The treatment of bone loss in revision total knee arthroplasty has evolved over the past decade. While the management of small to moderate sized defects has demonstrated good results with a variety of traditional techniques (cement and screws, small metal augments, impaction bone grafting or modular stems), the treatment of severe defects continues to be problematic. The use of a structural allograft has declined in recent years due to an increased failure rate with long-term follow-up and with the introduction of highly porous metal augments that emphasise biological metaphyseal fixation. Recently published mid-term results on the use of tantalum cones in patients with severe bone loss has reaffirmed the success of this treatment strategy.

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A successful revision total knee arthroplasty (TKA) requires a stable foundation for component placement, accurate mechanical alignment, durable fixation, and ultimately, an infection-free, well-balanced, mobile, and painless knee.1

The management of tibial and femoral bone loss is often necessary, and the severity and location of these bone defects determines the best type of reconstruction. Options include simple cement filling (with or without screws), modular metal augments, cemented or uncemented stems, cancellous or structural bone graft, and highly porous metaphyseal cones or titanium sleeves.2-5

Rarely, a hinged segmental distal femoral or a proximal tibial replacement is required for non-reconstructible bone defects.6 The development and adoption of highly porous metaphyseal metals – that gain fixation in the metaphysis and allow for biologic osseous ingrowth – has become a cornerstone in the treatment of bone loss in contemporary revision TKA.4 In this paper, the management options for each type of bone defect is presented according to the Anderson Orthopedic Research Institute (AORI) classification7 with an emphasis on moderate to severe bone defects.

Classification

The AORI classification is commonly used to describe femoral and tibial bone loss in revision TKA.7 A Type 1 defect has cystic lesions in cancellous bone with intact cortical bone near the original joint line. A Type 2A defect has damaged metaphyseal bone involving one condyle or hemi-plateau and a Type 2B has cancellous metaphyseal bone loss in both femoral condyles and/or the entire tibial plateau. A Type 3 defect has deficient femoral and/or tibial metaphyseal bone loss with possible damage to the collateral ligaments and patellar tendon attachments.

Surgical management

Modular stems in revision TKA. Modular stems gain fixation in viable host bone and bypass deficient or damaged areas. This enhances the structural stability of the revision construct. Stem options include fully cemented stems, hybrid stems (an uncemented press-fit stem combined with a cemented femoral or tibial baseplate), and fully uncemented stems. Nelson et al8 analysed the effect of femoral stems on rates of re-revision in 130 revision TKAs (67 with stems and 63 without femoral stems) with a minimum two year follow-up. Even though femoral stems were used in patients with more severe pre-operative bone loss, at four years the failure rate was significantly less when femoral stems were used (9% vs 44%, p < 0.05) and it was concluded that femoral stems should be used whenever a femoral component is revised. For the tibial component, Lachiewicz and Soileau9 reviewed 58 tibial component revisions treated with a 30 mm cemented stem extension and reported no revisions for loosening at a mean follow-up of five years. Regardless of the degree of pre-operative bone loss, these studies support the use of femoral and tibial stems in revision TKA.
AORI Type 1. An AORI Type 1 bone defect has intact metaphyseal bone and adequate cancellous bone near the original joint line. These defects, rarely seen in revision TKA, are less than 5 mm in size and can be treated with polymethylmethacrylate cement or morcelled cancellous bone allograft. While remaining bone stock can support primary components, stem fixation to offload the implant-host bone interface is still recommended.8,9

AORI Type 2. Type 2 defects are larger than 5 mm and are not adequately managed with simple cement fill but may also be treated with cement reinforced with several 5 mm or 6.5 mm screws inserted into the deficient condyle (Fig. 1). Even with additional screw fixation, post-operative radiolucent lines are common10 and this technique is best reserved for the low-demand, elderly patient. Type 2 bone loss is often managed with metal augments that allow for greater implant-host bone contact and improved axial and rotational stability. Distal femoral and posterior condylar bone loss is common after implant removal and metal augments up to 10 mm in size can effectively reconstruct these defects. Failure to identify distal femoral bone loss may result in inadvertent elevation of the joint line and if posterior bone loss is not adequately recognised, the revision femoral component will be undersized and malrotated. In revision TKA, the flexion gap is often larger than the extension gap and an undersized femoral component will exacerbate this mismatch. In some cases, the joint line must be elevated in order to increase the extension gap to match the flexion gap but this should only be done after alternative methods of gap balancing (such as upsizing and posteriorly translating the femoral component) have been performed. For most revisions, distal and posterior femoral defects managed with modular augments allow for the placement of a well-positioned and correctly sized femoral component in contact with host bone.

Tibial augments can be wedge or block shaped, ranging in size from 5 mm to 25 mm, and are designed to replace half or the entire width of the tibial plateau. Mechanical testing has shown that tibial block augments are more stable than wedge augments which have a higher shear force.11 Medial or lateral modular metal augments effectively reconstruct bone defects encountered in the revision of a unicompartmental knee arthroplasty where tibial bone loss is isolated to one compartment.12 The clinical results using small metal augments to treat these types of bone loss have been excellent. Patel et al13 reported a 92% survival rate at 11 years in 79 revision TKAs treated with metal augments. Non-progressive radiolucent lines were evident in 14% but this had no effect on the clinical outcome at final follow-up.13

