CME SAM

Current Concepts of Hip Arthroplasty for Radiologists

Current Concepts of Hip Arthroplasty for Radiologists: Part I, Features and Radiographic Assessment

Hyojeong Mulcahy[1]
Felix S. Chew

OBJECTIVE. This article will systematically review radiographic assessment of hip arthroplasty including classifications based on different types and techniques of hip arthroplasty, terminology for prosthetic designs and materials, surgical techniques, and initial and follow-up radiographic assessments.

CONCLUSION. Assessment of postoperative hip arthroplasty radiographs is extremely important. It is well known that patients with complications may be asymptomatic, and for this reason, routine radiographic follow-up is recommended for all patients with hip arthroplasty. The foundation of radiologic interpretation of hip arthroplasty is knowledge of the normal appearance of the many different types of prostheses. A standard approach to radiologic reporting should be undertaken.

The low-fraction total hip replacement developed by Charnley [1] more than 50 years ago began the modern era of surgery as the definitive treatment of symptomatic end-stage hip diseases. Building on experience with the Smith-Peterson cup, a loose-fitting metal cup that was simply interposed between the surgically prepared joint surfaces, and the Judet appliance, a metal hemisphere on a spike that replaced the amputated femoral head, Charnley developed a total hip replacement consisting of a press-fit plastic acetabular socket and a femoral component with a 22-mm head and a cemented intramedullary stem [1]. Advances in design, materials, manufacturing, and surgical techniques, coupled with broader indications and aging of the population, have resulted in an increasing demand for hip replacement. Approximately 267,000 primary total hip replacements were performed in the United States in 2009 [2], exceeding previous estimates of utilization [3]. Although advanced imaging techniques such as ultrasound [4], CT, and MRI have a role in this setting, radiography remains the mainstay for the initial evaluation of hip arthroplasty, both in the immediate postoperative period and at long-term follow-up. This article reviews the current status of hip replacement including different types and techniques of hip replacement, various designs of hardware, standard terms in describing prostheses, and the expected radiographic appearances. A companion article, part 2 [5], reviews the imaging appearance of complications of hip replacement and of revisions.

Types of Hip Arthroplasty

In a hemiarthroplasty, also called partial hip replacement, the femoral head and neck are replaced. Hemiarthroplasty is commonly performed to treat femoral neck fracture or other proximal femur conditions in which the acetabulum is spared. Two types of prostheses are in current use. Unipolar hip prostheses consist of a femoral stem with a fixed (monolithic) or modular head that articulates with the native acetabular cartilage (Fig. 1). Bipolar hip prostheses have a polyethylene-lined metal cup into which a small femoral head with attached stem is locked (Fig. 2). Motion with a bipolar prosthesis may occur between the prosthetic head and cup as well as between the cup and the acetabulum.

In a conventional total hip arthroplasty (THA), both the femoral head and the acetabulum are replaced by fixed prosthetic components (Figs. 3–5). The acetabular bed is prepared by reaming the cavity into the shape of the component; the femur is prepared by removing the head and neck and reaming the intramedullary cavity to receive the stem of the component. Osteoarthritis is the most common indication, but other hip conditions, including other forms of arthritis and fractures, may be treated with THA.

Keywords: hip arthroplasty, imaging, radiography, resurfacing hip arthroplasty

DOI:10.2214/AJR.12.8843

Received March 5, 2012; accepted after revision April 18, 2012.

[1]Both authors: Department of Radiology, University of Washington, UWMC-Roosevelt Radiology, 4245 Roosevelt Way NE, Box 354755, Seattle, WA 98105. Address correspondence to H. Mulcahy (hyomul@uw.edu).

CME/SAM
This article is available for CME/SAM credit.

AJR 2012; 199:559–569

0361–803X/12/1993–559

There is a trend toward the use of large femoral heads (≥ 36 mm) [2].

In resurfacing arthroplasty, only the articular surfaces are replaced in an attempt to preserve bone stock and reduce complications. The femoral head may be resurfaced alone (i.e., resurfacing hemiarthroplasty) (Fig. 6) or in combination with the acetabulum (i.e., resurfacing THA) (Fig. 7).

Implant Fixation

Implants may be cemented in place or fixed with cementless techniques. Bone cement is a mixture of an acrylic cement (polymethylmethacrylate) and various additives including barium or other materials, sometimes antibiotics, to render the mixture radiopaque. Bone cement is used more to fill voids between bone and implant and less as an adhesive. A plug placed in the medullary space allows the cement to be injected under pressure (Fig. 2). Cementless fixation is initially achieved by press-fitting a slightly oversized component into a prepared cavity. Screws are also sometimes used with the acetabular component (Fig. 4).

Special surface characteristics of the components allow ingrowth of bone into a porous coat or on-growth of bone onto a textured surface. Ingrowth surface treatments include sintered beads, fiber mesh, and porous metals. Sintered beads are microspheres of either a cobalt-chromium or titanium alloy attached by the use of high temperatures [6, 7]. Fiber mesh coatings are metal pads attached by diffusion bonding [6]. Porous metals have a uniform 3D network [8]. On-growth surfaces are created by grit blasting or plasma spraying. Grit blasting creates a textured surface by bombarding the implant with small abrasive particles such as aluminum oxide (corundum). Grit blasting may be used as an adjunct below fiber mesh or sintered beads. Plasma spraying involves mixing metal powders with an inert gas that is pressurized and ionized, forming a high-energy flame. The molten material is sprayed onto the implant, creating a textured surface. Hydroxyapatite is a calcium phosphate compound that is plasma sprayed directly on the implant alone or over a porous coating [9]. Bony ingrowth or on-growth provides long-term biologic fixation for all components.

A hybrid THA consists of a cemented femoral implant paired with a cementless acetabular component [10] (Figs. 3 and 4); a reverse hybrid THA has a cemented acetabular cup and a cementless stem [11]. The predominant practice has been hybrid fixation, but cementless fixation is becoming more common.

Design

Acetabular components can be constructed of a single piece (monoblock) or with two interchangeable parts (modular). Monoblock shells are made of polyethylene, ceramic, or metal, and they have the articular surface machined on the inside surface of the cup (Fig. 7). Modular cups consist of two pieces, a metal shell and liner. The inside of the shell contains a locking mechanism designed to accept a polyethylene (Figs. 3–5), metal, or ceramic liner. Many shells have spikes (Fig. 5), pegs, or screw holes to aid positioning and fixation.

Femoral stems are made of alloys of titanium, cobalt-chromium, or stainless steel. They can be monolithic, where the component has both a head and stem, or modular, where the component is assembled from separate heads and stems and sometimes from separate necks and collars as well (Figs. 8 and 9). Design features and surface finishes of femoral stems depend on the method of fixation.

