

Biologic fixation and bone ingrowth

Scott M. Sporer, MD, MS^{a,b,*}, Wayne G. Paprosky, MD, FRCS^{a,b}

^a*Orthopaedic Surgery, Rush Medical College, 1725 West Harrison Street, Suite 1063, Chicago, IL 60612, USA*

^b*Central Dupage Hospital, 25 North Winfield Road, Winfield, IL 60190, USA*

Total hip arthroplasty has provided thousands of patients with pain relief and has improved their quality of life. Advances in orthopaedic surgical techniques and implant biomaterials now allow predictable surgical results in the vast majority of patients. Despite the overwhelming success of this surgical procedure, the debate continues surrounding the optimal choice of implants for a primary total hip replacement. Femoral and acetabular implants with varying geometries and fixation methods are currently available. Acrylic bone cement has been used extensively in the past for acetabular and femoral fixation [1]. This mode of component fixation currently remains the technique used most frequently throughout Europe and has shown excellent long-term results (follow-up greater than 10 years). Problems inherent with acrylic bone cement, however, have encouraged other surgeons and scientists to use alternative surfaces to allow biologic fixation.

Acetabular fixation

Cemented acetabular components

Acetabular reconstruction with a cemented acetabular component has shown variable long-term results [2]. Most surgeons now believe that polyethylene wear with associated pelvic osteolysis is the underlying cause leading to most aseptic loosening [3]. Osteolysis is likely multifactorial, with the

most important parameters being surgical technique, thickness of the polyethylene, method of sterilization, and the host response to the debris. The reported long-term survival of cemented acetabular components reflects multiple patient, material, and surgical factors [4]. Callaghan et al have reported the long-term results of a single surgeon and have shown 13% aseptic loosening at 18 years [1]. The aseptic loosening rate increases, however, to 50% when the younger than 50-year-old cohort is reviewed [5]. Harris et al has shown similarly poor results of 52% loosening at 14 years. Other series have shown slightly improved mechanical failure rates, but none have yielded acceptable long-term results [6].

Cementless acetabular components

The poor results of cemented acetabular components prompted many surgeons to begin looking for alternative methods of fixation. Biologic fixation with acetabular bone ingrowth potentially allows the bone surrounding the cup to remain biologically active and remodel following component implantation. Midterm results (follow-up of 5–10 years) with first generation cementless devices showed significant improvement over cemented acetabular shells. Berger et al reported on 111 Zimmer (Warsaw, IN) Harris-Galante I cups at 7–10-year follow-up with no loosening and only 7.4% prevalence of osteolysis [7]. Similarly, Schmalzried et al showed no loosening and no osteolysis in 122 Zimmer Harris-Galante I cups at 4–6 years [8]. As longer follow-up became available on other first generation acetabular components, however, the results began to deteriorate [9]. The monoblock AML cup (Depuy, Warsaw, IN)

* Corresponding author. Central Dupage Hospital, 25 North Winfield Road, Winfield, IL 60190.

E-mail address: ssporer@hotmail.com (S.M. Sporer).

showed excellent early results. After 8–9 years, however, polyethylene wear and osteolysis became problematic with a 9% revision rate at 12 years (Fig. 1). Several other components such as the DePuy ACS, Howmedica PCA (Howmedica/Osteonics, Allendale, NJ), and the Mallory-Head I cup (Biomet, Warsaw, IN) showed even poorer results with polyethylene wear, polyethylene fracture, and severe periacetabular osteolysis [9]. Unlike the cemented acetabular shells, these cementless cups remained well fixed to the pelvis despite the dramatic surrounding bone loss. Poor locking mechanisms between the liner and shell, incongruity of the polyethylene liner, thin polyethylene, and the use of a 32-mm femoral head were believed to account for these poor results. During this time it was also determined that the degree of osteolysis was correlated to the volume of polyethylene debris.

