Total Hip Arthroplasty: MR Imaging of Complications Unrelated to Metal Wear

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Abstract

Hip arthroplasty is one of the most common and successful orthopedic procedures performed for the treatment of advanced osteoarthritis. Due to the high prevalence of these implants within the population, complications related to hip arthroplasty are commonly encountered by clinicians and radiologists alike. Knowledge of the diagnostic imaging options available for evaluation of these implants, as well as of the expected range of normal and pathologic findings following hip arthroplasty, is crucial in allowing the radiologist to formulate an appropriate imaging strategy and accurately interpret the subsequent imaging findings.

Keywords
- hip
- arthroplasty
- complications

Hip arthroplasty is one of the most common procedures performed for treatment of advanced osteoarthritis, with an estimated > 300,000 hip arthroplasties performed in the United States each year and > 1 million worldwide, and it has been described as one of the most overall successful orthopedic procedures, resulting in pain relief, restoration of function, and improved quality of life for many patients.[1,2] Given the large number of hip arthroplasties present within the population, however, periprosthetic complications are commonly encountered in routine medical practice, and diagnostic imaging is often performed. Various types of hip implants exist, and the specific type of implant may in some instances determine the type of periprosthetic pathology encountered. The bearing surfaces, or articulation between the acetabular and femoral components, may incorporate a combination of metal-on-metal, metal-on-polyethylene, ceramic-on-metal, ceramic-on-polyethylene, or ceramic-on-ceramic surfaces.[3–6] Arthroplasty stems may be nonmodular (which is very uncommon currently) or modular, with modular neck-head and/or neck-stem junctions. The configuration of the arthroplasty with respect to bearing surfaces and modular junctions has specific implications in terms of the various types of wear-related disease that may occur about a hip arthroplasty.[7] In addition to specific types of wear-related complications, a variety of more generalized complications may be encountered about hip arthroplasties. Clinically, this wide spectrum of complications may result in nonspecific signs and symptoms, making clinical diagnosis challenging. Therefore, diagnostic imaging is often key in establishing an accurate diagnosis and treatment plan, and knowledge of expected normal and pathologic appearances about hip arthroplasty is crucial in helping the radiologist provide an accurate interpretation of imaging findings.

Imaging Modalities

Various imaging modalities are commonly used in the evaluation of suspected pathology in patients with hip arthroplasties. These modalities each have their individual strengths and weaknesses, and they should be considered complementary in terms of formulating an optimal diagnostic imaging strategy.

Radiographs are often the initial diagnostic imaging study ordered for evaluation of a painful total hip arthroplasty. Although they provide less detailed evaluation then cross-sectional techniques, they are easily obtained and provide a

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good overview of the component positioning and alignment, and of the osseous structures, with limited evaluation of the soft tissues. Findings such as periprosthetic fracture and osteolysis may be evident on radiographs but are not uncommonly radiographically occult.

Computed tomography (CT) provides excellent evaluation of osseous morphology, with improved soft tissue evaluation compared with radiographs. In the setting of arthroplasty, streak artifact may obscure the periprosthetic region to varying degrees, and the use of ionizing radiation is an additional concern. That being said, CT is generally the most sensitive modality for the evaluation of fine osseous detail.[8]

Ultrasound (US) has been established as an effective method of imaging soft tissue, particularly the ligaments, tendons, and joints, and it has the additional ability to provide dynamic evaluation of structures in motion. But it is not optimal for the evaluation of osseous pathology. Therefore, US in the setting of hip arthroplasty is generally limited to evaluation of the periprosthetic soft tissues and joint capsule, but it may also be utilized for image-guided procedures such as joint aspiration and injection.

MRI, by virtue of a combination of superior tissue contrast and the ability to detect marrow edema, provides an accurate and sensitive evaluation of both soft tissue and osseous pathology. However, MR imaging in the presence of metal requires a variety of special considerations, as discussed next.

MR Imaging around Metal

MR imaging about metal presents challenges in terms of both technical considerations of image acquisition and interpretation of the resultant study, and it has often been avoided in the past due to these issues. Although technically demanding, careful parameter modification and utilization of advanced imaging can produce high-quality diagnostic scans about metallic implants.

