Cementless Femoral Fixation in Total Hip Arthroplasty

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Abstract

Cementless femoral fixation by means of bone ingrowth has been successful in total hip arthroplasty in patients with sufficient bone quality. Consistent bone ingrowth and resultant long-term success involve many factors, including surgical technique, initial mechanical stability achieved at time of implantation, stem design and material, and implant surface. One potential method for achieving faster, more consistent initial bone ingrowth is use of the osteoconductive ceramic hydroxyapatite. In addition, more stable initial fixation most likely improves long-term outcome.

In this article, we review the criteria for successful cementless femoral fixation and the long-term results reported in the literature.

Total hip arthroplasty (THA) is one of the most successful orthopedic procedures for restoring function and relieving pain in patients with end-stage arthritis of the hip.[1] Implant longevity and THA success depend not only on surgical technique but also on implant design, metallic alloy, and type of femoral fixation. Two popular types of femoral fixation are cemented and cementless. The success of cemented femoral fixation, particularly in elderly patients with osteoporotic bone, has been reported in long-term follow-up studies,[1-3] but, for younger patients, cemented fixation in THA results in higher rates of osteolysis and aseptic loosening.[4] Gruen and colleagues[5] described the mechanisms of failure in cemented THA. Cementless fixation was introduced as an alternative form of fixation, more suitable for younger patients with type A and B bone quality as classified by Dorr and colleagues.[6] To our knowledge, in 1978 Judet and colleagues[7] provided the earliest evidence of successful cementless fixation in THA. In the present article, we review the criteria for successful cementless femoral fixation: initial mechanical stability, stem design and material, surface texture, and theoretical advantages of hydroxyapatite coating.

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Indications

Cementless fixation is usually reserved for, though not limited to, young, active patients with type A and B bone quality.[6] Older patients with type C bone quality, Paget disease, certain inflammatory arthritis, tumor involvement, or postirradiation might not have good bone ingrowth potential and might not be ideal candidates for cementless fixation. However, cementless fixation has recently been reported as successful in patients 65 or older and in patients with type C bone.[8-10] These results suggest that older age and osteoporosis are not absolute contraindications for cementless fixation. Fixation type should be individualized, and, as with any surgical procedure, success depends partly on patient selection.

Early Mechanical Stability

Initial mechanical stability is absolutely required for successful bone ingrowth. Femoral component micromotion of more than 40 µm adversely affects bone ingrowth.[11] An important measure that can be taken to help reduce the chance of femoral motion is preoperative templating that assists in optimal sizing of the femoral component. One of the most important contributors to initial stability is the geometry of the stem. Traditionally, femoral stems are tapered, anatomical, or cylindrical.

Figure 1. Zweymüller prosthesis.

The classic tapered stem, such as the Zweymüller prosthesis (AlloPro, Baar, Switzerland), (Figure 1) was first implanted in 1979. It is now manufactured by Zimmer (Warsaw, Ind) and known as the Alloclassic. This stem, which has a taper of 3° from the proximal portion to the distal portion on the sagittal and

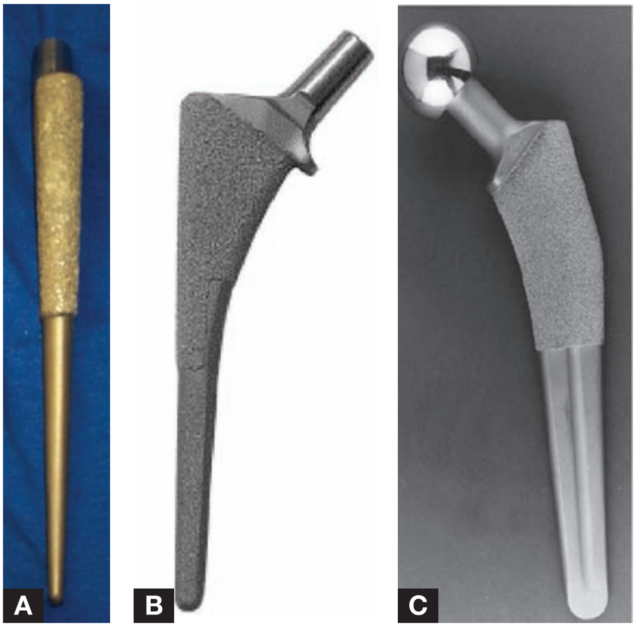

Figure 2. **Tapered stems: (A) Taperloc (Biomet, Warsaw, Ind), (B) Tri-lock (DePuy, Warsaw, Ind), and (C) Mallory-Head (Biomet).**

