Modern total hip arthroplasty (THA) is among the most successful operations in medicine. It has been a consistently effective treatment for end-stage osteoarthritis of the hip. With the increasing number of primary THA procedures being performed and the decreasing age of patients undergoing the procedure, there is an inevitable associated increase in revision burden for arthroplasty surgeons. Revision THA is most often indicated for instability, aseptic loosening, osteolysis, infection, periprosthetic fracture, component malposition, and catastrophic implant failure. Understanding the etiology of THA failure is essential for guiding clinical decision making. Femoral component revision presents a complex challenge to the arthroplasty surgeon because of modern implant design as well as bone loss in the proximal femur. Thorough patient evaluation, defect classification, and well-executed surgical reconstruction based on comprehensive preoperative planning may determine the postoperative results. Knowledge of various reconstructive options and the indications for each is necessary to achieve a successful outcome. This article highlights the most common indications for revision after THA and offers recommendations for how to approach revision of the femoral component. Specifically, the authors review preoperative assessment, common classification systems for femoral deficiency, techniques for component extraction, and modalities of femoral component fixation. [Orthopedics. 2016; 39(6):e1129-e1139.]

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Drs Brown, Mistry, Elmallah, and Chughtai have no relevant financial relationships to disclose.
Dr Cherian is a paid consultant for DJ Orthopaedics and Pacira Pharmaceuticals. Dr Harwin is a paid consultant for Stryker. Dr Mont has received grants and personal fees from TissueGene, Inc, Stryker, DJ Orthopaedics, Sage Products, Inc, Microport, Ongoing Care Solutions, and Orthosensor.
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Received: December 21, 2015; Accepted: January 7, 2016.
doi: 10.3928/01477447-20160819-06
and classification of femoral bony defects, with a focus on preoperative planning. In addition to component extraction techniques, this article discusses options for revision of femoral components in the case of simple and complex femoral bone stock deficiencies encountered during revision arthroplasty.

**INDICATIONS FOR REVISION**

More than 90% of THA procedures are successful at 10- to 15-year follow-up, but the annual revision rate is estimated to be 1% to 3%. After analyzing more than 51,000 revision THA procedures recorded in the Healthcare Cost and Utilization Project Nationwide Inpatient Sample database between October 2005 and December 2006, Bozic et al determined that the most common reason for revision was instability or dislocation (22.5%), followed by mechanical loosening (19.7%) and infection (14.8%). In this sample, all-component revision was the most common type of revision performed (41%). Conversely, Ulrich et al reviewed 237 revision procedures in 225 patients at 2 centers over a 6-year period and determined that aseptic loosening was the most common cause of failure (51.9%), followed by instability (16.9%) and infection (5.5%). Half of these revisions were performed within 5 years and were primarily needed because of instability and deep infection. Regardless of the etiology, to lower revision rates, it is imperative for surgeons to understand the modalities and timing of THA failure.

**PREOPERATIVE EVALUATION**

**History and Physical Examination**

Obtaining a preoperative history and performing a physical examination are vital steps in the evaluation of the patient undergoing revision THA. Proper evaluation of a painful THA is a considerable challenge for orthopedists, even though this is the most common symptom in patients presenting for revision. During the history and physical examination, physicians should determine the location, severity, and timing of pain as well as the presence or absence of a postoperative pain-free interval. Because hip pain is not always caused by the prosthesis, the surgeon must be able to differentiate between extrinsic and intrinsic (pain related to the prosthesis) origins.

The etiology of extrinsic pain after THA often provides confounding data for the treating surgeon. Common extrinsic causes of pain include radiculopathy, abductor failure or tendinitis, periprosthetic stress fracture, lumbar spine disease, trochanteric fracture, trochanteric bursitis, and iliopsoas tendinitis. Although groin or buttock pain after THA is often linked to intrinsic capsular or acetabular pathology, isolated buttock pain is commonly associated with sacroiliac or radicular disease. Radiculopathy may present as pain distal to the knee and may occur with paresthesias. Additionally, the orthopedic surgeon must consider non-musculoskeletal causes of pain, including hernia and vascular disease.

