

Imaging of Hip Arthroplasty

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ABSTRACT

Radiography is the mainstay of the imaging evaluation of the prosthetic hip, but arthrography, aspiration, scintigraphy, sonography, computed tomography, and magnetic resonance imaging all have roles in the evaluation of the painful prosthesis. This article reviews the appearance of normal hip arthroplasty as well as the appearances of potential complications.

KEYWORDS: Hip, arthroplasty, replacement, complications, imaging, CT, MRI

Surgeons have long recognized the concept of replacing the abnormal hip joint, but efforts were hampered by the lack of suitable materials and imprecise surgical technique. Primitive attempts at replacing the ankylosed or debilitating arthritic hip in the 1800s used wood, ivory, rubber, and even pig bladders.¹ In the first half of the 20th century, acetabular cups made of Pyrex and Teflon and femoral heads of acrylic cement were tried unsuccessfully.¹⁻³ In the 1930s, an alloy of cobalt-chromium-molybdenum called Vitallium was discovered,^{1,2} and cobalt-chrome alloys are one of the metals still used today.

The modern era of "low friction" hip arthroplasty began in the 1960s with the work of Sir John Charnley, who pioneered the use of stainless steel metal-on-polyethylene (MOP) prostheses.⁴ Many different variations and designs have since been introduced, but most follow his principle of a metal femoral head articulating against a polyethylene socket. Hip arthroplasty has become so successful, with some designs having a 25-year survivorship of almost 80%,⁵ that the hip is the most commonly replaced joint, with ~500,000 performed each year worldwide.⁶ Although radiography is the mainstay of the imaging evaluation of the prosthetic hip, aspiration, arthrography, scintigraphy, sonography, computed tomography (CT), and magnetic resonance (MR) imaging all have roles in the evaluation of the

painful prosthesis. This article reviews the appearance of normal hip arthroplasty as well as the appearances of potential complications.

NORMAL

Hemiarthroplasty refers to replacement of only the femoral side of the hip joint and is usually done for cases of hip fracture or avascular necrosis in which the acetabular cartilage is preserved and there is no degenerative arthritis. In a unipolar hemiarthroplasty the prosthetic femoral head articulates directly against the acetabular cartilage (Fig. 1). Over time, however, the articular cartilage wears away, leading to painful degenerative arthritis of the acetabulum. To protect the acetabular cartilage, a bipolar hemiarthroplasty may be performed in which a prosthetic cup is placed into the native acetabulum against which the prosthetic femoral head articulates; the acetabulum is not reamed or prepared, and the cup is not fixed in place (Fig. 2). Thus, some motion of the cup may occur against the acetabular cartilage, also eventually wearing it down. Total hip arthroplasty (THA) in which both the femoral head and the acetabulum are replaced by fixed prosthetic devices, is most often performed for disease processes that have affected both sides of the native joint, such as degenerative and rheumatoid arthritis.

An Update on Imaging of Joint Reconstructions; Editors in Chief, David Karasick, M.D., Mark E. Schweitzer, M.D.; Guest Editor, Theodore T. Miller, M.D. *Seminars in Musculoskeletal Radiology*, Volume 10, Number 1, 2006. Address for correspondence and reprint requests: Theodore T. Miller, M.D., Chief, Division of Musculoskeletal Imaging, Department of Radiology, North Shore University Hospital and Long Island Jewish Medical Center, 825 Northern Blvd., Great Neck, NY 11021. ¹Division of Musculoskeletal Imaging, Department of Radiology, North Shore University Hospital and Long Island Jewish Medical Center, Great Neck, New York. Copyright © 2006 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. 1089-7860,p;2006,10,01,030,046,ftx,en;smr00384x.



Figure 1 AP radiograph of a Moore unipolar prosthesis. The prosthetic femoral head articulates directly against the native acetabular cartilage, causing cartilage narrowing (arrow).

The acetabular and femoral components may be cemented or noncemented (either press fit or ingrowth), with the most common combination being a cemented femoral stem and noncemented acetabular cup. A high-density polyethylene (PE) liner is present in the acetabular cup, with which the prosthetic femoral head



Figure 2 AP radiograph of a bipolar hemiarthroplasty shows the acetabular cup (solid arrow), which is placed into the native socket but is not fixed to it. The inferior aspect of the prosthetic femoral head (dashed arrow) is just barely visualized.



Figure 3 AP radiograph of a normal-appearing total hip replacement. The femoral stem is cemented; the tip of the femoral stem is in mild valgus position, the cement column fills the medullary cavity well, and the flange of the prosthesis is flush against the cut surface of the femoral shaft (short arrow) indicating that no subsidence has occurred. Lucency is present in the greater trochanter (long arrow) because of stress shielding. Notice that the acetabular cup is fixed to the acetabular socket by screws and that it is inclined correctly at ~ 45 degrees.

articulates. In some THA designs, the PE is cemented directly to bone, without a metal backing.⁷

The femoral component should be placed in either mild valgus position, such that the tip of the stem is located in the medial aspect of the medullary canal, or neutral position with the tip located centrally in the medullary canal (Fig. 3). Varus positioning of the stem (with the tip against the lateral cortex) predisposes to loosening related to a cantilever effect.⁸ A “cement restrictor,” a plug made of plastic, cement, metal, or bioabsorbable material, is sometimes present in the femoral shaft, just distal to the tip of the stem; this plug keeps the cement contained in the medullary canal during its injection and stem insertion to maintain injection pressure and ensure good bonding of the cement with the endosteal trabeculae. The cement mantle should be at least 2 mm thick all the way around the stem⁹ to minimize the risk of subsequent cement fracture. A cemented stem may have a surrounding thin radiolucency at the cement–bone interface, representing a fibrous pseudocapsule that forms as a result of trabecular necrosis, due to either the marked exothermic curing of the cement or the surgical reaming of the medullary canal, with an adjacent thin sclerotic line along its outer margin representing reactive bone.¹⁰

An ingrowth stem usually has tiny beads or wires sintered onto its proximal surface to increase its surface

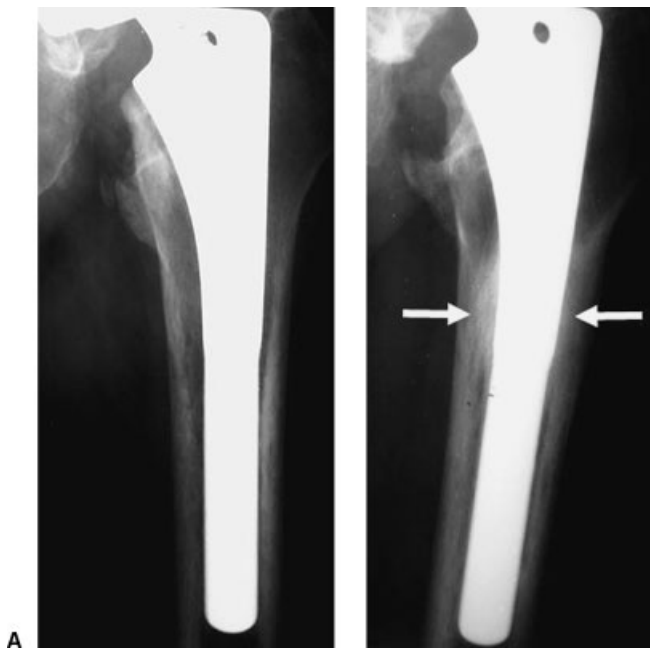


Figure 4 Ingrowth femoral component. (A) Initial post-operative radiograph shows lucency around the proximal aspect of the femoral stem. Porous coating is present along the proximal half of this particular stem. (B) AP radiograph approximately 2 years later shows ingrowth of bone (arrows) onto the stem.