Second generation acetabular components such as the Arthropor Cup (Joint Medical Products, Stamford, CT) provided a thicker minimum polyethylene thickness of 6 mm, an improved polyethylene locking mechanism, and more conformity between the liner and shell. These modifications resulted in improved clinical results. Paprosky et al evaluated 209 Arthropor cups at 8–11-year follow-up. During this time, 10 polyethylene liners required exchange because of eccentric wear, whereas only 1 component was revised for aseptic loosening. Despite the low prevalence of aseptic loosening, pelvic osteolysis was observed in 8.2% of patients. Implant retrievals and surgical observation demonstrated limited bone ingrowth into the acetabular shell. The areas without bone ingrowth allowed fluid and

particulate debris access behind the acetabular component. This “virtual joint space” as described by Schmalzried [3] resulted in areas of extensive bone loss despite a well fixed component. This method of biologic response is different from that observed with a cemented acetabular component in which a linear osteolytic pattern is observed. The linear pattern observed with a cemented component results in painful aseptic loosening rather than painless massive pelvic osteolysis observed with cementless components.

Various surface finishes and textures have been developed in an attempt to promote biologic ingrowth or on-growth of the acetabular component. Canine models comparing fiber metal versus a beaded surface demonstrated a higher percentage of bone ingrowth into the fiber metal substrate [10,11]. Clinical studies comparing these two surfaces support improved results with a fiber metal versus a beaded surface [12]. The effect of component geometry and polyethylene locking mechanism, however, must not be ignored. Similarly, the use of hydroxyapatite (HA) coating seems to provide earlier and stronger fixation to host bone [13]. The long-term clinical results of HA coated surfaces are varied but do suggest fewer retroacetabular radiolucencies compared with similar acetabular components without HA coating [12]. The clinical significance of these radiolucencies remains unknown.

Once osteolysis is observed around a cementless acetabular component, the treating physician must determine a clinical and radiographic threshold to intervene surgically. Unlike in patients with a loose cemented component, osteolysis surrounding a

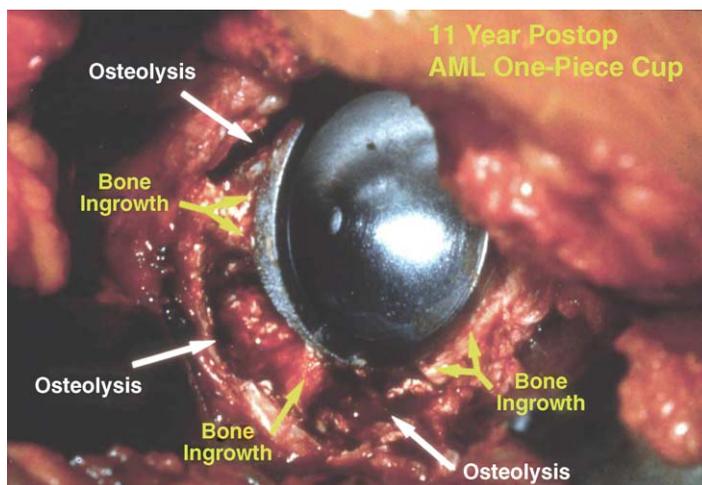


Fig. 1. Osteolysis surrounding a well fixed cementless AML monoblock acetabular component.

well fixed acetabular component is rarely symptomatic. If the osteolysis is left untreated and is allowed to progress, patients may develop severe bone loss before developing pain and a loose component. Surgical treatment of a well fixed acetabular component with associated osteolysis can include polyethylene liner exchange or removal of the component. Maloney et al reported the results of 35 patients who had well fixed acetabular components with retroacetabular osteolysis treated with polyethylene liner exchange and debridement of the granuloma with or without placement of allograft chips [14]. In this series none of the lesions progressed, and in one third of the patients the lesions completely resolved. This remains the senior author's method of treatment for a well fixed acetabular component. If the acetabular component demonstrates damage from the femoral head, the locking mechanism has been damaged, or replacement liners are not available, a new polyethylene liner should be cemented into the retained shell or the cup should be revised [15].

Acetabular component conclusions

The prevalence of pelvic osteolysis between cemented and cementless acetabular components remains similar. If left untreated, the severity of bone loss with either component may result in a more complex and less predictable revision situation. Cemented acetabular components more consistently show a linear osteolytic pattern that results in a greater rate of loosening [16]. Pain frequently is associated with a loose acetabular component and consequently most patients seek medical attention. In contrast, patients with cementless acetabular component can have massive pelvic osteolysis with a relative paucity of symptoms. These findings demonstrate the importance of annual radiographic follow-up. The lower rate of aseptic loosening and the ability to simply exchange the polyethylene liner rather than perform a complete acetabular revision are the main reasons the senior author continues to use biologic fixation for the acetabular component.