Intrinsic hip pain after THA is commonly related to aseptic loosening or peri-prosthetic joint infection. Pain in the anterior thigh, especially pain with motion, is commonly related to the femoral component and may indicate osteolysis. Additionally, pain associated with osteolysis often presents after a pain-free interval after the index procedure. Micromotion and loosening at the bone-implant interface may cause start-up pain and pain that ceases with rest. Conversely, pain that is unrelied by rest, night pain, lack of a pain-free interval after index arthroplasty, and pain associated with constitutional symptoms can suggest periprosthetic joint infection. Pain associated with recent trauma should prompt the surgeon to consider periprosthetic fracture. Patients with metal-on-metal implants should be evaluated for adverse local tissue reactions, which may be a consequence of wear of the bearing surface or corrosion of the modular taper junction.

Physical examination should include comprehensive assessment of the surgical site, neurovascular evaluation of the whole extremity, evaluation of range of motion, provocative maneuvers, and gait assessment. The skin should be examined for obvious signs of infection, including erythema around the previous incision site, drainage, induration, and sinus tracts. Thorough physical examination may exclude extrinsic causes of pain, such as trochanteric bursitis. Patients who have pain and poor gait may have abductor weakness or deficiency.

**Laboratory Testing**

Routine laboratory screening for suspected prosthetic joint infection in the setting of painful THA includes complete blood count with differential, C-reactive protein level (normal, <10 mg/dL), and erythrocyte sedimentation rate (normal, <20 mg/dL). Together, elevated C-reactive protein level and erythrocyte sedimentation rate are highly sensitive in predicting prosthetic joint infection. Elevation of these inflammatory markers, with or without systemic signs and symptoms of prosthetic joint infection, is an indication for aspiration of the hip joint.

The surgeon must note the time frame of aspiration in relation to the index arthroplasty because the threshold for prosthetic joint infection with regard to cell count and neutrophil differential changes with time. Synovial white blood cell count of greater than 4200 cells/μL and neutrophil differential of greater than 80% are highly suggestive of chronic infection after THA. Additionally, the onset of symptoms in relation to the primary operation can help to identify the causative organism. Early (<3 months postoperatively) and late (>12 months postoperatively) infections are commonly caused by Staphylococcus aureus, whereas delayed infections (3-12 months preoperatively) are commonly caused by Propionibacterium species.

To increase diagnostic yield and decrease false-negative culture findings, patients should discontinue antibiotics for at least 2 weeks before aspiration. Serum cobalt and chromium metal ion levels should be
obtained when evaluating painful metal-on-metal bearings. Although obtaining serum metal ion levels is recommended, there is no consensus on the exact metal ion threshold values for metal-on-metal bearings.20

**Imaging**

The most practical initial imaging modalities are plain radiographs, and these should include weight-bearing anteroposterior pelvis, anteroposterior hip, lateral hip, and full-length femur views. Surgeons should obtain and compare earlier images to detect nuances regarding progressive radiolucency, implant subsidence, peri-prosthetic fracture (old or new), osteolysis, aseptic loosening, or polyethylene wear.21,22 In the setting of complex deformity, full-length weight-bearing films can aid in the evaluation of overall limb alignment.

Most surgeons must perform revision of modern press-fit femoral components, and assessment of osseointegration is of paramount importance. Bugbee et al23 devised a largely accepted radiographic classification system of osseointegration for uncemented femoral implants, and these can be separated into major and minor signs. Although these signs are useful, they are uncommon and typically depend on the prosthesis. Major signs that indicate stability include a lack of radiodense lines around the porous ingrowth portion of the component and the presence of endosteal spot welds. Minor signs include a stable distal stem, calcar atrophy, and absence of a bony pedestal at the component tip. Critical evaluation of radiographs for periprosthetic fracture, osteolysis, and implant subsidence seems to be more important than classification of the mechanism of implant failure.

Loosening of a fully porous-coated implant is uncommon. These stems achieve diaphyseal fixation distally and thus have different radiographic parameters to predict loosening. A bony pedestal is highly suggestive of loosening. Similarly, reactive radiodense lines surrounding the stem also may indicate a loose femoral component. Detection of radiographic loosening of uncemented femoral components requires evaluation of subsidence, migration, and radiolucency.24

Cemented femoral components are evaluated with separate criteria. Multiple systems25-27 are used to describe and predict loose cemented femoral components. Gruen et al25 described a classification system that indicates where loosening around the femoral component may have occurred, and this system has been shown to be reliable and reproducible (Figure). O’Neill and Harris28 described definitive loosening of cemented femoral components as (1) implant subsidence, (2) new prosthesis cement radiolucency, (3) cement mantle fracture, and (4) implant fracture. This set of widely accepted criteria is simple to use and provides a reliable method for determining whether a cemented femoral component is loose. Plain radiographs play an integral role and are considered by many to be the most useful diagnostic imaging modality in preoperative planning of revision THA.

