SUBSPECIALTY PROCEDURES

POROUS TANTALUM FEMORAL METAPHYSEAL CONES FOR LARGE FEMORAL BONE DEFECTS IN REVISION TOTAL KNEE ARTHROPLASTY

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Introduction

The use of porous tantalum metaphyseal cones provides reliable metaphyseal support and fixation to help restore the joint line in difficult revision total knee arthroplasties (TKAs) in patients with large femoral bone defects.

Reconstruction of large bone defects of the femur remains a difficult problem during revision TKA. Smaller defects have generally been treated with morselized cancellous bone graft; filling of the defect with cement; use of reinforcing screws in cement; or commercially available modular block augments, which are offered as options for use in nearly all contemporary revision knee systems. However, larger bone defects may require more extensive reconstruction techniques in order to restore mechanical stability to the femoral component against axial and rotational loading. Traditionally, these problems have been addressed with impaction bone-grafting (when mainly contained defects are present), large structural allografts, segmental replacement hinged components, metaphyseal sleeves, or custom-fabricated prosthetic components¹⁻³. However, despite the variety of options available, reliable reconstruction with durable long-term fixation can be difficult to achieve, with the optimal choice of techniques remaining unclear.

Highly porous metal metaphyseal cones have shown promising early clinical results when used to treat major bone deficiencies encountered during revision TKA and, more recently, have demonstrated favorable mid-term clinical results^{2,4}. These porous metal cones were designed specifically as alternatives to periprosthetic structural allograft for the treatment of the variable patterns of large femoral and tibial bone defects encountered in revision TKA. Porous tantalum was used to fabricate these implants in an effort to improve biologic fixation via the material's high porosity and interconnected pores. The synergistic combination of both cemented and cementless fixation of an individual component appears to have advantages whereby the cement provides immediate secure fixation and a motionless interface while the subsequent growth of bone into the device decreases the

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loads at the cement-bone interfaces over time and is protective mechanically over the long term. In addition, these cones are designed to work with most femoral implant systems.

These porous tantalum metaphyseal cones have been used mainly in patients with type-2 or 3 bone defects as described in the Anderson Orthopaedic Research Institute (AORI) bone defect classification system⁵. Moderate-to-severe bone cavitory defects that affect 1 femoral condyle are classified as type 2A whereas type-2B defects affect both femoral condyles. Type-3 femoral defects affect both condyles but are more severe in that they generally involve extensive combined cavitory and segmental bone loss.

Indications & Contraindications

Indications

- Large contained or segmental femoral metaphyseal bone defects in a patient with a failed TKA due to instability, infection, aseptic loosening, or osteolysis in whom a portion of the metaphysis is still available to support the cone.
- AORI types 2B and 3 are typically the defects that benefit from use of porous femoral metal metaphyseal cones.

Contraindications

- Active infection.
- Well-contained bone defects and those <1 cm in depth are better addressed with other types of augmentation such as standard metal augments, cement, or smaller cones or sleeves within the medullary canal and more central in the metaphysis of the femur.
- It may be preferable to use bulk allograft to address some large defects in younger patients who will probably need another revision, to help reconstitute bone stock for that future revision.
- Massive segmental metaphyseal bone loss preventing invagination of the cone shape into the residual metaphysis may require a whole distal femoral allograft or segmental replacement tumor-type megaprosthesis.

Step 1: Preoperative Planning

Adequate preoperative radiographs are important to determine the approximate size of the femoral bone defect prior to surgery.

