CHAPTER 36

Tapered, Fluted Femoral Fixation

Todd Swanson

CHAPTER PREVIEW

CHAPTER SYNOPSIS: The tapered, fluted revision hip stem has solved a serious problem in revision arthroplasty. By using the remaining intact diaphyseal bone stock for fixation, these stems offer a treatment option for proximally deficient femora and provide a reliable result in most cases.

IMPORTANT POINTS:
1. Tapered, fluted revision stems are most useful for proximally deficient femora (Paprosky types IIIA, IIIB, and IV).
2. Such stems also are useful for periprosthetic fractures associated with nonsupportive proximal femoral bone (Vancouver types B2 and B3).
3. Most modular stems require proximal bony support to protect the modular junction.

CLINICAL/SURGICAL PEARLS:
1. Determining the highest level of supportive femoral bone is important to place the taper into this bone. An extended trochanteric osteotomy is useful for removal of the old stem and facilitates placement of a relatively straight, tapered, fluted stem down a bowed femur, thus preventing anterior perforation of the stem through the anterior cortex. The intact diaphysis often will benefit from a cable around the highest level of intact bone to prevent fracture and provide a better end point during stem insertion. The proximal, nonsupportive metaphyseal bone should be reconstructed around the upper stem for support.

CLINICAL/SURGICAL PITFALLS:
1. Axial stability is difficult to achieve when the bone is osteoporotic or when the length of intact diaphysis is less than 4 cm. A cable around the uppermost part of the intact diaphysis, with or without strut grafts, will help provide axial stability and discourage subsidence. Reconstruction of proximal bone stock provides support to the upper stem and averts stem fracture at the modular junction.

VIDEO AVAILABLE:
A video demonstrating insertion of a tapered, fluted revision stem after extended trochanteric osteotomy is available.

INTRODUCTION

The number of revision total hip replacements is predicted to more than double over the next 25 years from an estimated 40,800 in 2005 to approximately 96,700 in 2030.¹ Total hips are now being implanted in much younger patients, and the risk of multiple revisions demands better means of reconstruction. Although revision arthroplasty is amenable to many options when bone stock is good, the risk of multiple revisions demands better means of reconstruction. Although revision arthroplasty is amenable to many options when bone stock is good, poor bone stock often jeopardizes reconstruction with more customary implants.

Before the use of cementless implants, cemented components served as the workhorse for revision arthroplasties. However, cemented revision components present several problems, including difficulty obtaining adequate interdigitation and fixation of cement into the smooth, sclerotic, endosteal bone of the femur; extrusion of cement through femoral defects; and the need for a large volume of cement that impedes subsequent revisions and can threaten the patient’s cardiopulmonary system during introduction.²

Cementless fixation provides solutions to many of these problems. However, proximal femoral bone loss continues to challenge adequate fixation and osseointegration with proximally fixed components. Long, extensively porous coated femoral components allow more distal fixation. However, with severe proximal bone loss or large, ectatic canals, even these stems can fail.³,⁴ In addition, fitting the stem to the canal often proves difficult, resulting in undersizing of the femoral component and failure of bony ingrowth in up to 18% of cases or fracture of the femur in as many as 30% of cases in some studies.⁵–⁷

Wagner⁸ first described the use of a distally tapered, fluted, revision femoral component in 1987 (Fig. 36–1). Axial
stability was achieved by driving the tapered stem into the intact femoral diaphysis, which had been milled into a conical shape to accept the distally tapered femoral component. Longitudinal flutes provided rotational control of the prosthesis. However, subsidence of the stem, particularly in cases of weak or osteoporotic bone, continued to be an obstacle to complete success.9–13

Because the final height of the stem at which axial stability was attained was somewhat unpredictable, a modular proximal body was introduced in subsequent design modifications. Modularity in total hip components initially raised concern about corrosion and breakage at the modular junctions. However, although some modular designs have seen fatigue failures, the ability to adjust the height and anteverision of the proximal stem after achieving solid primary fixation of the distal stem proved extremely valuable in correcting leg length and achieving hip stability. At least one manufacturer has redesigned the modular junction in its stems of 17 mm or larger to improve the strength in this high-stress area.14 Modular, tapered, fluted stems have now become one of the mainstays for reconstructing femurs with significant proximal bone loss.