Various parameter modifications may be used to reduce susceptibility artifact about metallic implants when utilizing conventional MR pulse sequences. These include increasing the receiver bandwidth, orienting the long axis of the implant along the frequency encode axis, decreasing voxel size, increasing the number of excitations, using inversion recovery fat suppression instead of frequency selective fat saturation, and scanning at 1.5 T rather than $\geq$ 3.0 T.[9–11]

In the presence of large metallic components, such as those comprising a hip arthroplasty, a prohibitive degree of susceptibility artifact may be generated in spite of appropriate parameter modification. Given that the area of clinical concern is often the immediate periprosthetic region, which is commonly obscured by susceptibility artifact on conventional sequences, this can become problematic. Utilization of advanced sequencing especially designed to markedly reduce, if not eliminate, susceptibility artifact can be extremely beneficial in this situation. Two of the advanced sequences more commonly used for the purposes of metal reduction include multiacquisition variable resonance image combination (MAVRIC) and slice encoding metal artifact correction (SEMAC). MAVRIC is an advanced sequence using multiple image acquisitions at varying spectral frequency bins centered about the precessional frequency of 1H, which are subsequently combined during postprocessing to generate a composite image in which metal susceptibility is markedly reduced about most typical orthopedic implants. SEMAC is a metal reduction technique that uses an additional phase encoding pulse in the Z axis to reduce metal susceptibility artifact via a combination of robust spatial encoding and view angle tilting.[9,12,13] Both of these sequences have been demonstrated to reduce the degree of susceptibility artifact to the degree that pathology not evident on conventional sequences may often be unmasked.

At my institution, routine hip arthroplasty imaging is performed utilizing a combination of three-plane intermediate-weighted fast-spin echo (FSE) images plus complementary coronal MAVRIC inversion recovery and FSE images that provides an optimal balance of high spatial resolution and suppression of susceptibility artifact while providing fluid contrast not afforded by T1-weighted sequences (►**Table 1** and ►**Fig. 1**).

Table 1 MR imaging parameters for routine total hip arthroplasty at 1.5 T

Parameter	Coronal MAVRIC IR	Axial FSE	Sagittal FSE	Coronal FSE	Axial FSE	Coronal MAVRIC
Imaged	Whole pelvis	Whole pelvis	Affected hip	Affected hip	Affected hip	Whole pelvis
TR, ms	4,000–5,000	4,500–5,500	5,500–6,500	4,500–5,800	4,500–5,500	4,000–5,000
TE, ms	40	21.4–32	23–30	24–30	24–30	40
TI, ms	150	NA	NA	NA	NA	NA
BW, kHz	± 125	83–100	83–100	83–100	83–100	± 125
NEX	0.5	4	4–5	4–5	4–5	0.5
FOV, cm	40	32–36	17–18	18	17–19	40
Matrix	256 × 192	512 × 256	512 × 352	512 × 352	512 × 256–288	320–512 × 256–384
Slice/gap, mm	5/0	5/0	2.5–3/0	4/0	4/0	3–4.5/0

Abbreviations: BW, receiver bandwidth; ETL, echo train length; FOV, field of view; FSE, fast spin echo; IR, inversion recovery; NA, not applicable; NEX, number of excitations; TR, repetition time; TE, echo time; TI, time to inversion.

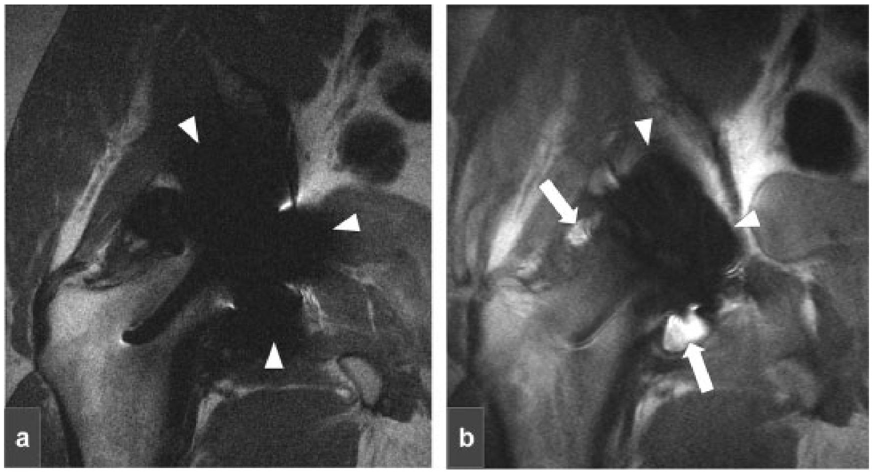

Fig. 1 (**a**) Coronal fast spin-echo proton-density (PD)-weighted image in a patient with right hip resurfacing arthroplasty demonstrates extensive susceptibility artifact (white arrowheads) related to highly metallic implant, in spite of the application of parameter modifications designed to reduce susceptibility artifact. Coronal multiacquisition variable resonance image combination). (**b**) PD-weighted image demonstrates marked reduction in susceptibility artifact (white arrowheads), unmasking synovitis (arrows) not evident on the conventional images.