- It is important to have in place a preoperative plan to address femoral bone loss so that the appropriate implants and augments will be available to the surgeon.
- Obtain anteroposterior, lateral, and Merchant radiographs preoperatively to evaluate alignment, radiolucent lines, bone quality, component design, and bone loss. These views are sufficient to assess the severity and location of bone loss in the majority of cases (Figs. 1-A, 1-B, and 1-C), although keep in mind that radiographs can underestimate the true extent of the bone loss.
- Standing hip-to-ankle radiographs are helpful for evaluating pathological involvement of the hip or ankle, the weight-bearing mechanical axis, and any bone deformity.
- Computed tomography (CT) can be helpful when radiographs do not provide adequate information or the surgeon desires a more clear understanding of the bone loss prior to surgery.
- The surgeon should have information about the previous reconstruction, including the previous surgical approach, type and size of implants, and any additional reconstructions or complications that occurred during the previous surgery (extensor mechanism repair or reconstruction, vascular injury, issues with soft-tissue coverage, etc.).
- Use of either standard acetate TKA implant templates or the newer electronic templating software can allow the surgeon to estimate the sizes of the TKA implants, the femoral and tibial stems, and the augmentation of the femur and tibia to prepare for the reconstruction.

Fig. 1-A

Fig. 1-B

Fig. 1-C

Figs. 1-A, 1-B, and 1-C Anteroposterior (**Fig. 1-A**), lateral (**Fig. 1-B**), and Merchant (**Fig. 1-C**) radiographs made before revision surgery in the left knee of a patient who has an osteolytic lesion within the femur. These radiographs indicate that femoral bone loss will need to be addressed during the revision surgery.

Step 2: Incision and Exposure

Adequate exposure during revision knee surgery is key for the safe removal of implants and to minimize bone loss.

- Place the patient supine on the operating room table.
- A tourniquet is generally used, and whether it is inflated prior to the incision or only during the cementing is according to the surgeon's preference. However, it is safer to inflate it just prior to cementing in prolonged, complex operations to decrease the risk of nerve injury or other adverse effects associated with prolonged tourniquet inflation. The surgeon may want to consider using a sterile tourniquet in certain cases if there is a need to prepare the entire lower limb in the operative field.
- Make a midline incision over the anterior aspect of the knee using the previous incision. If there were multiple previous incisions, it is generally best to utilize the most lateral one and leave skin bridges of >5 cm.
- Perform a standard revision TKA exposure, creating full-thickness subcutaneous flaps by subfascial dissection to maintain the blood supply to the skin.
- Perform a medial parapatellar arthrotomy with synovectomy and reestablishment of the medial and lateral gutters.
- If exposure is not adequate with the standard exposure, additional techniques such as a quadriceps snip or, rarely, a tibial tubercle osteotomy may be necessary.

Step 3: Component Removal

It is essential to disrupt the prosthesis-cement interface before attempting to extract well-fixed components.

- After adequate exposure has been obtained, proceed with component removal.
- Before attempting to extract well-fixed components, make sure to disrupt the prosthesis-cement interface as completely as possible on the basis of the access to this interface. Failure to do so can lead to excessive bone loss and/or fracture. Pay special attention to the posterolateral corner of the tibia and the posterior aspects of the femoral condyles during this process as they are more difficult to access and can lead to bone loss if ignored.
- Tools that should be made available to efficiently remove components with minimal bone loss include the following:
 - thin-blade oscillating saws
 - thin osteotomes
 - high-speed burrs
 - Gigli saw
 - ultrasonic device for removing intramedullary cement
 - commercially available disimpaction tools for axial pressure.
- After the components have been successfully extracted, remove all of the osteolytic and fibrous tissue from the femoral and tibial metaphyseal cavities. Failure to adequately debride the bone will make it difficult to accurately determine the actual sizes of bone defects. However, do not be too aggressive so as to minimize removal of cancellous and/or cortical bone.

Step 4: Establishing a Tibial Platform

The first step in revision knee reconstruction is to establish a stable tibial platform.

- Because the tibia affects the flexion and extension gaps equally, address the tibia first in the revision knee reconstruction.
- The goal of the tibial reconstruction is to create a stable tibial platform that is perpendicular to the mechanical axis and reestablishes the tibial joint line (~1 cm proximal to the head of the fibula). This may require tibial augmentation or buildup.
- Tibial bone defects can be addressed with cement and screws, modular block augments, morselized allograft, bulk allograft, metaphyseal sleeves, or porous metal metaphyseal cones. The technique for using porous metal metaphyseal cones for the tibia has been reported previously⁶.
- For secure fixation, use a tibial stem—either a cemented or an uncemented press-fit diaphyseal stem depending on your preference. We prefer a cemented stem of intermediate length that extends just beyond the junction of the metaphysis and diaphysis; we also prefer to “instrument long” for alignment purposes and “cement shorter” when implanting tibial stems. We always obtain an intraoperative radiograph to verify the alignment.
- Once a stable tibial platform has been established, the remainder of the reconstruction can be based off of this platform.