coronal planes, provided axial stability at implantation. Its rectangular cross-section has 4 corners and 4 flat surfaces that are compressed into the proximal femur. Compaction broaching is used. The cancellous bone is compacted along the flat surfaces of the stem, and, with fixation of the 4 corners, rotational stability is achieved.[12,13] The success of compaction broaching in Europe led to its being incorporated, with modification, into the design of prostheses in the United States. Taperloc (Biomet, Warsaw, Ind), Tri-lock (DePuy, Warsaw, Ind), and Mallory-Head (Biomet) are some examples of successful tapered stems (Figure 2). Unlike the Zweymüller prosthesis, its counterparts do not possess the rectangular geometry. Taperloc and Tri-lock stems have flat but tapered anterior and posterior surfaces with rounded medial and lateral sides. However, axial and rotational stability is achieved in a similar manner. Most tapered stems achieve fixation in the high diaphyseal cortical bone just below the lesser trochanter, and the stem used depends on the largest broach size that achieves cortical fixation.[14] No reaming of the femoral canal is required before implantation. Furthermore, straight tapered stems allow for easier insertion, and, theoretically, risk for femoral fracture during implantation is reduced. Numerous successful long-term results of different tapered stems have been reported.[15-20]

The second, equally popular design consists of anatomically shaped stems, such as Anatomic Porous Replacement (APR; Zimmer) and Porous Coated Anatomic (PCA; Howmedica, Rutherford, NJ) (Figure 3), that use different surgical techniques and philosophies for initial stability. Unlike tapered stems, anatomical stems are designed to match the shape of the proximal femur. Complex shaping of the femoral canal to accommodate the implant requires reaming to achieve a tight diaphyseal fit.[21] This precise "fit-and-fill" philosophy is important for initial stability. Anatomical stems achieve maximum 3-point fixation and loading in the metaphysis plus the tight diaphyseal fit. Some criticisms of this design have been raised. First, there is large variation in shape and size of the proximal femur across populations, as demonstrated in a cadaveric study by Noble and colleagues,[22] requiring a large inventory of right- and left-specific implants to decrease mismatch between femoral component and canal. Second, the posterior bow of the anatomical stem that matches that of the proximal femur increases the risk for femoral fracture during implantation. Despite these concerns, these stems have had successful long-term results as well.[23-25] Kawamura and colleagues[23] reported a 90.0% overall survival rate for PCA stems at 14-year follow-up. Similarly, Archibeck and colleagues[25] reported 100% survivorship for Anatomic Hip stems after 10 years. Clearly, anatomical and tapered stems are equally effective, and we are not aware of any study that suggests the superiority of one design over the other.

The third design, with its different philosophy of fixation, consists of cylindrical, straight, nontapered, and extensively coated stems. A commonly used implant of this design is the Anatomic Medullary Locking (AML; DePuy) stem (Figure 4). Unlike the tapered and anatomical stems, which provide mostly proximal fixation, the AML stem achieves distal fixation at the isthmus by means of a "scratch fit" between the fully roughened porous surface of the implant and the slightly smaller, underreamed femoral canal, as described by Engh and Massin.[26] Long-term follow-up studies have proved that these prostheses function well and have a survivorship rate of more than 95% at 15 years or more.[27-30] Nevertheless, there are some concerns with this design. First, proper seating of this femoral component depends largely on feel, and advancing the stem in a smaller, underreamed canal carries a risk for femoral fracture. Second, axial stability of the cylindrical stem in a canal of similar shape might be jeopardized without proper seating of the stem. Most important, initial mechanical stability depends largely on the rotational stability achieved by a "scratch fit" between the porous surface and the cortical bone. Finally, distal fixation might cause proximal bone loss

Figure 3. **Anatomical stems: (A) Porous Coated Anatomic (Howmedica, Rutherford, NJ) and (B) Anatomic Hip (Zimmer, Warsaw, Ind).**

Figure 4. Cylindrical stem, anteroposterior **(A)** and lateral **(B)** views: Anatomic Medullary Locking (DePuy, Warsaw, Ind).

