Open repair tuberosity non-union and glenoid component placement
HHR	Sequelae of trauma	Anterior-superior subluxation	No	No	Yes	Arthroscopy, capsular release
HHR	Sequelae of trauma	Superior subluxation	No	No	Yes	Open capsular release
HHR	Sequelae of trauma	Superior subluxation, glenoid arthrosis	No	SST tear	No	Arthroscopy, acromioplasty, debride rotator cuff
HHR	Sequelae of trauma	Superior subluxation	SST tear	SST tear	Yes	Open acromioplasty, removal heterotopic ossification, debride SST
HHR	Sequelae of trauma	Anterior-superior subluxation, glenoid arthrosis	No	No	Yes	Open capsular release
HHR	Sequelae of trauma	Superior subluxation, glenoid arthorsis	SSC tear	No	No	TSA
HHR	Sequelae of trauma	Anterior subluxation, glenoid arthrosis	SSC, SST tear	SSC, SST, IST tear	Yes	TSA with rotator cuff repair and acromioplasty
HHR	Sequelae of trauma	Anterior subluxation, glenoid arthrosis	Upper SSC, SST tear	SST, IST, TM tear	Yes	TSA with rotator cuff repair
HHR	Instability-associated arthritis	Anterior-superior subluxation, glenoid arthrosis	SSC, IST tear	SSC, IST tear	Yes	TSA with rotator cuff repair, bone graft glenoid, and new humeral head

TSA, Total shoulder arthroplasty; *HHR*, hemiarthroplasty; *SSC*, subscapularis; *SST*, supraspinatus; *IST*, infraspinatus; *TM*, teres minor.

Figure 1 Oblique coronal fast spin-echo MRI in a patient after hemiarthroplasty. The metallic humeral component is at the lateral (right) aspect of the image, and the acromion is noted on the top. A full-thickness tear of the supraspinatus tendon is present *(straight arrow)*. There is moderate atrophy and fatty infiltration of the supraspinatus muscle, which may be contrasted to the trapezius, seen above the supraspinatus. There is additional full-thickness cartilage loss over the glenoid, noted by lack of intermediate-signal *(gray)* cartilage over the low-signal *(black)* subchondral plate *(curved arrow)*.

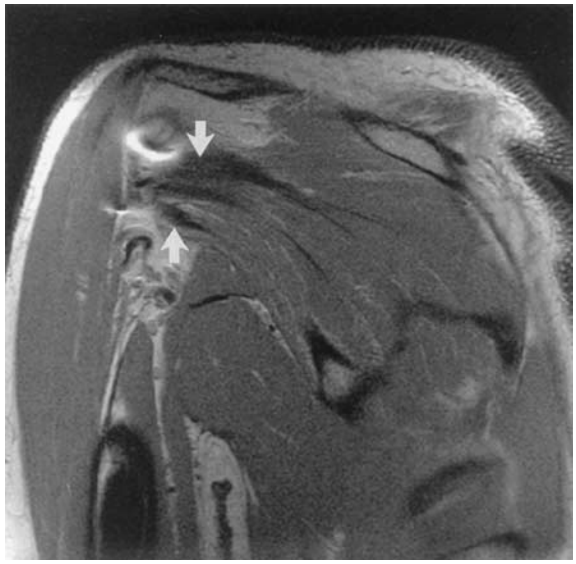

Figure 2 Oblique coronal fast spin-echo sequence in a patient after total shoulder replacement demonstrates an intact posterior cuff, inclusive of the infraspinatus and teres minor tendons *(arrows)*. Note the uniform signal, without fatty infiltration, of the posterior cuff and adjacent deltoid.