Step 5: Reconstruction of the Femur

Restoring the joint line and posterior condylar offset are the goals of femoral reconstruction.

- Use an intramedullary stem trial or guide to perform an appropriately aligned freshening cut of the distal part of the femur to reconstitute a distal femoral surface that is perpendicular to the mechanical axis of the limb and usually in 5° to 6° of valgus in relation to the femoral canal.
- Next, determine the appropriate size for the femoral component, making sure to take the bone loss into consideration to avoid undersizing. Undersizing will result in loss of posterior condylar offset and thus a larger flexion gap, which ultimately could lead to imbalance between the flexion and extension gaps and consequently either flexion instability or flexion contracture. Therefore, select a femoral component that is larger than the residual bone and augment the posterior condyles in order to restore the original anteroposterior dimension of the femur.
- Refer to the medial and lateral epicondyles to help you to assess the rotation of the femoral component. If these anatomic landmarks are unavailable, set the femoral component rotation parallel to the previously recreated tibial platform while tensioning the knee in 90° of flexion.

Step 6: Intraoperative Assessment of Femoral Bone Loss

Thoroughly assess the quality, quantity, and location of the remaining cancellous and cortical bone to determine the proper technique for reconstruction.

- Fully assess the femoral bone defects and whether they are contained or not contained (Fig. 2).
- In addition, thoroughly evaluate the quantity, quality, and location of the remaining cancellous and cortical bone to determine if a porous metal metaphyseal cone is indicated.
- Porous metal metaphyseal cones are indicated for AORI type-2B and 3 defects—i.e., severe cancellous bone deficiency of the medial and lateral condyles with an intact but minimally supportive cortical rim.

Fig. 2

Fig. 2 After removal of the femoral component and debridement of the osteolytic and fibrous tissue, the femoral defect is thoroughly evaluated. This patient had an AORI type-3 femoral bone defect, and a porous metal metaphyseal cone was appropriate to reconstruct the distal part of the femur.

Step 7: Selecting the Appropriate Metaphyseal Cone and Shaping the Femoral Metadiaphysis for the Femoral Cone

There are different sizes and shapes of metaphyseal cones that can be used when addressing large femoral bone defects.

- When major bone loss is present, the first step in femoral reconstruction is to create a stable metaphyseal foundation to support the femoral component.
- Familiarity with the various porous metal metaphyseal cones and the cone trials is very helpful. These implants are available in a number of different shapes and sizes to accommodate the patient's femoral metaphysis and the variety of bone defects that can be encountered during the surgery.
- Use the femoral cone trials to select the appropriate size and shape of the metaphyseal cone with respect to its fit within the femoral metaphysis (Figs. 3-A and 3-B). Also take into account the required position of the cone in order to reconstitute the joint line.
- Use a high-speed burr to contour the metaphyseal bone to accommodate the metaphyseal cone trial with the goal of achieving the maximal bone contact and implant stability possible. Avoid excessive removal of the supporting cancellous or cortical bone. If you find yourself removing too much, it may be a sign that the cone is not actually necessary or a smaller cone would be preferable (Fig. 4, Video 1). Some systems include broaches for preparation for this type of metaphyseal fixation, but, given the design of these large cones, a burr is much better for shaping the bone for the present procedure.
- Performing the impaction of the cone with the trial stemmed component (inserting the stem through the cone) can also be helpful in guiding proper component orientation and final contouring of the metaphyseal bone to accept the metaphyseal cone.
- Do not be concerned about the stability of the smooth plastic trial after impaction. The real porous metal metaphyseal cone has a much greater interference fit and stability due to frictional resistance of its porous tantalum surface (Video 1).
- Once the femur is adequately prepared for the intended femoral cone, it is important to confirm that overall limb alignment, joint stability, and recreation of the joint line are adequate by trialing with both the cone and the stemmed femoral TKA component trial in place (Video 1).

