A number of cementless femoral stems are associated with excellent long-term survivorship. Cementless designs differ from one another in terms of geometry and the means of obtaining initial fixation. Strict classification of stem designs is important in order to compare results among series. Loosening and thigh pain are less prevalent with modern stem designs. Stress-shielding is present in most cases, even with newer stem designs.

In 1995, the NIH (National Institutes of Health) Consensus Development Panel on Total Hip Replacement supported the use of hybrid fixation with a cemented stem and a noncemented cup because of excellent long-term results\(^1\). However, today, 60% to 90% of the approximately 200,000 total hip arthroplasties performed yearly in the United States involve both a cementless cup and a cementless stem\(^2,3\). There are a variety of cementless femoral stems that have been associated with excellent long-term clinical and radiographic outcomes\(^4-12\). We reviewed these stem designs and geometries and summarize their long-term outcomes. This review does not include prostheses that were designed for fixation in the femoral neck, as they are used less commonly and long-term follow-up data are not available.

**Basic Science of Cementless Fixation**

In 1981, on the basis of human retrieval studies, Albrektsson et al. described "osseointegration" as the attachment of lamellar bone to implants without intervening fibrous tissue\(^13\). Both animal studies and human retrieval analyses of implants have led to a better understanding of this process, which takes approximately four to twelve weeks after implantation and may continue for up to three years\(^14,15\). Adequate osseous contact and firm fixation of the implant minimize micromotion\(^14\). Micromotion of >150 μm leads to fibrous tissue formation, between 40 and 150 μm leads to a combination of bone and fibrous tissue formation, and <20 μm results in predominantly bone formation\(^16-18\).

Initial fixation is obtained by press-fitting a slightly oversized component. A number of factors that influence the initial stability or primary fixation will be discussed. These include geometry, roughness and coating of the stem, technique of preparation, and bone quality.

**Surfaces and Coatings**

Ingrowth occurs when bone grows inside a porous surface. Ongrowth occurs when bone grows onto a roughened surface. The surface characteristics of an implant determine which occurs. Ingrowth requires a pore size between 50 and 400 μm, and the percentage of voids within the coating should be between 30% and 40% to maintain mechanical strength\(^15,19\). Ingrowth surfaces include sintered beads, fiber mesh, and porous metals. Sintered beads are microspheres of either cobalt-chromium or titanium alloy attached by the use of high temperatures\(^20-21\). Fiber mesh coatings are metal pads attached by diffusion bonding\(^20\). Porous metals have a uniform threedimensional network\(^22\), with high interconnectivity of the...
voids and a high porosity (75% to 85%) compared with that of sintered beads and fiber metal coatings (30% to 50%). Ongrowth 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). The surface roughness ranges from 3 to 5 μm. 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. There is less interconnecting porosity than with the ingrowth surfaces; however, 90% of the implant fatigue strength is retained, whereas only 50% is retained after diffusion bonding and sintering.

Hydroxyapatite is a calcium phosphate compound that is plasma sprayed directly on the implant alone or over a porous coating. It is osteoconductive and enhances growth of mineralized bone onto the implant. There is concern about interface strength when these coatings have been applied to an underlying porous surface. Interface degradation could lead to implant loosening. The optimal thickness of the coating is 50 μm, which does not compromise its strength. Studies have demonstrated no difference in the clinical and radiographic outcomes when stems with hydroxyapatite were compared with the same stems without hydroxyapatite.

It is generally accepted that fixation surfaces need to be circumferential and continuous. These qualities enhance metaphyseal osseointegration and proximal stress transfer and decrease bone loss from stress-shielding. Stems without circumferential coating have been found to have high failure rates. Circumferential coating also provides a seal, which minimizes migration of wear particles and prevents distal osteolysis. Emerson et al. found that stems without circumferential coating were associated with significantly greater distal osteolysis than the same stems with circumferential coating (p = 0.0004). Cobalt-chromium-molybdenum alloys and titanium-aluminum-vanadium alloys are most commonly used for cementless femoral stem designs. The modulus of elasticity of titanium alloys is closer to that of bone than is that of cobalt-chromium alloys. Theoretically, this should produce less thigh pain and stress-shielding. Thigh pain, however, is believed to be a result of not only the stiffness of the metal, but also the stem geometry. Comparison of implants that had the same design but were made of different alloys showed no significant difference in the outcomes or rates of thigh pain.