tified in 9 of 21 shoulders. The proximal aspect of the long head of the biceps tendon could be visualized in 13 of 21 shoulders. The greater tuberosity was visualized in 17 of 21 shoulders. The glenoid component could be visualized clearly in 4 of 9 magnetic resonance images obtained in total shoulder arthroplasties. Two glenoid components that appeared to have polyethylene wear on MRI were loose with polyethylene wear at the time of surgery. One shoulder with signal alteration around the glenoid component was loose at the time of surgery. One glenoid component without surrounding signal alteration was stable at the time of surgery. Among all of the total shoulder arthroplasties, 4 glenoid components were loose at the time of revision surgery. The accuracy of MRI in determining the integrity of the long head of the biceps and the position of the tuberosities could not be determined because of a lack of intraoperative documentation. Heterotopic ossification, capsular contraction, synovitis, and anteversion of the humeral component were visualized on MRI (Figure 7). However, at the time of revision surgery, attention was not directed to all of these findings in the operative report.

DISCUSSION

In this study, all 12 hemiarthroplasties were performed at an outside institution. Moreover, 11 of the 12 shoulders underwent hemiarthroplasty for the sequelae of trauma. Therefore, as noted previously, the consulting shoulder surgeon was confronted with painful shoulder arthroplasty with distorted bony anatomy without firsthand knowledge of the quality of the rotator cuff or glenoid articular cartilage. In this study, MRI of shoulder arthroplasties was an accurate and useful technique for determining the integrity of the rotator cuff and residual glenoid articular cartilage. With regard to the rotator cuff, there were 2 false-positive results and 1 false-negative result. The rotator cuff and glenoid articular cartilage were consistently visible on MRI, allowing prediction of pathology.

Determining the quality and condition of glenoid articular cartilage in the presence of a painful hemiarthroplasty is important. The development of painful glenoid arthritis has been shown to be the most frequent complication of hemiarthroplasty, requiring revision surgery in a review of 34 studies involving 581 shoulders that underwent hemiarthroplasty.[7] Plain radiographs may be sufficient to evaluate glenoid cartilage wear, based on the presence of joint space narrowing, subchondral sclerosis, osteophyte formation, and subluxation. MRI is not intended to replace the use of plain radiographs. Its utility lies in helping to assess arthroplasties in patients with pain and/or weakness that is unexplained by standardized radio-

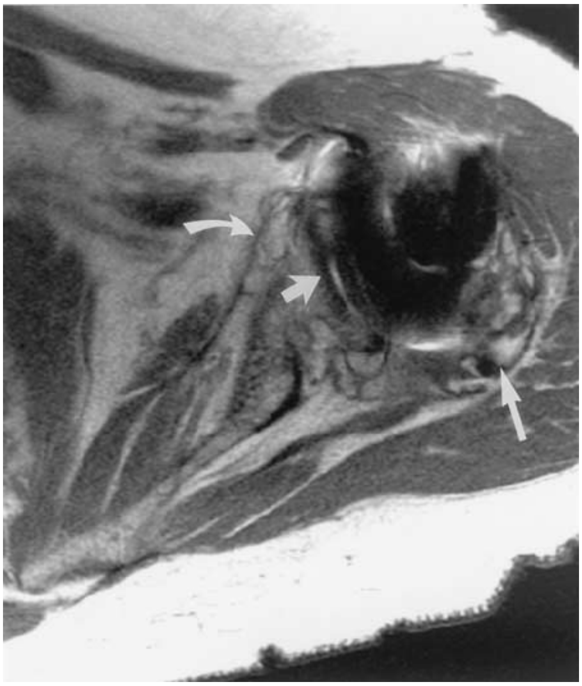

Figure 3 Axial fast spin-echo sequence in a 76-year-old patient after hemiarthroplasty demonstrates full-thickness cartilage wear over the glenoid with subchondral sclerosis *(short, straight arrow)*. Also of note is retraction of the subscapularis with atrophy *(curved arrow)*. The infraspinatus tendon is noted to insert onto heterotopic ossification as a result of prior fracture *(long, straight arrow)*.

graphs. Whereas the presence of cartilage wear must be inferred on radiographs, MRI allows one to visualize the articular cartilage directly.