area for bonding with bone, and the sintered surface gives the prosthesis a fuzzy edge. The noncemented component may also be coated with hydroxyapatite to induce bone formation onto the component's surface. Radiographically, the well-fixed ingrowth component shows bone sclerosis extending onto the prosthesis (Fig. 4). There may normally be some cortical or endosteal sclerosis and thickening of the femoral shaft at the level of the tip of the femoral component because of normal transfer of load stresses along the femoral stem.¹¹ Thin linear lucencies, less than 2 mm wide, representing fibrous ingrowth rather than bone ingrowth may also be seen, most often along the proximal aspect of the stem medially and laterally.¹¹ Radiolucency less than 1 mm at the metal-bone interface of a noncemented acetabular component, even if circumferential, is due to fibrous ingrowth.¹²

If the greater trochanter was osteotomized during surgery to allow greater surgical exposure for femoral stem implantation, a clamp or cerclage wires may be present around it; occasionally, the cerclage wires may be broken, which is of no clinical significance as long as the greater trochanter itself has healed to the femur. The greater trochanter, osteotomized or not, may have decreased radiodensity due to "stress shielding" because the implant shifts physiologic load away from the greater trochanter.¹³ Similarly, resorption of the calcar of the femur related to stress shielding may occur with both cemented and noncemented stems,^{10,11,14} but its presence depends on the particular model of stem.¹⁵

The acetabular component is usually placed in about 40 degrees of vertical tilt ("inclination") from the horizontal, depending on the model of the prosthesis and preoperative condition of the acetabulum. Similarly, the cup is usually anteverted (i.e., open facing anteriorly)

10 to 20 degrees.¹⁰ The prosthetic head should be symmetrically seated within the cup, appearing on a frontal radiograph as being equidistant from the superior and inferior margins of the cup (Fig. 3). If the type of PE liner implanted by the surgeon has a thicker superior rim (called an "offset" liner), the head may be slightly inferiorly located in the cup, but a head located superiorly in the cup, even mildly so, is never normal and indicates PE wear. Most femoral heads are made of some type of metal and are thus radiographically dense; ceramic heads, used in an attempt to decrease PE wear (see later), are less radiodense (Fig. 5).

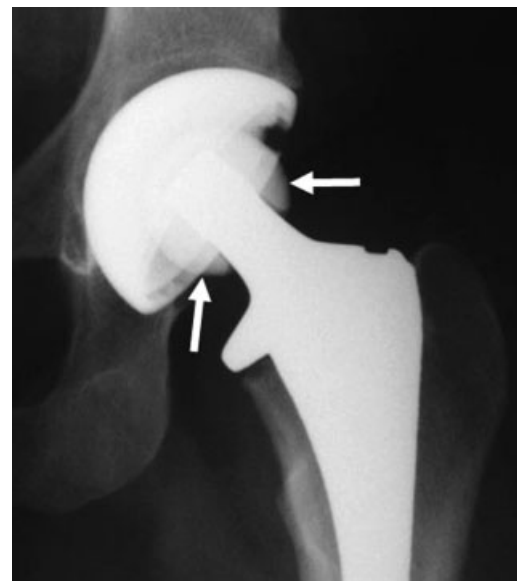


Figure 5 AP radiograph of a ceramic femoral head. The head (arrows) is less dense than the adjacent metal components. The cylindrical taper to which the head is attached can be seen through the less dense head.

The rim of the PE liner is usually flush with the rim of the metal cup, but sometimes additional mechanical constraint is needed, such as for patients with poor tissue elasticity in whom recurrent dislocation of the femoral head is a problem because the soft tissues are too lax to maintain the head within a standard cup. In this group of patients, a constrained liner extends beyond the cup itself, to deepen the articulation and limit the range of motion. Lastly, during reaming of the acetabular socket in preparation for cup placement, the medial wall is occasionally breached. To prevent cement from leaking into the pelvic cavity, where its exothermic curing can be damaging to vessels, nerves, and pelvic organs, a small metal mesh, resembling a hat, is placed into the bone defect to contain the cement within the acetabulum.

COMPLICATIONS

Complications of total hip arthroplasty can be grouped into aseptic loosening and osteolysis, dislocation, infection, periprosthetic fracture, hardware failure, and heterotopic ossification.

Aseptic Loosening and Osteolysis

Aseptic loosening of the prosthesis is the most common reason for revision surgery.^{9,16} Radiographic appearances of loosening of a cemented femoral prosthesis are lucency at the cement-bone interface of more than 2 mm surrounding the component, progressive widening of the lucency at the cement-bone interface (Fig. 6), lucency at the metal-cement interface,¹⁷ and fracture of the cement mantle. The orthopedic classification for modes of stem failure is listed in Table 1. Radiographic appearances of loosening of a noncemented femoral prosthesis are lucency at the metal-bone interface greater than 2 mm surrounding the component, development or widening of the lucency at the metal-bone interface, and subsidence of more than 1 cm and/or which continues to progress more than 1 year after placement.^{10,18} Shedding of surface beads can be seen with both loose and stable implants.^{19,20} The radiographic appearance of loosening of cemented and noncemented acetabular components is lucency greater than 2 mm at the cement-bone or metal-bone interface around its entire circumference.^{12,21,22} Additional radiographic features of loosening, regardless of whether the components are femoral or acetabular or cemented or noncemented, are migration of the component or change of position of the component, fracture of the component, and component motion with stress views.^{17,23} Review of previous radiographs is necessary to detect subtle serial change.²⁴

The description of the location of the lucencies should follow the standard orthopedic descriptions of femoral and acetabular "zones" (Fig. 7): there are seven



Figure 6 Progressive lucency due to loosening. (A) Initial AP radiograph shows a cemented stem in mild valgus position. A thin radiolucency is present at the cement bone interface laterally and proximal-medially because of the normal fibrous capsule that forms due to the curing of the cement. (B) AP radiograph ~2 years later shows the development of radiolucency (arrows) around the entire cement mantle. The lucency is irregular and focally wide, particularly at the tip.

femoral zones on the anteroposterior (AP) radiograph, with the first three numbered from proximal to distal along the lateral aspect of the stem, zone 4 at the tip of the stem, and zones 5 to 7 numbered from distal to proximal along the medial aspect of the stem.⁸ There are an additional seven zones on the lateral radiograph, numbered 8 through 14, beginning at the anteroproximal aspect of the femoral stem. The region around the acetabular component is divided into three equal zones, I, II, III, from lateral to medial around the periphery of the cup.²¹

Arthrography is still occasionally performed to evaluate suspected loosening of an implant. The

Table 1 Modes of Failure of Cemented Stems⁸

Mode I. Pistoning (up-and-down motion)
A. Pistoning of the stem within the cement mantle.
B. Pistoning of the stem and cement mantle within the medullary canal.
Mode II. Medial midstem pivot (medial migration of proximal stem and lateral migration of stem tip)
Mode III. Calcar pivot (medial-lateral toggling of the stem tip, analogous to the "windshield wiper" phenomenon of uncemented stems)
Mode IV. Bending cantilever fatigue (medial migration of the proximal stem with distal fixation of the stem) Often the result of initial varus positioning of the stem.