### Designs Utilized in Cementless Fixation

Cementless fixation design principles have evolved since the first outcomes were reported in 1979. Various femoral stem geometries are currently in use. The implant shape determines cortical contact and initial stability. Porous surfaces are located where fixation is desired. The aim of each design is to obtain initial stability and osseous contact.

### TABLE I Classification System of Cementless Femoral Stem Designs

<table>
<thead>
<tr>
<th>General Category</th>
<th>Type</th>
<th>Geometry</th>
<th>Description</th>
<th>Location of Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight stems</td>
<td>1</td>
<td>Single wedge</td>
<td>Narrows medially-laterally. Proximally coated. Flat stem, thin in anterior-posterior plane</td>
<td>Metaphyseal</td>
</tr>
<tr>
<td>Tapered proximal fixation</td>
<td>2</td>
<td>Double wedge, metaphyseal filling</td>
<td>Narrows distally in both medial-lateral and anterior-posterior planes. Wider than Type 1. Fills metaphyseal region</td>
<td>Metaphyseal</td>
</tr>
<tr>
<td>Tapered proximal fixation</td>
<td>3A</td>
<td>Tapered, round</td>
<td>Rounded tapered conical stem with porous coating at proximal two-thirds</td>
<td>Metaphyseal-diaphyseal junction</td>
</tr>
<tr>
<td>Tapered proximal fixation</td>
<td>3B</td>
<td>Tapered, splined</td>
<td>Conical taper with longitudinal raised splines</td>
<td>Metaphyseal-diaphyseal junction and proximal diaphyseal</td>
</tr>
<tr>
<td>Tapered distal fixation</td>
<td>3C</td>
<td>Tapered, rectangular</td>
<td>Rectangular cross section with four-point rotational support in metaphyseal-diaphyseal region</td>
<td>Metaphyseal-diaphyseal junction and proximal diaphyseal</td>
</tr>
<tr>
<td>Distally fixed</td>
<td>4</td>
<td>Cylindrical, fully coated</td>
<td>Extensive porous coating. Proximal collar to enhance proximal bone oading and axial stability</td>
<td>Primarily diaphyseal</td>
</tr>
<tr>
<td>Modular</td>
<td>5</td>
<td></td>
<td>Metaphyseal and diaphyseal components prepared independently</td>
<td>Metaphyseal and diaphyseal</td>
</tr>
<tr>
<td>Curved, anatomic stem</td>
<td>6</td>
<td></td>
<td>Proximal portion is wide in both lateral and posterior planes. Posterior bow in metaphysis, anterior bow in diaphysis</td>
<td>Metaphyseal</td>
</tr>
</tbody>
</table>
The first cementless stems were classified as straight or curved and engaged the femur in the metaphysis and distally. Today, stems are often referred to as proximally porous-coated tapered or fully-coated cylindrical. While these simplifications are acceptable general categories, they miss important design characteristics and make comparisons misleading. As current designs are followed for longer periods and newer ones evolve, a comprehensive classification system will aid in comparisons of results.

Cementless stems can be categorized according to distinct geometries that govern where fixation is obtained. We define six general types based on shape, which are a modification of the four categories described by Berry (Table 1). This system is based on the amount of osseous contact and the progression of stem fixation from proximal to distal. It does not include designs that rely predominantly on femoral neck fixation.

In this classification, Types 1 through 4 are straight stems, and as the number increases so does the fixation area. Types 1, 2, and 3 are tapered, designed to obtain more proximal fixation, and Type 4 is fully coated to obtain distal fixation. Type 5 is a modular prosthesis, and Type-6 stems are curved, anatomic designs and are used less commonly (Table 1, Fig. 1). While future prostheses may not fit into one of these categories, this classification system represents the great majority of the cementless stems currently in use and with long-term follow-up.