CLASSIFICATION SYSTEMS
Revision Femoral Components

Femoral reconstruction can be accomplished in numerous ways. No standard classification system has been adopted, but the most commonly used methods for femoral fixation and reconstruction are shown in Table 36–1. Revision femoral components can be cemented or cementless, although cemented revision components have largely fallen out of favor.

Cementless fixation method includes proximal fixation, distal fixation, or a combination of the two. Extensively porous coated stems are designed to achieve both, although in practice the fixation more commonly is distal.3,15 Cementless stems can be modular or nonmodular; straight or bowed; porous coated, grit blasted, or hydroxyapatite coated; and fluted or nonfluted.

A third option for femoral fixation is the requisite use of bone graft to obtain primary stability. Bone grafting may be either structural or morselized. Although structural allograft-prosthesis composites can successfully rebuild bone stock—particularly important in younger patients—they present the potential complications of nonunion, graft resorption, component loosening, infection, and fracture.4,16 Morselized impaction grafting has met with reasonably good success in the hands of experienced surgeons. It provides primary structural support of the femoral component, even in extremely deficient femurs.17

### Table 36–1 Classification of Femoral Reconstruction Options

<table>
<thead>
<tr>
<th>Reconstruction Technique</th>
<th>Cement</th>
<th>Modularity</th>
<th>Fixation Location</th>
<th>Mandatory Bone Graft</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cemented component</td>
<td>Yes</td>
<td>No</td>
<td>Proximal and Distal</td>
<td>No</td>
<td>Any long-stem cemented component</td>
</tr>
<tr>
<td>Cementless proximal fixation</td>
<td>No</td>
<td>Yes or no</td>
<td>Proximal (metaphyseal)</td>
<td>No</td>
<td>S-Rom (DePuy, Warsaw, Ind.); Mallory/Head (Biomet Inc., Warsaw, Ind.)</td>
</tr>
<tr>
<td>Cementless distal fixation</td>
<td>No</td>
<td>Yes or no</td>
<td>Distal (diaphyseal)</td>
<td>No</td>
<td>Wagner SL (Protek AG); Link MP (Exactech)</td>
</tr>
<tr>
<td>Cementless proximal and distal fixation</td>
<td>No</td>
<td>Yes or no</td>
<td>Metaphyseal and diaphyseal</td>
<td>No</td>
<td>Solution (DePuy); Echelon, extensively porous coated (Smith &amp; Nephew, Memphis, Tenn.)</td>
</tr>
<tr>
<td>Proximal structural allograft prosthesis composite</td>
<td>Yes (to allograft); also may cement to host bone</td>
<td>Yes or no</td>
<td>Proximal–to distal to host bone</td>
<td>Yes (structural)</td>
<td>Any long-stem component</td>
</tr>
<tr>
<td>Morselized (impaction) grafting</td>
<td>Yes</td>
<td>No</td>
<td>Proximal and distal</td>
<td>Yes (morselized)</td>
<td>Exeter (Exeter, UK)</td>
</tr>
</tbody>
</table>
Femoral Bone Deficiencies

Numerous classification systems for femoral bone loss have been described. Although these systems have many similarities, the author believes a classification system that helps guide the type of fixation and predicts the results of intervention is most useful. For those reasons, this author prefers the Paprosky system (Table 36–2).19

The Paprosky system breaks femoral bone loss into types I, II, III, and IV. Type I femurs have only minimal loss of metaphyseal cancellous bone and an intact diaphyseal isthmus. Type II femurs have more extensive loss of proximal metaphyseal bone but an intact femoral diaphysis. Types I and II femoral metaphyses are supportive. Type III femurs are subdivided into IIIA and IIIB. Type IIIA femurs have extensive, nonsupportive metaphyseal damage but more than 4 cm of intact diaphyseal isthmus, whereas type IIIB femurs have similar extensive metaphyseal loss with some intact diaphyseal femur of less than 4 cm in length. Type IV femurs have global bone loss without supportive bone in either the metaphysis or diaphysis.