Normal Appearance

The expected normal postoperative MR imaging appearance of a particular arthroplasty depends not only on the type of implant but also on the postoperative time frame at the time of imaging.

In the immediate postoperative period following total hip arthroplasty, one may encounter synovitis and extensive edema or fluid in the area of the implant, as well as tracking along soft tissue planes. Although these findings may appear alarming, they typically resolve with time (►**Fig. 2**).

Over a period of months following surgery, synovitis, soft tissue fluid, and marrow and soft tissue edema typically resolve, although signal abnormality may persist along the surgical incision site. Occasionally, a loculated postoperative seroma may persist, but in the absence of signs of infection or compression of adjacent structures, this is generally considered a relatively benign finding. The radiologist should remain cognizant, however, of common areas of signal perturbation related to metal susceptibility about the implant, such as along the superior aspect of the acetabular component and immediately adjacent to the femoral stem (►**Fig. 3**).

Complications

Periprosthetic Fracture

Periprosthetic fractures may be challenging to diagnose. Although grossly displaced periprosthetic fractures may be readily apparent on all imaging modalities, a nondisplaced fracture may be difficult to visualize, even on MR if there is only mild associated marrow edema, and particularly in the setting of an excessive degree of susceptibility artifact, which easily obscures subtle findings (►**Fig. 4**).[2,4,6,10] Additionally,

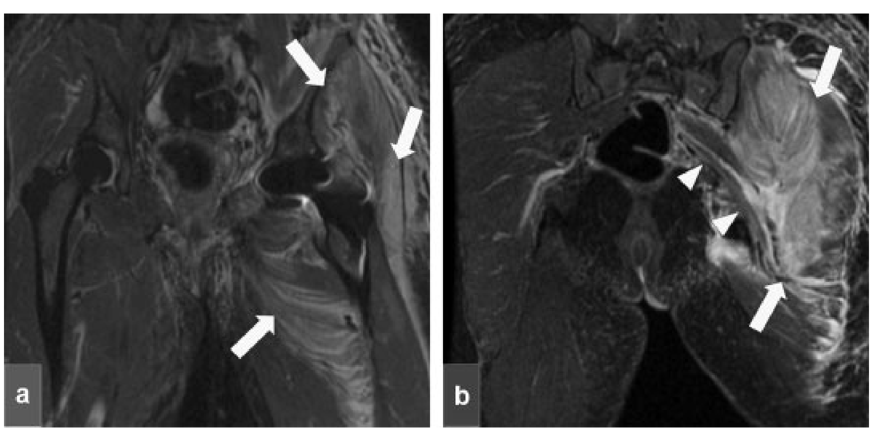

Fig. 2 (**a, b**) Coronal inversion recovery images in a 52-year-old woman status post left total hip arthroplasty demonstrate extensive soft tissue edema and fluid (white arrows) within the periprosthetic soft tissues, tracking along the left sciatic nerve (white arrowheads). Interpretation of this finding requires consideration of the postoperative time frame; in this case, the patient was presenting with foot drop on postoperative day 1, and this degree of edema and fluid was an expected finding. If the patient were more remote from surgery, these findings would be more concerning for infection.

