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Metaphyseal Fixation Using Highly Porous Cones in Revision Total Knee Arthroplasty: Minimum Two Year Follow Up Study

Kevin M. Denehy, MD [a], Sarag Abhari, MS [b], Viktor E. Krebs, MD [c], Carlos A. Higuera-Rueda, MD [d], Linsen T. Samuel, MD, MBA [c], Assem A. Sultan, MD [c], Michael A. Mont, MD [e], Arthur L. Malkani, MD [f, *]

[a] Department of Orthopaedic Surgery, University of Louisville, Louisville, KY
[b] University of Louisville School of Medicine, Louisville, KY
[c] Department of Orthopaedic Surgery, Cleveland Clinic, Cleveland, OH
[d] Department of Orthopaedic Surgery, Cleveland Clinic Florida, Weston, FL
[e] Department of Orthopaedic Surgery, Lenox Hill Hospital, New York, NY
[f] University of Louisville, Adult Reconstruction Program, KentuckyOne Health, Louisville, KY

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ABSTRACT

Background: Highly porous metaphyseal cones have been introduced to restore metaphyseal integrity for improved cement interdigitation to achieve durable fixation in revision total knee arthroplasty (TKA). The purpose of this study is to review the survivorship, clinical results, and complications of revision TKA using highly porous 3-dimensionally printed titanium metaphyseal cones.

Methods: This is a review of 62 revision TKAs using metaphyseal tibial cones, with 15 cases utilizing both tibial and femoral cones. The mean age of the patients was 66 years (range 32-84) who had a mean follow-up of 27 months (range 24-34). There were 38 women and 24 men, who had a mean body mass index of 33 (range 18.3-62).

Results: Revision-free survival of the cones was 90.2%. If infection was excluded, survivorship was 100%. There were no cases of aseptic loosening. The mean Knee Society Score improved from 51 points preoperatively to 80 points at the time of latest follow-up. The mean Knee Society Functional Score improved from 48 points preoperatively to 68 points. A total of 15 of the 62 patients (24%) required additional surgery: 10 (16%) for infection, 3 (5%) for contracture, 1 for patellar subluxation, and 1 for quadriceps tendon rupture.

Conclusion: Metaphyseal fixation is important for survivorship in revision TKA which can be challenging due to cancellous and structural bone loss encountered at the time of revision. Prosthetic joint infection continues to be the leading cause of failure in revision TKA. The use of highly porous titanium metaphyseal cones produced from 3-dimensionally printed technology used in this study demonstrated excellent short-term results with no cases of aseptic loosening. Further follow-up is required to determine if these results can be durable over a longer period.

Revision total knee arthroplasty (TKA) can be challenging for several reasons including metaphyseal bone loss, which creates difficulty in providing cement interdigitation for long-term durable fixation. There are several treatment options and techniques utilized to address bone loss at the time of revision TKA including methyl methacrylate, cancellous, or structural allograft bone, and distal femoral arthroplasty prostheses with hinged implants [1–11]. The Anderson Orthopedic Research Institute (AORI) bone loss classification system for revision TKA has been utilized as a means for stratifying varying degrees of bone loss as a tool to assist in these treatment options [12].

In an effort to improve metaphyseal fixation for long-term durable stability, the use of cones and metaphyseal sleeves have been introduced [13]. These highly porous cones and metaphyseal

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* Reprint requests: Arthur L. Malkani, MD, University of Louisville, Adult Reconstruction Program, KentuckyOne Health, 550 South Jackson Street, Louisville, KY 40202.

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sleeves with porous coating allow for direct contact with the host bone to promote biologic fixation or osseointegration, but rely on 2 different fixation techniques. Metaphyseal sleeves fill the metaphyseal defect with bulk titanium metal and rely on the surface porous coating for long-term fixation [14,15]. Additionally, metaphyseal sleeves require a broaching technique against sclerotic bone, which can result in an intraoperative fracture [14,15]. Metaphyseal sleeves are also linked devices where the sleeve and stem are unitized, which can create challenges with independent metaphyseal and diaphyseal fixation, including restoration of the joint line. With metaphyseal sleeves, fixation is first achieved through sequential broaching until rigid fixation in the femoral and tibial canal is obtained followed by attempting to restore the joint line. On the other hand, with metaphyseal cones, fixation into the metaphysis is independent of the tibial and femoral stems. The surgical technique consists of re-establishing the joint line and balancing the flexion and extension gaps, followed by restoring the metaphyseal defect using highly porous cones for improved cement interdigitation using the various cone sizes.