Stems of the “loaded-taper” type are smooth and are highly polished to allow subsidence (sinking) into a stable position within the cement mantle [12] (Fig. 4). Thus, subsidence within the cement mantle in the first postoperative months is an essential feature of this stem and does not predict failure [13].

Stems of the “composite-beam” type have roughening surfaces and a collar to increase the cement-stem bonding and proximal fixation [12] (Fig. 3). Cementless stems have distinct geometries and surface treatments that govern whether fixation is obtained proximally or distally. The distal shaft may be slotted to reduce its stiffness.

An “anatomic” stem has a curve in the sagittal plane designed to fit the curve of the femoral shaft.

Bearing Surfaces

Bearing surfaces of the acetabulum may be made of polyethylene, metal, or ceramic. Femoral heads may be made of metal or ceramic. The most common combination of bearing materials is metal-on-polyethylene, which is categorized with ceramic-on-polyethylene (Fig. 9) as hard-on-soft. Hard-on-hard bearings are metal-on-metal, ceramic-on-ceramic, and metal-on-ceramic.

An analysis of bearing surface usage in the United States in 2005–2006 showed the most common one was metal-on-polyethylene (51%), followed by metal-on-metal (35%) and ceramic-on-ceramic (14%) [14]. In 2009, there were decreases in the use of metal-on-metal (21%) and ceramic-on-ceramic (4%) bearings and increases in the use of hard-on-soft (72%) bearings [2].

Hard-on-Soft Bearings

Current polyethylene bearings are made of ultra–high-molecular-weight (HMW) polyethylene. Polyethylene is a durable, high-performance, plastic resin. Radiation cross-linking of ultra-HMW polyethylene to produce highly cross-linked polyethylene strengthens the material and reduces the generation of polyethylene particles from abrasive wear [15, 16]. Wear reduction is proportional to the amount of cross-linking achieved; however, the irradiation makes it more brittle by forming free radicals that cause it to oxidize. Doping the ultra-HMW polyethylene with vitamin E stabilizes the free radicals and prevents oxidation [17]. The presence of free radicals may also be ameliorated by annealing or melting the irradiated highly cross-linked polyethylene [18].

Hard-on-Hard Bearings

Hard-on-hard bearings were developed in an attempt to improve the longevity of hip implants by decreasing particle formation from abrasive wear. Ceramic bearings are made of alumina, zirconia, or a mixed oxide of the two. Compared with metal and polyethylene bearings, ceramic bearings have the lowest coefficient of friction and lowest wear rate. Developments in ceramic bearings are leading to new material formulations such as zirconia-toughened alumina and to new bearing couples such as ceramic-on-metal [18].

Metals used for bearings include cobalt-chromium, molybdenum, and titanium alloys. First-generation cobalt-chromium alloy metal-on-metal bearings were introduced in the 1960s [19] with second-generation designs introduced in the late 1980s [20], but the second-generation bearings did not prove superior to metal-on-polyethylene bearings. The popularity of metal-on-metal THA systems surged, with new designs and the promise of greater durability in younger patients, and peaked in 2010 after a manufacturer’s voluntary recall of a metal-on-metal THA system in the United States because of high early failure rates [21]. Metal-on-metal bearings may be recognized on properly exposed radiographs by the lack of demarcation between the metal femoral head and the metal acetabulum (Fig. 10).

Current designs for resurfacing THA incorporate a metal-on-metal bearing with a press-fit acetabular component and a cemented femoral component (Fig. 7). Hip resurfacing is generally reserved for relatively young, active patients who have isolated hip disease with good proximal femoral bone quality and morphology and normal kidney function. The advantages of resurfacing arthroplasty are bone conservation, decreased morbidity at the time of revision, decreased dislocation rates, decreased stress-shielding, and decreased prevalence of thromboembolic phenomenon. Pain relief, the primary goal of hip replacement, is not as good with resurfacing THA as with conventional THA [22]. Decreased pain relief is the most common disadvantage of resurfacing arthroplasty.

Surgical Techniques

Minimally Invasive Surgery

The traditional and still most commonly used approaches for primary THA are the posterior and direct lateral approaches (Fig. 11A). The technique of minimally invasive surgery in THA was developed to reduce postoperative bleeding, speed patient recovery, and improve the early clinical results [23]. Minimally invasive THA has been defined as an incision length of 10–12 cm or less either with a single- or double-incision approach (Fig. 11B). The benefits of minimally invasive surgery include decreased soft-tissue trauma, reduced blood loss, and quicker return to function, but the limited visibility of anatomic landmarks and vital structures may result in increased risks for neurovascular injury, fracture, and component malposition [24].

Digital Templating in Hip Arthroplasty

Digital preoperative planning enables the surgeon to select from a library of templates and electronically overlay them on a radiograph. The surgeon can then select the optimal combination of modular components for an individual patient and provide the list to the operating room. The preoperative planning process is fast, precise, and cost-efficient, and it provides a permanent, archived record of the templating process [25] (Fig. 12).

Computer-Assisted Orthopedic Surgery

Computer-assisted orthopedic surgery (CAOS) systems provide real-time digital image maps for guidance during surgery [26]. The maps may be based on CT or MR images obtained preoperatively, on fluoroscopic images obtained at the time of surgery, or on an anatomic model embedded in the software. The computer uses infrared technology to recognize beacons attached to specific instruments, jigs, and cutting blocks. Once the patient's anatomy has been registered with respect to the map, the CAOS system can display the positions of instruments relative to the anatomy. Although CAOS has been shown to increase the precision with which acetabular components may be placed [27], CAOS has not yet gained widespread acceptance in the United States for THA. The addition of a robotic arm may improve the functionality of CAOS systems [28].

Initial Radiographic Assessment

Total Hip Arthroplasty

The initial placement of prosthetic components should correspond with the expected anatomic site of each. In the initial evaluation of a patient who has undergone THA, leg length, vertical and horizontal centers of rotation, lateral acetabular inclination, acetabular anteversion, and femoral stem position should be assessed [10].

Limb-length inequality is common after hip arthroplasty. Limb length can be measured on an anteroposterior standing pelvic radiograph as described by Woolson et al. [29]. A horizontal line is drawn through points at the most inferior aspect of the acetabular teardrop of each hemipelvis (line B in Fig. 13). Two other lines are drawn parallel to the teardrop line through points at the center of the lesser trochanter for each femur (line C in Fig. 13). The difference between the distances from the teardrop line to the lesser trochanters of each femur is defined as the leg-length discrepancy.

The vertical center of rotation of the acetabular component is assessed by measuring the vertical distance between the center of the femoral head (dots in Fig. 13) and the transischial tuberosity line (line A in Fig. 13). This distance should be similar to that of the contralateral hip. The horizontal center of rotation is assessed by measuring the distance between the center of the femoral head and the teardrop shadow or an alternative medial landmark (line D in Fig. 13). This distance should be equal to that of the contralateral hip [30].