Fig. 3-A

Fig. 3-B

Fig. 4

Figs. 3-A and 3-B The plastic trials for the porous metaphyseal cones, which are available in different sizes and shapes, should be used to help contour the metaphyseal bone to accept the porous metal cone.

Fig. 4 The femoral bone defect has been debrided and shaped to accept the porous metal metaphyseal cone. The selected trial was used to contour the bone to accept the cone.

Video 1 The overall process and tips and tricks of selecting the proper size of the femoral cone, shaping the metaphyseal bone to fit the anatomic design of the cone, trialing with the cone and femoral trials, final impaction of the real cone, and cementing the real femoral component into place.

Step 8: Implanting the Actual Porous Metaphyseal Cone

During the final impaction of the femoral metaphyseal cone, take care to not cause a fracture.

- Select the final porous tantalum femoral cone and impact it with the appropriately sized stemmed femoral trial component in place to help control the depth of cone insertion, rotation, and orientation (Fig. 5, Video 1). Alternately, use a size-specific impactor for insertion of the cone.
- Be careful to not be overly aggressive with this final impaction of the actual component to avoid intraoperative periprosthetic fracture. The frictional coefficient of the real porous tantalum implant creates greater resistance to insertion than what was experienced with the plastic trial.
- Once the real porous cone is in its final stable position, fill any space on the periphery between the cone and the bone with morselized cancellous bone or bone-graft substitutes. The bone from the reaming of the femoral canal and from the osseous femoral cuts can also be used for bone-grafting around the cone. This helps with osseous integration of the cone and restoration of bone stock to the metaphysis and also prevents cement extrusion between the cone and host bone during cementation of the final stemmed femoral component (Figs. 6-A through 6-E).
- Be aware that the final rotation of the stemmed femoral component is not going to depend on the final rotation of the metaphyseal cone. There is generally enough room in the femoral cones to allow for some rotation of the final femoral component. However, the rotational freedom may vary among implant systems and the sizes of femoral components within the same system. Therefore, it is important to verify that the femoral stem does in fact fit through the cone easily so that it does not limit the final femoral component rotation and position.

Fig. 5

Fig. 6-A

Fig. 6-B

Fig. 6-C

Fig. 6-D

Fig. 6-E

Fig. 5 The trial femoral component with the appropriate stem and augments can be used to impact the final porous metal metaphyseal cone. This helps to achieve the correct depth and rotation for insertion.

Figs. 6-A through 6-E After the final porous metal metaphyseal cone has been impacted into place (**Fig. 6-A**), there are areas between the edges of the cone and the bone that need to be filled with bone graft substitute (**Figs. 6-B and 6-C**) and/or morselized cancellous bone graft (**Figs. 6-D and 6-E**).

Step 9: Final Trial and Cementing of the Final Stemmed Femoral Component

Place the final stemmed femoral component through the metaphyseal cone and cement it into place.

- After implantation of the final femoral metaphyseal cone, insert the femoral and tibial trials.
- Then perform the final soft-tissue balancing in a routine fashion. Decide on the tentative level of constraint needed at this time.
- Check the final alignment on an intraoperative radiograph with the final cone and trial components in place. This should be routine for those who occasionally perform this procedure and is especially helpful if a short or mid-length cemented stem is being used instead of a press-fit diaphyseal stem, which can guide alignment.
- Once it is determined that the reconstruction is adequate, remove the trial components for cementation of the final components.
- Insert the femoral revision component through the cone. A cemented or cementless stem can be used, although we prefer a short or intermediate-length cemented metaphyseal-diaphyseal stem when using femoral cones.
- Regardless of whether a cemented or cementless stem is used, place polymethylmethacrylate (PMMA) between the porous cone and the box and augments of the femoral component. This is best done by coating the undersurface of the implant itself with adequate PMMA prior to insertion (Video 1).
- As the PMMA is hardening, smooth out and contour the PMMA around the cone and implant (Fig. 7).
- After the PMMA has hardened, trial once again and then choose the final insert, snapping the final polyethylene into position.
- Perform standard wound closure according to your personal preference.
- Postoperative anteroposterior and lateral radiographs are helpful to verify alignment (Figs. 8-A and 8-B).