Periprosthetic Femoral Fractures

The most accepted classification system for periprosthetic femoral fractures is the Vancouver classification system described by Duncan and Masri (Table 36–3).20 The Vancouver system divides periprosthetic femoral fractures into types A, B, and C. Type A fractures involve the trochanteric region only and spare the femoral shaft. Type B fractures occur about the femoral component. Type B fractures are further subdivided into types B1, B2, and B3. In B1 fractures the femoral component remains stable within the proximal femur. In B2 fractures the femoral component is loose, but the bone stock surrounding the implant is supportive. B3 fractures occur about the femoral component, and the surrounding bone is deficient and nonsupportive. Type C fractures occur well distal to the femoral component.

INDICATIONS AND CONTRAINDICATIONS

Wagner’s revision stem is a straight stem tapered 2 degrees along its entire length. It uses 8 longitudinal flutes for rotational control, is grit blasted on its surface, and ranges from 190 to 305 mm in length.21 Cementless diaphyseal fixation allows treatment of proximally deficient femora without the use of structural allograft or cement. Although Wagner met with reasonable success, the prosthesis of his design is not without complications, most notably axial subsidence, leg shortening, and hip instability (Fig. 36–2).9–11,13,22–24

Some of the early problems with subsidence may have been attributable to inexperience with this new mode of fixation, resulting in undersizing of the stem. Other causes were likely the relatively shallow taper angle of 2 degrees and difficulty seating the prosthesis at a level that was both axially stable and provided the desired leg length and hip joint stability. Because of these problems, design modifications soon followed, including steeper taper angles and modularity. Although advantageous for attaining correct leg length and soft tissue tension, proximal modularity was soon found to be a weakness, with several modular stems designs fracturing at this high-stress location, particularly when unsupported by proximal bone (Fig. 36–3).25,26

In hips with good proximal metaphyseal bone (Paprosky types I or II), many fixation choices are available, including those that use the metaphysis for primary stability and secondary fixation. Because some femora remodel into retroversion over time, the surgeon using a metaphyseal-filling stem must take care to place the component in the correct antversion because the canal often dictates the version of the stem.27 Straight, distally tapered stems will work in these cases as well, with care taken to avoid perforation of the tip of the stem through the anterior femoral cortex because of the natural anterior bow of the femur.

Types II and IIIA femoral deficiencies can be handled quite effectively with extensively porous coated stems. Type IIIB and IV femoral bone loss presents a challenge for most cementless stems. Although type IIIB femoral deficiencies with canal diameters less than 19 mm do reasonably well with extensively porous coated stems, type IIIB femurs larger than 19 mm in diameter and type IV femurs—with minimal or no supportive bone in either the metaphysis or diaphysis—often require the use of cement, structural allograft, impaction allografting, or a tapered diaphyseal fixation stem.28

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**TABLE 36–2** Paprosky Classification of Femoral Bone Loss for Revision Total Hip Arthroplasty

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Minimal loss of metaphyseal cancellous bone and an intact diaphysis</td>
</tr>
<tr>
<td>II</td>
<td>Extensive loss of metaphyseal cancellous bone but an intact diaphysis</td>
</tr>
<tr>
<td>IIIA</td>
<td>Severe nonsupportive metaphyseal damage with &gt;4 cm intact diaphyseal bone at isthmus</td>
</tr>
<tr>
<td>IIIB</td>
<td>Severe nonsupportive metaphyseal damage with &lt;4 cm intact diaphyseal bone at isthmus</td>
</tr>
<tr>
<td>IV</td>
<td>Severe bone metaphyseal and diaphyseal bone loss with no supportive bone in diaphysis</td>
</tr>
</tbody>
</table>