![Fig. 1](https://example.com/fig1.png)

Schematic drawings illustrating the classification of the cementless femoral stem designs. Type 1 is a single wedge, Type 2 is a double wedge, Type 3A is tapered and round, Type 3B is tapered and splined, Type 3C is tapered and rectangular, Type 4 is cylindrical and fully coated, Type 5 is modular, and Type 6 is anatomic. P = posterior and A = anterior. (Reprinted with permission of Sinai Hospital of Baltimore, Inc., 2010.)
**Type 1**

Type-1 stems, also called *single-wedge prostheses*, are designed to engage metaphyseal cortical bone in one plane: medial to lateral. They are flat and thin in the anterior-posterior plane. The component narrows proximally, primarily in the medial-lateral plane, and tapers distally. The coating is typically on the proximal one-third to five-eighths of the implant \(^{49,55}\). Initial stability is obtained by wedge fixation in the medial-lateral plane or three-point fixation along the stem length \(^{56,57}\). With three-point fixation, the implant contacts the femoral canal posteriorly, proximally, and distally, as well as anteriorly in its midportion. Rotational stability is achieved by the broad flat shape \(^{55,56}\). A collarless implant allows full seating into the prepared canal \(^{56}\).

Preparation requires broaching and no distal reaming. This theoretically lessens the risk to the endosteal blood supply, making the stem less invasive than a fully-coated or diaphyseal-engaging stem \(^{56}\). Attention to the native metaphyseal-diaphyseal anatomy and the component shape is important. If the femoral diaphysis narrows substantially, the implant may engage only distally. If a proximally porous-coated prosthesis engages only below the coating, osseointegration may not occur.

**Type 2**

In contrast to Type 1, Type-2 stems were designed to obtain proximal cortical contact in two planes: anterior-posterior and medial-lateral. They are considered to be double-wedge or metaphyseal-filling designs. They are wider than single-wedge stems in the anterior-posterior plane. The distal portion may be tapered or rounded for canal fill. Diaphyseal engagement is necessary to enhance the rotational stability of some Type-2 designs \(^{58}\). When splines are used to engage the endosteum distally, they are often combined with longitudinal slots or flutes to decrease stem stiffness. These modifications reduce the elastic modulus to minimize stress-shielding and thigh pain (Fig. 2). Preparation involves distal femoral reaming and proximal broaching.

**Type 3**

Type-3 stems have a long, consistent taper in both the medial-lateral and the anterior-posterior plane. Unlike Types 1 and 2, there is no abrupt change in geometry or coating and fixation is obtained more at the metaphyseal-diaphyseal junction than in the metaphysis. We divided Type-3 stems into three subgroups on the basis of their shape and means of fixation.

Type-3A components are tapered, rounded conical designs. Most have porous coating on the proximal two-thirds and obtain three-point fixation \(^{58}\). Proximal fins or ribs may be added for rotational stability \(^{59}\). Preparation requires reamers distally and broaches proximally.

Type-3B stems have a conical taper with longitudinally-raised splines for fixation. The sharp edges cut into bone and provide rotational stability \(^{60}\). Given the stem’s narrow profile proximally, there is freedom in controlling version, making it useful in complex cases with distorted proximal femoral anatomy \(^{59,61}\). Conical reamers are used to prepare a matching canal for these stems.

Type 3C is a rectangular, tapered, conical stem that is grit-blasted across its entire length. It has a rectangular cross section that obtains three-point fixation in the metaphyseal-diaphyseal junction and proximal part of the diaphysis. Its cross section provides four-point rotational support \(^{62}\). This stem does not require the use of reamers for femoral preparation, only rectangular femoral broaches.

**Type 4**

This design relies on fixation along the entire prosthesis engaging cortical bone in the diaphysis. The majority of this cylindrical prosthesis is coated with an ingrowth surface. A proximal collar enhances axial stability and transmits forces to the calcar, which is more important with this stem than it is with tapered designs.

Preparation requires distal reaming and proximal broaching. Endosteal bone engagement induces cortical bone ingrowth \(^{63}\). The distal diameter of the prosthesis is typically 0.5 mm larger than the last reamer to obtain a so-called diaphyseal scratch-fit.

**Type 5**

Modular designs allow independent preparation and separate components for the metaphysis and diaphysis \(^{64}\). They offer a combination of proximal and distal fixation and are typically reserved for complex operations. Indications include anatomic abnormalities and rotational malalignments, such as are seen with hip dysplasia.