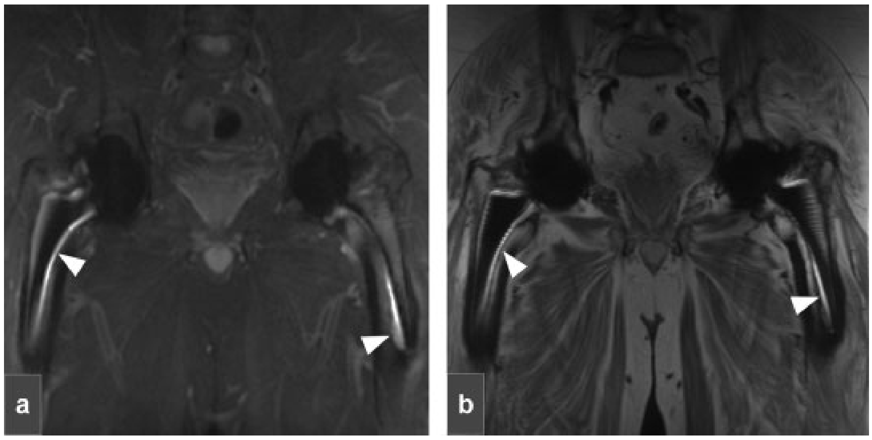

Fig. 3 (**a**) Coronal multiacquisition variable resonance image combination (MAVRIC) inversion recovery and (**b**) proton-density-weighted images demonstrate the typical MR imaging appearance of uncomplicated bilateral total hip arthroplasties. Note areas of metal-related artifact resulting in mild apparent marrow hyperintensity (black arrowheads) and signal pile-up (white arrowheads) in spite of the utilization of the MAVRIC sequence for advanced metal suppression.

as previously mentioned, the radiologist must remain aware of the typical distribution of, and signal perturbations associated with, periprosthetic susceptibility artifact while carefully scrutinizing the images for subtle marrow edema to avoid both false-positive and false-negative interpretations.

Mechanical Loosening

Component loosening may result from extensive fibrous membrane formation, circumferential osteolysis, or poor osseous integration of a noncemented component. Classically on radiographs, a circumferential linear lucent interface is described about the component, although in the setting of loosening related to extensive osteolysis, the osseous resorption will appear bulky and lobular rather than linear. The diagnostic criteria for component loosening on MR imaging are essentially identical to those used during interpretation of other modalities, in that the observed bone resorption is present circumferentially about the component, with the exact MR imaging appearance of the resorption depending on the etiology (►**Fig. 5**). Typically, implant loosening is secondary to circumferential fibrous membrane formation, which appears as a hyperintense thin linear gap with sclerotic margins at the metal–bone or cement–bone interface. A similar imaging appearance occurs in the setting of poor osseous integration of a noncemented component. Osteolysis, which most commonly occurs in the setting of polymeric wear, discussed later, may also result in component loosening when extensive enough to circumferentially invest an implant.

Fig. 4 (**a**) Coronal inversion recovery image in a 69-year-old woman with pain following total hip arthroplasty demonstrates minimal marrow signal hyperintensity about the femoral stem (black arrowheads) without associated fracture line. (**b**) Dedicated radiographs performed 2 weeks following the initial MRI demonstrate well-defined periprosthetic fracture (white arrowhead) that had developed in the interval since the MRI.

Polymeric Wear and Osteolysis

Particulate debris arising from wear of polyethylene bearing surfaces may incite an immune-mediated reaction in which tissue macrophages attempt to isolate foreign particles from the surrounding host tissues via phagocytosis or giant cell encapsulation, inciting a histiocytic foreign body host response.[14–16] This process is generally much less inflammatory and destructive than the atypical lymphocytic vasculitis associated lesion that may be observed in the setting of metal hypersensitivity in the presence of metallic wear debris. MR imaging demonstrates characteristic synovitis with isointense signal intensity polymeric debris that is often associated with bulky osteolysis and/or indolent osseous erosions (►**Fig. 6**). The term *osteolysis* typically refers to periprosthetic osseous resorption secondary to the foreign body reaction to polymeric wear debris, although this process can be seen in the setting of metal wear as well. MR imaging in patients with osteolysis demonstrates areas of focal osseous resorption that are most commonly isointense with well-defined sclerotic margins; however, the signal characteristics of these foci may vary based on the nature of the wear debris. For example, in

