SUBSPECIALTY PROCEDURES

MANAGEMENT OF BONE DEFECTS IN REVISION TOTAL KNEE ARTHROPLASTY WITH USE OF A STEPPED, POROUS-COATED METAPHYSEAL SLEEVE

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Abstract

Background: Revision total knee arthroplasty is a costly operation associated with many challenges including bone loss in the distal end of the femur and proximal end of the tibia^{1,2}. Reconstruction of bone defects remains a difficult problem that may require more extensive reconstruction techniques to restore mechanical stability and ensure long-term fixation. Use of porous-coated metaphyseal sleeves is a modern technique to address bone deficiency in revision total knee arthroplasty^{3,4}. Midterm reports have shown excellent survivorship and osseointegration⁵⁻⁷.

Description: The use of a porous-coated metaphyseal sleeve begins with intramedullary canal reaming to determine the diameter of the diaphyseal-engaging stem. Bone loss is assessed followed by broaching of the tibial and/or femoral metaphyses. Broaching continues until axial and rotational stability are achieved. The sleeve typically occupies most, if not all, of the proximal tibial and distal femoral cavity osseous defects often encountered during revision total knee arthroplasty. However, a sleeve does not address all distal and posterior femoral condylar bone loss, for which augments are often required.

Alternatives: Previously described methods to address various bone deficiencies include use of morselized or structural bone-grafting, reinforcing screws within cement, metal augments, and metaphyseal cone fixation⁸⁻¹⁷.

Rationale: Structural allografts or metal augments remain a suitable option for uncontained metaphyseal defects. Metaphyseal structural allografts may undergo stress-shielding, resorption, and late fracture. Metaphyseal sleeves offer long-term biologic fixation to host bone while creating a stable platform to receive a cemented femoral and/or tibial component⁷. This hybrid combination may provide mechanically protective properties to decrease the loads at the cement-bone interfaces and enhance loads to metaphyseal bone to ensure long-term implant fixation in the setting of substantial bone deficiencies¹⁸⁻²⁰.

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Introductory Statement

Metaphyseal sleeve fixation in revision total knee arthroplasties with large femoral or tibial bone defects provides reliable stability of the construct while decreasing shear and torsional stresses at the cement-bone interface by sharing load with the metaphysis through biologic fixation.

Indications & Contraindications

Indications

- While there are no absolute guidelines for the use of metaphyseal fixation in revision total knee arthroplasty, sleeves are most useful when the remaining osseous metaphysis is compromised and appears to be lacking in sufficient supportive structure for reconstruction. Patients with Anderson Orthopaedic Research Institute (AORI) type-2A, type-2B, and type-3 defects may benefit from the use of metaphyseal sleeves (Table I)².
- Large contained or segmental metaphyseal defects in patients with failure of a total knee arthroplasty secondary to instability, infection after eradication, aseptic loosening, or other causes are considered good candidates for the use of metaphyseal sleeve reconstruction.

TABLE I AORI Classification of Total Knee Arthroplasty Bone Loss^{2*}

Type	Description
1	Intact metaphyseal bone, contained defect
2	Cortical bone loss in metaphysis (uncontained)
A	1 femoral condyle or tibial plateau
B	Both femoral condyles or tibial plateaus
3	Substantially deficient metaphysis

*AORI = Anderson Orthopaedic Research Institute.

Contraindications

- Active infection.
- Massive segmental femoral or tibial metaphyseal bone defects preventing rigid fixation of the metaphyseal sleeve typically require consideration for structural allograft or segmental knee megaprotheses.
- Small, well-contained defects in which sleeve insertion would result in unnecessary removal of supporting host bone.

Step-by-Step Description of Procedure

Step 1: Preoperative Planning

Perform appropriate radiographic and clinical evaluation of a failed total knee replacement, which is essential to characterize the bone defect, ensure the availability of implants necessary to provide a successful result, and ensure the absence of infection.

- Obtain and critically review radiographs, operative reports, and clinic notes.
- Obtain laboratory analyses, including erythrocyte sedimentation rate and C-reactive protein level to rule out infection. Perform an aspiration if these values are outside the reference range or if clinical concern for infection is high.
- Make standard anteroposterior, lateral, and Merchant radiographs; however, they may underestimate the true extent of bone loss. Oblique radiographs evaluating the posterior femoral condyles and posterior proximal part of the tibia may also be made to reveal bone loss “hidden” from standard views²¹.
- Standing hip-to-ankle radiographs may be helpful to define the weight-bearing mechanical axis and address abnormalities seen between the hip and ankle.
- If further information regarding the extent of bone loss is needed, obtain a computed tomography (CT) scan.