Figure 5. Most modern implants, such as the Natural Hip prosthesis, (Zimmer, Warsaw, Ind), have distal modifications, such as spline and coronal slot, to decrease stiffness and improve rotational stability.

from stress shielding. Bone remodeling caused by stress shielding was shown by Bobyn and colleagues[31] and Engh and Bobyn[32] to occur predominantly in the first year and seldom after 2 years. Although Bugbee and colleagues[29] demonstrated that stress shielding has no clinical consequences at long-term follow-up, the resulting proximal bone loss remains a concern and might present a challenge in revision scenarios.

Many modern prostheses cannot be categorized as tapered, anatomical, or cylindrical simply because they have adopted features from these 3 designs. For example, the Natural Hip (Zimmer) femoral prosthesis (Figure 5), with its straight, dual-tapered design, incorporates 9° anteversion into its neck and a 3.5-mm anterior build-up in the metaphyseal portion of the stem. Furthermore, the coronal slot in its distal stem not only lowers the stem stiffness but allows the tip to self-adjust from 2 mm to 4 mm in the anteroposterior direction to fill the distal canal. The distal splines and flutes, common features of many prostheses, permit cortical purchase and enhance rotational stability. Hofmann and colleagues[33] recently reported excellent midterm follow-up results using these cementless stems. Therefore, thorough knowledge of the chosen implant along with good surgical techniques and patient selection are key in a successful operation.

Other factors that might affect micromotion are attributed to stem design. Some believe that adding a collar can improve axial stability by preventing distal migration of the stem and might increase axial loading to failure.[34,35] Additional benefits of a collar include reducing proximal bone loss from stress shielding by loading of the medial femoral cortex. A collar might also aid in reducing wear debris entry into the femoral canal and therefore lower the risk for distal osteolysis.[35] Ultimately, these benefits occur only with intimate collar–calcar contact. Collar–calcar contact might not be consistently achieved, despite proper templating and neck cut. Despite the theoretical advantages, there are also some concerns regarding collar use. Meding and colleagues[36,37] found no significant difference in hip scores, pain, function, or radiographic changes between collared and collarless uncemented THA in prospective, randomized studies. Nevertheless, a collar is a feature of many modern implants. Its use remains controversial.

Materials

Two types of metallic alloys are used for cementless femoral prostheses: cobalt based and titanium based. Cobalt-based alloys consist mostly of cobalt (Co), chromium (Cr), and molybdenum. Co-Cr alloys have high yield strength and are very resistant to surface deformation (high hardness, wear resistance). These properties make these materials ideal for articulating surfaces. Midterm and long-term success with Co-Cr femoral stems has been reported.[23-25,38,39] However, the stiffness of Co-Cr is almost twice that of the cortical bone—a mismatch that causes clinical problems. The higher rate of thigh pain in patients who receive Co-Cr femoral stems can be attributed to this mismatch. In the study by Kawamura and colleagues,[23] the incidence of thigh pain with Co-Cr PCA stems was 36% at follow-up of 10 years or more. Similarly, Healy and colleagues[24] and Bourne and colleagues[39] reported 25.6% and 27% incidence of thigh pain at follow-ups of 12 years and 5 years, respectively. Fully porous coated AML stems with a Co-Cr substrate have thigh pain rates ranging from 7% to 21%.[27,29,40] Tapered Co-Cr stems appear to have lower rates of thigh pain in some studies.[17,20]

In contrast, titanium-based femoral stems contain titanium, aluminum, and vanadium (Ti-6Al-4V). Titanium alloys are more biocompatible than Co-Cr alloys are. Furthermore, Ti-6Al-4V has high strength, fatigue resistance, and, most important, low elastic modulus, similar to that of cortical bone. These physical attributes promote gradual loading from the proximal femur to the distal femur more physiologically, and therefore minimize proximal bone resorption from stress shielding. Consequently, titanium alloy is ideal for tapered or anatomical femoral prostheses. Moreover, the similarity in stiffness between Ti-6Al-4V alloys and cortical bone appears to minimize occurrence of thigh pain. In one study, the incidence of thigh pain with tapered titanium stems was only 2.3% at 10- to 15-year follow-up.[15] In other midterm and long-term studies with tapered titanium prostheses, Bourne and colleagues[18] and Hofmann and colleagues[33] found incidence of thigh pain at latest follow-up to be 3% and 1%, respectively. No patient with thigh pain had radiographic evidence of loosening or required revision of femoral components. In addition, rates of thigh pain were lower for anatomical stems with titanium substrate than for anatomical stems with Co-Cr substrate.[25,41]