Highly porous metaphyseal cones used with cement fixation were initially introduced using tantalum cones as a biocompatible, corrosive-resistant transition metal. The results of revision TKA with these cones have been favorable, although they require trial and error with bone preparation using high-speed burrs for fixation [16–20]. More recently, highly porous tapered titanium cones have been introduced using a cannulated reaming technique to provide ease of insertion with predicable sizing options located on the reamer itself [21–23]. The bone preparation for this second-generation metaphyseal cone is simplified with a reamer system that matches the cone geometry than traditional burring systems used with first-generation cones.

Therefore, the purpose of this study is to review the results of this novel, highly porous second-generation titanium metaphyseal cone produced using 3-dimensionally printed technology. More specifically, we evaluated the following: (1) survivorship, (2) clinical results, and (3) complications in this series of revision TKAs.

Methods

This is a review of 68 patients who underwent revision TKA using a second-generation titanium metaphyseal cone and who were identified from a prospective total joint replacement registry from 2 institutions with a minimum follow-up of 2 years, which is the inclusion criterion. There was 1 death and 5 were lost to follow-up after the 3-month postoperative follow-up, leaving 62 patients available for completed clinical and radiographic evaluation. The primary diagnosis leading to revision TKA included aseptic loosening, instability, prosthetic joint infection, contracture, and periprosthetic fracture. Patient age, gender, body mass index, Knee Society Score (KSS), Knee Society Functional Score (KSFS), and range of motion (ROM) were recorded (Table 1). In addition, tibial and femoral bone loss was classified using the AORI [12] classification system and was determined using preoperative radiographs, as well as intraoperative assessments (Table 2). Postoperative KSS, KSFS, and ROM were recorded from the latest follow-up. Routine postoperative follow-up included clinical and radiographic evaluation at 2 weeks, 3 months, 1 year, and 2 years. All patients in this study were evaluated for signs of clinical or radiographic loosening. Additional factors such as length of hospital stay, postoperative complications, subsequent reoperation, and revision of any component were also identified. The mean age of the patients was 66 years (range 32-84) and there were 38 women and 24 men, who had a mean body mass index of 33 (range 18.3-62).

The most common indication for the index revision was aseptic loosening (25 patients, 40%), followed by instability (16 patients, 26%) and infection (13 patients, 21%) (Table 3). Statistical significance for preoperative and postoperative KSS and KSFS was determined using 2-tailed *t*-tests using GraphPad (GraphPad Software Inc, San Diego, CA) and *P*-values less than .05 were considered statistically significant.

Highly porous metaphyseal titanium cones were utilized along with a Stryker Triathlon revision knee system (Stryker, Mahwah, NJ) (Fig. 1). Three patients had only the tibial component revised, 1 patient had only the femoral component revised, and 58 patients had both components revised. The bone preparation for the metaphyseal cones was performed using a simplified cannulated conical reamer with markings to identify the depth of reaming based on the size of the tibial tray utilized. With metaphyseal bone loss, a symmetric cone was utilized and with segmental bone loss an asymmetric cone was inserted again with a cannulated reaming technique designed for exact fixation without any broaching or burring of the existing host bone. A tibial cone and a short cemented stem were utilized in all tibial reconstructions except for one case where a longer stem was utilized to bypass bone defect. On the femoral side, a bilobed cone was utilized to restore bone loss when indicated using a highly porous cone for improved cement interdigitation into the femoral metaphysis. On the femoral side, either long cementless stems or cemented stems were utilized based on bone quality and preference. There were 40 cementless and 20 cemented stems utilized on the femoral side. The medial and lateral femoral condyles were reamed to the exact depth identified on the reamer guides. Trial cones and implants were inserted to confirm fixation, rotation on the implants, along with flexion and extension gap stability, joint line restoration, ROM, and patella tracking followed by insertion of the actual cones and cement fixation of the tibial and femoral components (Fig. 2).