Femoral fixation

Cemented fixation

The optimal method to obtain femoral fixation remains controversial. Unlike the acetabulum in

which long-term results favor cementless fixation, the results of cemented and cementless femoral fixation are comparable. Excellent long-term results have been observed for cemented and cementless stems, whereas poor short-term results also have been observed for both methods of fixation. Callaghan et al have shown excellent long-term results of cemented Charnley stems with a 7% prevalence of revision for aseptic femoral revision at a minimum of 25 years [17]. Several series, however, have shown a higher rate of loosening in the higher demand patients [18,19]. Cement fixation failure is a nonreversible and progressive phenomenon. As the surgical indications for total hip replacement are broadened and younger, more active patients elect to have total hip replacement, alternative methods of femoral fixation have been explored.

Proximal cementless fixation

Cementless fixation relies on a biologic substrate to in-grow into the femoral component. Potential benefits with this type of fixation are its ability to remodel actively and to repair over time. Ideally the ability to adapt to changes in load and the femoral geometry will provide stable long-term fixation. Cementless femoral fixation can be obtained proximally or distally. Proximal fixation relied on a wedge fit between the component and the metaphyseal bone, whereas extensively porous coated stems rely on a scratch fit between the component and the diaphyseal bone. Several surgeons advocate the use of a proximally coated stem because of the belief that proximal porous coating results in proximal stress transfer to the femur and results in less cortical atrophy. A wide variety of proximally fixed stems have been manufactured with varying designs and characteristics. The long-term clinical results depend heavily on the geometry of the stem, component composition, and the area for potential bone ingrowth. First generation circumferentially porous coated cobalt chrome stems such as the Howmedica PCA yielded acceptable midterm results as shown in the Swedish Multicenter Trial [20]. Noncircumferentially coated stems, however, such as the Anatomic Porous Replacement I have shown a high rate of failure. Dorr et al demonstrated a 16% revision rate and a 70% progressive loss of fixation in 100 stems at an average of 6.7 years [21]. The noncircumferentially titanium mesh Harris-Galante stem showed similarly poor early results, with a 22% incidence of osteolysis at 44 months and a 52% incidence of osteolysis at 71 months [22,23]. In this later cohort, more than two thirds of the lytic lesions seen at

44 months increased in size by 71 months (Fig. 2). The poor midterm results of noncircumferentially proximally coated stems were believed to be caused by the ability of wear particles to reach the distal metaphyseal and diaphyseal bone through channels. The enlarged effective joint space allowed distal osteolysis and early aseptic loosening [3].

Implants with circumferential proximal coatings did not seem to have problems with distal osteolysis, assuming that implant fixation occurred with a stable fibrous or osseous integration. Hozak et al reported on the 5-year results of 105 hips using a circumferentially proximally coated Taperloc (Biomet, Warsaw, IN) stem [24]. In this series, all hips were considered to be bone ingrown and only one stem required femoral revision. Several other investigators demonstrated similar results using the Mallory Head (Biomet, Warsaw, IN) and Omnifit (Howmedica/Osteonics, Allendale, NJ) stem at intermediate and long-term follow-up [25–27]. Hellman et al reported the results of 94 hips using the Omnifit stem at an average 10-year follow-up with a 3% femoral revision rate and no radiographic loosening.

The intermediate results of total hip arthroplasty with stems using proximal fixation clearly demonstrate that a successful long-term result depends highly on initial component fixation in the proximal metaphyseal bone. Initial fixation can be promoted through a component design that allows intimate contact with the host endosteal bone and through the

use of enhanced biologic surfaces. HA coating has been applied to proximally coated stems in an attempt to facilitate bone ingrowth and apposition. Capello et al reported the 6-year results of 152 Omnifit stems with HA coating. At intermediate follow-up all stems were considered bone ingrown and no stems were revised for aseptic loosening. Osteolysis, however, was noted in 32% of the stems limited to Gruen zones 1 and 7 [28]. Although HA coating may promote biologic fixation, retrieval analysis of polyethylene inserts demonstrated a greater number of larger particles present in patients who had HA coated implants compared with those without HA coating [29]. It is believed that these particles may contribute to third body wear and contribute to this high rate of osteolysis.