With regard to total shoulder arthroplasty, determining the presence of a rotator cuff tear is also crucial. In a review of 22 patient series and 1183 total shoulder arthroplasties, the most common complication was a rotator cuff tear.[1] Clinical evaluation of rotator cuff function after shoulder arthroplasty can be very difficult, limited as a result of pain and stiffness, which are common findings in these patients.[2] Plain radiographs are limited in their ability to assess the integrity of the rotator cuff, the quality of the muscle, and the degree of retraction in the case of a torn tendon. Therefore, MRI facilitates the diagnosis of the most common problems encountered in cases of hemiarthroplasty and total shoulder arthroplasty.

One of the limitations of the technique was the difficulty in evaluating the biceps tendon, lesser tuberosity, and glenoid component. The former two sites were obscured by artifact created by the proximal, spherical humeral component. Osteolysis around the glenoid component could be visualized with MRI. The presence of abnormal signal alone surrounding the glenoid component did not seem sufficient evidence by which to diagnose component loosening, but the numbers in our series are small. The advantage of operative inspection lies in the ability to load the components in real time, allowing for inspection of the metal-polyethylene interface.

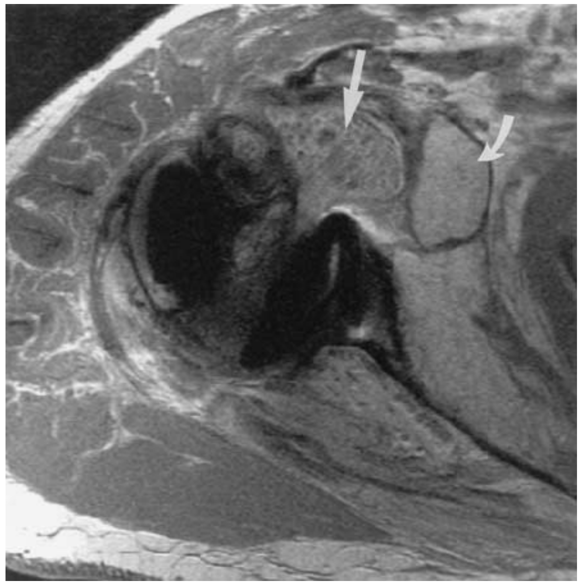

Figure 4 Axial magnetic resonance image in a 79-year-old patient with an infected total shoulder arthroplasty, presenting as a soft-tissue mass in the shoulder region. Note the particulate debris in the anterior capsular recess *(straight arrow)*. A separate loculated fluid collection is identified medial to the synovial recess *(curved arrow)*. The findings were confirmed after intraoperative culture.

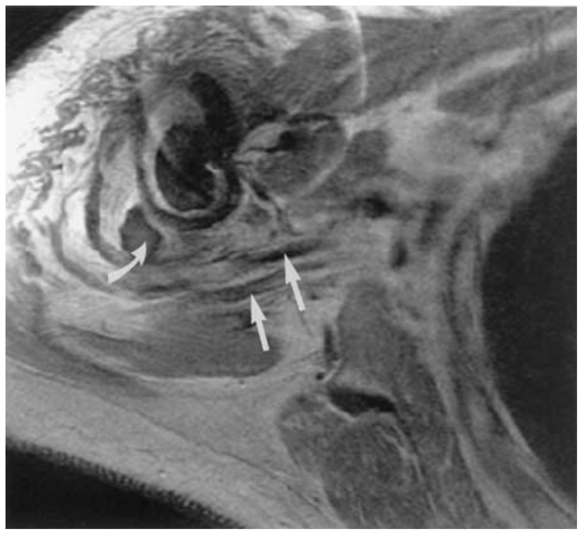

Figure 5 Axial magnetic resonance image in a 48-year-old woman after hemiarthroplasty demonstrates extruded cement *(curved arrow)* within an inferior fluid collection adjacent to the humeral shaft. Although the extruded cement was noted on radiographs, its location relative to neurovascular structures remained uncertain. Note the presence of the axillary nerve and posterior humeral circumflex vessels *(straight arrows)* immediately adjacent to the cement. The findings were confirmed at the time of surgical exploration.