Results

Revision-free survival of the metaphyseal cones was 90.2%. There were no cases of aseptic loosening in this study. If prosthetic joint infection was excluded, survival was 100%. The mean KSS improved from 51 points (range 8-92) to 80 points (range 42-99) at latest follow-up ($P < .0001$). The mean KSFS improved from 48 points (range 20-90) to 68 points (range 30-100) at latest follow-up ($P < .0001$). Mean postoperative flexion improved from 104° (range 45°-130°) to mean 110° (range 60°-130°) at latest follow-up. After excluding cases of prosthetic joint infection, there was no evidence of radiographic loosening or progressive radiolucent lines in the study group at latest follow-up.

There were 15 patients (24%) who required additional surgery. The most common postoperative complication was periprosthetic

Table 1
Patient Demographics.

Total number of patients	62
Age	66 (32-84)
Body mass index	33 (18.3-62)
Gender distribution	38 females/24 males
Mean follow-up (mo)	26.5

Table 2
AORI Bone Loss Classification.

AORI Grade	Tibia (No. of Patients)	Femur (No. of Patients)
I	1	23
IIA	25	23
IIB	31	15
III	5	1

AORI, Anderson Orthopedic Research Institute.

Table 3
Indications for Revision TKA.

Indication for Revision	Number of Patients
Aseptic loosening	25 (40%)
Instability	16 (26%)
Infection	13 (21%)
Failed TKA (unspecified etiology)	4 (6%)
Contracture	2 (4%)
Arthrofibrosis	1 (2%)
Periprosthetic fracture	1 (2%)

TKA, total knee arthroplasty.

joint infection (10 patients, 16%), with 7 of the 10 postoperative infections (70%) having a prior diagnosis of prosthetic joint infection. Additional postoperative complications requiring revision surgery included 2 cases (3%) of arthrofibrosis requiring arthroscopic debridement, 1 postoperative contracture requiring manipulation under anesthesia, 1 revision (1.6%) due to patella-femoral instability, and 1 exploration/repair (1.6%) due to a postoperative extensor mechanism rupture (Table 4).

Discussion

Revision TKA can be challenging due to multiple factors. The surgeon's goal at the time of revision is to provide durable implant stability, restore bone loss and the joint line, maintain alignment, and provide symmetric flexion and extension gaps, as well as adequate ROM. Historically, allograft bone has been utilized to restore bone loss necessary for stable implant fixation and maintenance of the joint line. However, the results with the use of allograft bone have not been predictable, with some studies with high failure rates [4–7]. There are advantages and disadvantages unique to the use of allograft bone in either cancellous or bulk form. Impaction grafting offers the facilitation of restoring cancellous graft to the femoral and tibial canals for improved cement fixation. However, impaction grafting can be a time-consuming and technically difficult reconstruction with the risk for fracture and infection [2,3].

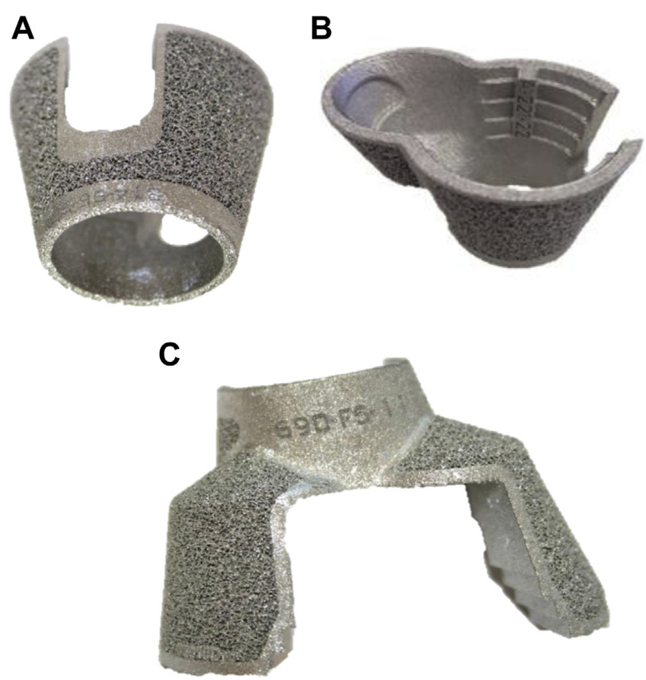

Fig. 1. Second-generation metaphyseal tibial and femoral cones: (A) symmetric tibial cone; (B) asymmetric tibial cone; and (C) bicondylar femoral cone.