Successful designs consist of a separate metaphyseal sleeve and diaphyseal stem. Preparation involves diaphyseal reaming for the stem to obtain cortical contact, and the metaphysis and calcar are machined over the distal stem or stem trial \(^{64}\).
Type 6
Type-6 prostheses are curved, anatomic stems that match the proximal femoral endosteal geometry. These stems have anteverision of the neck and are produced for right or left femora. Distally, they are either tapered or cylindrical. Stability is achieved through metaphyseal fill and the distal curve. Preparation, consisting of distal reaming and metaphyseal broaching, is less forgiving because of the close match of the shape of the prosthesis to the femoral canal.

Results of the Use of Cementless Stems
Initially, problems with cementless stems included proximal femoral fractures, loosening, thigh pain, and stress-shielding. The long-term results of successful designs of each type are presented in the Appendix.

Type 1
This stem has been the subject of more published reports than any other design. Results with first-generation implants are encouraging. Müller et al. described the results, after a mean of seventeen years (range, fifteen to eighteen years) of follow-up, in eighty hips with a titanium wedge taper stem with a rough grit-blasted surface and proximal rotational ribs. Survivorship at seventeen years was 98.8%. However, there was a 25% prevalence of thigh pain and an 84% prevalence of proximal stress-shielding. In another study in which stems of the same design were followed in 115 patients who were less than fifty-five years old, the twenty-year survivorship was 90% and no thigh pain was reported. Thus, this first-generation design has demonstrated excellent results, although there have been high rates of thigh pain and stress-shielding.

Modifications to Type-1 designs primarily included the addition of porous coatings, and long-term follow-up results are now available for those stems. A study of a titanium-plasma-sprayed component in sixty-five hips followed for a mean of twenty years (range, eighteen to 22.6 years) showed a twenty-two-year survivorship, with aseptic loosening as the end point, of 99%. Two (3%) of sixty-five stems were associated with thigh pain.

In a study of forty-two young patients (mean age, fifty years) with a total of forty-nine Dorr Type-A or B hips (Fig. 3) treated with a cobalt-chromium stem with sintered beads, three stems failed and only 2% were associated with thigh pain at the time of final follow-up at a minimum of ten years. The prevalence of thigh pain decreased from 5% at two years. Decreases in thigh pain over time have been reported by others.

As Type-1 stems proved reliable, indications for their use expanded. In a retrospective review of fifty hips in patients with rheumatoid arthritis, Purtill et al. reported no radiographic evidence of loosening and thigh pain in 2% at a mean of fifteen years (range, 14.5 to 16.9 years) postoperatively. These authors reported a 100% survivorship at five years in seventy-eight hips in octogenarians. Keisu et al. demonstrated a 100% survivorship in ninety-two hips in octogenarians, including 26% with Dorr Type-C bone, after a mean of five years (range, two to eleven years) of follow-up. Four patients had mild thigh pain.

The long-term results of Type-1 stems with porous coating are excellent. Thigh pain is present in up to 6% of

Fig. 3
Dorr classification of femoral bone quality. Dorr Type A indicates thick medial and lateral cortices and a large posterior cortex, giving a champagne-flute appearance. Dorr Type B indicates bone loss at the medial and posterior cortices. Dorr Type C indicates a stovepipe appearance due to complete loss of both the medial and the posterior cortex and a widened intramedullary diameter. (Reprinted with permission of Sinai Hospital of Baltimore, Inc., 2009.)
patients\textsuperscript{49}. These stems are good options for younger and older patients and those with type-C bone.

**Type 2**

Studies have demonstrated excellent medium and long-term results after the use of Type-2 stems\textsuperscript{6,36,77,79}. Epinette and Manley reported on 571 hips in 504 patients (mean age, sixty-five years) followed for fifteen to twenty years after treatment with a titanium-alloy stem that was collarless, grit-blasted, and hydroxyapatite-coated on its proximal one-third\textsuperscript{77}. There were four femoral revisions (0.7%), and survivorship at seventeenth years was 99.2%. Capello et al. reported 99.5% survivorship, with aseptic loosening as the end point, in a study of 166 hips followed for a minimum of fifteen years after treatment with the same prosthesis\textsuperscript{77}.