Lateral acetabular inclination is defined as the angle between the face of the cup and the transverse axis [31]. It is evaluated on anteroposterior views as the angle of the lateral edge of the cup to the transischial tuberosity line (angle between lines E and A in Fig. 13). This angle ranges from 30° to 50° normally. Lesser angulations result in a stable hip but limited abduction; greater angulations substantially increase the risk of hip dislocation.

Acetabular anteversion is defined as the angle between the acetabular axis and the coronal plane [31]. Anteversion can be measured using a true lateral radiograph as the angle formed by a line drawn tangential to the face of the acetabulum and a line perpendicular to the horizontal plane (Fig. 14). Normal values range from 5° to 25°. Accurate measurement of anteversion on an anteroposterior radiograph can be complex [32], but an impression of version can be obtained by looking at the inferior and superior edges of the cup. If the edges are sharp, this infers no version because the cup is being viewed dead on, but if the edges are rounded, some version is present; however, this assessment does not discern between ante- or retroversion [33].

The aim of femoral stem positioning in THA is to place the stem in a neutral position within the shaft and allow slight anteversion of the neck. On an anteroposterior view, the stem should be seen to be in neutral alignment with the longitudinal axis of the shaft and the tip should be in the center (F in Fig. 13). Many studies have shown that failure of femoral stems, both cemented and cementless, is associated with varus malpositioning (with the tip against the lateral cortex) [34–36] (Fig. 13). Femoral anteversion is an important factor in allowing adequate flexion of the hip and is suggested to be between 10° and 15° [37]. Like assessment of acetabular cup anteversion, assessment of femoral anteversion is qualitative because changes occur with pelvic or thigh rotation. If a true measurement of anteversion is required, it can be assessed with CT [10].

The prosthetic femoral head should be either symmetrically seated within the acetabular cup or slightly inferiorly located in the cup; the polyethylene liner has a thicker superior rim. However, a femoral head located superiorly in the cup, even mildly so, is never normal and indicates polyethylene wear.

Resurfacing Arthroplasty

Currently, it is recommended that the acetabular component should be placed at 5–25° of anteversion and 30–50° of lateral inclination and that the femoral component is placed in a relative valgus position of 5–10° to avoid notching the neck, especially laterally, and to cover all of the reamed bone with the femoral prosthesis (Fig. 15).

Follow-Up Radiographic Assessment

Periprosthetic Radiolucency

Periprosthetic radiolucencies can occur adjacent to both acetabular and femoral components and are identified in both cemented and cementless hip arthroplasty. To describe the location of periprosthetic radiolucencies, investigators have proposed standard zones: The bone adjacent to the acetabular component is divided into three equal zones, labeled I, II, and III from lateral to medial on anteroposterior views [38] (Fig. 16A). Fourteen different zones adjacent to the femoral stem are defined in THA. They are conventionally numbered 1 through 7 on anteroposterior views with the first three numbered from proximal to distal on the lateral aspect of the stem, zone 4 at the tip, and the last three zones numbered from distal to proximal on the medial aspect of the stem [39] (Fig. 16A). Seven additional zones are numbered on lateral views from zone 8 at the anterior proximal aspect of the stem through zone 14 at the posterior proximal aspect of the stem [40] (Fig. 16B). In resurfacing hip arthroplasty, there are three zones around the peg numbered from 1 through 3 on anteroposterior view, from the lateral to the medial aspect of the stem [41] (Fig. 16C).

It is common to identify a thin, linear, radiolucent zone at the component-cement interface, especially at the proximal lateral aspect of the stem (zone 1). This radiolucency may result from an incomplete contact between the cement and the stem at the time of surgery. This finding should be considered as normal if stable, but any enlargement of this radiolucent area at follow-up should be reported as loosening. The interface between cement and adjacent cancellous bone can appear slightly irregular, especially in the greater trochanteric region, reflecting interdigitation of cement with bone, but should be considered as normal. Also, a thin radiolucent band that is less than 2 mm thick, is demarcated by a sclerotic dense line, and runs parallel to the stem along the bone-cement interface is also a common finding [38, 42]. This band results from a reaction between the cement and the adjacent bone, with formation of a fibrous membrane [43].

Similar to the band seen around cemented components, a thin (< 2 mm) isolated radiolucent band around the rough surface of a cementless component, frequently well delineated by a thin sclerotic margin, that is nonprogressive after 2 years can be considered as normal (Fig. 5). Although suboptimal, this finding indicates fibrous rather than bony ingrowth and is thought to provide sufficient stability [43].

Bone Remodeling

The load that is transferred over the artificial joint is taken up by the femoral implant and is transferred distally to the host bone. The reduction in mechanical loading of the periprosthetic bone proximally leads to a loss of bone mineralization through adaptive atrophy, sometimes referred to as "stress shielding," and may be seen radiographically as focal bone resorption (Fig. 5). Adaptive atrophy commonly occurs with cementless components in the superomedial acetabulum and the proximal medial femur. The process generally occurs within the first 2 years after surgery and implies stability; however, the long-term implications are unknown [44].

Bony sclerosis surrounding the prosthesis can occur and indicates bone ingrowth or on-growth. New bone formation originating from the endosteal surface and reaching the prosthesis is termed a "spot weld." It is predominantly seen at the junction between the rough and smooth surfaces of a cementless femoral stem. The presence of spot welds is a strong indicator of stability [45] (Fig. 17). A "bone pedestal" is a transverse sclerotic line below the tip of the stem in zone 4, bridging the medullary canal [46] (Fig. 8). It is sometimes but not always associated with loosening; therefore, careful evaluation and sequential review of follow-up radiographs is advised. Cortical thickening and periosteal reaction occurring in the femoral shaft at the level of the distal end of the stem result from stress alterations and reflect a successful fixation of the stem [47] (Fig. 18).

Component Migration

During the first 2 years after surgery it may be normal for some types of prostheses to subside. The collarless, polished, tapered design of the stem is specifically designed to subside into its cement mantle, and superolateral subsidence from 1 mm to approximately 2 mm is often normal [48]. Cementless stems may also subside during the initial postoperative months, but any progressive movement more than 2 years after surgery or more than 10 mm is thought to be abnormal [43].

Conclusion

With increasing utilization and evolution of materials and techniques of hip arthroplasty, assessment of postoperative radiographs has become more challenging for radiologists. This article reviews current concepts of hip arthroplasty including different types of hip arthroplasty, terminology for the prosthetic designs and materials, surgical techniques, and initial and follow-up radiographic assessments. Radiologists should be familiar with these current concepts for efficient patient care.