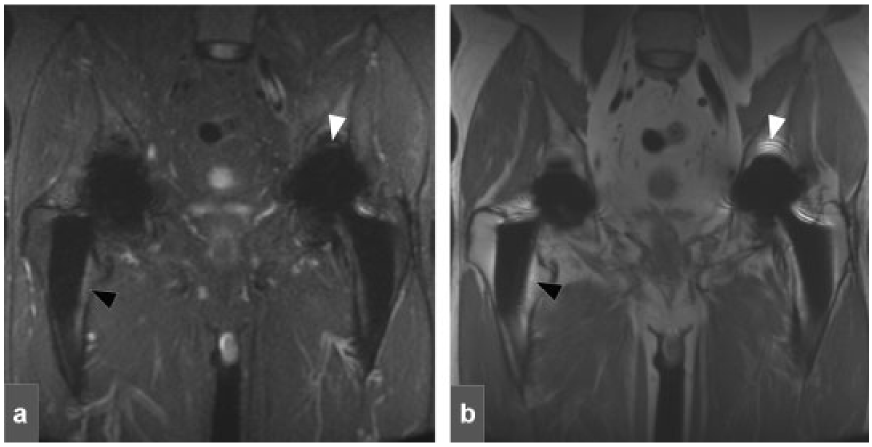

Fig. 5 (**a**) Coronal multiacquisition variable resonance image combination inversion recovery and (**b**) intermediate weighted images in a 52-year-old man status post bilateral total hip arthroplasties demonstrate extensive osseous resorption (white arrowheads) about both femoral stems, which was determined to be circumferential upon examination of all imaging planes, consistent with bilateral femoral component loosening. Signal hyperintensity is due to fluid imbibition along the interface between the implant and surrounding bone.

patients with metal-on-metal implants, extensive deposition of metallic wear debris may yield foci of markedly hypointense osteolysis. As previously mentioned, advanced osteolysis may yield extensive osseous resorption sufficient to cause component loosening. Decompression of reactive synovitis, often into the surrounding bursae and soft tissues, may result in impingement of periprosthetic structures such as the neurovascular bundles and tendons.

Periprosthetic Infection

MR imaging findings associated with periprosthetic infection typically include severe inflammatory synovitis, often lamellated in appearance, and oftentimes with associated ancillary findings characteristic of infection, such as pronounced soft tissue edema, bone marrow edema, lymphadenopathy, and associated fluid collections (►**Fig. 7**).[17] The administration of intravenous gadolinium-based contrast material may be useful in differentiating phlegmon from abscess, and defining sinus tracts and pathways of fluid communication, but it is generally unnecessary for establishing a diagnosis of infection.[10,18]

Heterotopic Ossification

The initial diagnosis of heterotopic ossification often involves radiographs, with CT providing more sensitive cross-sectional evaluation. MR imaging may be warranted to assess the relationship of ossific deposits to surrounding soft tissue structures and the presence and degree of associated impingement, particularly when surgical resection is being considered. The appearance of heterotopic ossification is

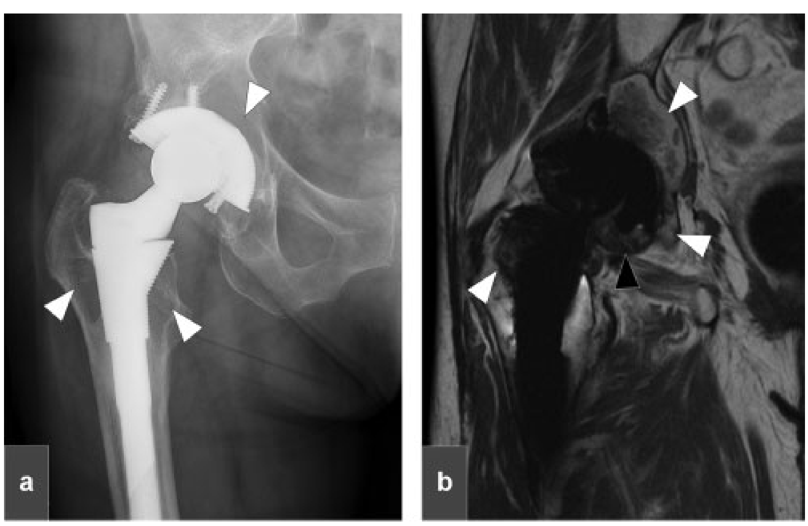

Fig. 6 (**a**) Frontal radiograph in a 76-year-old woman status post total hip arthroplasty demonstrates extensive lobulated lucencies (white arrowheads) about both the femoral and acetabular components, with corresponding findings on (**b**) coronal multiacquisition variable resonance image combination proton-density image including bulky periprosthetic osteolysis (white arrowheads) in the setting of synovial expansion with prominent intermediate signal intensity debris (black arrowhead), consistent with polymeric wear.