In a study of patients under the age of fifty years followed for a minimum of ten years, the failure rate was 4.5% (five of 111 hips); one failure was due to aseptic loosening, and four were due to thigh pain\textsuperscript{7}. Lee et al. reported 100% survivorship in a study of eighty-five hips (mean age, fifty-two years; range, twenty-seven to seventy-eight years) followed for a mean of 10.3 years (range, seven to twelve years)\textsuperscript{77}.

Modifications to the original design comprise offset options and changes to enhance rotational stability, including distal splines and flutes, and a slotted distal stem to decrease stiffness\textsuperscript{76}. At the time of short-term follow-up, there was no reported loosening but the prevalence of thigh pain was 12% (ten of eighty-one hips)\textsuperscript{79}. Ten patients (12%) had Dorr Type-C bone. At the time of mid-term follow-up (at five to ten years) of the same hydroxyapatite-coated stem, there were no femoral failures, although the prevalence of thigh pain was not reported\textsuperscript{80}.

There has been long-term success of Type-2 prostheses with a first-generation design. Reported prevalences of thigh pain are as high as 12%, but most cases are mild. Success has been shown in hips with Dorr Type-C bone\textsuperscript{36,79}.

**Type 3**

Excellent long-term results have been achieved with use of Type-3A designs\textsuperscript{35,80}. Lombardi et al. reviewed the results of 1866 arthroplasties done with use of a titanium prosthesis\textsuperscript{3}. The proximal third was plasma-sprayed and had rotational fins, the middle third was grit-blasted, and the distal third was smooth. Only twelve femoral revisions (1%) were related to ingrowth failure. Survivorship with revision as the end point was 95.5% at twenty years.

Bourne et al. reviewed the results in a study of 307 hips that had been treated with this type of femoral stem and followed for a minimum of ten years\textsuperscript{3}. Stem survivorship was 99%. Ten (4%) of 283 patients reported mild-to-moderate activity-related thigh pain. Mild stress-shielding was noted proximally in 153 hips (50%). Another group of authors demonstrated a rate of proximal shielding of 88% in seventy-six hips\textsuperscript{80}, suggesting that fixation may be more distal with this design.

Use of this stem has been successful in young and elderly patients and in those with Dorr Type-C bone. Ellison et al. studied 249 hips in 201 patients with an age of forty years or younger and reported survivorship to be 98.2% at up to eighteen years\textsuperscript{81}. Reitman et al. reported no revisions in thirty-three patients with Type-C femora that had been followed for a mean of 13.2 years\textsuperscript{82}.

Mid-term results are available for a newer design that has grit-blasting in the distal two-thirds and a polished bullet tip. In one study, survivorship was 99.5% at seventy-five months\textsuperscript{84}. Thigh pain occurred in 2.4% (five) of 210 hips, but it resolved in three patients. Cortical thickening was seen in 14% (twenty-one) of 155 patients. Calcar changes occurred in 54% (eighty-three patients); these changes included rounding off of the calcar without height loss in sixty patients and calcar resorption of between 2 and 7 mm in twenty-three patients.

The long-term survivorship of Type-3A stems has been excellent, with success in hips with Dorr Type-C bone. Up to 4.4% of patients have activity-related thigh pain\textsuperscript{80}. There is a high prevalence of proximal stress-shielding, which is indicative of the more distal fixation compared with the fixation of Type-1 and 2 stems.

The survivorship for ninety-four Type-3B femoral stems that had been followed for a mean of 11.5 years (range, ten to fourteen years) was 91.5% with eight revisions, only three of which were for aseptic loosening\textsuperscript{80}. The majority were complex cases, including hips with dysplasia and prior intertrochanteric osteotomies. Proximal radiolucent lines were seen in twenty-seven cases, with findings of distal fixation in eighteen. Of the first 100 reported cases in which a Type-3B femoral stem had been used, twenty-one had distal engagement of the prosthetic tip\textsuperscript{80}. The authors stressed the importance of templating and canal preparation so that the prosthetic midportion engages the canal and the tip is free\textsuperscript{80}. Failure to accomplish this results in more distal fixation. This stem has not been modified from its original design. While not commonly used in routine cases, the design has proven useful in revision settings\textsuperscript{84,85}.