References

1. Charnley J. Arthroplasty of the hip: a new operation. *Lancet* 1961; 1:1129–1132
2. Huo MH, Dumont GD, Knight JR, Mont MA. What's new in total hip arthroplasty. *J Bone Joint Surg Am* 2011; 93:1944–1950
3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am* 2007; 89:780–785
4. Miller TT. Sonography of joint replacements. *Semin Musculoskelet Radiol* 2006; 10:79–85
5. Mulcahy H, Chew FS. Current concepts of hip arthroplasty for radiologists. Part 2. Revisions and complications. *AJR* 2012; 199:570–580
6. Bourne RB, Rorabeck CH, Burkart BC, Kirk PG. Ingrowth surfaces: plasma spray coating to titanium alloy hip replacements. *Clin Orthop Relat Res* 1994; 298:37–46
7. Pilliar RM. Powder metal-made orthopedic implants with porous surface for fixation by tissue ingrowth. *Clin Orthop Relat Res* 1983; 176:42–51
8. Bobyn JD, Stackpool GJ, Hacking SA, Tanzer M, Krygier JJ. Characteristics of bone ingrowth and interface mechanics of a new porous tantalum biomaterial. *J Bone Joint Surg Br* 1999; 81:907–914
9. Khanuja HS, Vakil JJ, Goddard MS, Mont MA. Cementless femoral fixation in total hip arthroplasty. *J Bone Joint Surg Am* 2011; 93:500–509
10. Manaster BJ. From the RSNA refresher courses: total hip arthroplasty—radiographic evaluation. *RadioGraphics* 1996; 16:645–660
11. Lindalen E, Havelin LI, Nordsletten L, et al. Is reverse hybrid hip replacement the solution? *Acta Orthop* 2011; 82:639–645
12. Scheerlinck T, Casteleyn PP. The design features of cemented femoral hip implants. *J Bone Joint Surg Br* 2006; 88:1409–1418
13. Huiskes R, Verdonschot N, Nivbrant B. Migration, stem shape, and surface finish in cemented total hip arthroplasty. *Clin Orthop Relat Res* 1998; 355:103–112
14. Bozic KJ, Kurtz S, Lau E, et al. The epidemiology of bearing surface usage in total hip arthroplasty in the United States. *J Bone Joint Surg Am* 2009; 91:1614–1620
15. Dorr LD, Wan Z, Shahrdar C, Sirianni L, Boutary

M, Yun A. Clinical performance of a Durasul highly cross-linked polyethylene acetabular liner for total hip arthroplasty at five years. *J Bone Joint Surg Am* 2005; 87:1816–1821

16. Fukui K, Kaneuji A, Sugimori T, Ichiseki T, Kitamura K, Matsumoto T. Wear comparison between a highly cross-linked polyethylene and conventional polyethylene against a zirconia femoral head: minimum 5-year follow-up. *J Arthroplasty* 2011; 26:45–49
17. Bracco P, Oral E. Vitamin E–stabilized UHMWPE for total joint implants: a review. *Clin Orthop Relat Res* 2011; 469:2286–2293
18. Manley MT, Sutton K. Bearings of the future for total hip arthroplasty. *J Arthroplasty* 2008; 23(suppl 7):47–50
19. Zahiri CA, Schmalzried TP, Ebramzadeh E, et al. Lessons learned from loosening of the McKee-Farrar metal-on-metal total hip replacement. *J Arthroplasty* 1999; 14:326–332
20. Dorr LD, Wan Z, Longjohn DB, Dubois B, Murken R. Total hip arthroplasty with use of the Metasul metal-on-metal articulation: four to seven-year results. *J Bone Joint Surg Am* 2000; 82:789–798
21. Gonzalez MH, Carr R, Walton S, Mihalko WM. The evolution and modern use of metal-on-metal bearings in total hip arthroplasty. *Instr Course Lect* 2011; 60:247–255
22. Shimmin A, Beaule PE, Campbell P. Metal-on-metal hip resurfacing arthroplasty. *J Bone Joint Surg Am* 2008; 90:637–654
23. Vicente JR, Croci AT, Camargo OP. Blood loss in the minimally invasive posterior approach to total hip arthroplasty: a comparative study. *Clinics (Sao Paulo)* 2008; 63:351–356
24. Reininga IH, Zijlstra W, Wagenmakers R, et al. Minimally invasive and computer-navigated total hip arthroplasty: a qualitative and systematic review of the literature. *BMC Musculoskelet Disord* 2010; 11:92
25. Bono JV. Digital templating in total hip arthroplasty. *J Bone Joint Surg Am* 2004; 86(suppl 2):118–122
26. Sikorski JM, Chauhan S. Computer-assisted orthopaedic surgery: do we need CAOS? *J Bone Joint Surg Br* 2003; 85:319–323
27. Beckmann J, Stengel D, Tingart M, Gotz J, Grifka J, Luring C. Navigated cup implantation in hip arthroplasty. *Acta Orthop* 2009; 80:538–544
28. Dorr LD, Jones RE, Padgett DE, Pagnano M, Ranawat AS, Trousdale RT. Robotic guidance in total hip arthroplasty: the shape of things to come. *Orthopedics* 2011; 34:e652–e655
29. Woolson ST, Hartford JM, Sawyer A. Results of a method of leg-length equalization for patients undergoing primary total hip replacement. *J Arthroplasty* 1999; 14:159–164
30. Massin P, Schmidt L, Engh CA. Evaluation of cementless acetabular component migration: an experimental study. *J Arthroplasty* 1989; 4:245–251
31. Murray DW. The definition and measurement of acetabular orientation. *J Bone Joint Surg Br* 1993; 75:228–232
32. Widmer KH. A simplified method to determine acetabular cup anteversion from plain radiographs. *J Arthroplasty* 2004; 19:387–390
33. McBride TJ, Prakash D. How to read a postoperative total hip replacement radiograph. *Postgrad Med J* 2011; 87:101–109
34. Khalily C, Lester DK. Results of a tapered cementless femoral stem implanted in varus. *J Arthroplasty* 2002; 17:463–466
35. Vresilovic EJ, Hozack WJ, Rothman RH. Radiographic assessment of cementless femoral components: correlation with intraoperative mechanical stability. *J Arthroplasty* 1994; 9:137–141
36. Munuera L, Garcia-Cimbrelo E. The femoral component in low-friction arthroplasty after ten years. *Clin Orthop Relat Res* 1992; 279:163–175
37. Fackler CD, Poss R. Dislocation in total hip arthroplasties. *Clin Orthop Relat Res* 1980; 151:169–178
38. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res* 1976; 121:20–32
39. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 1979; 141:17–27
40. Johnston RC, Fitzgerald RH Jr, Harris WH, Poss R, Muller ME, Sledge CB. Clinical and radiographic evaluation of total hip replacement: a standard system of terminology for reporting results. *J Bone Joint Surg Am* 1990; 72:161–168
41. Amstutz HC, Beaule PE, Dorey FJ, Le Duff MJ, Campbell PA, Gruen TA. Metal-on-metal hybrid surface arthroplasty: two to six-year follow-up study. *J Bone Joint Surg Am* 2004; 86:28–39
42. Beckenbaugh RD, Ilstrup DM. Total hip arthroplasty. *J Bone Joint Surg Am* 1978; 60:306–313
43. Pluot E, Davis ET, Revell M, Davies AM, James SL. Hip arthroplasty. Part 2. Normal and abnormal radiographic findings. *Clin Radiol* 2009; 64:961–971
44. Moore MS, McAuley JP, Young AM, Engh CA Sr. Radiographic signs of osseointegration in porous-coated acetabular components. *Clin Orthop Relat Res* 2006; 444:176–183
45. Engh CA, Bobyn JD, Glassman AH. Porous-coated hip replacement: the factors governing bone ingrowth, stress shielding, and clinical results. *J Bone Joint Surg Br* 1987; 69:45–55
46. Engh CA, Massin P, Suthers KE. Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. *Clin Orthop Relat Res* 1990; 257:107–128
47. Taljanovic MS, Jones MD, Hunter TB, et al. Joint arthroplasties and prostheses. *RadioGraphics* 2003; 23:1295–1314
48. Alfaro-Adrián J, Gill HS, Murray DW. Cement migration after THR: a comparison of charnley elite and exeter femoral stems using RSA. *J Bone Joint Surg Br* 1999; 81:130–134