Thigh pain is an additional consideration when determining the optimal stem to be used in total hip replacement. Early studies with proximally coated devices have shown a high incidence of thigh pain [26,27]. Barrack et al studied patients' perceived thigh pain following total hip replacement. The prevalence of thigh pain in proximally coated implants was twice that in a cemented or an extensively coated stem, whereas the severity of pain among the groups was similar [30].

Extensively coated cementless fixation

The high rate of failure in some early proximally coated stem designs encouraged the senior author to use an extensively coated device. The Anatomic Medullary Locking (AML) stem (Depuy, Warsaw, IN) was designed to maximize diaphyseal contact to achieve axial and rotation stability. The AML is a straight, nontapered, cylindric stem constructed from cobalt chrome. This device has shown excellent long-term results. Patient series by Paprosky et al and Engh et al have shown revision rates of less than 5% at 10–15-year follow-up, with more than 98% of patients demonstrating radiographic signs of bone ingrowth [31,32] (Fig. 3). The anatomic variation in the shape of the proximal femur creates difficulties in obtaining sufficient fit/fill and rotational stability in all patients with a proximally coated device. The diaphyseal bone, however, tends to be more cylindric in shape and more robust to allow circumferential reaming. As a result, a nontapered cylindric stem provides greater flexibility in adjusting leg length and rotation without compromising fixation when compared with a proximally fixed, wedge-shaped stem.

Thigh pain was an initial concern with the proposed use of an extensively coated stem. Some



Fig. 2. Distal osteolysis associated with a proximal non-circumferentially coated femoral stem.

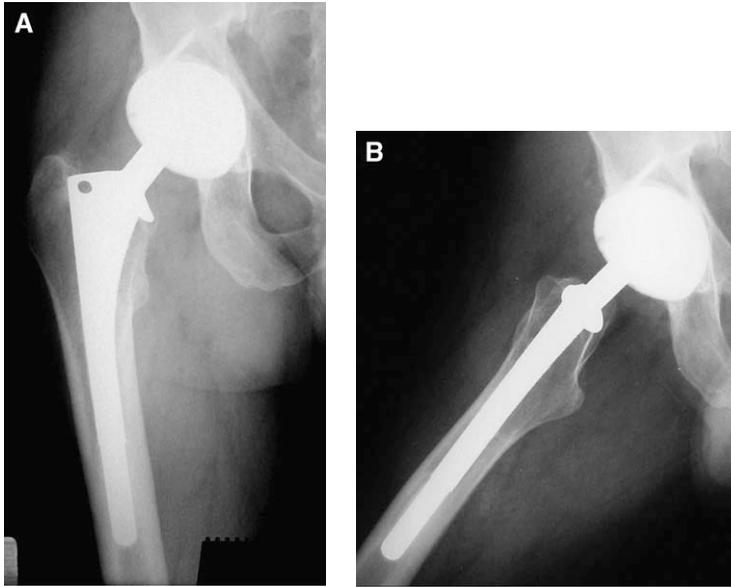


Fig. 3. Sixteen-year postoperative radiographs of a well functioning extensively coated femoral stem. (A) Anterior-posterior radiograph demonstrating distal ingrowth. (B) Lateral radiograph demonstrating proximal stress shielding indicating distal fixation.

surgeons believed that the modulus mismatch would cause an increased incidence of thigh pain specifically in the larger diameter stems. The senior author, however, does not believe that thigh pain is related to stem stiffness. Studies comparing the incidence of thigh pain between cemented and fully porous coated stems demonstrated no statistical difference [30]. Other surgeons expressed concerns about proximal stress shielding with the use of an extensively coated stem. Although proximal stress shielding does occur, it occurs in proximal and extensively coated devices. Engh et al studied bone remodeling in 13 cemented and 11 extensively coated stems and used the non-operated contralateral femur as a control [33]. The bone mineral density in the implanted femur was correlated strongly to the bone mineral density in the control femur. These findings, however, were independent of the type of implant or the type of fixation. In other words, patients with a higher bone mineral density before surgery had less proximal stress shielding [34].