Type-3C stems have been widely used in Europe\textsuperscript{86-89}. Grubl et al. reviewed the results in ninety-two hips in eighty-seven patients who had been followed for a mean of 15.5 years (range, fifteen to seventeen years)\textsuperscript{87}. Only three stems were revised. The stem survival rate was 98% at fifteen years, and 2% (two) of the eighty-seven patients reported thigh pain.

Suckel et al. reported similar findings in 320 hips after a minimum duration of follow-up of fifteen years (range, fifteen to seventeen years)\textsuperscript{89}. The stem survival rate was 98%. One stem (0.3%) was revised because of aseptic loosening. Proximal stress-shielding was observed in one-third of hips. In another study, of seventy-five hips in seventy patients who had a mean age of fifty-two years (range, twenty-four to sixty-eight years), survivorship was 95% at a mean of sixteen years (range, fifteen to eighteen years)\textsuperscript{88}. Two revisions were due to aseptic loosening.

In summary, Type-3C stems have excellent long-term survivorship. There have been no substantial modifications of the original design. The rate of proximal stress-shielding suggests a more distal femoral loading. Despite this, the prevalence of thigh pain remains low. The shape of the stem and the ability
to obtain fixation along its entire length makes it an attractive option for hips with Dorr Type-C bone.

**Type 4**

There have been a number of long-term studies demonstrating excellent outcomes with Type-4 stem designs. Belmont et al. reported on a cobalt-chromium stem with porous coating on 80% of its proximal portion. One hundred and nineteen hips had survivorship of 98% at a mean of twenty-two years (range, 20.0 to 25.0 years); only six of 223 stems had loosened.

This design has done well in younger patients. McAuley et al. reported survivorship of 96.1% at fifteen years in 293 hips in patients under fifty years (range, sixteen to fifty years) of age. Moyer et al. found component survival of 99.1% at a mean of 8.6 years (range, five to ten years) in 115 hips in patients who had a mean age of 39.6 years (range, seventeen to fifty years).

Type-4 stems are associated with proximal stress-shielding and reports of thigh pain. Engh et al. studied 1545 extensively porous-coated components to determine if larger stem sizes resulted in poorer outcomes. The prevalence of activity-limiting thigh pain was 3.9% (sixty-one hips); the overall survival rate was 97.9% at fifteen years; and there was no difference in survivorship, pain, or satisfaction among stems of different diameters.

Modifications of the original designs have included full surface coating, a medial cutout, and the addition of a polished bullet tip. These changes were made to limit micromotion, decrease implant stiffness, and prevent pain at the distal part of the stem. A study of 100 consecutive second-generation stems in patients who had a mean age of forty-eight years (range, eighteen to seventy-two years) and who had been followed for a mean of 11.4 years (range, ten to twelve years) showed a 100% survival rate with thigh pain in 2%

The survivorship of Type-4 stems has been excellent at twenty years. Thigh pain has been a concern, but the prevalence has been reduced by modifications that decrease the stiffness of second-generation designs. These stems are options for most patients, but studies have not adequately addressed the use of these stems in femora with Dorr Type-C bone.

**Type 5**

The most popular modular design, a titanium proximal sleeve with a distal slotted stem with flutes, has been studied with long-term follow-up by several investigators. This stem is often reserved for complex arthroplasties. In a study of 795 primary hip arthroplasties followed for a mean of eleven years (range, two to seventeen years), Cameron et al. reported two cases of aseptic femoral loosening (0.25%) and five cases of thigh pain (1.8%).

Biant et al. studied the results of primary hip arthroplasties in patients with unusual anatomy (50% had developmental dysplasia) and reported 100% survivorship in fifty-five hips followed for a mean of ten years (range, five to sixteen years). Christie et al. reported a 0.6% rate of femoral failures (one of 175) at the time of follow-up at a mean of 5.3 years (range, four to 7.8 years); eleven patients (6%) had thigh pain.

Modifications to modular designs include the addition of a variety of proximal and distal geometries and coatings allowing versatility in revision settings. Although they are not used as commonly as nonmodular designs in primary arthroplasty, Type-5 stems are excellent options for cases with abnormal anatomy. While most studies of the use of these stems in primary arthroplasty did not address bone type, the implants have been used in Dorr Type-C femora. Modular femoral prostheses are more costly than one-piece designs. Because multiple combinations of proximal and distal segments are possible, a larger inventory of components is necessary. The economic implications of these two factors need to be considered before modular stems are chosen for routine cases.