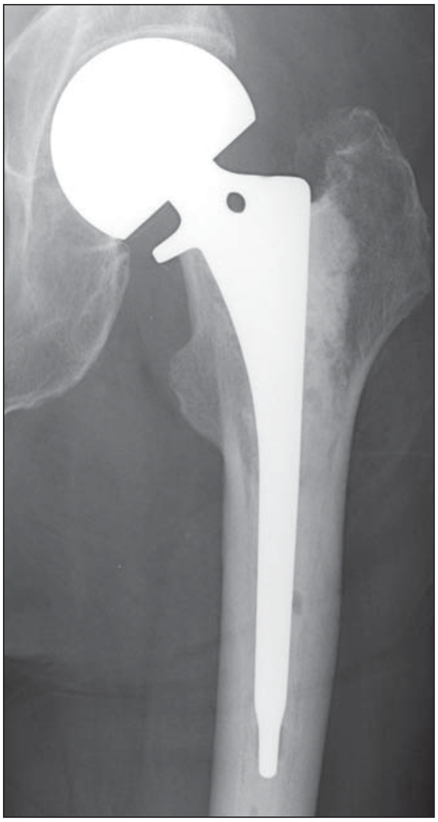

Fig. 1—Radiograph shows cemented unipolar hemiarthroplasty.

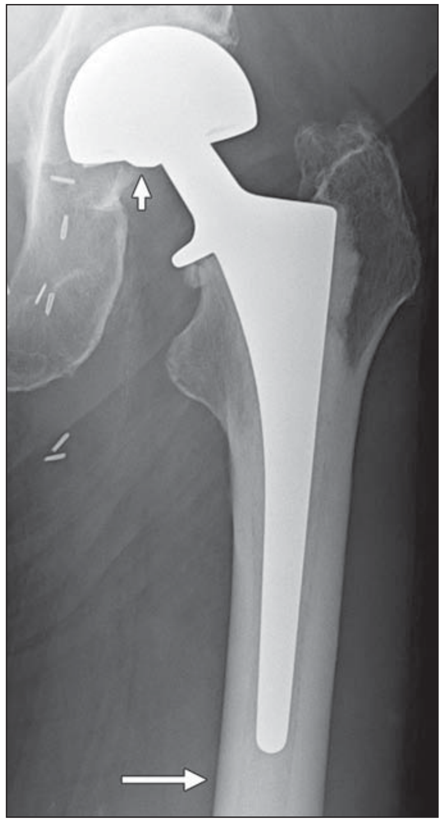

Fig. 2—Radiograph shows cemented bipolar hemiarthroplasty. Inferior aspect of prosthetic femoral head (*short arrow*) barely projects beyond cup. Intramedullary plug (*long arrow*) restricts flow of cement beyond femoral stem during surgery.

Fig. 3—Radiograph shows hybrid total hip arthroplasty with composite-beam femoral stem and metal-on-polyethylene bearing surface.

Fig. 4—Radiograph shows hybrid total hip arthroplasty with loaded-tapered stem and metal-on-polyethylene bearing surface.
←

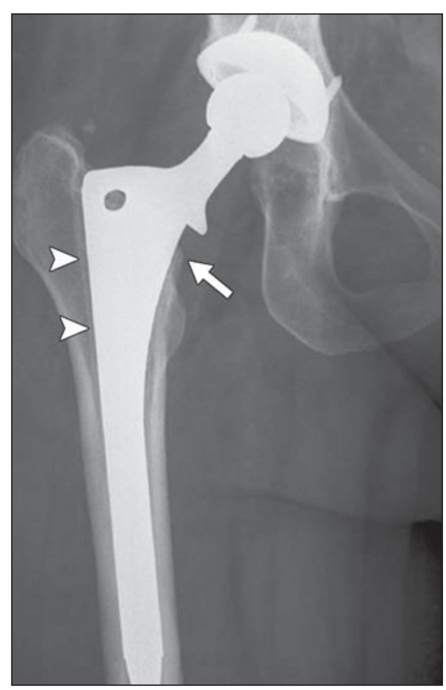

Fig. 5—Radiograph shows cementless total hip arthroplasty with metal-on-polyethylene bearing surface. Narrow radiolucent band (*arrowheads*) parallels lateral metaphyseal metal-bone interface. Adaptive bony atrophy (*arrow*) is present at proximal medial femoral cortex. →

Fig. 6—Radiograph of shows resurfacing hip hemiarthroplasty.
←

Fig. 7—Radiograph of 27-year-old man shows resurfacing total hip arthroplasty with metal-on-metal bearing surface. Femoral stem is in valgus position relative to native femoral neck and monoblock acetabular cup (metal) is inclined at 38°.
→