Excellent long-term results of extensively coated stems also can be expected in the younger patient population. The senior author followed a cohort of 102 patients younger than age 50 years who had primary total hip arthroplasty. At an average 8.3-year follow-up, 96% of stems were bone ingrown, whereas 3% were stable fibrous and 1% was unstable.

Osteolysis was noted in only 4% of patients, most commonly in the greater trochanter [35]. Archibeck et al have shown similarly good results at 10 years in 85 patients (92 hips), with no revisions occurring for femoral loosening or osteolysis [36].

Summary

Extensively coated femoral stems remain the implant of choice for the senior author. Stable fixation has been shown to occur in greater than 98% of stems at long-term follow-up including the younger age cohort. Osteolysis is a rare phenomenon with this method of fixation. If osteolysis does occur in the femur of a well fixed, extensively coated stem, however, it does not seem to progress below the level of the lesser trochanter, and late loosening at up to 18 years has not been seen. Proximally coated stems were developed to address the potential concerns of stress shielding and thigh pain associated with extensively coated stems. The same concerns also are associated with proximally coated stems, however, and the prevalence of thigh pain seems to be the highest in a proximally coated device. The anatomic variation of the proximal femur and the differing bone quality among patients increases the difficulties associated with the use of proximally

coated stems. Anatomic variation is minimized with the use of a diaphyseal fitting stem and implant fixation is therefore more predictable.