Bulk allografts have been a widely used option for AORI type 3 defects and some severe type 2B defects [13]. This technique allows for flexibility in creating the shape or size of the construct required to fill large defects or to restore the joint line and any structural defects. Disadvantages with bulk allograft include prolonged operative time, limited availability of adequate graft, nonunion, delayed union, and graft resorption with a 10-year survival rate ranging from only 72% to 76% in one study [7] or even less [10]. These bone grafting techniques rely on host bone to reincorporate into the allograft, which can be variable in the revision setting given the compromised sclerotic host bone. Studies of revision TKA using bulk allograft with 10-year follow-up have demonstrated a 50% survival rate, mainly due to graft resorption [10]. Bauman et al [24] published 5-year follow-up on bulk allograft with an 11.4% failure rate, excluding infection. Clatworthy et al [6] reported on the 10-year follow-up of revision TKA using allograft with a 13.4% failure rate even when excluding infections.

First-generation metaphyseal cones were introduced to help provide durable long-term fixation of the revision implants, especially with the loss of the metaphyseal cancellous bone required for cement interdigitation [25]. Kamath et al published 5-year mean follow-up on revision TKA using tantalum tibial cones with cemented stems with >95% survivorship [26]. Lachiewicz et al reported on 27 patients with 33 tantalum cones, with 94% developing osseointegration at 2-year mean follow-up [17]. Burastero

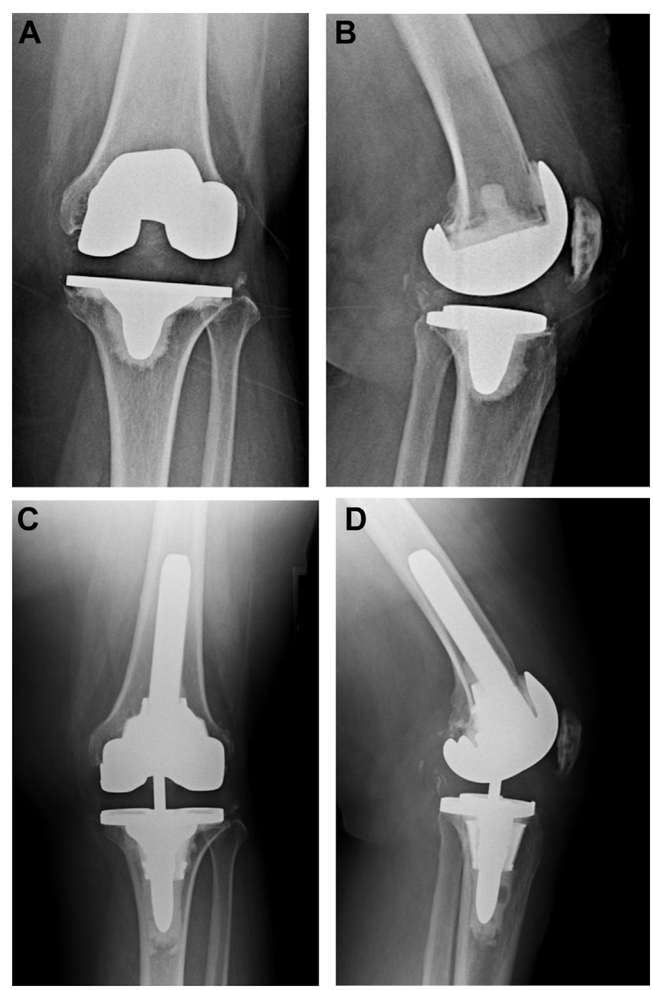

Fig. 2. (A, B) AP/lateral X-rays of 62-year-old female with a failed primary TKA due to instability. (C, D) AP/lateral X-rays of postoperative revision TKA with metaphyseal femoral and tibial cones. AP, anteroposterior.

Table 4
Postoperative Complications Requiring Additional Surgery.