**Type 6**

The first generation of these components performed poorly. There was a high prevalence of thigh pain (up to 36%) and loosening. Heekin et al. studied 100 hips managed with a cobalt-chromium anatomic prosthesis with sintered porous coating and found a 5% failure rate by five years, with 15% of the patients having thigh pain. Kim et al. found a clinical failure rate of 9% (eleven of 116 hips) and thigh pain in 28% (thirty-two of 116 hips) at a mean of six years.

Modifications were made to the initial design to obtain more reliable fixation. The proximal and lateral metaphyseal portions were widened for more fill, and a gentle curve was added to the stem tip to minimize endosteal abutment. At the time of follow-up, at a minimum of five years postoperatively, only one of 115 of these stems had been revised.

Results have been design-dependent. A study of seventy-two hips treated with a titanium proximally porous-coated and distally grit blasted prosthesis showed 100% survivorship at ten years. A study of seventy-eight hips treated with another design, with fiber metal coating, demonstrated 100% survivorship at ten years, with seven patients (9%) having thigh pain.

In a recent study of a titanium anatomic stem in 471 patients (601 hips) who had a mean age of fifty-three years (range, twenty to sixty-two years) and were followed for a mean of 8.8 years (range, five to twelve years), no components required revision. There was no thigh pain or radiographic loosening.

Historically, Type-6 stems have been associated with a higher rate of thigh pain and inferior results. Modifications to the stem design to enhance rotational stability and a better understanding of cementless fixation have led to improved outcomes. Studies of these stems have not consistently addressed bone type.

**Short-Stem, Bone-Preserving Designs**

With less invasive hip arthroplasty, attention is turning to bone-conserving designs. Collectively, these stems have not had long-term follow-up. Many newer short designs are modifications of one of the above stems, with no more than two years of follow-up. Others designs have distinct geometries for more proximal fixation in the femoral neck or for metaphyseal bone conservation. A short stem with a unique trapezoidal, tapered
wedge shape was designed to minimize osseous engagement in the proximal metaphysis. One study of 159 hips showed survivorship of 98.2% at ten years\textsuperscript{16}. A neck-engaging titanium threaded design demonstrated results comparable with those provided by a cemented total hip replacement in a study of forty hips followed for two years\textsuperscript{14,15}. A curved design that engages the neck demonstrated excellent midterm results, with 99% survivorship at just over six years\textsuperscript{16}. With further follow-up the utility of these designs, the improvements that they may represent over previous designs may become apparent.

**Overview**

Cementless femoral fixation is generally associated with excellent long-term results. Despite marked differences in their design principles and methods of femoral preparation, the six types of cementless stems have similar survival rates. Differences in currently used materials and fixation surfaces do not appear to affect outcomes as much as differences in geometric design do. Results also depend on operative technique, which is influenced by the stem geometry and the location of femoral fixation. It is important for the practicing surgeon to understand these principles. Any design may be acceptable for routine cases. When there is major deformity or when distal fixation is needed, Types 3B, 3C, 4, and 5 are useful, with the choice governed by the surgeon’s familiarity with each type of stem.

Failure rates have decreased with these designs, although no type is completely free of thigh pain or stress-shielding. Cementless femoral fixation is durable in young patients and has had promising results in older patients, although limitations of the current literature make it difficult to assess and compare different designs to determine optimal indications for each type.

**Appendix**

Tables summarizing the results associated with the six types of cementless femoral stems are available with the electronic version of this article on our web site at jbjs.org (go to the article citation and click on “Supporting Data”).

**References**


**Cementless Femoral Fixation in Total Hip Arthroplasty**

The outcomes associated with newer materials and designs will need to be compared with these excellent long-term results. The basic classification system described in this article will need to be expanded, but most designs fit into one of the six categories. A separate classification should be considered for short-stem designs, which do not fit into one of the categories. Future studies of cementless implants should consistently address patient age, activity level, bone type, and deformities so that more definitive conclusions can be made about when to use each design. Investigators should report their clinical findings and all radiographic osseous changes.

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