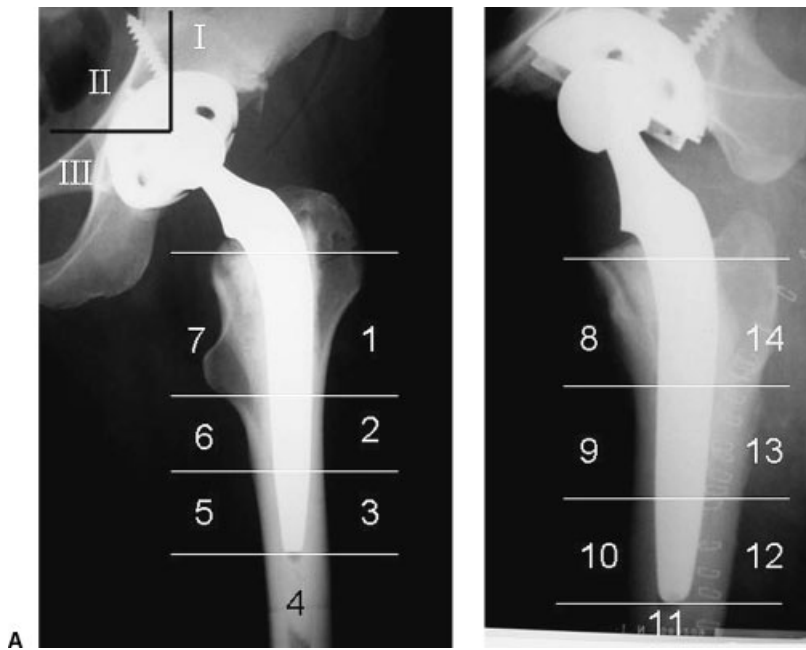


Figure 7 Femoral zones and acetabular zones. (A) AP radiograph shows the seven femoral zones and the three acetabular zones. (B) True lateral radiograph shows the additional seven femoral zones.

arthrographic criterion of loosening of either the femoral stem or acetabular cup is the presence of contrast in either the metal-cement interface or the cement-bone interface, although the criteria and results are very variable²⁵ (Fig. 8); for evaluation of stem loosening, Murray and Rodrigo used the presence of contrast within the cement-bone interface of at least 1 cm long,²⁶ O'Neill and Harris used 2 cm of insinuation of contrast,²⁷ Hendrix et al used insinuation of contrast material involving half the length of the stem,²⁸ and Hardy et al suggested insinuation of contrast around a "significant portion."²⁹ For the acetabular component, contrast material should insinuate

into at least two adjacent zones, if not all of the cement-bone interface.^{23,28,29} The accuracy of arthrography is hampered by many false-negatives and false-positives; for example, granulation tissue may prevent ingress of contrast material around a loose component, and spot welding fixation may allow insinuation around a clinically stable implant.²⁵ Attempts to increase the accuracy of arthrography have included the use of ambulation after injection,^{28,29} subtraction techniques, and arthroscintigraphy.^{30,31}

Often, however, the important clinical question is not whether the prosthesis is loose but what has caused

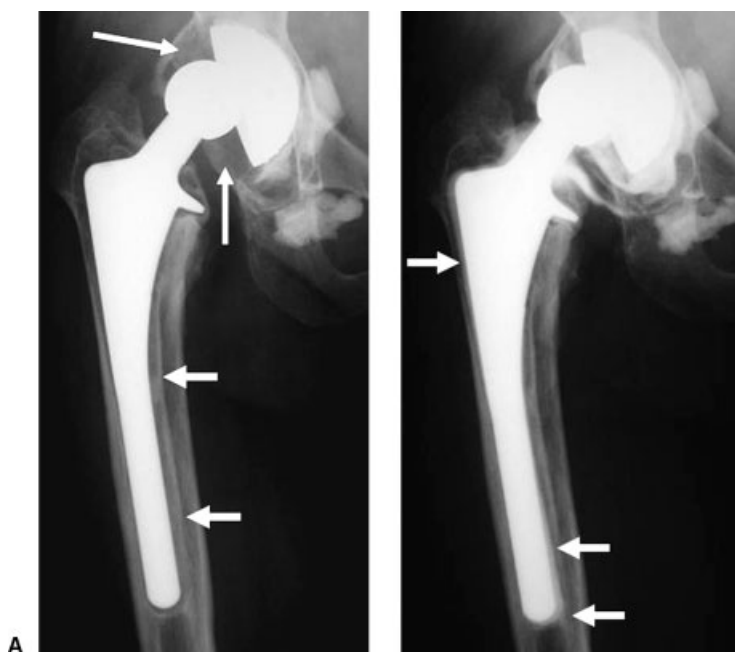


Figure 8 Loosening. (A) AP radiograph shows lucency around the metal bone interface with a sclerotic rim of demarcation (short arrows). Lucency related to osteolysis is also present in the acetabulum (long arrows), and the cemented acetabular cup has become vertically inclined because of loosening. Radiodense cement is present along the medial and inferior aspects of the pelvis. (B) Corresponding AP arthrographic image shows contrast insinuating itself along the metal bone interface (arrows). Contrast did not convincingly insinuate around the acetabular component.

Table 2 Mechanisms of Wear^{40,41}

Abrasion: the scratching of one surface by some other, usually harder, surface.
Adhesion: transient bonding of the bearing surfaces to each other, usually due to poor lubrication, which pulls particles from the weaker surface.
Fatigue: stress of the material beyond its normal mechanical limits, with resultant release of particles.

the loosening. The most common cause is mechanical loosening, but osteolysis related to “particle disease” and infection can also look similar. Any of the components of a hip replacement, such as the metal, PE liner, or cement, can become microscopically fragmented because of wear, shedding small particles of material that can induce a histiocytic inflammatory reaction,^{32–36} but the acetabular PE is the most common source because it is constantly worn against the metal femoral head, an example of abrasive wear (Table 2). In some cup designs with poor locking of the PE liner into the cup, wear of the inner surface of the PE related to micromotion against the cup produces so-called backside wear.^{37,38} Moreover, PE wear can be accelerated by third-party abrasion because of metal or cement fragments in cemented THAs or shed beads or hydroxyapatite granules in noncemented THAs³⁹ (Table 3). The average PE wear rate of MOP designs is about 100 to 200 μ /year.⁴⁰ The particles are engulfed by macrophages, which then release various factors and cytokines, such as interleukins, prostaglandins, and tumor necrosis factor. The cytokines attract other inflammatory cells and stimulate osteoclastic activity, leading to osteolysis.^{32,33,41}

Osteolysis related to particle disease is suggested radiographically by focal well-defined radiolucencies around either the acetabular or femoral components^{13,23,42} (Fig. 9). The presence of osteolysis at sites away from the actual articulating surfaces of the arthroplasty is explained by the concept of the “effective joint space,”⁴³ which states that joint fluid (and the particulate debris contained therein) may insinuate itself around

Table 3 Classification of Wear⁴⁰

Type I. Normal articulation between two bearing surfaces.
Type II. Articulation between a bearing surface and non-bearing surface (e.g., prosthetic head penetrating through PE liner to articulate against metal backing).
Type III. Third-body abrasion, caused by a fragment of material interposed between the normally articulating surfaces.
Type IV. Motion between two non-bearing surfaces (eg, between the backside of the PE liner and the metal acetabular backing, or between the modular head and its connecting taper).