Advanced imaging techniques, including computed tomography and magnetic resonance imaging, also play a key role in the preoperative evaluation of failed femoral components. When preoperative radiographs suggest substantial bone loss, computed tomography scan may be an invaluable adjunct for further evaluation. Similarly, local soft tissues can be better defined with magnetic resonance imaging with the metal artifact reduction sequence protocol. Although there is no specific clinical guideline for its use in the evaluation of failed THA, magnetic resonance imaging has an expanding role in the assessment of pseudotumors and other lymphocyte-mediated soft tissue masses with metal-on-metal bearing surfaces and the complications of trunnionosis.29

**CLASSIFICATION OF FEMORAL DEFICIENCY**

Of the numerous available classification systems for femoral deficiency, the 2 most commonly used are the American Academy of Orthopaedic Surgeons (AAOS) classification (Table 1)30 and the Paprosky classification (Table 2).31-33 The AAOS classification is simple and can be used to describe femoral bone deficiencies in both primary and revision settings. The Paprosky classification correlates well with surgical complexity, can assist in predicting reconstruction options, and is solely used in the revision setting. It correlates well with surgical complexity, can assist in predicting reconstruction options, and is solely used in revision. Therefore, the Paprosky classification is preferred when describing femoral bone loss before revision surgery. Type I defects present with essentially normal femoral bone stock. These are often seen in isolated acetabular component revisions and may be managed with standard-length cemented or uncemented, fully porous-coated femoral components, based on surgeon preference.32 Type II defects are the most common. In this scenario, the loss of metaphyseal bone, combined with an intact diaphysis, precludes the use of standard-length implants. Although metaphyseal bone loss can be considerable, a type II defect may still contain enough proximal
bone to provide metaphyseal support. Common reconstructive options for type II deficiencies include modular metaphyseal engaging stems (with or without sleeves), diaphyseal fit-and-fill stabilizing stems, and long, fully porous-coated stems. Type III defects are subclassified by the amount of intact diaphyseal bone remaining. Type IIIA defects have 4 cm or more of intact diaphysis, whereas type IIIB defects have less than 4 cm of intact diaphysis. The reconstruction options are significantly more complex in these scenarios because of the need for adequate distal fixation. When considering the use of modular cementless stems in type IIIA and IIIB femoral defects, most authors recommend obtaining at least 4 cm distal fixation. With decreasing distal bone stock, the native femoral bow must be considered when attempting to maximize distal fixation. Cementless, fully porous-coated stems and modular cone-conical constructs are increasingly used for the reconstruction of type III femoral defects, with promising results. Type IV defects present a challenge because of the combination of a nonsupportive metaphysis and diaphysis. With both a metaphyseal defect and a femoral isthmus that cannot support adequate distal fixation, implant options are limited. To assist in implant choice, type IV defects may also be subclassified into contained and uncontained defects of the proximal femur. Contained defects, or those with an intact cortical rim, may be treated with impaction bone grafting, whereas uncontained defects are more amenable to allograft prosthetic composite implants or proximal femoral replacement.

### Removal of the Femoral Component

**Approach to Component Extraction**

Removal of both cemented and uncemented femoral components poses a challenge for orthopedists. Despite advances in surgical techniques and implant characteristics, there is a high possibility of damage to existing bony structures. Planning for adequate surgical exposure and component visualization plays a vital role in the outcome, but the surgical approach may be largely based on surgeon preference and training.

Numerous surgical approaches have been determined to be appropriate for revision hip arthroplasty. Proponents of the anterolateral and direct lateral approaches cite both postoperative stability and avoidance of critical posterior neurovascular structures, specifically, the sciatic nerve. However, the potential postoperative morbidity associated with violation of the abductor complex cannot be ignored and must be discussed with the patient preoperatively. The increasing popularity of the direct anterior approach to the hip also has come with an increasing interest in performing revision arthroplasty through the same approach. Revision hip arthroplasty may be safely performed through the anterior approach. However, the inherent pitfalls associated with this approach, including injury to the lateral femoral cutaneous nerve and intraoperative fracture, appear to be magnified, given the need for more extensile exposure in revision.

Although nearly every surgical approach to the hip has been shown to be effective for performing revision THA, the posterior approach is the most widely used because of its extensile nature and its familiarity to hip surgeons.