Step 2: Incision and Exposure

Ensure that exposure is adequate to allow for safe visualization of the joint and removal of implants while avoiding unnecessary bone loss or ligament and/or tendon compromise.

- Place the patient in the supine position with all other extremities secured and well-padded to avoid injury or pressure ulceration.
- Consider use of a sterile or unsterile tourniquet depending on the surgeon’s need for whole-limb skin preparation and draping.
- Use the preexisting skin incision whenever possible followed by a medial parapatellar arthrotomy.
- If multiple previous incisions are present, select the most lateral usable incision, with an ideal skin bridge of 5 to 7 cm.
- It is imperative to perform subfascial dissection of skin flaps to maintain the blood supply to the skin.
- Perform a synovectomy with reconstitution of the suprapatellar pouch and medial and lateral gutters to assist with adequate exposure and postoperative motion.
- Additional techniques, such as a quadriceps snip, may be necessary in addition to the standard exposure.

Step 3: Component Removal

To minimize unnecessary bone removal, disrupt the implant-cement interface in well-fixed tibial and femoral components.

- Using an array of tools, such as a thin oscillating saw, Gigli saw, or thin osteotomes, disrupt the implant-cement interface to minimize bone loss.
- A single-sided reciprocating saw is particularly useful for disrupting the implant-cement interface around the keel of the tibial component.
- After component removal, remove the bone cement under direct vision with osteotomes, high-speed burrs, and/or ultrasonic devices. If using saws or high-speed burrs when removing cement, the use of irrigation is wise to avoid thermal necrosis of the bone.
- Remove all osteolytic and fibrous tissue from the femoral and tibial metaphyseal cavities. This allows for accurate evaluation of the size and configuration of bone defects.

Step 4: Establish a Stable Tibial Platform

Our preference is to establish a stable tibial platform as the first step in reconstruction.

- Begin initial preparation with reaming the medullary canal of the tibia. The senior author prefers to place a longitudinal mark on the anterior aspect of the tibia in line with 1 of the early reamers to represent the center of the medullary canal (Fig. 1). Continue sequential reaming until diaphyseal endosteal contact is achieved. This determines the stem diameter. Stem length is based on defect severity and the presence of anatomical variations in canal shape, particularly at the junction of the metaphysis and diaphysis. A diaphyseal-engaging stem is optimal. However, a diaphyseal-engaging stem may not be appropriate if there is substantial bowing of the metaphyseal-diaphyseal junction. If this scenario presents, explore an alternative form of metaphyseal fixation.
- Once the stem diameter is determined, assemble the broaching stem-sleeve construct (Fig. 2). The sleeve portion of the broach is labeled appropriately so that the surgeon is aware of where to place the anterior portion of the broach.
- Beginning with the smallest permissible size, perform sequential broaching with progressively increasing sizes until axial and rotational stability is achieved. Once stability is achieved, fill any remaining defects by impacting cancellous autograft or allograft prior to the insertion of the final component. Use the previously drawn longitudinal line on the anterior aspect of the tibia to guide the angle of the broach as well as to ensure the coronal position is correct (centered within the medullary canal) (Fig. 3). In cases in which 1 side of the tibial metaphysis is more sclerotic, the broach can deviate away from the sclerotic side in error. Keeping the broach in line with the anterior tibial line is imperative. The construct should sit 1 to 2 mm distal to the desired tibial bone resection (Video 1).

Fig. 1

Fig. 2

Fig. 3

Fig. 1 Intraoperative photograph demonstrating marking of the proximal part of the tibia in line with the intramedullary reaming rod for the cementless stem. This allows for proper centering of tibial sleeve broaches.

Fig. 2 Tibial sleeve broach set.

Fig. 3 Intraoperative photograph demonstrating tibial sleeve broaching in line with the previously placed mark in Figure 1.

Video 1 The overall process as well as tips and tricks of preparing and implanting a tibial sleeve during revision of a tibial component.

- “Freshen” the proximal tibial cut using the broach as a platform perpendicular to the mechanical axis of the tibia (Fig. 4, Video 1). This technique is effective only in the absence of abnormal bowing of the tibia. Otherwise, we recommend a freshening proximal tibial cut using an extramedullary cutting guide prior to broaching.
- Remove the trial broach.
- Select an appropriately sized tibial component allowing the most coverage of viable tibial bone.
- A revision tibial tray of varying thickness (4.8, 15, or 25 mm) may be selected if it is necessary to elevate the joint line in the setting of proximal tibial bone loss (Figs. 5-A through 5-D).
- Next, assemble the trial stem, sleeve trial, and tibial baseplate and place them in the tibia. We favor the use of metaphyseal sleeves with mobile bearing technology, which lessens fixation stresses. Therefore, the selected tibial rotation is based on optimized bone coverage by the tibial tray with avoidance of tray overhang. Leave this construct in place for trialing purposes.