Fig. 7

Fig. 8-A

Fig. 8-B

Fig. 7 The final femoral implant has been cemented into place, and all PMMA has been contoured and smoothed out around the implant and cone.
Figs. 8-A and 8-B Postoperative anteroposterior (**Fig. 8-A**) and lateral (**Fig. 8-B**) radiographs of the knee after reconstruction using a porous tantalum metaphyseal cone.

Step 10: Postoperative Protocol

If a stable construct was achieved, the patient may bear weight as tolerated with no specific restrictions on range of motion.

- Postoperative care after revision TKA with a porous femoral metal metaphyseal cone is generally no different from that after standard revision TKA.
- If a stable construct was achieved, the patient may bear weight as tolerated. If you have any concern that the mechanical stability is tenuous or very poor bone quality makes the reconstruction less stable, then the patient can be restricted to partial weight-bearing.
- The use of a metaphyseal cone does not in itself place any limitations on patients working to regain range of motion. However, motion restrictions may be necessary depending on the extensor mechanism integrity, the quality of the soft tissues, or the wound closure itself. This is at the discretion of the surgeon.

Results

We recently performed a retrospective review of the midterm outcomes at mean of 5 years (range, 2 to 10 years) after 159 consecutive revision TKAs with a porous metal femoral metaphyseal cone in 157 patients with large bone defects⁴. All patients had either a type-2B bone defect (127; 80%) or a type-3 defect (32; 20%) at the time of revision surgery. The reasons for revision surgery included reimplantation after resection for a prior infection (75; 47%), aseptic loosening (56; 35%), osteolysis (26; 16%), implant failure (16; 10%), instability (11; 7%), and fracture (1; 0.6%). A cemented femoral stem was used in all 159 cases. Ninety-six cases (60%) required components with increased varus-valgus constraint, 56 (35%) were treated with hinged constructs, and 7 (4%) were treated with posterior-stabilized components as determined with intraoperative assessment of the ligamentous and soft-tissue status.

We reported a 5-year implant survival rate of 96% when the end point was revision for aseptic loosening of the femoral cone and 84% when the end point was revision for any reason. At 5 years, 23 femoral cones had been revised: 14 because of infection, 6 because of aseptic loosening of the femoral cone, and 3 because of ligamentous laxity. Radiographically, all 134 unrevised knees had evidence of osseointegration with reactive osseous trabeculation at the interface on the most recent follow-up imaging. The cases of aseptic loosening were generally in patients with extreme bone loss. Thus, conversion to a segmental replacement may be better than using a femoral metaphyseal cone in some cases; however, it is unclear from this limited number of cases exactly where that distinction lies.

Pitfalls & Challenges

- Thorough debridement of fibrous tissue and osteolytic debris from the metaphyseal cavity is necessary to be able to evaluate the full position, location, and type of bone loss so that the decision of whether a porous metal metaphyseal cone is required can be made.
- Knowledge of the different shapes and sizes of porous metal metaphyseal cones available is helpful when evaluating the bone defects. Use the cone trials to select a proper cone for the specific defect and for the intended revision component.
- A high-speed burr is needed to help contour the metaphyseal bone to accept the large metaphyseal cone.
- Avoid removing excessive cancellous and/or cortical bone. If this happens, it may indicate that the metaphyseal porous cone is not needed or a smaller cone is preferable.
- Impact the real porous metal metaphyseal cone into place with the stemmed femoral component (inserted through the cone), with the appropriate trial buildups and augments, to control the insertion depth and rotation of the cone.
- Overly aggressive impaction of the final metaphyseal cone can cause a fracture and thus should be avoided.

- The final stemmed femoral component is inserted through the metaphyseal cone, and cement is placed between the porous cone and the box and augments of the femoral component regardless of whether the stem is cemented or cementless.

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