Although single-component revision may be planned, the surgical approach should not limit the ability to perform

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### Table 1

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>Segmental defects (loss of femoral cortical shell)</td>
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<tr>
<td>II</td>
<td>Cavitary defects with loss of cancellous bone and intact cortex</td>
</tr>
<tr>
<td>IIIA</td>
<td>Severe loss of proximal metaphyseal bone with ≥4 cm diaphyseal bone intact</td>
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<tr>
<td>IIIB</td>
<td>Severe loss of proximal metaphyseal bone with &lt;4 cm diaphyseal bone intact</td>
</tr>
<tr>
<td>IV</td>
<td>Extensive loss of metaphyseal and diaphyseal bone, thin cortices, widened canals</td>
</tr>
</tbody>
</table>

*Data from D’Antonio et al.*

### Table 2

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>Minimal loss of proximal metaphyseal bone with intact diaphysis</td>
</tr>
<tr>
<td>II</td>
<td>Moderate loss of proximal metaphyseal bone with intact diaphysis</td>
</tr>
<tr>
<td>IIIA</td>
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*Data from Valle and Paprosky, Paprosky and Aribindi, and Paprosky et al.*
revised of both the femur and the acetabulum if necessary. Thus, anterior-based approaches, although effective in approaching the femur in uncomplicated revision, may not be a wise choice if an unexpectedly loose cup is encountered, more distal access to a femoral stem is required, or intraoperative fracture occurs during removal of a very well-fixed femoral component. Although addressing these challenges through the direct anterior approach is more technically demanding in revision surgery, this approach is an option for those who use it almost exclusively for primary and revision surgery. If preoperative evaluation suggests a loose acetabular component or the need for more distal femoral exposure, the direct lateral or posterior approach may be more effective.

Preoperative evaluation and planning is critical in identifying potential pitfalls of femoral component removal and ensuring that proper instrumentation is available for implant extraction. In addition to manufacturer-specific explant tools, the following instrumentation should be readily available in the revision setting: power tools (eg, high-speed instruments, burrs); hand tools (eg, cement removal set, reverse curettes, taps); and ultrasonic tools (eg, osteotomes, ultrasonic disk drills, plug pullers). In addition, the following tools should be available: extra-long pituitary rongeurs, trephines, “light-on-a-stick” devices, femoral strut allografts, cerclage cables or wires, claw or cable plates, and universal extraction instruments. In addition, fluoroscopy and intraoperative plain radiographs should be available.

Several variations of extended trochanteric osteotomy for proximal femoral mobilization and implant extraction have been described. The surgeon should be facile with these techniques to safely approach and extract well-fixed components in complex revision cases. Trochanteric slide osteotomy, although often used in complex primary THA and acetabular component revision, has been well described for femoral mobilization.40,41 It offers technical ease and the ability to preserve the abductor complex during extensive lateral approaches to the hip. After standard exposure of the hip, the greater trochanter is osteotomized from its tip to just distal to the insertion of the vastus lateralis, creating a wafer of approximately 2 cm. In this way, the surgeon can preserve the attachments of the gluteus medius and vastus lateralis. This fragment is then mobilized anteriorly, providing access to the hip joint. The osteotomy is then repaired with cerclage wires, and active abduction is prohibited for 6 weeks postoperatively. This technique helps to reduce the risk of overzealous femoral retraction and decreases tension to the surrounding soft tissues. However, the risk of nonunion of the osteotomized fragment has been well documented. Wieser et al42 reviewed the risk factors for nonunion of trochanteric osteotomy and found that the use of cement on the femoral side was an independent technical risk factor. Because the use of cemented femoral components is often unavoidable in revision arthroplasty, the risk of nonunion must be weighed against the need for component visualization.

Single-plane longitudinal split osteotomy is not commonly used, although it provides the revision surgeon with another simple and effective technique to remove a well-fixed femoral stem. This osteotomy allows expansion of the femoral canal and theoretically easier removal of the femoral component. With a standard approach to the hip, the osteotomy is created along the linea aspera, extending distal to the tip of the femoral component, and fixed after reimplantation of the femoral component with cables. Common indications for longitudinal split osteotomy include removal of uncemented stems with minimal bony ingrowth or stable fibrous ingrowth.43 Longitudinal split osteotomy is a useful adjunct because it can be easily converted to the more ubiquitous extended trochanteric osteotomy if necessary.