Figure 9 AP radiograph shows a well-defined focus of osteolysis in zone 7 of the femoral component (long arrow). A more subtle area of osteolysis is present in zone 3 of the acetabular component (short arrow).

both the femoral and acetabular components because of the hydrostatic pressure generated by joint movement; thus, for example, screw holes in acetabular components or the screw tracts themselves provide an avenue for particulate debris to reach pelvic bone. Although radiographic evaluation of osteolytic lucencies seems straightforward, it is not, especially around the acetabulum; interobserver variability for detecting osteolysis is poor,^{24,44} and AP and lateral radiographs have low sensitivity.^{45,46} Oblique radiographs of the pelvis have been advocated for improved detection of acetabular osteolysis,^{45,46} but Claus et al found that sensitivity was more dependent on the size and location of the lesion rather than on the radiographic view⁴⁷; sensitivity for lesions in the ilium was five times greater than for lesions in the ischium or around the acetabular rim, and larger lesions were more easily detected than smaller ones. Using AP and oblique radiographs, Walde et al evaluated the accuracy of ballooning and discontinuity of Kohler’s line (the ilioischial line) and iliopubic line for detecting medial wall osteolysis and found 75% sensitivity for ballooning of either line and 87.5% sensitivity for discontinuity of either line.⁴⁸ However, radiographs underestimate the extent of osteolysis⁴⁷; CT scanning is more sensitive and accurate for evaluating acetabular osteolysis and should be performed when there is radiographic suspicion of medial wall loss^{48,49} (see later).

Osteolysis is dependent on the number of shed particles (reflected in the volumetric and linear wear rates of the bearing surfaces) and the histiocytic response to

those particles. Although there is no absolute threshold for the number of shed PE fragments necessary to incite the histiocytic response, the fewer shed particles the less likely an inflammatory response, and Dumbleton et al believe that a linear wear rate of less than 100 μ /year should be considered a practical threshold level.⁵⁰ Moreover, the type of particle itself is important because PE particles have a high inflammatory profile and metal and ceramic particles do not.⁵¹⁻⁵⁴ Therefore, in an attempt to minimize the histiocytic response, different materials and combinations of articulations have been investigated.

Ceramic-on-ceramic (COC) designs have the lowest coefficient of friction and the lowest wear rate and are made of alumina, zirconia, or a mixed oxide of the two; the mixed oxide combines the excellent smoothness and wettability of alumina with the hardness of zirconia.^{40,53,55} First-generation models from the 1980s and early 1990s were subject to catastrophic breakage with an incidence of 2%,⁵⁶ which could affect either the head or socket. Mechanisms of fracture include edge loading of the femoral neck on the rim, impaction of the head into the socket, and third-body abrasion such as from dislocation.⁵⁷ Improved manufacturing techniques leading to increased purity, smaller grain size, and increased density of the ceramic materials have markedly increased the strength of current generation bearings, with a current fracture rate of 0.001 to 0.002%.⁴⁰ COCs are advocated for the young active adult patient⁵⁸ in whom particle disease from a standard MOP design would leave the patient with insufficient bone stock for the expected multiple revisions needed over the patient's lifetime, but disadvantages are their high cost, dependence on precise positioning, and difficulty in management of fracture; a broken ceramic head should not be replaced with a metal head because microshards of ceramic cause severe third-body abrasion leading to marked metallosis,⁵⁹⁻⁶² nor should it be replaced with a new ceramic head because damage to the underlying taper of the femoral neck (to which the head connects) predisposes the new head to fracture.^{53,58,63}

Metal-on-metal (MOM) designs, in which a cobalt-chromium-molybdenum femoral head articulates against a similar acetabular surface, also have a low wear rate (\sim 3-5 μ /year)^{51,64} after an initial "wear-in" period. Metal particles are smaller than PE particles and produce a lower grade histiocytic response,^{51,52} resulting in less osteolysis.⁶⁵ Moreover, even first-generation implants, such as the McKee-Farrar design, used in the 1970s, have shown excellent survivorship up to 20 years. However, positioning of the MOM implant must be precise to avoid impingement wear, and patients with MOM designs have higher serum and urine levels of chromium and cobalt than control subjects,⁶⁶⁻⁶⁹ raising concern about eventual carcinogenesis. Visuri et al found that the rate of all cancers is 1.23 times greater in patients with MOM than with

MOP and the risk of leukemia is 3.77 times greater with MOM than with MOP⁷⁰; although the difference between the MOM and MOP groups was not statistically significantly different, the numbers do raise concern. Looking at cancer risk for all types of THA designs, the rate of sarcoma at the implantation site is not increased compared with a control population,⁷¹ but some studies have found increased rates of myeloma and leukemia^{72,73} in patients with THAs and one study found that patients with cobalt-chrome prostheses had 2.5 times more nuclear aneuploidy and 3.5 times more chromosomal translocations than patients with stainless steel prostheses.⁷⁴

Lastly, much attention has also been focused on improving the PE bearing surface. The traditional method of gamma sterilization in air of ultrahigh-molecular-weight PE causes PE chain scission and the production of free radicals, which then oxidize, leading to loss of PE cross-links and increased brittleness (less wear resistance) of the material. This oxidative degeneration continues even as the implant lies in its air-filled packaging. Gamma sterilization in a vacuum or non-oxygen environment, however, allows the free radicals to form cross-links, which lead to increased wear resistance. Poststerilization thermal annealing of the PE further reduces the concentration of free radicals for longer shelf life.^{40,75,76} Highly cross-linked PE, as this material is called, is more resistant to wear than the previous generation of ultrahigh-molecular-weight PE and has a wear rate similar to that of MOM components. The development of highly cross-linked PE allows the use of MOP designs, which are more familiar to surgeons,



Figure 10 AP radiograph of a dislocated total hip replacement shows a vertically inclined acetabular component.

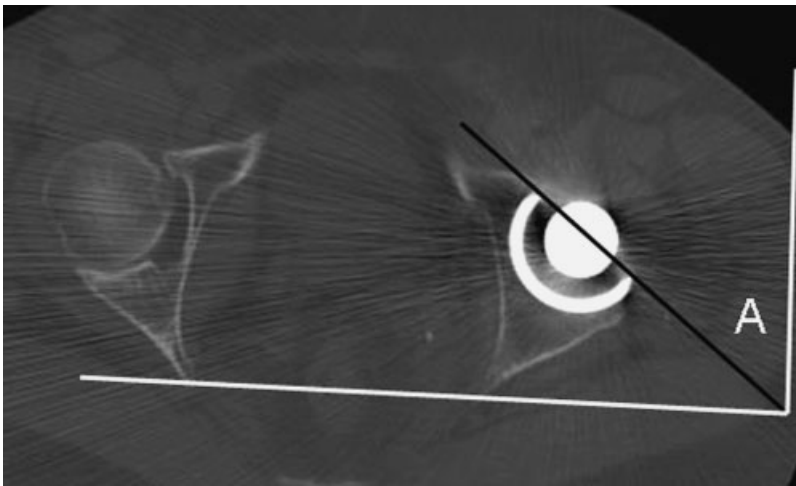


Figure 11 CT image through the acetabulum of a patient with recurrent anterior dislocations. The angle of acetabular anteversion (A) is measured by drawing a line tangential to the opening of the acetabulum and measuring it compared with a line in the AP plane of the patient (short white line). Because the patient may be lying slightly rotated on the CT table, a line should be drawn tangential to the posterior aspects of the posterior columns (long white line) to find the correct AP line against which to measure the acetabular version.