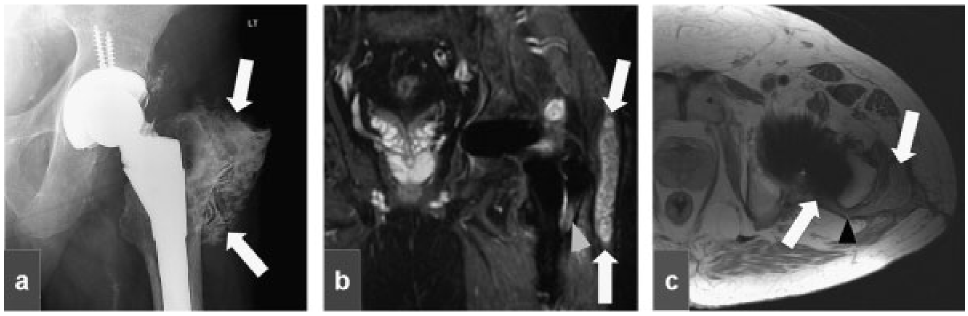

Fig. 7 (**a**) Static exposure in a 60-year-old man with left total hip arthroplasty obtained during fluoroscopically guided joint aspiration demonstrates contrast decompressing from the joint space into the lateral soft tissues (white arrows), where there is pronounced synovial irregularity and thickening, consistent with severe inflammatory synovitis. (**b**) Corresponding inversion recovery image demonstrates severe inflammatory synovitis distending the greater trochanteric bursa (white arrows), decompressing from the joint space via lateral dehiscence in the posterior pseudocapsule (black arrowhead), demonstrated on (**c**) axial fast spin-echo proton-density image. Note signal hyperintensity along the lateral aspect of the proximal femoral component on inversion recovery image (b) is attributed to focal susceptibility artifact (gray arrowhead).

variable on MRI, with mature deposits characterized by the presence of internal fatty marrow signal, and immature deposits often having a more variable appearance that may appear like an aggressive inflammatory process in the early phases (►**Fig. 8**).[19]

Hardware Complications

Although rare, arthroplasty hardware may fail, leading to prosthetic fracture, component displacement, and malpositioning (►**Fig. 9**).[4,6] Occasionally, instruments or a trial component may be unintentionally left within a patient (►**Fig. 10**), although this may be known to the surgeon. For example, a drill bit may break off within bone and may not be worth the difficulty of retrieval but not known to the radiologist. Additionally, component malposition, particularly acetabular version and inclination, as well as soft tissue insufficiency, may predispose the patient to prosthetic dislocation.[4,6,20]

Periprosthetic Neurovascular Complications

A variety of causes may contribute to periprosthetic neurovascular complications. In the immediate postoperative period, postsurgical edema may commonly invest the sciatic nerve adjacent to the operative region, causing irritation of nerve fascicles and symptomatology that typically resolves over time with expectant management. Although less common, however, direct neurovascular impingement related to hardware malposition or postoperative fluid collections may also result in an identical clinical presentation and should be differentiated from the more benign scenario of nerve irritation related to postoperative edema because intervention may be necessary.[10] Other neurovascular complications that may be encountered in the recent postoperative period include traction neuritis, hemorrhage, and vascular thrombosis (►**Fig. 11**). Doppler US provides an excellent noninvasive means of assessing the lower extremity vasculature; however, US evaluation of deep pelvic vasculature is generally limited, and CT or MR angiography may be useful for evaluation if pathology involving the pelvic vasculature is a concern.[21,22]

When encountered within a more chronic time frame, periprosthetic neurovascular complications are commonly related to synovial expansion with secondary impingement of adjacent neurovascular structures, as may be seen in the setting of adverse reactions to wear debris. Additionally, migration of components may occur in the setting of implant failure, and these may then compress adjacent neurovascular structures. Periprosthetic neuroma formation, although rare, may also be detected utilizing MRI.[10]