Perhaps the most commonly used technique to remove a well-fixed femoral component is extended trochanteric osteotomy. This technique is useful in revision surgery because it provides nearly entire access to the proximal femur.22,44 It should be used when the cement mantle extends distal to the apex of the femoral bow, when varus or valgus femoral remodeling is needed, when well-bonded distal cement is used, when a fully porous-coated stem is present, and when there is a proximally porous-coated stem that is difficult to remove. The traditional technique for extended trochanteric osteotomy, as described by Younger et al,44 uses a posterior approach to the hip and a takedown of the short external rotators. However, modifications of this technique, as described by Lakstein et al,45 attempt to preserve the posterior insertions of the short external rotators as well as the attachments of the abductor complex and vastus lateralis. This technique hinges the anterior one-third of the circumference of the femoral canal while maintaining an intact lateral soft tissue sleeve. The osteotomy is reconstructed with standard cable techniques after reinsertion of the revision component. Healing after extended trochanteric osteotomy has been favorable. Paprosky and Sporer46 evaluated 122 revision THA procedures performed with extended trochanteric osteotomy and reported a 98% union rate of the osteotomized fragment at a mean 2.6-year follow-up.

Removal of Cementless Stems

Critical factors to consider when removing a cementless femoral component are the location and the extent of the porous coating. Any proximal bone covering the component should be removed. These components often can be removed with their designated extraction devices.

Modular Stems. Modular components can be difficult to extricate. Careful preoperative planning is crucial to identify the specific manufacturer of the failed component so that extraction devices...
specific to the implant can be available. The revision surgeon should have a low threshold for extended trochanteric osteotomy and possible implant transection with a metal-cutting burr with associated trephination for removal of the well-fixed distal segment.

**Fully Coated Stems.** Removal of well-fixed, fully porous-coated stems can be an arduous task, even for the most experienced revision surgeons. After an initial attempt is made to disrupt the bone-implant interface with the previously mentioned techniques, the surgeon should plan and perform extended trochanteric osteotomy. In determining the length of the osteotomy, it is necessary to achieve a balance between accessing the femoral component and leaving enough distal bone to allow stable fixation of the revision component. If the component does not easily disengage from the remaining proximal femur after extended trochanteric osteotomy, the femoral stem can be transected at the level of the osteotomy with a carbide burr, and the remaining distal stem can be addressed with a trephine. Care must be taken during transection to avoid damaging the opposite femoral cortex, which may compromise fixation of the revision femoral component.

**Proximally Coated Stems.** Well-fixed, proximally porous-coated stems present a challenge during femoral component removal. The bone-implant interface must be debonded with a combination of flexible and rigid osteotomes and/or a reciprocating saw blade. The proximal medial interface must be accessed, and an implant collar, if present, must be removed with a metal cutting burr. The trunnion may again be notched to assist with attachment of the extraction device. If the component is not easily removed with moderate retrograde force after these techniques, extended trochanteric osteotomy should be performed.

### Removal of Cemented Stems

The type of implant that is being extracted and revised must be determined preoperatively. Removal of cemented femoral components requires 3 sequential steps: (1) disruption of the cement-prosthesis interface; (2) extraction of the component; and (3) extraction of retained cement. After adequate surgical exposure is obtained, the entire proximal portion of the retained component, particularly the lateral shoulder, is exposed with use of a combination of osteotomes, oscillating saw blades, and a high-speed burr. If the femoral component is a collared prosthesis, the medial calcar must be adequately exposed to facilitate removal. If stem subsidence has occurred, extensive bone removal along the medial calcar will likely be needed. In addition, all remaining heterotopic bone and scar tissue must be removed at the level of the previous femoral cut to facilitate extraction of the component.

When possible, the surgeon should ascertain whether the retained component is highly polished or textured. This distinction is valuable because highly polished stems are often easier to remove with retrograde blows with a tamp, an implant-specific removal device, or a universal extraction device. Removal of highly polished components often can be accomplished without further disruption of the cement-prosthesis interface. The use of a carbide burr to notch the trunnion is helpful in enhancing fixation of the extraction device onto the prosthesis. Before extraction of well-fixed textured or precoated components, disruption of the cement-prosthesis interface is required. Flexible osteotomes are commonly used, although there a noteworthy risk of iatrogenic femoral canal perforation and fracture associated with their use. A collar on the retained implant that impedes access to the medial cement mantle can be removed with a carbide burr.