AORI Type 2B and Type 3. The three surgical options for the treatment of moderate to severe Type 2B and Type 3 defects are impaction grafting,14 structural allograft,3,15 and highly porous metal metaphyseal cones or sleeves.4,16-18 All of these techniques are designed to rebuild the damaged femoral and/or tibial metaphysis and create a stable platform for implant placement. Impaction grafting uses morcelled allograft to covert smooth and sclerotic femoral or tibial bone into a more variegated surface by packing it with cancellous allograft in order to improve cement interdigitation and stem fixation. Impaction grafting may be beneficial in younger patients as bone stock restoration is possible with this technique. Peripheral cortical defects are more difficult to manage with impaction grafting as a wire mesh is required to contain the graft. Clinical results at mid-term follow-up of 42 patients treated with impaction bone grafting and fully cemented components reported no mechanical failures, demonstrating the efficacy of this treatment method (Fig. 2).14

Structural allografts replace deficient segments of the femur and tibia and can be used to address central or peripheral defects without the need for additional wire mesh. The femoral or tibial structural graft is customised intra-operatively to fill any type of bone defect. However, with longer term follow-up structural allograft can resorb.
fracture, become infected, or go on to nonunion (Fig. 3). Several studies have reported the long-term outcomes of structural allografts in revision TKA with an average 74% graft survivorship at ten years.3,19 A recent systematic review of 551 structural allografts in revision TKA with an average follow-up of 5.9 years reported a 6.5% rate of graft failure, a 3.4% rate of aseptic component loosening, and a 5.5% rate of deep infection.20 These results show that even at mid-term follow-up, the durability and infection risk of structural allograft is a cause for concern. The increased failure rate with structural allografts stimulated the development of highly porous tantalum cones that function as a prosthetic structural allograft alternative. These devices achieve robust initial metaphyseal fixation and eventual biologic fixation without the risk of graft resorption or fracture. Currently, the two metaphyseal prosthetic options are highly porous tantalum cones (Trabecular Metal cones; Zimmer, Warsaw, Indiana) and titanium sleeves (DePuy, Warsaw, Indiana).

Highly porous tantalum cones
Tantalum is highly porous metal with low stiffness and a high coefficient of friction.21 Highly porous tantalum cones were developed to address the weaknesses of structural allograft and have been used in a variety of reconstructive applications in both the hip and knee.22 The surgical technique for cone insertion involves host bone preparation with a broach or burr to optimise cone contact and enhance bone ingrowth. The cone is press-fit into position and then united to the undersurface of the femoral or tibial implant with cement, allowing for fine adjustments in implant rotation and alignment. Tantalum cones are often inserted with short or intermediate length cemented stems to ensure adequate initial stability needed for osseointegration.23 Once metaphyseal ingrowth occurs, the loads to the implant-host bone interface are dispersed away from the joint line, serving to protect this interface from the repetitive stresses that contribute to mechanical loosening. Tantalum cones come in a variety of sizes (48 mm to 67 mm in diameter, 15 mm or 30 mm in vertical height) and are symmetrical or stepped. (Figs 4 and 5) While the cement interface between the cone and the implant can, in theory, be considered a site of junctional mechanical failure, this has not been observed clinically.

Several clinical studies with porous tantalum cones for bone loss in revision TKA have shown promising results with a cumulative mean revision rate for aseptic cone loosening of 1.1%. (Table I).23-31 A recent study of 66 tantalum tibial cones with minimum five- to nine-year follow-up...
reported a 96% rate of revision-free cone survivorship confirming the long-term durability of this device in patients with moderate to severe bone loss.\(^{23}\) On the femoral side, tantalum cones have performed equally well. Early published results on 23 femoral cones with Type 2B or 3 defects and a minimum of 29 months of follow-up showed no evidence of radiographic or clinical loosening.\(^{4}\)

**Titanium sleeves**

Titanium sleeves are stepped in shape and coated with titanium beads to produce an interconnected porous surface for bone ingrowth. Host bone is prepared with an instrumented broach and the sleeve is then united to the femoral or tibial component with a Morse taper junction. Titanium sleeves come in various sizes and lengths to fill a variety of metaphyseal defects and sleeve position can differ from the tibial component rotation within 15°. For the sleeve to be uncemented, sufficient axial and rotational stability must be achieved in metaphyseal bone at time of implantation. The clinical outcomes of titanium sleeves at short-term follow-up have been excellent, with a 2.6% revision rate for aseptic loosening. (Table II).\(^{32,33}\) 

In conclusion, the contemporary treatment of bone loss in revision TKA depends on defect size and location. We recommend using stem fixation whenever a femoral or tibial component is revised. In bone loss management, Type 1 defects of less than 5 mm can be filled with cement or morcellised bone graft. Type 2 defects of 5 mm to 10 mm can be treated with cement and screw augmentation, but are more reliably managed with a modular tibial or femoral augment. Larger Type 2B and Type 3 defects that involve both condyles and/or the entire plateau, with varying amounts of the metaphyseal damage, may best be managed with metaphyseal reconstruction. Impaction grafting with cemented stems is an option in the younger patient but for larger defects, highly porous tantalum cones or titanium sleeves have largely replaced structural allografts and have been shown to have excellent results at mid-term follow-up. Currently, the senior author’s preferred treatment method for moderate to severe bone loss in revision TKA is a short or enhanced intermediate length cemented stem and a tantalum cone for enhanced metaphyseal fixation.

### Table I. Current literature on highly porous tantalum cones

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<tr>
<th>Study</th>
<th>Year</th>
<th>Mean age (yrs)</th>
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<th>Number of cones</th>
<th>Follow-up (mths)</th>
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### Table II. Current literature on titanium sleeves

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<th>Number of sleeves</th>
<th>Follow-up (mths)</th>
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P. K. Sculco: research, writing paper.
M. P. Abdel: writing paper.
A. D. Hanssen: writing paper.
D. G. Lewallen: writing paper.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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References