Postoperative Complications	Number of Patients
Periprosthetic infection	10 (16%)
Contracture requiring arthroscopic debridement	2 (3%)
Contracture requiring manipulation under anesthesia	1 (2%)
Patellar instability	1 (2%)
Quadriceps tendon tear	1 (2%)
Total complications	15 (24%)

et al reported on a series of 60 patients treated with tantalum metaphyseal cones following 2-stage revision for septic TKA. They found a 98% survivorship incidence at a minimum 2-year follow-up. They also reported a 5% aseptic loosening rate when a cone was not utilized and 2 cases of periprosthetic joint infections and 1 case of a periprosthetic fracture [27]. Villanueva-Martínez et al [28] reported a 24% fracture rate in their series of revision TKA using metaphyseal tantalum cones. This fracture rate is much higher than what we observed in our study and reflects the complications associated with these first-generation tantalum cone constructs.

The challenges with the first generation of cones were the difficulty in cone preparation and insertion using a burring technique to machine the host sclerotic bone for implant insertion with a trial and error method until the implant was adequately fixed. The second-generation metaphyseal cones used in this study were produced from titanium powder using 3-dimensionally printed technology and were prepared for insertion with a simplified cannulated technique with markings on the reamers to identify the depth and size of the cone required to meet the surgical objectives. Meneghini et al [25] described the rationale and design method for this second-generation metaphyseal cone developed from a computed tomography database of the proximal tibia and distal femur used to identify the ideal location for optimum coverage and support for the cone. Studies have demonstrated relative equivalency and, in some cases, superiority of these new second-generation porous titanium cones to the traditionally used tantalum cones, with respect to mechanical stability measured by micromotion testing under physiological loading [19].

The highly porous metaphyseal titanium cone and cement construct used in this study provided rigid metaphyseal fixation. A rigid metaphyseal construct avoids the need for diaphyseal stem fixation that can cause morbidity with stem pain. The use of metaphyseal cones also provides the surgeon the option to use antibiotic cement in the metaphysis, which has been demonstrated to help minimize risk of infection in revision TKA [26]. Patel et al [23] were the first to publish data with these newer generation metaphyseal cones in a small case series that demonstrated excellent clinical and radiological outcomes after 3-6 months of follow-up. Metaphyseal sleeves that use cement have been shown in multiple studies to also have excellent results in this difficult revision knee patient population [29,30]. For example, Chalmers et al. had excellent results in 280 revision knee patients (393 sleeves) at mean 3 year (range, 2 – 8 years) followup, with 5-year survivorship for aseptic loosening of 96 and 99.5% for femoral and tibial sleeves, respectively [29].

Tibial cones were utilized in every revision TKA in this series and all cases had at least AORI type 2 bone loss with 1 case of tibial type I defect. Despite available metaphyseal bone in these type I and II defects, the bone can be sclerotic and therefore making it difficult to achieve rigid cement interdigitation for long-term fixation. The use of a cone in cases of sclerotic bone provided an improved bed for cement fixation and therefore in our opinion improving our opportunity for long-term durable fixation. The metaphyseal bone can also be damaged after removal of well-fixed implants and cement leading to compromised metaphyseal bone that could limit cement interdigitation. Femoral cones were used in selective cases with significant metaphyseal bone loss. Despite the additional costs of these metaphyseal cones, the benefits perhaps of a more durable metaphyseal construct vs failure and redo revision have to be considered. The surgeon has to take into account multiple factors such as bone quality, extent of bone defect, and patient-related factors when considering the use of additional metaphyseal fixation using cones.

There are several limitations to this study. It has a relatively small cohort of patients without a control group. However, this is a series from 2 large institutional prospective databases of difficult and uncommon cases. The length of follow-up of these second-generation metaphyseal cones is short and therefore difficult to compare to first-generation cones. This cohort of patients will need continued monitoring to evaluate the long-term clinical results of these second-generation cones.

Conclusion

Revision TKA can be challenging due to loss of cancellous and the structural bone required for implant stability and cement interdigitation. The demand for primary TKAs is increasing and a study has shown that surgeons can expect an increase in demand for revisions of 601% by 2030 [31]. These numbers make improving the stability and longevity of these implants essential. Metaphyseal fixation in revision TKA is paramount for revision survivorship. Highly porous titanium metaphyseal cones appear to restore metaphyseal integrity and provide a substrate for cement interdigitation with the potential for good fixation in revision TKA. The short-term results of this study using a second-generation highly porous titanium cones designed to simplify insertion using a cannulated reaming system demonstrated excellent clinical results with 100% aseptic survivorship.

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