When the cement-prosthesis interface extends beyond the metaphysis, proximal femoral osteotomy may be required to gain adequate access to the implant. Alternatively, an anterior cortical window can be made at the distal stem with a combination of drill holes and a burr. The location of this cortical window should be determined preoperatively with a premeasured distance from the tip of the greater trochanter. After the distal cement mantle is exposed, a burr can be used to disrupt the cement mantle. Retrograde blows with a bone tamp and mallet can be used to explant the component. The cortical window is replaced and fixed with cables. Although the cortical window technique is novel and straightforward, it is uncommon because most surgeons are familiar with proximal femoral osteotomy.

After component extraction, the cement mantle is critically assessed for defects. In select cases, cementing a new component into a well-fixed cement mantle may be appropriate. In this case, the retained cement mantle is roughened with a high-speed burr or an ultrasonic tool, with care taken to avoid perforating the distal cement mantle. A new, smaller-diameter prosthesis is recemented into the existing cement mantle. More commonly, the entire cement mantle is removed and a new cemented prosthesis is inserted. In this case, the loose cement mantle may be attacked by drilling the center of the cement and using a tap or a reverse curette to remove large segments of retained cement. Metaphyseal cement must be removed with care to prevent damage to the remaining bone stock. All cement is cleared from the proximal metaphyseal region before the surgeon proceeds distally. This enhances visualization and helps to prevent inadvertent perforation or fracture of the canal.

Diaphyseal cement is removed circumferentially with reverse curettes. The distal cement plug may be removed with various strategies, with care taken to prevent cortical perforation. The cement plug is perforated with a long drill bit or an X-shaped osteotome, and a reverse hook or a curette is inserted to free the cement plug and deliver it from the femoral canal. Controlled perforation of the femoral canal can be used to access a well-fixed ce-
ment plug, but this technique is associated with a risk of fracture.\textsuperscript{50} If extended trochanteric osteotomy has been performed, the cement plug may be removed under direct visualization. If a cement restrictor is present, it must be removed completely.

In the case of loose femoral components, a distal bony pedestal is often present and can be perforated with either a drill bit or an X-shaped osteotome, followed by retrograde extraction with a curette. Alternatively, flexible intramedullary reamers may be used. Reaming is most safely performed with intraoperative fluoroscopy.

After cement removal is complete, the canal is inspected meticulously for cortical perforations. A ball-tipped guide wire is an effective tool, as is a “light-on-a stick” device or a lighted suction/irrigator. If fracture or cortical perforation is suspected, the femur is screened with intraoperative fluoroscopy before reaming or insertion of a revision stem. Cortical perforations should be bypassed with the revision stem by at least 2 cortical diameters, or 5 cm.\textsuperscript{51} If a cemented component is used, the perforation sites can be covered with digital compression or wire mesh until the cement is cured to prevent extrusion into the soft tissues.

**Modalities of Femoral Fixation**

The goals of femoral component revision are to achieve implant stability and to restore hip biomechanics. Multiple fixation options are used for proximal femoral reconstruction, including cemented components with or without associated bone restoration techniques, uncemented components, and patient-specific implants, such as modular or custom components. As mentioned previously, the Paprosky classification is most commonly used to describe proximal femur deficiency.\textsuperscript{31,33,52} This classification system allows effective communication between surgeons and is a good predictor of surgical complexity. Intraoperative bone deficits and reconstruction options can be predicted based on the preoperative classification of the proximal femoral deficiency. Clinical success may be achieved with any of the options available.\textsuperscript{53-58} Although the availability of multiple fixation options is beneficial, to achieve the best patient and implant outcomes, surgeons must consider the design and fixation of the previous implant, the presence of bone deficiencies or other abnormalities of the proximal femur, and the quality of remaining bone stock.

**Uncemented Fixation**

Uncemented femoral fixation has become the preferred method of achieving long-term stability in revision THA. Evaluation of femoral deficiency is critical in the choice of uncemented stem, with special attention paid to the amount of isthmus, remodeling of the proximal femur, and canal diameter. The most commonly used components include proximally porous-coated stems with distal fit-and-fill constructs, extensively porous-coated stems, modular stems with cone-conical constructs, and in specific cases, megaprostheses.

Proximally porous-coated stems are useful in patients with minimal metaphyseal bone loss. In those with proximal bone loss, these stems are not ideal. In a review of 375 revision THA procedures, Berry et al.\textsuperscript{50} showed only 52% survivorship for proximally porous-coated components at 8 years, with aseptic loosening as an end point. Poor survivorship was directly correlated with poor integrity of the remaining proximal metaphyseal cancellous bone. In general, these stems are not sufficient for most revisions.