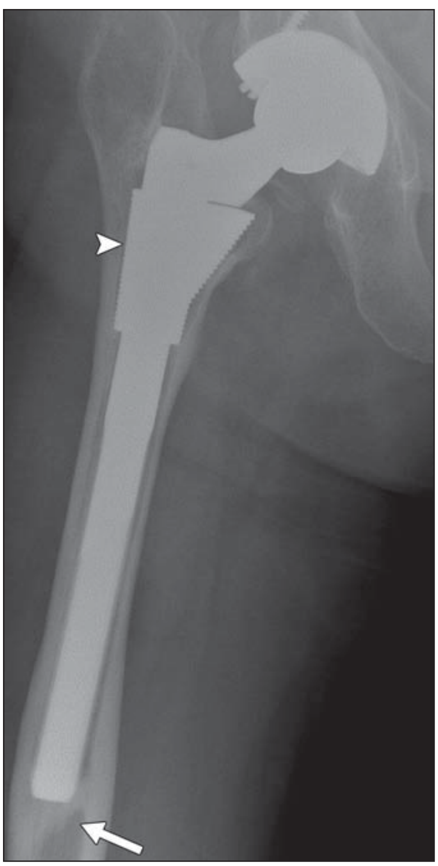

Fig. 8—Radiograph shows cementless total hip arthroplasty with modular femoral component and metal-on-polyethylene bearing surface. Metaphyseal collar (*arrowhead*) allows variable anteversion of femoral neck at time of surgery. Bone pedestal (*arrow*) is present below tip of femoral component.
←

Fig. 9—Radiograph of 58-year-old woman shows cementless total hip arthroplasty with ceramic-on-polyethylene bearing surface.
→

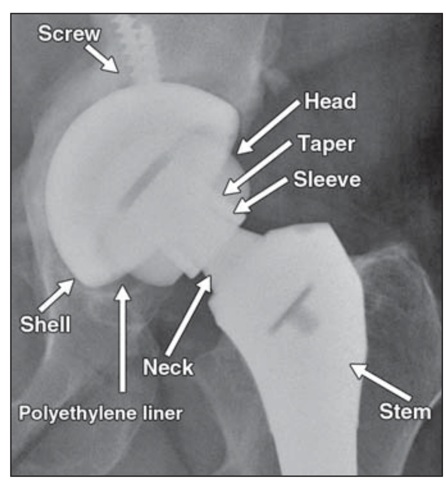

Fig. 10—Radiograph shows cementless total hip arthroplasty with metal-on-metal bearing surface.

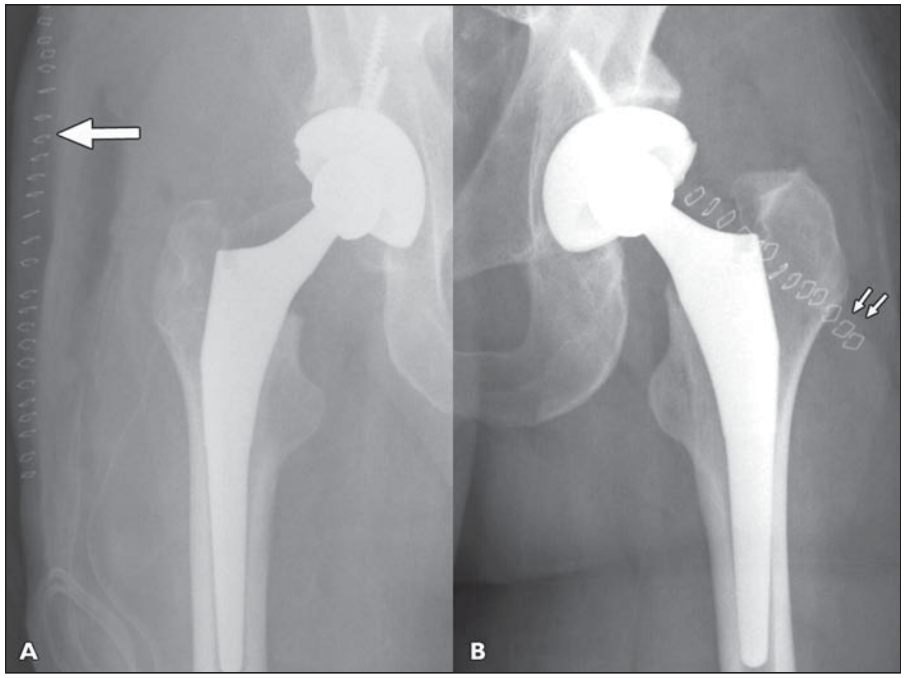

Fig. 11—Minimally invasive surgery (i.e., cementless total hip arthroplasty.
A, Radiograph of 67-year-old man shows skin staples (*arrow*) that demarcate incision for traditional direct lateral approach.
B, Radiograph of 56-year-old man shows skin staples (*arrows*) that demarcate incision for minimally invasive approach.

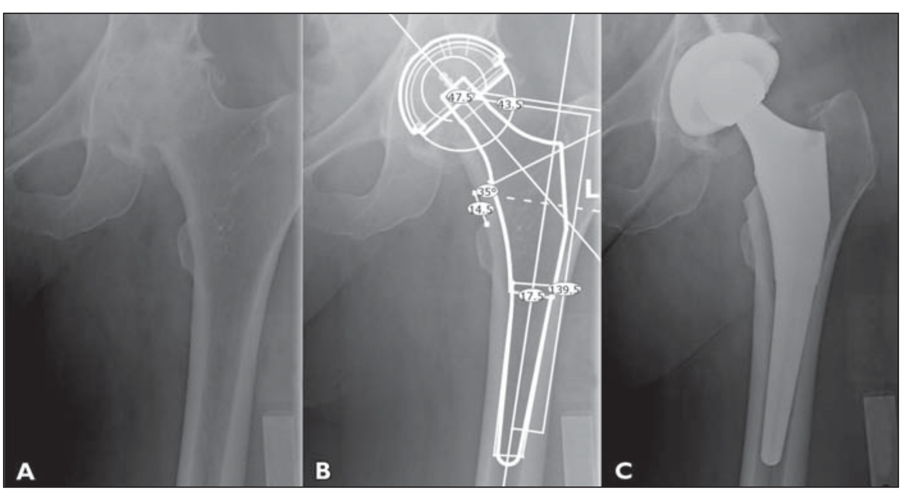

Fig. 12—Digital templating for total hip arthroplasty (THA).
A, Preoperative left hip radiograph shows osteoarthritis.
B, Preoperative radiograph has digital template for THA.
C, Postoperative radiograph shows resulting THA.