**TABLE 36–3** Vancouver Classification System for Periprosthetic Femoral Fractures

<table>
<thead>
<tr>
<th>Classification</th>
<th>Subclassification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A1</td>
<td>Trochanteric region</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>Lesser trochanter</td>
</tr>
<tr>
<td>B</td>
<td>B1</td>
<td>Around the femoral component</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>Prosthesis stable</td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>Prosthesis unstable but surrounding bone supportive</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>Prosthesis unstable and surrounding bone deficient and nonsupportive</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>Distal to prosthesis</td>
</tr>
</tbody>
</table>
Periprosthetic femoral shaft fractures, particularly Vancouver types B2 and B3, lend themselves well to fixation with a distally tapered, fluted femoral stem. Because the proximally fractured femur usually is nonsupportive, distal fixation into the intact diaphysis provides axial and rotation stability, allowing reconstruction of the fracture fragments around the upper part of the stem. Several authors have reported excellent results treating periprosthetic fractures in this manner.28–31

SURGICAL TECHNIQUE

Any hip reconstruction must achieve rotational and axial stability, restoration of leg length, and hip stability. Extensive bone loss makes these goals challenging. Tapered diaphyseal fixation achieves both rotational and axial stability by secure contact with the remaining diaphyseal isthmus. If the isthmus is deficient, it can sometimes be reconstructed with cortical struts and cables to provide secure fixation of the stem within the canal.

Good preoperative planning is essential. The length of the stem chosen must position the taper at the level of the intact diaphyseal isthmus of the femur (Fig. 36–4). If the taper is too far proximal or distal, axial stability of the stem in the canal cannot be achieved. Preoperative planning also will determine the vertical position of the stem needed to restore leg length, the offset needed to restore hip stability, and whether an osteotomy will be necessary to correct femoral deformity.

Many difficult reconstructions of this type will benefit from an extended trochanteric femoral osteotomy, first described by Wagner8 in 1987 as a “transfemoral approach.” Since then many surgeons have popularized the technique, with minor modifications (Fig. 36–5).32,33 Proximal femoral osteotomy helps to visualize the diaphyseal femur and remove the old implant and cement and insert a straight stem down a bowed or deformed femur, thus averting perforation of the stem tip through the femoral cortex. The standard, lateral, extended trochanteric osteotomy mobilizes the greater trochanter with abductors, vastus lateralis, and at least 8 cm of lateral femoral cortex attached, hinging the osteotomy anteriorly on its muscular attachments.

Whether or not an osteotomy is used, the key to successful femoral fixation is reaming a taper into the healthy diaphyseal femur such that the stem taper wedges snugly into the femur canal. Once the reamer makes initial cortical contact, the surgeon may need to ream an additional 2 to 3 mm in diameter to create a diaphyseal taper sufficient to provide good axial support for the tapered stem. A minimum of 2 cm of good cortical contact is necessary to obtain axial stability of a tapered stem; a distance of 4 to 8 cm is optimal. With a stem tapered 3 degrees, each millimeter of reaming provides 19 mm additional longitudinal bony contact with the taper (Fig. 36–6). For a 2-degree taper, each millimeter of reaming provides 29 mm additional longitudinal contact. However, the smaller the taper angle, the closer to parallel the surfaces of the stem and bone become. The geometry eventually approaches a cylinder in a tube, which can resist subsidence only by frictional forces and not by the geometric attributes of the taper. Placement of a cable at the most proximal aspect of the intact diaphysis often can prevent subsidence.