Fig. 4

Fig. 5-A

Fig. 5-B

Fig. 5-C

Fig. 5-D

Fig. 4 When axial and rotational stability are achieved with the broach, the impactation handle is detached and the top of the broach can be used as a guide to freshen the tibial resection.

Figs. 5-A through 5-D A left total knee replacement with evidence of a loose tibial component and proximal tibial bone loss. **Figs. 5-A and 5-B** Preoperative anteroposterior (**Fig. 5-A**) and lateral (**Fig. 5-B**) radiographs.

Figs. 5-C and 5-D Postoperative anteroposterior (**Fig. 5-C**) and lateral (**Fig. 5-D**) radiographs following revision left total knee arthroplasty with a 15-mm-thick revision tibial tray, tibial sleeve, and diaphyseal-engaging, cementless stem.

Step 5: Estimate the Size of the Flexion-Extension Gaps

Estimate flexion and extension gaps prior to preparation of the distal end of the femur to determine if distal femoral augmentation is necessary.

- After the tibia is prepared, assess flexion and extension gap dimensions with spacer blocks while estimating femoral component size and need for distal and/or posterior femoral condylar augmentation (Video 1).
- Manage gap imbalances with a combination of soft-tissue releases, adjustment of femoral component size, and/or the addition of prosthetic augmentation. In cases in which ideal gap balance cannot be obtained, increased prosthetic constraint is utilized. The technique described involves the use of a single implant system (PFC Sigma; DePuy Synthes). Some technique variations may exist with metaphyseal sleeve systems from different manufacturers, although the principles described apply to most of the sleeve systems.

Step 6: Intraoperative Assessment of Femoral Bone Loss

Perform a detailed assessment of femoral cancellous and cortical bone loss as it is essential to a sound reconstruction.

- At this point, determine if a femoral metaphyseal sleeve is indicated. Typically, a porous-coated, stepped, metaphyseal sleeve is indicated for some AORI type-2A as well as most type-2B and type-3 bone defects. In summary, if substantial bone loss is present in both condyles and there is a large, unsupportive metaphyseal void, use of a femoral sleeve is indicated.

Step 7: Establish a Stable Femoral Platform

When reconstructing the distal aspect of the femur, it is essential to consider femoral bone loss to ensure appropriate sizing of the femoral component.

- Begin reaming for stemmed diaphyseal fixation in a sequential, progressively increasing fashion until adequate endosteal contact of diaphyseal bone has been achieved (Video 2).
- Estimate the size of the required femoral component. A common pitfall during this step is to undersize the femoral component because of bone loss, which results in a mismatch of the flexion and extension gap dimensions. Based on the estimation of the extension gap in the previous step, select an appropriately sized femoral component to restore the anterior-posterior dimensions of the distal end of the femur. Use posterior augments as necessary to “fill the space” left between the remaining bone and implant surface.
- Assemble the broaching stem-sleeve construct. Pay attention to the construct as it directs the surgeon to the medial aspect for appropriate orientation.
- Next, impact the smallest femoral metaphyseal sleeve broach until stability is obtained. The small broach is essentially serving as an intramedullary guide to allow cutting blocks to be applied. At this point, an intramedullary guide is attached to the distal aspect of the sleeve trial. Place the distal femoral cutting jig onto the guide in 5° of valgus orientation to allow for a freshening cut of the distal end of the femur. Then apply the anteroposterior cutting block onto the guide and rotationally position it parallel to the transepicondylar axis (Fig. 6). Freshen the anterior and posterior cuts including cutting for posterior femoral augments if necessary.
- Perform a trial reduction to assess joint stability and joint line level. If extension gap instability is present or if the joint line is excessively elevated, perform broaching with sequentially larger metaphyseal sleeve broaches until rigid axial and rotational fixation of the broach is obtained and the joint line is restored to a proper level. Then use distal femoral augments to fill the distal femoral defect present (Video 2).
- If the extension gap width is appropriate but the flexion gap remains loose, a common maneuver is to place the femoral component more posteriorly. With use of a femoral sleeve, this is not possible. An alternative in this situation is to elevate the joint line by removing the trial femoral component and resecting additional distal femoral bone. Then select a smaller femoral sleeve size (to sit deeper within the metaphysis) and perform re-trialing to assess the equality of the extension and flexion gaps.
- Remove the trial broach.