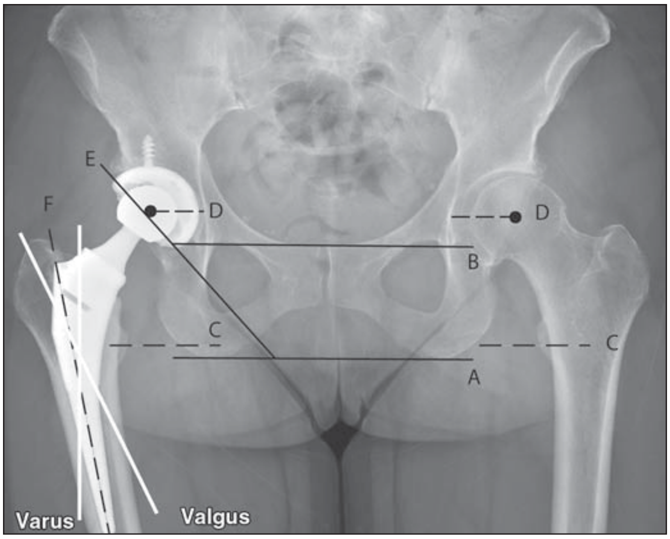

Fig. 13—Assessment of total hip arthroplasty component position on anteroposterior radiograph of 70-year-old woman. Line A is one horizontal line through points at most inferior aspect of ischial tuberosity of each hemipelvis, line B is one horizontal line through points at most inferior aspect of acetabular teardrop of each hemipelvis, line C is two horizontal lines parallel to teardrop line through points at center of lesser trochanter for each femur, line D is one horizontal line between center of femoral head (dots in each femoral head) and teardrop shadow, line E is one tangential line between medial and lateral edges of acetabular cup, line F is one line along axis of femoral stem. Difference in vertical distance between lines B and C assesses leg-length discrepancy in each hip. Acetabular vertical center of rotation is vertical distance between center of femoral head (*dots*) and line A. Acetabular horizontal center of rotation is horizontal distance between center of femoral head and teardrop shadow (line D). Angle between lines E and A assesses lateral acetabular inclination.

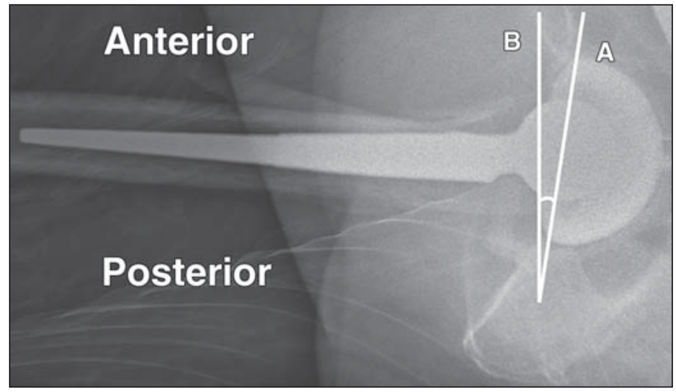

Fig. 14—Assessment of total hip arthroplasty component position on lateral radiograph of 58-year-old woman. Line A is one line tangential to face of acetabulum, and line B is one line perpendicular to horizontal plane. Acetabular anteversion is angle between lines A and B (normal = 5–25°).

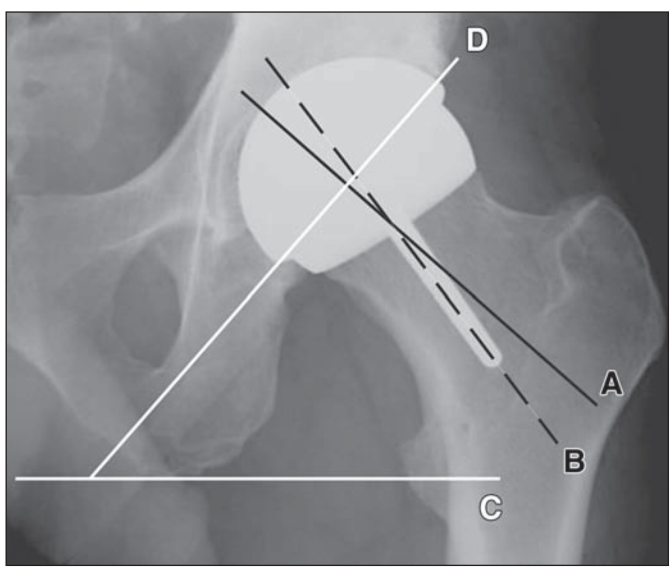

Fig. 15—Assessment of resurfacing total hip arthroplasty component position on anteroposterior radiograph of 41-year-old man. Line A is one line along axis of femoral neck. Line B is one line along axis of femoral stem. Line C is one horizontal line through most inferior aspect of ischial tuberosity. Line D is one tangential line between medial and lateral edges of acetabular cup. Femoral component should be placed in valgus position of 5–10° relative to native femur to avoid notching neck. Lateral acetabular inclination angle is 48° (normal = 30–50°).