FIGURE 36–2. Subsidence of a modular, tapered, fluted distal fixation revision stem. A custom modular body was manufactured to correct the 15-mm shortening resulting from stem subsidence. A, Original implantation. B, Subsidence of 15 mm 3 months postoperatively. C, Restoration of leg length with a custom modular body.
a longitudinal crack in the cortex and provide better fixation in this area, even more important if the bone is thin or osteoporotic. For more extensive thinning or osteoporosis, the surgeon may place struts and cables around the diaphyseal femur, with the option to extend them proximally into the deficient, ectatic metaphyseal area.

With the use of modular tapered stems, the stem is driven distally to its final, stable level at the outset. The leg length and hip stability are then adjusted with a proximal body of the correct height and offset. Most manufacturers now recommend trying to achieve some additional support proximally because most of these stems bear high stresses at the subtrochanteric level of the modular connection. Proximal bodies with porous ingrowth surfaces can be used, with cables and strut grafts providing additional proximal support for the stem.

If an extended trochanteric osteotomy has been performed, it can be closed down on the upper stem with cables and strut grafts if needed. Conversely, if no osteotomy has been performed, epistomy of the ectatic metaphyseal femur often is useful to reduce it around the upper prosthesis, thus giving support and encouraging bony ingrowth to the modular body. Cables or wires can augment support with or without the addition of strut grafts.

**POSTOPERATIVE RESTRICTIONS AND REHABILITATION**

Most distally tapered, fluted, revision femoral stems have a corundum-blasted titanium surface. Multiple studies show reliable osseointegration to this type of surface finish over the course of several weeks. In most cases weight bearing should be restricted to toe touch until secondary osseointegration has been achieved, usually for a minimum of 6 weeks. Depending on the quality of the bone stock, partial weight bearing often can be instituted at 6 weeks if the stem remains stable and the femur appears to be healing. Any evidence of subsidence in the early postoperative period should be treated with an extended period of toe-touch weight bearing. Weight-bearing restrictions past 3 months are not likely beneficial.

The condition of the metaphyseal femur and greater trochanter may require avoidance of active abduction and active hip flexion for a period to minimize muscular pull on the trochanter during healing. If the trochanteric fixation seems durable, these exercises can be instituted early.

**OUTCOMES AND RESULTS**

Multiple factors influence short- and long-term results of femoral reconstruction with fluted, distally tapered, cementless stems. The earliest results reported were with the Wagner nonmodular prosthesis, for which the incidence of significant early subsidence was as high as 20%. Causes included probable undersizing of the stem during the initial learning curve, a relatively small taper angle of 2 degrees, and a tendency to seat the prosthesis at the level appropriate to correct leg length and provide hip joint stability rather than the point at which the stem achieved axial stability within the femoral canal.
With the advent of modular bi-body stems, some of these problems were solved but others surfaced. Modularity allowed seating of the distal stem to a level where axial stability was achieved, whereas leg length and offset were adjusted through the proximal modular body. However, introduction of a modular interface at the subtrochanteric level, where the highest stresses occur, produced several reports of stem fractures, some within the first year. Since then most manufacturers have recommended that surgeons supplement distal fixation with some type of proximal support—by using ingrowth bodies and collapsing the ectatic metaphysis around them to attain bony contact, with or without placement of cortical strut grafts, or by using proximal structural allograft.

Kwong et al\textsuperscript{41} reviewed 143 patients from three centers receiving the Link MP modular tapered distal fixation stem (Exactech Inc., Gainesville, Fla.) who were followed for a mean of 40 months. Satisfactory results included a 97.2\% survival rate and average subsidence of only 2.1 mm. One undersized stem subsided 11.3 mm. Murphy and Rodriguez\textsuperscript{42} reported minimal subsidence and stable osseointegration in 34 of 35 revision arthroplasties with the same stem followed for a minimum of 2 years, although six reoperations were necessary for recurrent dislocations.