more forgiving in their positioning, and more versatile for making offset liners and constrained liners compared with MOM or COC designs.⁷⁶ However, although highly cross-linked PE is more resistant to wear against smooth bearing surfaces, it is not more resistant to third-body abrasion.^{77,78}

Dislocation

Dislocation is the second most common reason for revision surgery^{16,79} and is multifactorial, including such diverse factors as the age and gender of the patient, the surgical approach, size of the components, and position of the components.^{79,80} Dislocation within the first 3 months after surgery is usually due to laxity of the immature pseudocapsule of the joint and surrounding soft tissues. Atraumatic dislocation occurring between 3 months and 5 years after surgery is usually due to component malposition, such as an acetabular component that is either too vertically inclined (more than 60 degrees of inclination), too anteverted (opening more than 20 degrees anteriorly), or retroverted (opening posteriorly). Inclination can be assessed on radiographs, and acetabular version is well assessed on CT scan^{79,80} (Figs. 10, 11). Dislocation occurring more than 5 years after placement is usually due to gradual stretching of the pseudocapsule and surrounding soft tissue laxity, and women are at greater risk than men.⁷⁹ Surgical options for treating recurrent dislocation include correction of acetabular malposition, placement of a constrained liner that provides stability by both deepening the articulating socket and limiting the femoral range of motion, and larger femoral heads.⁸¹⁻⁸⁴

Infection

Infection is the third most common reason for revision arthroplasty,¹⁶ occurring in 1 to 5% of hip replace-

ments.⁴¹ Radiographic findings suggestive of infection include a wide irregular radiolucency around the cement-bone interface (in the case of cemented components) or at the metal-bone interface (in the case of noncemented components) and frank bone destruction (Fig. 12, 13).⁴² However, a distinction between infectious osteolysis and aseptic osteolysis related to mechanical loosening or particle disease often cannot be made on a single radiograph. Usually, previous radiographs are necessary for comparison, with mechanical loosening and histiocytic response usually taking a slowly progressive course, whereas an acute infection occurs with a more rapid time course and more aggressive appearance. However, even this feature is not always reliable because infections can be subclinical and smoldering, leading to slowly progressive loosening in an afebrile patient. Erythrocyte sedimentation level

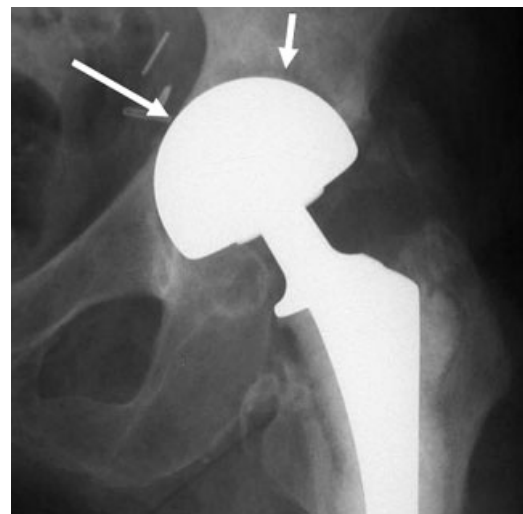


Figure 12 AP radiograph of a patient with a painful septic hip shows ill-defined lucency around zone 1 of the acetabular cup (short arrow) and frank perforation of the cup through the medial wall of the acetabulum (long arrow).

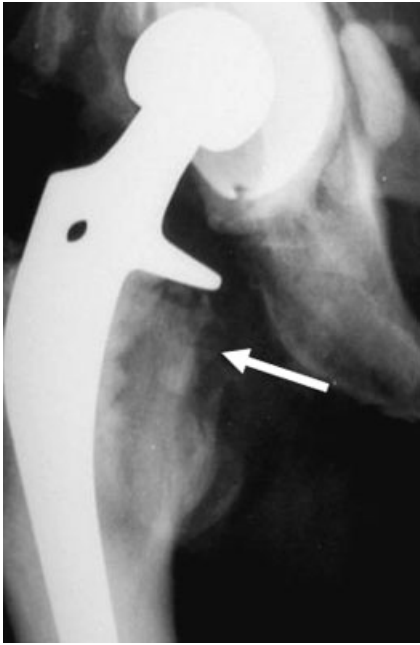


Figure 13 AP radiograph of a patient with a septic hip shows destruction of the femur in zone 7 (arrow).

above 32 mm/hr and peripheral white blood cell level are also not perfect predictors of infection.⁸⁵ The distinction between an infected loose prosthesis and a noninfected loose prosthesis is important because revision arthroplasty in the former case has to be performed as a two-stage procedure, with removal of the infected prosthesis, placement of antibiotic-impregnated cement for 6 to 8 weeks, intravenous antibiotic treatment, and finally placement of the new components, as opposed to a single-stage revision in the case of the noninfected loose prosthesis.

Although the appearance of osteolysis per se cannot distinguish infectious from noninfectious loosening,⁸⁶ the presence of periosteal reaction, demonstrated with either radiographs or CT, is highly predictive of infection.⁸⁷ Moreover, the presence of an adjacent soft tissue collection, visualized with either sonography^{88,89} or CT,⁸⁷ is also highly predictive. Keep in mind that a collection of contrast material pooling over the greater trochanter, supra-acetabular region, or along the iliopsoas tendon on arthrography may be a normal communicating bursa or an expected postsurgical space related to disruption of normal soft tissue planes.^{90,91}