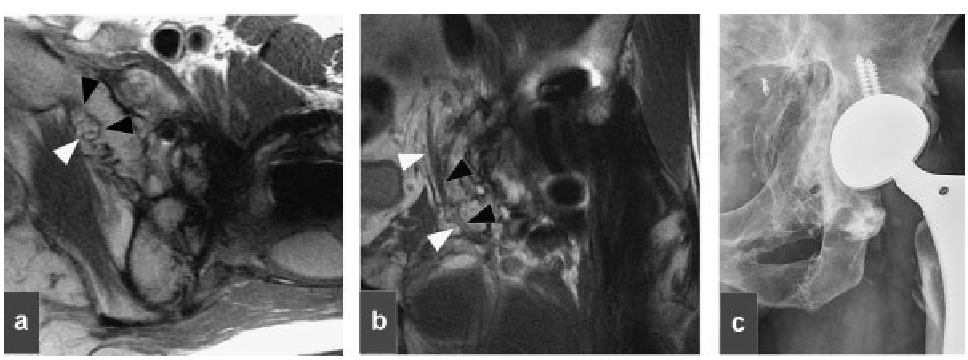

Fig. 8 (**a**) Axial and (**b**) coronal fast spin-echo images in a 33-year-old man status post total hip arthroplasty secondary to traumatic injury demonstrates encasement of the obturator nerve (white arrowheads) within an osseous tunnel (black arrowheads) formed by extensive heterotopic ossification, the extent of which is well appreciated on the concomitant radiograph (**c**).

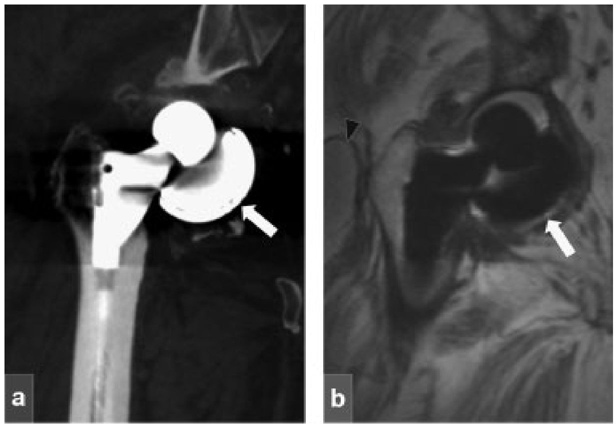

Fig. 9 (**a**) Coronal computed tomography (CT) image in a 63-year-old man status post right total hip arthroplasty demonstrates loosening and displacement of the acetabular component (white arrow), which is inferomedially rotated relative to its expected normal positioning, with corresponding findings demonstrated on (**b**) coronal multiacquisition variable resonance image combination proton-density image. Also note synovitis decompressing into and distending the greater trochanteric bursa (black arrowhead).

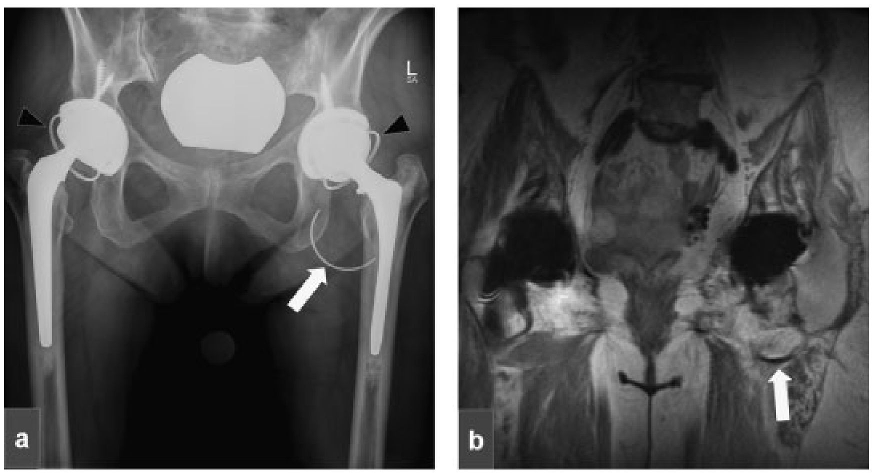

Fig. 10 (**a**) Frontal radiograph and (**b**) coronal multiacquisition variable resonance image combination proton-density image in a 76-year-old woman with bilateral total hip arthroplasties demonstrates curvilinear density/signal abnormality (white arrows) along the inferomedial aspect of the left hip, consistent with broken constraining ring, although additional intact constraining rings are visible bilaterally (black arrowheads). Findings represent a retained broken constraining ring present following revision of a prior constrained left hip arthroplasty.