Park et al\textsuperscript{43} reviewed 62 revision THAs with a fluted, modular, distally tapered stem (Lima-Lto, Udine, Italy). Fifty-two percent of the revisions were performed with an extended trochanteric osteotomy. Mean subsidence was only 1.1 mm, and complications included 6\% diaphyseal split, 6\% cortical perforations, and 5\% dislocations. Overall, the rates of cortical perforation and more than 5 mm stem subsidence were significantly less in the group treated with an extended trochanteric osteotomy.\textsuperscript{13}

Sporer and Paprosky\textsuperscript{4} reported satisfactory results in 15 of 16 patients reviewed with the Link or ZMR (Zimmer, Warsaw, Ind.) modular fluted, tapered stems in types IIIB and IV femurs at 2.0 years with only one repeat revision.\textsuperscript{27} Schuh et al\textsuperscript{45} reported satisfactory results in 77 of 79 revision arthroplasties with the modular MRP-Titan revision stem (Peter Brehm GmbH, Weisendorf, Germany) at 4-year follow-up.

However, some modular, distally tapered revision stems have not fared as well. McInnis et al\textsuperscript{46} reviewed 70 PFM stems (Zimmer) followed for a mean of 47 months. Although only two stems required repeat revision during this period, six (8.6\%) were judged to be loose radiographically and 84\% of the stems subsided a mean 9.9 mm, with one stem subsiding 52 mm. In addition, seven hips (10\%) dislocated, with a mean subsidence of 23 mm.

Several authors have suggested that the use of distally tapered, fluted stems may allow reconstitution of the proximal bone stock. Gutiérrez del Alamo et al\textsuperscript{47} found proximal new bone regeneration in 50 of 79 hips revised with the Wagner stem and an increase in the thickness of the femoral cortex and outer femoral diameter compared with immediate postoperative radiographs. McInnis et al\textsuperscript{48} noted restoration of proximal bone stock in 56\% of 70 patients after 47 months of follow-up. Bohm and Bischof\textsuperscript{49} found good,
FIGURE 36–5. Extended trochanteric osteotomy. A, The osteotomy is made along the proximal shaft of the femur from posterior to anterior, hinging it on the attached anterior soft tissues. B, Reaming of the intact femoral canal after removal of the loose prosthesis and placing a prophylactic cable around the upper end of the intact femoral cortical tube, just distal to the osteotomy. C, Distally tapered, fluted stem being inserted into the intact femoral isthmus. D, Proximal modular body attached to distal stem and extended osteotomy being cabled back around proximal prosthesis.

FIGURE 36–6. The magnitude of the distal taper angle affects the resistance to subsidence and the amount of taper in contact with bone. Most newer designs use an included taper angle of approximately 3 degrees. With a 3-degree taper angle, each millimeter of increased diameter reamed increases the longitudinal contact area by 19 mm.
or excellent restoration of proximal femoral bone stock in 88% of 129 Wagner stems followed up for 8.1 years. Others have noted similar reconstitution of proximal bone stock after revision with distally fixed, tapered revision stems.

REFERENCES

As with any technology, innovative design of revision replacement prosthesis for the proximal femur will be imperative until a better means of rebuilding or restoring proximal bone stock. In addition, better means of rebuilding proximally porous bone. Other methods of achieving axial stability are required. Modular junctions must be strengthened or eliminated to control the risk of stem fracture. Axial stability remains somewhat unpredictable, particularly in soft, osteoporotic bone. It also provides an excellent option for periprosthetic femur fractures that render the proximal femur nonsupportive.

FUTURE CONSIDERATIONS

The concept of distal femoral fixation with a taper and flutes has created another option for revision of the proximally deficient femur, but present modular designs still have problems. Modular junctions must be strengthened or eliminated to control the risk of stem fracture. Axial stability remains somewhat unpredictable, particularly in soft, osteoporotic bone. Other methods of achieving axial stability likely will be developed in the future to ensure that stems do not subside. In addition, better means of rebuilding proximal bone stock in these deficient femora will be imperative because younger and younger patients are requiring revision arthroplasties. As with any technology, innovative design modifications will likely improve current results.

REFERENCES