References

- [1] Callaghan JJ, et al. Charnley total hip arthroplasty with cement. Minimum twenty-five-year follow-up. *J Bone Joint Surg [Am]* 2000;82(4):487–97.
- [2] Ranawat CS, et al. Prediction of the long-term durability of all-polyethylene cemented sockets. *Clin Orthop* 1995;317:89–105.
- [3] Schmalzried TP, Jasty M, Harris WH. Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. *J Bone Joint Surg [Am]* 1992;74(6):849–63.
- [4] Ranawat CS, Peters LE, Umlas ME. Fixation of the acetabular component. The case for cement. *Clin Orthop* 1997;344:207–15.
- [5] Callaghan JJ, et al. Charnley total hip arthroplasty in patients less than fifty years old. A twenty to twenty-five-year follow-up note. *J Bone Joint Surg [Am]* 1998;80(5):704–14.
- [6] Barrack RL, Mulroy Jr RD, Harris WH. Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty. A 12-year radiographic review. *J Bone Joint Surg [Br]* 1992;74(3):385–9.
- [7] Berger RA, et al. Primary cementless acetabular reconstruction in patients younger than 50 years old. 7- to 11-year results. *Clin Orthop* 1997;344:216–26.
- [8] Schmalzried TP, et al. The Harris-Galante porous acetabular component press-fit without screw fixation. Five-year radiographic analysis of primary cases. *J Arthroplasty* 1994;9(3):235–42.
- [9] Barrack RL, et al. Pelvic lysis and polyethylene wear at 5–8 years in an uncemented total hip. *Clin Orthop* 1997;335:211–7.
- [10] Turner TM, et al. A comparative study of porous coatings in a weight-bearing total hip-arthroplasty model. *J Bone Joint Surg [Am]* 1986;68(9):1396–409.
- [11] Sumner DR, et al. Remodeling and ingrowth of bone at two years in a canine cementless total hip-arthroplasty model. *J Bone Joint Surg [Am]* 1992;74(2):239–50.
- [12] Thanner J. The acetabular component in total hip arthroplasty. Evaluation of different fixation principles. *Acta Orthop Scand* 1999;286(Suppl):S1–41.
- [13] Oonishi H, et al. The effect of hydroxyapatite coating on bone growth into porous titanium alloy implants. *J Bone Joint Surg [Br]* 1989;71(2):213–6.
- [14] Maloney WJ, et al. Treatment of pelvic osteolysis associated with a stable acetabular component inserted without cement as part of a total hip replacement. *J Bone Joint Surg [Am]* 1997;79(11):1628–34.
- [15] Paprosky WG. Cementless sockets: optimums and outcomes. *Orthopedics* 1997;20(9):777–9.
- [16] Zicat B, Engh CA, Gokcen E. Patterns of osteolysis around total hip components inserted with and without cement. *J Bone Joint Surg [Am]* 1995;77(3):432–9.
- [17] Keener JD, et al. Twenty-five-year results after Charnley total hip arthroplasty in patients less than fifty years old: a concise follow-up of a previous report. *J Bone Joint Surg [Am]* 2003;85A(6):1066–72.
- [18] Sporer SM, et al. Hybrid total hip arthroplasty in patients under the age of fifty: a five- to ten-year follow-up. *J Arthroplasty* 1998;13(5):485–91.
- [19] Sullivan PM, et al. Total hip arthroplasty with cement in patients who are less than fifty years old. A sixteen to twenty-two-year follow-up study. *J Bone Joint Surg [Am]* 1994;76(6):863–9.
- [20] Malchau H, et al. Scandinavian multicenter porous coated anatomic total hip arthroplasty study. Clinical and radiographic results with 7- to 10-year follow-up evaluation. *J Arthroplasty* 1997;12(2):133–48.
- [21] Dorr LD, et al. Failure mechanisms of anatomic porous replacement I cementless total hip replacement. *Clin Orthop* 1997;334:157–67.
- [22] Maloney WJ, Woolson ST. Increasing incidence of femoral osteolysis in association with uncemented Harris-Galante total hip arthroplasty. A follow-up report. *J Arthroplasty* 1996;11(2):130–4.
- [23] Clohisy JC, Harris WH. The Harris-Galante uncemented femoral component in primary total hip replacement at 10 years. *J Arthroplasty* 1999;14(8):915–7.
- [24] Hozack WJ, et al. Primary cementless hip arthroplasty with a titanium plasma sprayed prosthesis. *Clin Orthop* 1996;333:217–25.
- [25] Mallory TH, et al. Clinical and radiographic outcome of a cementless, titanium, plasma spray-coated total hip arthroplasty femoral component. Justification for continuance of use. *J Arthroplasty* 1996;11(6):653–60.
- [26] Mulliken BD, et al. Results of the cementless Mallory-Head primary total hip arthroplasty: a 5 to 7 year review. *Iowa Orthop J* 1996;16:20–34.
- [27] Hellman EJ, Capello WN, Feinberg JR. Omnifit cementless total hip arthroplasty. A 10-year average followup. *Clin Orthop* 1999;364:164–74.
- [28] Capello WN, et al. Hydroxyapatite-coated total hip femoral components in patients less than fifty years old. Clinical and radiographic results after five to eight years of follow-up. *J Bone Joint Surg [Am]* 1997;79(7):1023–9.
- [29] Bloebaum RD, et al. Analysis of particles in acetabular components from patients with osteolysis. *Clin Orthop* 1997;338:109–18.
- [30] Barrack RL, et al. Patients' perception of pain after total hip arthroplasty. *J Arthroplasty* 2000;15(5):590–6.
- [31] Engh Jr CA, et al. Long-term results using the anatomic medullary locking hip prosthesis. *Clin Orthop* 2001;393:137–46.
- [32] Della Valle CJ, Paprosky WG. The middle-aged patient with hip arthritis: the case for extensively coated stems. *Clin Orthop* 2002;405:101–7.

- [33] Sychterz CJ, et al. Effect of femoral stiffness on bone remodeling after uncemented arthroplasty. *Clin Orthop* 2001;389:218–27.
- [34] Maloney WJ, et al. The Otto Aufranc Award. Skeletal response to well fixed femoral components inserted with and without cement. *Clin Orthop* 1996;333:15–26.
- [35] Kronick JL, Barba ML, Paprosky WG. Extensively coated femoral components in young patients. *Clin Orthop* 1997;344:263–74.
- [36] Archibeck MJ, et al. Second-generation cementless total hip arthroplasty. Eight- to eleven-year results. *J Bone Joint Surg [Am]* 2001;83A(11):1666–73.