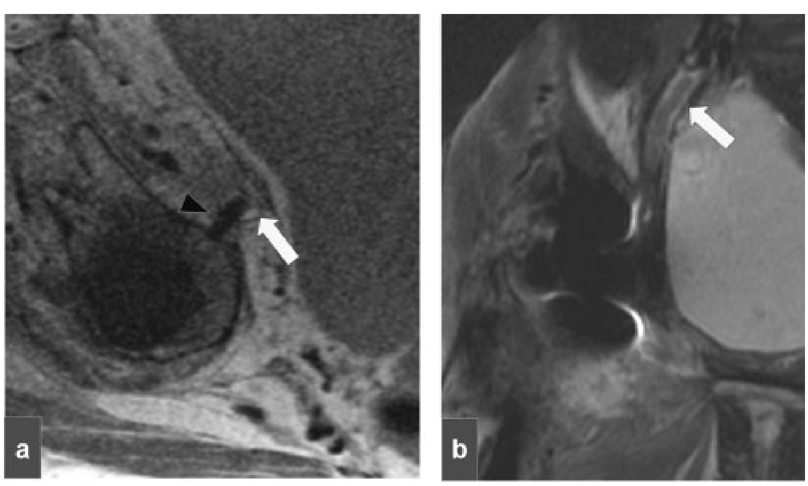

Fig. 11 (**a**) Axial fast spin-echo (FSE) image in a 57-year-old woman 8 days status post total hip arthroplasty demonstrates an acetabular fixation screw (black arrowhead) protruding beyond the medial acetabular cortex to impinge the external iliac vein (white arrow). (**b**) Coronal multiacquisition variable resonance image combination inversion recovery image demonstrates isointense filling defect within the external iliac vein (white arrow), consistent with deep vein thrombosis secondary to vascular impingement.

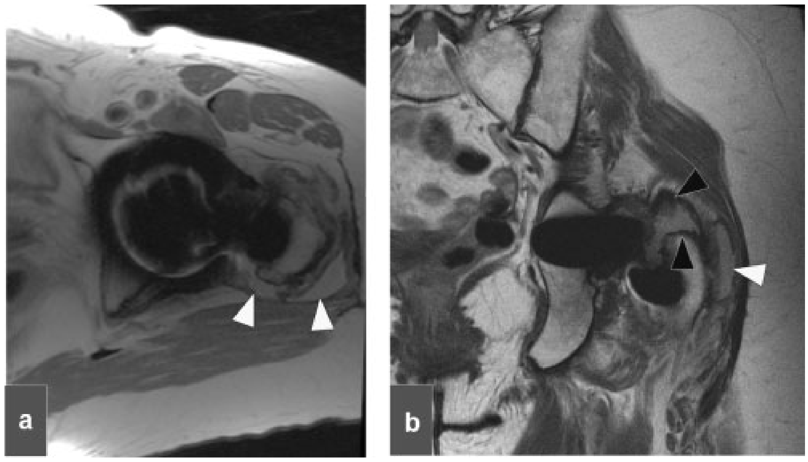

Fig. 12 (a) Axial and (b) coronal fast spin-echo images in a 69-year-old woman status post left total hip arthroplasty demonstrate synovial expansion with decompression of synovitis into the greater trochanteric bursa via a lateral dehiscence in the posterior pseudocapsule (white arrowheads), with fluid undermining the hip abductors, resulting in disruption of the posterior fibers of the gluteus medius at their insertion upon the superoposterior facet of the greater trochanter (black arrowheads).

Periprosthetic Soft Tissues

Pathology involving the periprosthetic soft tissues may be encountered following hip arthroplasty. Not uncommonly, failure of the posterior capsular and/or short external rotator repair may be seen, oftentimes allowing synovitis to decompress into the greater trochanteric bursa. Tendinosis and tears of the hip abductors and iliopsoas may occur, often as a result of ongoing degeneration; however, this may also be related to tendon impingement. For example, excessive anteversion of the acetabular component may result in iliopsoas tendon impingement, and synovial expansion in the setting of wear related disease may impinge and ultimately undermine the hip abductor insertions (►**Fig. 12**).[10]

Conclusions

Hip arthroplasties are a common orthopedic implant, and various types of pathology may be encountered about these implants. Clinical symptoms are oftentimes nonspecific, and therefore diagnostic imaging often plays a key role in diagnosis and treatment. A variety of complementary imaging modalities are available for evaluation of suspected pathology about hip arthroplasties, each with their individual strengths and weaknesses. MRI provides superior sensitivity for both soft tissue and osseous pathology, and with optimal parameter modification, it is an excellent modality for evaluation of suspected pathology about metallic implants such as hip arthroplasties.

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