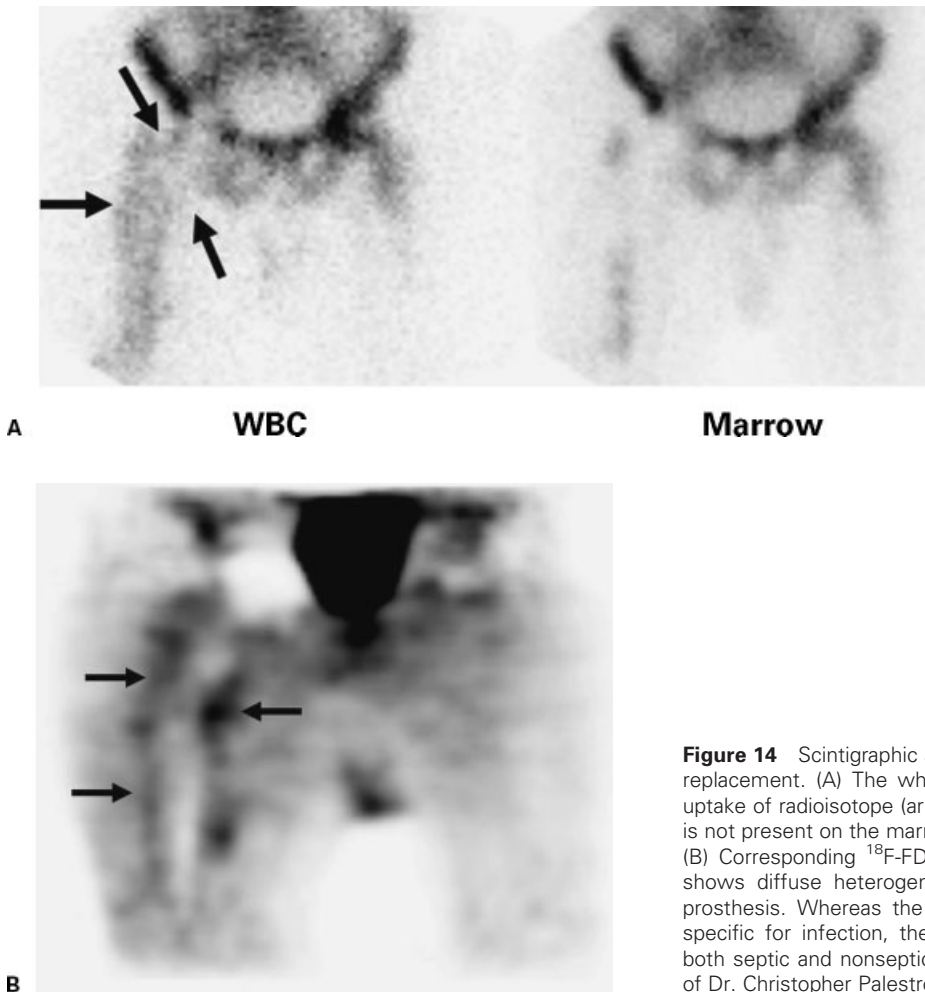


Figure 14 Scintigraphic assessment of an infected total hip replacement. (A) The white blood cell study (WBC) shows uptake of radioisotope (arrows) around the prosthesis, which is not present on the marrow study, thus indicating infection. (B) Corresponding ¹⁸F-FDG-PET image of the same patient shows diffuse heterogeneous uptake (arrows) around the prosthesis. Whereas the white blood cell-marrow study is specific for infection, the PET appearance can be seen in both septic and nonseptic loose prostheses. (Case courtesy of Dr. Christopher Palestro.)

A communicating nonbursal cavity with an irregular, nonsmooth lining is more likely to be infected.^{91,92}

The gold standard for the evaluation of a clinically suspected infected joint is aspiration, with Gram stain and culture and sensitivity of joint fluid. Although it is considered the definitive diagnostic test, its reported sensitivity is quite variable, ranging from 28% to 92%.^{85,93} Some of the reported variability may be due to the cohorts of patients that have been studied, and more accurate results are obtained if aspiration is reserved for cases with high clinical suspicion of infection or periosteal reaction.⁹⁴

Various scintigraphic methods are also available for evaluation. Three-phase bone scan can be used but suffers from poor specificity because a cemented femoral component can show increased uptake around the prosthesis for several years after placement and because a normal noncemented prosthesis also shows increased radiotracer uptake related to the normal bony ingrowth that occurs around the prosthesis. Moreover, new areas of radiotracer uptake compared with prior scans can be caused by both infectious and noninfectious loosening. However, as a normal bone scan is reliable for excluding loosening, it can be used as an initial screening test. Adding a gallium scan to the standard technetium bone scan can improve the diagnostic accuracy for infection to 70 to 80%: infection is excluded if the gallium scan is normal or has less intense uptake than the corresponding bone scan, and infection is diagnosed when there is uptake of gallium without corresponding Tc uptake or the gallium uptake is more intense than corresponding Tc uptake.⁹⁵

The combination of technetium- or indium-labeled white cells and technetium-labeled sulfur colloid has excellent results, with accuracy of over 90%, and is currently the scintigraphic method of choice for evaluating suspected infection.^{95,96} The imaging feature of infection is spatial incongruence, in which there is uptake of the labeled white cells (regardless of intensity) without uptake of the sulfur colloid (Fig. 14).

Fluorodeoxyglucose-positron emission tomography (FDG-PET) scanning has variable performance. Chacko et al reported 92% sensitivity and 97% specificity.⁹⁷ Stumpe et al reported sensitivity of only 22 to 33%, with an overall accuracy of 69%, which was the same as that of radiographs and worse than that of three-phase bone scan.⁹⁸ Similarly, Love et al, using four different combinations of uptake criteria, had an accuracy of only 43 to 78%.⁹⁶ Normal persistent post-surgical uptake in the soft tissues around the prosthetic head and neck is a potential pitfall in interpretation,⁹⁷ and aseptic loosening related to particle disease can also cause increased FDG uptake and thus false-positive scans.^{96,98} (Fig. 14) Chacko et al advised that the location of the uptake is more important than the intensity of the uptake.⁹⁷



Figure 15 AP radiograph shows a fracture of the femur at the tip of the femoral stem with overriding of the fracture fragments. Irregular lucency is also present around the cement-bone interface at the distal aspect of the stem, which probably contributed to the stress riser effect.

Periprosthetic Fracture

Periprosthetic fractures are rare and occur more often around the femoral than the acetabular component. Fracture of the femur may occur during placement of the femoral stem, usually as either focal cortical penetration or longitudinal splitting of the bone, and happens more often with uncemented components than cemented ones (5% versus 0.3%) because of the tight press fit needed with uncemented stems.⁹⁹ The incidence is even higher in revision THA, with an incidence of 6.3% for cemented THAs and almost 18% in noncemented cases.¹⁰⁰ In addition, intraoperative periprosthetic femur fractures occur more often during revision arthroplasty (7.8%) than primary arthroplasty (1%) because of poor bone stock resulting from osteoporosis or prior osteolysis.⁹⁹ In the case of longitudinal splitting, a long stem (to bypass the fracture) and circumferential banding wires are usually used to correct the problem. Fracture of the femur may also occur any time after hip replacement, typically at the level of the tip of the femoral stem because of “stress risers” at this level caused by the difference in stiffness between the metal stem and bony shaft (Fig. 15). These fractures are also more common in revision hips (4%) than primary arthroplasties (1.1%) because of deficient bone stock.⁹⁹

Hardware Failure

Hardware failure can affect both the femoral and acetabular components. The stem of the femoral

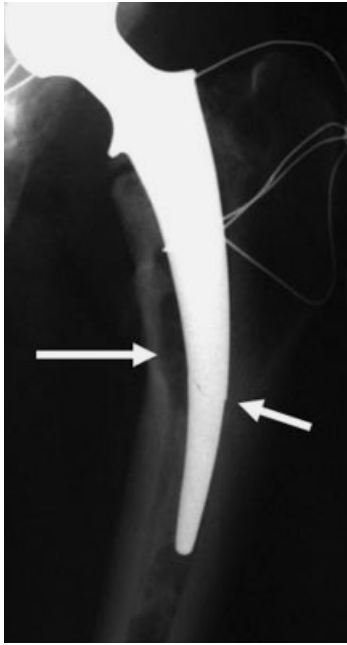


Figure 16 AP radiograph shows a subtle fracture through the femoral stem (short arrow). Well-defined osteolysis is present in zone 6 (long arrow), which probably contributed to the development of this stem fracture.

component can break, representing a metal fatigue stress fracture, because the metal stem is more stiff and less yielding than the surrounding femoral bone, although the incidence of fracture depends on the geometry and metal composition of the stem¹⁴ (Fig. 16). The sintered beads of an ingrowth stem may shear off, indicating either micromotion or frank loosening of the stem, and may act as a cause of third-party abrasion.^{19,20}