Extensively porous-coated stems are the workhorse implant for most femoral revisions. The surgical technique is familiar to arthroplasty surgeons, and long-term results have been excellent. Paprosky type I, II, and IIIA defects usually can be reconstructed with stems of standard length (6 inches). In cases of poor diaphyseal bone stock, longer (8-inch) bowed stems may be required to acquire a distal scratch-fit in the remaining femoral isthmus. Difficulties such as restoration of femoral anteversion may be encountered, especially when considerable proximal femoral remodeling has occurred, and the choice of stem may be dictated by the mismatch between the component and the femoral bow.

The excellent survivorship of these stems is well described. A retrospective review by Hamilton et al.\textsuperscript{60} examined 905 femoral revisions performed with extensively porous-coated stems from 1980 to 2006. This cohort showed a re-revision rate of 2.2%, with a 1.3% incidence of aseptic loosening. Analysis of patients undergoing revision who again were treated with fully coated nonmodular implants showed excellent results at a mean of 9.8 years, with no need for further revision.\textsuperscript{61} Weeden and Paprosky\textsuperscript{55} evaluated 170 revisions with fully porous-coated stems. Most patients had Paprosky type IIIA femurs (48%), and the overall rate of failure in the entire cohort was 4.1%. Follow-up imaging showed evidence of ingrowth in 82% of patients, and only 4% of patients presented with a radiographically unstable stem. The highest rates of failure (21%) were seen in patients who had worse bone stock (Paprosky type IIIB).

The limitations of extensively porous-coated stems have been described. Sporer and Paprosky\textsuperscript{62} reviewed a series of 51 patients who had substantial (Paprosky type III and IV) femoral defects that were reconstructed with fully porous-coated stems. Poor survivorship was shown in femurs with canal width greater than 19 mm or large defects in the femoral isthmus. In these cases, the authors recommended impaction grafting or use of a modular tapered stem. Although concerns about the theoretical risk of proximal stress shielding and thigh pain as a result of component modulus mismatch remain with these implants, modifications such as hydroxyapatite coating are being evaluated. Further research is needed to evaluate the clinical success of more modern component modifications in extensively porous-coated stems.
Modular stems have the option of multiple neck and stem structures, and these are beneficial for achieving stability in patients with extra-articular deformity or bone loss. These stems consist of a press-fit metaphyseal sleeve with a proximal porous coat that mates to a slotted diaphyseal segment of the required length. Proximal modularity allows for increased stability by allowing proximal femoral retroversion to be addressed by dialing in version separately. Although patients with good host bone have shown good results, diaphyseal bone loss is related to failure of these implants.63

Tapered, fluted, porous-coated stems, such as the Wagner stem, were developed to address stress shielding associated with extensively porous-coated implants.64 These stems were widely successful. However, instability, abductor weakness, and leg length discrepancy were common with monoblock tapered stems because of the inherent difficulty in determining the level of implant seating that would provide axial stability. More recently, modular tapered stems have been developed to combine the advantages of modular stems in the reconstruction of femoral defects. Axial stability is first achieved with insertion of the distal segment of the stem. Rotational stability is maintained with flutes in the distal stem, and leg length, offset, and version are recreated independently through modular proximal segments. These components address many issues seen in both extensively porous-coated monoblock stems and nonmodular tapered revision stems. However, the addition of modularity brings the risks of implant breakage at the modular junction and taper corrosion.65

The results of fluted Wagner-type, titanium modular tapered stems in patients who had severe diaphyseal bone loss have been excellent. Richards et al66 examined a series of 115 revision THA procedures, of which 65% were Paprosky type IIIB or type IV, and reported 87% survivorship at 3-year follow-up. Comparison of titanium modular stems and fully porous-coated stems showed higher postoperative Western Ontario and McMaster Osteoarthritis Index pain and stiffness scores, Oxford hip scores, and overall satisfaction in patients undergoing revision with titanium modular stems, despite the larger femoral defects in the modular stem group.67 Titanium modular tapered stems provide several advantages to the revision surgeon faced with complex proximal femoral deficiency. However, the cost and potential disadvantages of fracture and corrosion at multiple modular junctions must be considered. Long-term analysis is needed to determine the efficacy of this approach.