Fig. 6

Fig. 6 Intraoperative photograph outlining the transepicondylar axis (blue marks) to ensure proper rotation of the anteroposterior femoral cutting block.

Video 2 The overall process as well as tips and tricks of preparing and implanting a femoral sleeve during revision of a femoral component.

Step 8: Patellar Component Preparation

Prepare the patellar component.

- Assess for patellar component loosening or excessive wear. If it is loose or has an unacceptable amount of wear present, remove it at this point with a small oscillating saw or thin osteotomes.
- When reconstructing the patellar component, avoid excessive lateralization and inferior component positioning; this will minimize patellofemoral tracking problems and patellar button impingement on the polyethylene insert, respectively. If patellofemoral imbalance persists, despite optimizing femoral component rotation and patellar position, then a lateral retinacular release can be considered.

Step 9: Final Insert Trialing

Perform final trialing to determine stability, alignment, and level of the joint line.

- Place a polyethylene liner to assess stability and determine the level of constraint required. Since a more constrained insert trial may require a robust anterior drawer maneuver, we recommend trialing with a less constrained insert to assess knee stability while enhancing cement pressurization. Assess gaps to see if the initial augmentation and component size selection resulted in symmetry between the flexion and extension gaps. Critically examine limb alignment and recreation of the joint line.
- Radiographs may be made at this time. We recommend routine intraoperative radiographs for surgeons who are learning or occasionally performing this procedure.

Step 10: Bone Preparation and Implantation of Components

Ensure that rotation of the femoral and tibial sleeves relative to the femoral component and tibial baseplate is precisely replicated when assembling the final modular components.

- Remove trial components. When trial components are removed, take care to maintain the alignment of the sleeve with the femoral and tibial components to allow for appropriate rotational alignment when the final components are assembled (Figs. 7-A through 7-D).
- Occasionally, an asymmetric contained defect (tibial or femoral) may persist despite the use of the metaphyseal sleeve (Figs. 8-A, 8-B, and 8-C). Bone graft (autologous or allograft) may be used to fill the void, and the trial components are then placed back into the area of interest to assist in packing and contouring the bone graft (Videos 1 and 2).

Fig. 7-A

Fig. 7-B

Fig. 7-C

Fig. 7-D

Fig. 8-A

Fig. 8-B

Fig. 8-C

Figs. 7-A through 7-D Removal of trial components and assembly of final components. **Fig. 7-A** Example of rotation of the femoral sleeve compared with the femoral component following trialing and insertion of a locking set screw. **Fig. 7-B** Using a bird's eye view, the surgeon must precisely replicate the rotation of the sleeve relative to the tibial or femoral components from the trial components when assembling the final tibial and femoral sleeves.

Figs. 7-C and 7-D Comparison of trial and final components. **Fig. 7-C** Bird's eye view of precisely replicated final femoral sleeve-femoral component rotation. **Fig. 7-D** Final and trial femoral constructs.

Figs. 8-A, 8-B, and 8-C Intraoperative photographs of an asymmetric tibial defect (**Fig. 8-A**), the residual asymmetric defect following sequential broaching (**Fig. 8-B**), and the result of tibial bone-grafting following removal of the trial sleeve (**Fig. 8-C**).

- Place a thin application of dough-phase cement on the condylar surfaces of the distal end of the femur and proximal part of the tibia as well as on the condylar portion of the prosthetic components. Avoid cement placement into the metaphysis as such cement may prevent osseointegration of the sleeve (Figs. 9-A and 9-B, Videos 1 and 2). Gently impact the tibial component with care to avoid fracture. Ensure that the sleeve is properly oriented rotationally before impaction. Preparation and impaction of the femoral construct follow in a similar manner. Hold the knee in extension with a trial polyethylene insert in place while the cement cures.
- After the bone cement has hardened, perform final trialing, followed by placement of the final polyethylene insert.
- Perform a layered wound closure according to surgeon preference.

Fig. 9-A

Fig. 9-B

Figs. 9-A and 9-B A thin layer of bone cement is applied to the condylar surfaces of the proximal part of the tibia (**Fig. 9-A**) and distal end of the femur (**Fig. 9-B**). No cement should be present in the metaphysis, as that can inhibit bone ingrowth into the porous surface of the tibial and/or femoral sleeves.

Step 11: Postoperative Protocol

Manage the patient with restricted weight-bearing to assist with osseointegration.