Surface Texture

In cementless THA, femoral stem surface texture is one of the most important factors for long-term fixation. A porous surface is created when Co-Cr beads are sintered onto the exterior of the femoral stem. A fiber-metal surface is generated by plasma-spraying titanium substrate onto the surface of the stem. Although the minimal thickness surface texture for successful long-term fixation is not known, experience with first-generation APR, Harris-Galante, and BIAS stems (all are Zimmer products) has shown that porous coatings must be circumferential. Patch porous coating resulted in a higher rate of distal osteolysis and aseptic loosening because a nonporous surface lacked bone ingrowth and served as a pathway for distal migration of wear particles.[42,43] In addition, Dorr and colleagues[42] found that porous-coated APR stems that covered less than 10% of the total stem surface area had shown evidence of loosening at autopsy.

Some cementless femoral components can be extensively (eg, AML) or proximally porous-coated. Extensively coated stems have a porous coating that covers at least four fifths of the total surface area. By contrast, most proximally coated stems have a porous coating in the proximal third. Long-term outcomes for extensively and proximally coated stems have been excellent.

Proximal bone is often diseased in revision cases. In this scenario, extensively coated stems are the cementless prosthesis of choice. This style of implant is preferred, as it bypasses poor proximal bone and achieves thorough distal fixation. However, there are concerns regarding fully porous stems for primary THA. Distal fixation of fully coated stems often leads to proximal bone loss from stress shielding.[31,32] However, this does not adversely affect the long-term outcome of primary THA.[29]

Hydroxyapatite

Hydroxyapatite (HA) has osteoconductive properties. Osteoconduction is defined as the ability to stimulate the attachment, migration, and distribution of vascular and osteogenic cells within an implant or graft. HA has many practical applications in orthopedics. It was first introduced in 1985 for cementless THA in an effort to accelerate bone ongrowth. HA can be applied to both porous and nonporous surfaces by plasma-spraying. Its properties are defined by the thickness of the HA coating and the calcium-to-phosphorus ratio. Ideally, coating thickness is between 50 µm and 75 µm, and the calcium-to-phosphorus ratio is approximately 1.67.

Numerous reports support using HA coating to improve initial integration and long-term mechanical stability of uncemented prostheses. In a multicenter study with 436 hips and a 15-year-minimum follow-up, Capello and colleagues[44] found only 1 revision of a femoral component for aseptic loosening. In addition, there were no radiographically unstable stems. This finding yielded an overall mechanical failure rate of less than 1% for HA-coated stems. These results, evaluated against results with cementless uncoated prostheses and a similar follow-up period, were superior for long-term fixation. Similarly, Landor and colleagues[45] found significantly higher degree and quality of osteointegration for HA-coated hip stems than for identical uncoated implants. These results were based on radiographic findings and Harris Hip Scores. The study used follow-up data from 11.4 years (HA-coated group) and 10.6 years (uncoated group).

In other studies, HA coating had no additional benefit.[46] At a mean follow-up of 9.8 years, Parvizi and colleagues[47] found no significant clinical or radiographic difference in a matched-pair analysis of HA-coated and uncoated stems implanted within the same patient. Another matched-pair study presented 15 patients who had bilateral THA with an HA-coated prosthesis on one side and a non–HA-coated stem on the contralateral side.[48] HA-coated femoral stems showed better bone remodeling and less radiolucent lines. However, there was no notable improvement in clinical outcomes over non-HA hips at 7-year follow-up. In short, HA coating might improve early progression of bone ingrowth but has not been shown to confer superior results over non-HA stems at long-term follow-up. Despite its availability on many modern stems, HA coating remains controversial.

"In cementless THA, femoral stem surface texture is one of the most important factors for long-term fixation."

Summary

The improved techniques and outcomes of THA perhaps account for why this procedure is used more often in younger patients with end-stage arthritis. Cementless fixation in THA has clearly become the preferred method for younger, high-demand patients and might well be the preferred fixation technique in older patients. With use of appropriate technique and implant selection, the surgeon can better achieve early mechanical stability and long-term femoral component durability.

Authors' Disclosure Statement

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