Figure 6 Axial fast spin-echo magnetic resonance image in a 73-year-old patient with a painful total shoulder replacement demonstrating a loose glenoid component. Note the rind of intermediate signal intensity surrounding the keel of the glenoid component *(straight arrows)*. Also note the cortical penetration of the tip of the keel toward the medial cortex of the scapula *(curved arrow)*.

Figure 7 Axial fast spin-echo magnetic resonance image in a 76-year-old woman after hemiarthroplasty with pain and weakness. The humeral component *(asterisk)* is markedly anteverted relative to the glenoid, such that the articular surface of the humeral component faces the anterior subcutaneous soft tissues. The humeral anteversion was not prospectively detected on plain radiographs.

Shoulder arthroplasty provides a particular imaging challenge to the radiologist, as the position of the shoulder close to the imaging bore, where the magnetic field is inherently inhomogeneous, accentuates imaging artifacts. The artifact that is generated from a shoulder replacement is in the form of magnetic susceptibility, which results from the acquired magnetism of a substance exposed to a high-strength magnetic field. Adjacent tissues with different susceptibilities distort the local field, creating artifacts that obscure and distort regional structures such as the rotator cuff. Standard MRI will not visualize the rotator cuff tendons or muscle-tendon junction nor will it provide visualization of the glenoid. Rather, one would be faced with a large "black hole" in the region, obscuring all regional structures.

The intensity of the susceptibility artifact is a function of the relative ferromagnetism of the components, with titanium being less ferromagnetic (and thus causing less artifact) than cobalt-chrome alloy components, as well as the orientation of the components relative to the external field. The orientation of the external magnetic field (B_0) in a closed magnet is parallel to the long-axis of the patient's body, and the artifact is increased when any metallic implant is oriented perpendicular to B_0 and minimized when parallel to B_0. This finding accounts for the consistent visualization of the biceps tendon over the humeral shaft, where the stem is parallel to B_0, as opposed to the biceps origin, which is adjacent to the nonparallel humeral head component. Further, the shape of the component affects the intensity of the artifact, and spherical components create the greatest artifact, seen adjacent in the humeral head.

Technical considerations to reduce susceptibility artifact include reduction of the echo time to minimize T_2 decay, as well as the use of fast spin-echo sequencing, in which multiple 180° refocusing pulses and diminished interecho spacing limit the degree of artifact by increasing regional signal to noise.[5,6] Wider receiver bandwidths also aid in reducing the artifact.[3,8] Gradient-echo techniques, because of their lack of 180° refocusing pulses, should be avoided, as well as frequency-selective fat-suppression techniques. The latter are hampered because of the focal inhomogeneity created in the field by the presence of the orthopaedic implants.[8] Although lower field strength (open) units yield less susceptibility, they also yield markedly less signal resulting from the recruitment of fewer protons and, therefore, are to be avoided in the presence of joint arthroplasty.

In summary, MRI of the shoulder arthroplasty presents several challenges. The proximity of the shoulder to the edges of the imaging bore and the spherical nature of the humeral head component accentuate the artifact present. With modified fast spin-echo sequencing, MRI of the shoulder arthroplasty is a feasible technique that continues to evolve with advancing MRI technology. With further refinements, it is anticipated that the current limitations, including inability to consistently evaluate the lesser tuberosity and proximal biceps tendon, will be overcome. MRI has the capability of identifying treatable pathology, which may lead to improved results of revision surgery and will disclose the integrity of the rotator cuff, as well as muscle quality and the degree of tendon retraction and the residual glenoid cartilage, and thus is a potentially useful tool in the management of painful shoulder arthroplasty.

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