Proximal femoral replacement has substantial disadvantages and can be used as a salvage option. Although disadvantages such as early loosening, instability, limb length discrepancy and associated sciatic nerve palsy, and decimation of remaining proximal femoral bone stock cannot be ignored, these implants can be inserted quickly, and they provide immediate stability and predictable results. A recent study of proximal femoral arthroplasty in revision THA for severe bone loss68 showed stable prostheses and independent ambulation in all patients at a mean follow-up of 4.8 years. Malkani et al69 examined long-term results of proximal femoral arthroplasty for nonneoplastic conditions. At 12 years, overall survivorship was 64%, and almost half of the patients had substantial ambulatory dysfunction (ie, severe limp or inability to walk) postoperatively. However, mean Harris Hip Score increased from 46 to 76 at the most recent follow-up. Although the notable disadvantages associated with proximal femoral replacement cannot be discounted, further study is needed to determine its role in revision THA.

Cemented Fixation

The success of cemented femoral primary THA has been well documented. A systematic review by Bedard et al70 showed excellent long-term (20-year) durability of polished-finish cemented femoral components, with aseptic loosening-free survival of 95%. Modern third-generation cementing techniques have shown similarly outstanding long-term results, with revision rates of 0% at both 10- and 15-year follow-up.71,72 However, the proven track record of cemented fixation has not translated to revision. Initial results reported poor outcomes at midterm (<5 year) follow-up, with failure rates approaching 39%, 73,74 The reason for these poor results is likely multifactorial, with the use of standard-length stems in the setting of poor diaphyseal bone posing a considerable risk of failure of cemented fixation. In patients with intact diaphyseal bone, modern third-generation cementing techniques have achieved greater than 90% survivorship at 10-year follow-up.53,58,68 These techniques may be a viable option for patients who have good host bone stock (ie, Paprosky type I), but are likely to be used infrequently for the types of bone loss typically observed in the revision setting. The use of long-stemmed cemented components in low-demand patients who have contained femoral defects is an exception to the often maligned use of cemented components in revision arthroplasty.

In combination with a cemented stem, impaction grafting can be used to restore bone stock in young or active patients who have severe proximal femoral bone loss (ie, Paprosky type IIIB or IV).75,76 The technique for impaction grafting is labor intensive because of the need for large amounts of bone graft, and it requires considerable surgeon experience. After extraction of the old stem, the canal is thoroughly debrided of cement and reactive fibrous tissue. The canal is inspected, and defects are reinforced with wire mesh, strut allograft, and cables. A plug is placed distally, and the canal is tightly backfilled with morcellized cancellous allograft over a guide wire with cammulated tamps and broaches. The revision stem is then cemented into the femur in the usual fashion.

The reported results of impaction grafting have been mixed. Substantial
The use of an allograft prosthetic composite over a proximal femoral replacement prosthesis has many advantages, including the ability to restore bone stock and facilitate reattachment of host soft tissue. However, the surgical technique is technically demanding, and the logistical factors associated with obtaining the considerable amounts of allograft necessary may be prohibitive. Abductor reattachment and functional recovery can be unpredictable, and dislocation may necessitate acetabular revision to a constrained or bipolar component. However, recent studies with allograft prosthetic composite in revision THA have shown encouraging results. Babis et al. evaluated the use of allograft prosthetic composite in setting of complex bone loss. Their study showed allograft prosthetic composite survivorship of 69% at 10-year follow-up, with 19 of 57 hips requiring revision at a mean follow-up of 44.5 months. The authors found that the degree of preoperative bone loss (ie, Paprosky type IV) and the number of previous hip surgeries (ie, >2) were risk factors for failure. In cases of severe circumferential bone loss, careful execution of this demanding technique has shown promising results.

CONCLUSION

Successful femoral component revision is challenging, even to the most experienced orthopedic surgeon. It begins with complete preoperative evaluation, including history and physical examination, laboratory tests, and imaging studies to determine the cause of component failure. Proximal femoral deficiency should be classified to determine the appropriate prosthesis and fixation strategy and to identify the associated equipment and implants necessary to address the challenging scenarios that may be encountered. The use of thorough preoperative evaluation and planning minimizes intraoperative complications. Once appropriate preparation is complete, surgery may proceed safely. In general, Paprosky type I, II, and IIIA defects are best managed with extensively porous-coated, uncremented femoral components. These have been associated with excellent and predictable long-term function. Paprosky type IIIB defects are commonly managed with modular tapered fluted stems, although, based on surgeon experience, impaction grafting produces excellent results. Allograft prosthetic composites and proximal femoral replacement components provide reconstruction options for Paprosky type IV defects. Given the complexity of these cases, it is imperative that joint arthroplasty surgeons be comfortable with approaching femoral component revision following THA.

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