The superior aspect of the PE liner can become gradually worn down, appearing radiographically as an



Figure 17 AP radiograph shows wear of the superior aspect of the polyethylene liner (long arrow) manifest as superior migration of the femoral head. Osteolysis is present around the acetabulum manifest as ballooning of the iliopubic line (dotted arrow) and by lucency around the inferior aspect of the acetabulum (short arrows).

asymmetric superior location of the femoral head within the acetabular cup, constituting type I wear (Table 3) (Fig. 17). Serial radiographs are necessary to detect subtle change, and care must be taken to make sure that the patient's positioning and beam alignment are the same from one examination to the next. Ebrahimzadeh et al showed that manual measurement of clinical radiographs is accurate for the assessment of wear,¹⁰¹ and Sychterz et al found that the single AP view was good enough to assess femoral head position as an indicator of PE wear in 95% of people, the other 5% needing a lateral

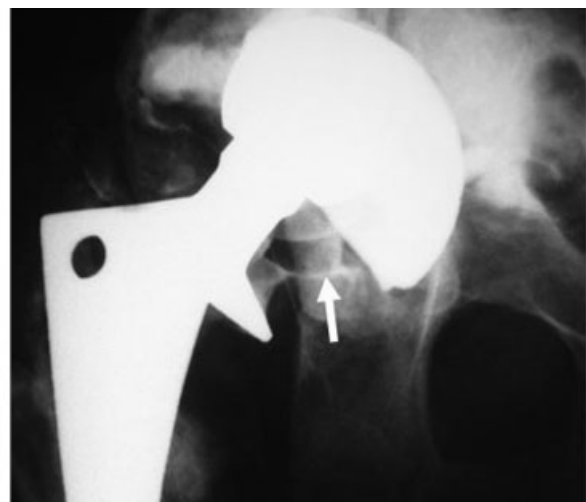
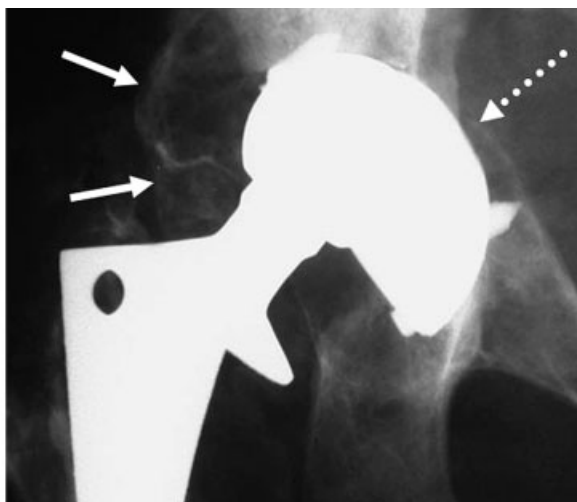


Figure 18 Breakage and displacement of the polyethylene liner: (A) AP radiograph shows the metal femoral head superiorly located in the metal acetabular cup. Severe osteolysis is present manifest by lucency along the lateral aspect of the acetabulum (solid arrows) and by destruction of the medial wall in zone 2 (dotted arrow). (B) AP arthrographic image shows a crescentic piece of a lucent polyethylene (arrow) outlined by contrast and floating freely in the joint space.

view to detect posterior PE wear.¹⁰² Interestingly, however, there is no difference in the position of the femoral head between upright weight-bearing and supine AP radiographs.¹⁰³ Caution should be exercised when interpreting mild penetration of the femoral head into the cup in the first 2 years after implantation because such change may merely be due to “bedding-in” of the femoral head related to creep (permanent deformation of the PE liner) or settling of the PE in the cup. Bedding-in is analogous to normal subsidence of the femoral stem and is not related to PE wear.¹⁰⁴

In addition to gradual wear, the PE liner can frankly break and dissociate from the metal acetabular shell. In this scenario, the femoral head is superiorly seated against the acetabular shell, and displaced pieces of the lucent PE liner and possibly displaced broken metal tines are seen on radiographs.^{37,105–107} The broken pieces of the liner can also be visualized arthrographically as lucent filling defects within the contrast pool (Fig. 18). Su et al reported a case of PE liner breakage resulting in articulation of the metal femoral head against the metal acetabular cup, causing marked metal debris (“metallosis”) that distended the hip capsule, appearing radiographically as a dense “bubble” around the joint.¹⁰⁸

Heterotopic Ossification

The incidence of heterotopic ossification (HO) after total hip arthroplasty ranges from 8 to 90%,¹⁰⁹ with one large study of over 59,000 cases reporting an incidence of 43%¹¹⁰ and smaller series reporting 26%¹¹¹ and 67%.¹¹² Risk factors include male gender, age older than 65 years, history of previous HO, ankylosing spondylitis, and diffuse idiopathic hyperostosis.^{109,111,113} Kasetti et al found that noncemented hydroxyapatite-coated femoral stems did not have a higher incidence of HO,¹¹² and Schara and Herman found that neither did the operative approach.¹¹¹ The radiographic description of HO is performed on the AP view, utilizing the Brooker classification¹¹⁴: grade 0, no HO; grade 1, one or two foci of

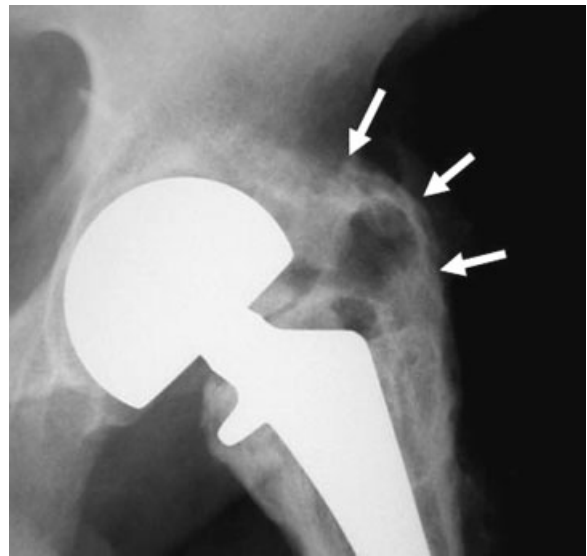


Figure 19 AP radiograph in a patient with a bipolar hemiarthroplasty shows Brooker type IV heterotopic ossification (arrows) that bridges the acetabulum and the femur.