- We generally recommend limiting weight-bearing to 30 lb (14 kg) for the initial 4 weeks.
- Obtain radiographs at 4 weeks (Figs. 10-A through 10-D) and have patients begin progressive weight-bearing, typically reaching full weight-bearing over a 2-week period. However, this is largely dependent on the stability of the construct and quality of bone. Metaphyseal sleeve fixation does not impart limitations on postoperative range of motion in a standard total knee arthroplasty revision without complications or soft-tissue or osseous concerns.

Fig. 10-A

Fig. 10-B

Fig. 10-C

Fig. 10-D

Figs. 10-A through 10-D A patient with bilateral total knee replacements. **Fig. 10-A** Preoperative anteroposterior radiograph of both knees. The left total knee replacement had evidence of distal femoral osteolysis (white arrow). **Fig. 10-B** Preoperative lateral radiograph of the left knee demonstrates evidence of radiolucent lines along the anterior flange and distal aspect of the femur suggestive of a loose femoral component.

Figs. 10-C and 10-D Postoperative anteroposterior (**Fig. 10-C**) and lateral (**Fig. 10-D**) radiographs following revision of the left total knee replacement with a femoral sleeve and a diaphyseal-engaging, cementless stem.

Results

Aseptic loosening is one of the most common failure modes of revision total knee arthroplasty^{6,22}. Our center recently performed a review of metaphyseal sleeves used for severe femoral and tibial bone loss in revision total knee arthroplasty⁶. One hundred and sixteen revision total knee arthroplasties with use of 152 metaphyseal sleeves (111 tibial and 41 femoral) were evaluated. Most defects were classified as AORI type 2B (Table II). With a mean follow-up of 5.3 years (range, 2 to 9.6 years), 16.4% required reoperation, most commonly for infection. Only 1 sleeve demonstrated failed osseointegration radiographically but did not require revision. There were 3 intraoperative fractures (1.9%) while broaching. Survivorship at 5.3 years based on all-cause sleeve revision was 97.8%. Our results are similar to the mid-term results of Chalmers et al., who demonstrated a 5-year survivorship free of revision for aseptic loosening of 96% and 99.5% for femoral and tibial sleeves, respectively²³. The authors cited an intraoperative broach preparation fracture rate of 6.5%. While these findings are promising, longer follow-up is needed to determine long-term durability of this methodology.

TABLE II AORI Bone Loss Classification in Knees Having Revision Total Knee Arthroplasty in Watters et al.^{6*}

Femoral Defects			Tibial Defects		
Type 2A	Type 2B	Type 3	Type 2A	Type 2B	Type 3
3	34	4	5	89	17

*AORI = Anderson Orthopaedic Research Institute.

Pitfalls & Challenges

- When removing implants, first disrupt the implant-cement interface to avoid unnecessary bone removal.
- A thorough debridement of the remaining bone is essential to evaluate the size and character of the bone deficiency.
- The appropriately sized femoral or tibial metaphyseal sleeve is determined once axial and rotational stability with the smallest permissible broach is achieved.
- Excessive valgus bowing of the proximal aspect of the tibia will likely result in valgus malalignment of the revision construction as the sleeve and stem will follow the metaphyseal-diaphyseal anatomy. In this circumstance, we recommend other means of fixation such as a shorter cemented stem used in conjunction with a metaphyseal cone.
- An estimation of flexion and extension gaps is critical to help select the appropriately sized femoral component.
- When preparing for a femoral sleeve, initially impact the smallest sleeve and attach the alignment rod. Cutting blocks are then applied and the femoral finishing cuts are completed. Then insert trial components and assess extension gap stability and joint line level. Broaching with larger sleeves is performed as necessary at this point to ensure rigid sleeve fixation, extension gap stability, and correct level of the joint line.
- We recommend the use of a femoral sleeve when distal femoral augments with a width of ≥ 12 mm are utilized to decrease the stress on the condylar implant-cement interface.
- When assembling the trial components, take care to replicate the rotation of the sleeve relative to the femoral component or tibial baseplate. The femoral or tibial sleeve will drive the final rotational position of the femoral or tibial component.
- Overly aggressive impaction of the trial or final components may result in fracture and should be avoided. A high-speed burr may be used when intramedullary sclerotic bone is encountered to avoid such complications.
- When cementing, ensure that cement does not become entrenched in the porous coating of the metaphyseal sleeve. A light application of bone cement onto the condylar surfaces of the tibia and femur as well as the back side of the prosthetic components will lessen the risk of cement contact with the porous coating.

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