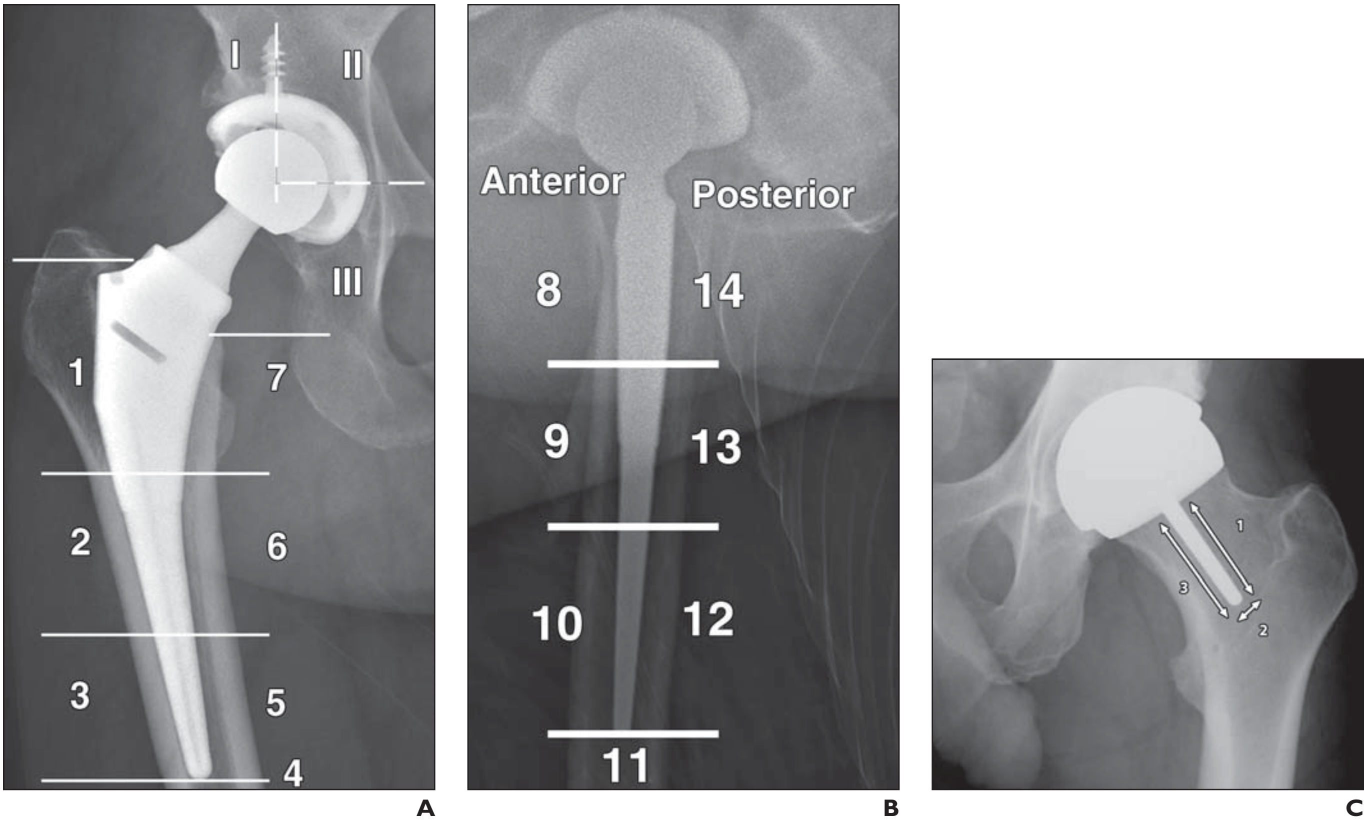

Fig. 16—Radiographic assessment of periprosthetic lucency.
A, 39-year-old man. Bone adjacent to acetabular component is divided into three equal zones, labeled I, II, and III, from lateral to medial on anteroposterior views. Bone adjacent to femoral stem is divided into seven zones on anteroposterior views. First three zones are numbered from proximal to distal on lateral aspect of stem, zone 4 is at tip, and last three zones are numbered from distal to proximal on medial aspect of stem.
B, 58-year-old man. Seven additional zones are numbered on lateral views from 8 at anterior proximal aspect of stem through 14 at posterior proximal aspect of stem.
C, 41-year-old man. In resurfacing hip arthroplasty, there are three zones around peg numbered from 1 through 3 on anteroposterior views, from lateral to medial aspect of peg.

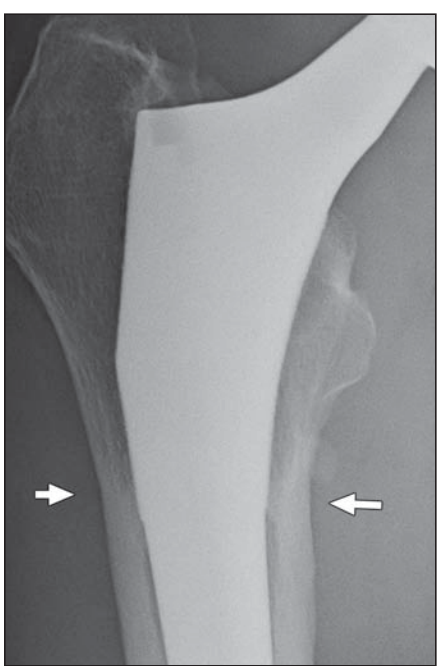

Fig. 17—Bone remodeling in 45-year-old man. Anteroposterior radiograph of right femur shows cementless femoral stem with new bone in zones 1 and 7 (*arrows*); these findings are consistent with "spot weld."

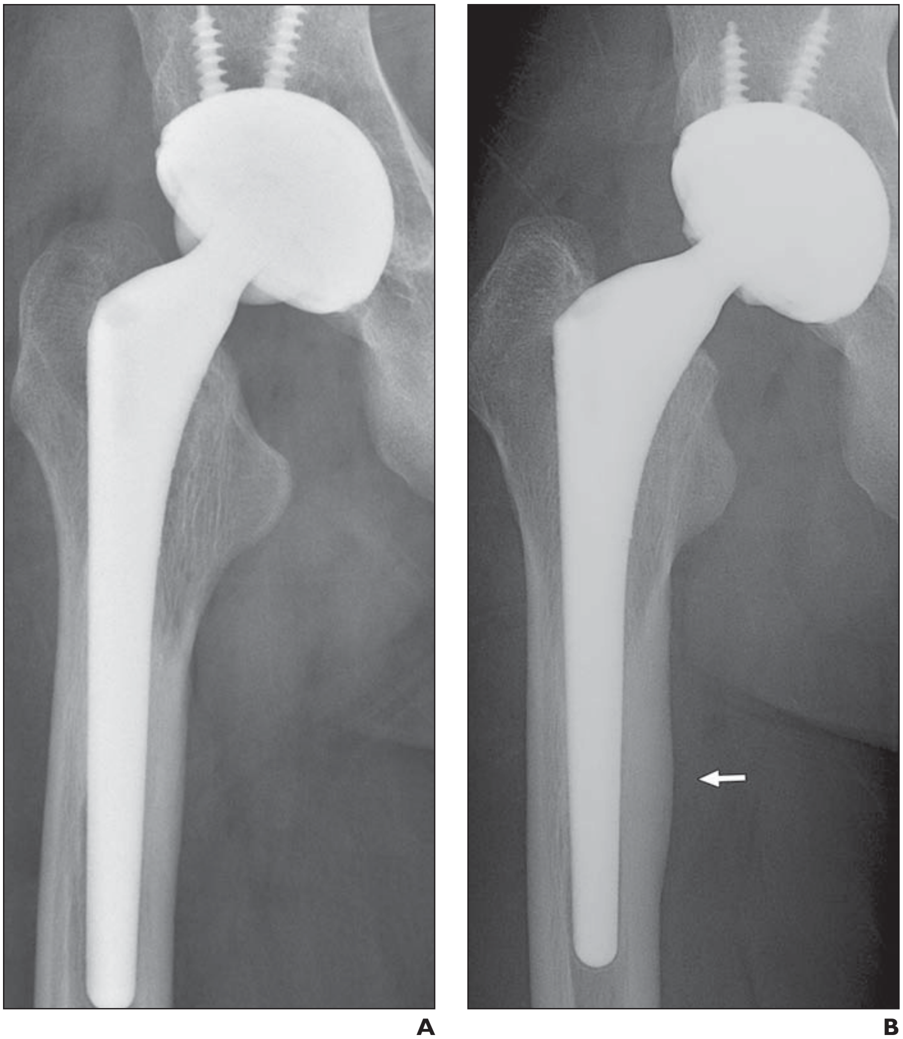

Fig. 18—Bone remodeling in 24-year-old man who underwent right total hip arthroplasty.
A, Initial postoperative anteroposterior radiograph shows cementless femoral stem in neutral position with ceramic-on-polyethylene bearing and cementless acetabular component with screws.
B, Anteroposterior radiograph obtained 2 months after **A** shows focal cortical thickening (*arrow*) along medial aspect of distal portion of stem.