HO less than 1 cm each; grade 2, ossification or osteophytes occupying less than half the space between the femur and pelvis; grade 3, ossification or osteophytes occupying more than half the space between the pelvis and femur; grade 4, ossification that bridges the pelvis and femur (Fig. 19). Despite seeming to be a straightforward diagnosis, the interobserver variability of this classification is only 0.43 (poor)¹⁰⁹ to 0.57 (fair).¹¹⁵ Both low-dose radiation¹¹⁶ and nonsteroidal anti-inflammatory drugs¹¹³ are useful for postoperative prophylaxis, although a meta-analysis of the literature suggests that radiation is more effective.¹¹⁷

ADVANCED IMAGING

The technical aspects and utility of sonography, CT scanning, and MR imaging of joint replacements are discussed in separate articles elsewhere in this issue, but some general comments related to the hip are

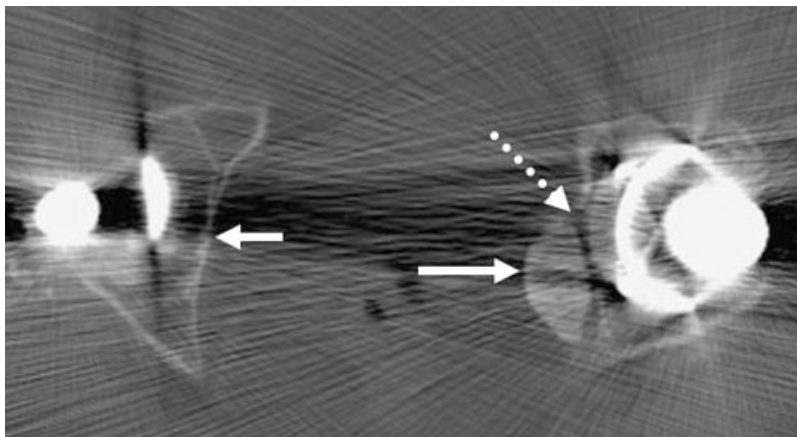


Figure 20 CT image through the acetabuli in a patient with bilateral hip replacements shows preservation of bone stock and the medial wall of the right acetabulum (short arrow). In the left hip there has been extrusion of cement (long solid arrow) through a defect of the medial wall of the acetabulum (dotted arrow). These findings are well seen despite the marked beam-hardening streak artifact.

appropriate here. Sonography can be used to evaluate the presence of joint effusion or periarticular fluid collections associated with an infected prosthesis. It has been suggested that a joint effusion that distends the joint pseudocapsule more than 3.2 mm away from the proximal femoral shaft strongly suggests the presence of acute infection,⁸⁹ but other studies have questioned this.⁹⁰

CT and MR imaging are limited by beam-hardening artifact and dephasing artifact, respectively, caused by the metal components, but multidetector CT scanning with overlapping slices and MR imaging using metal artifact reduction techniques allow these modalities to be used in the evaluation of the painful hip arthroplasty. CT is more sensitive than radiographs for evaluation of lysis of the medial wall of the acetabulum,^{118–120} and it can be helpful for evaluating the amount of surrounding femoral and acetabular bone stock in preparation for revision surgery^{24,121} (Fig. 20). Cup and femoral neck version can also be measured from either standard two-dimensional (2D) axial images^{122,123} or 3D models.¹²⁴

MR imaging, specifically tailored to reduce metal artifact, can depict the periprosthetic tissue on both high-field-strength^{125,126} and low-field-strength magnets¹²⁷ (Fig. 21). The appearance of periprosthetic soft tissue masses related to histiocytic osteolysis is variable; Potter et al described intermediate signal intensity collections with low-signal-intensity rims on T2-weighted images,¹²⁶ and White et al described low-signal-intensity collections on T1-weighted sequences that were heterogeneously low to intermediate signal intensity on T2-weighted images.¹²⁵ Infected collections have a signal intensity more similar to that of fluid,¹²⁶ with

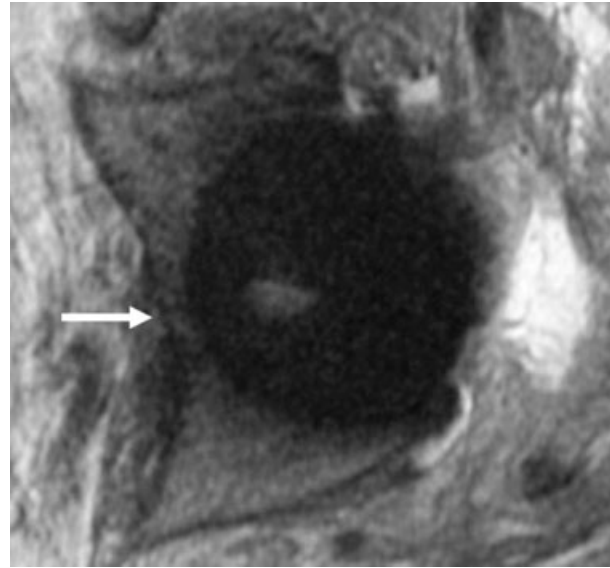
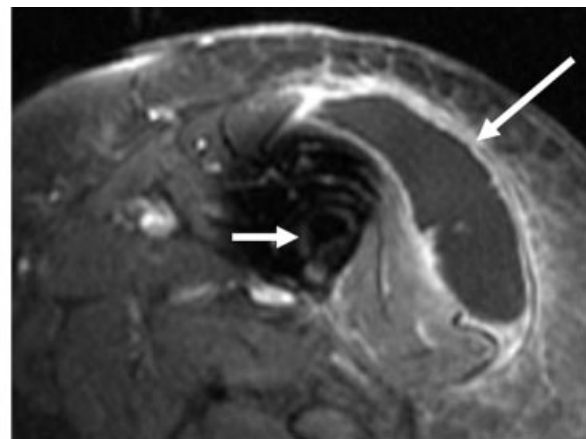
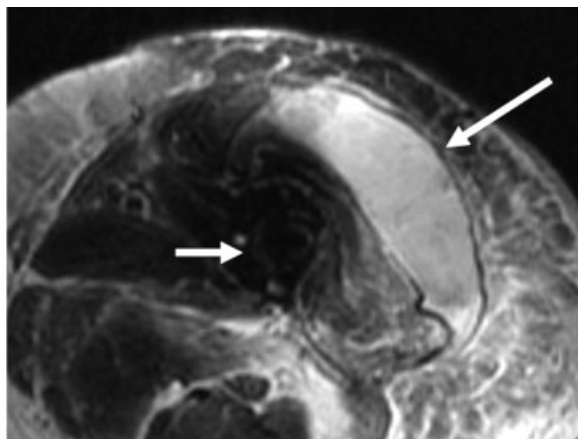


Figure 21 Axial proton density image on a 1.5T scanner through the acetabulum of a patient with a total hip replacement shows dephasing artifact around the acetabular cup itself but the surrounding bone and medial wall of the acetabulum (arrow) are still well visualized.

contrast-enhancing rims¹²⁵ (Fig. 22). Other causes of pain after THA detected with MR imaging include avulsion of the abductor muscles from the greater trochanter¹²⁸ and fracture of the femoral stem.¹²⁹ Using a 0.5 T magnet to evaluate the femoral stem, Sugimoto et al reported that high signal intensity surrounding the stem on short inversion time inversion recovery (STIR) images, either with or without contrast enhancement, indicated loosening or a histiocytic response, and low signal intensity correlated with a normal radiographic appearance and a stable stem.¹²⁷



A

B

Figure 22 Periprosthetic abscess using a 1.5T scanner: (A) Axial fat-suppressed T2-weighted image through the thigh at the level of the prosthetic femoral stem shows signal void due to the stem (short arrow) with surrounding dephasing artifact, but the high-signal-intensity abscess in the lateral soft tissues is well seen (long arrow). (B) Corresponding axial fat-suppressed T1-weighted image after the intravenous administration of gadolinium contrast material shows the low-signal-intensity abscess with the brightly enhancing rim (long arrow). The signal void from the prosthetic stem (arrow) and surrounding dephasing artifact does not affect the appearance of the abscess.

CONCLUSION

Radiography should always be the first step in the imaging evaluation of hip arthroplasty, as most abnormalities can be diagnosed radiographically. Arthrography/arthrocentesis and advanced imaging with scintigraphy, sonography, CT, and MR imaging can be useful in certain specific clinical situations.

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