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Modular augmentation in revision total knee arthroplasty

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Abstract
Purpose Controversy exists about the real effectiveness of modular augmentation to manage bone defects in revision total knee arthroplasty. The purpose of this study was to determine whether use of modular augmentation to reconstruct severe defects (1) significantly increased overall outcomes, (2) caused radiolucency or osteolysis and (3) affected mid-term survivorship of knee revisions. The hypothesis was that modular augmentation provides a good survivorship of knee revisions.
Methods Thirty-eight consecutive revision knee arthroplasties were followed for a median follow-up period of 7 (4.5–9) years. Type 2 and 3 defects were treated with metal augments, tantalum cones and modular cementless stems. Patients were assessed using the IKS knee and function scores and the HSS score.
Results The median IKS knee and function scores and HSS score were 34 (15–58), 19.5 (13–39) and 30 (24–60) points before the operation, respectively, and 78 (49–97), 76 (58–90) and 80.5 (64–98) points ($p < 0.001$) at the latest follow-up. The median knee flexion increased from 82° (31°–110°) to 116° (100°–129°) ($p < 0.01$). Tibial radiolucencies were observed in 2 (5.2 %) cases. Re-revision was necessary in three (7.9 %) patients.
Conclusions Modular augmentation may reduce the need for allografting to treat severe bone defects, providing a well-functioning and durable knee joint reconstruction.
Level of evidence Case-series study, Level IV.

Keywords Knee arthroplasty · Revision · Bone loss · Modular augmentation · Tantalum

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Introduction

The greatest challenge during revision total knee arthroplasty (TKA) is the management of bone loss that could affect the functionality and final survival of the knee joint reconstructions [33]. The variability in size and location of bone defects has led to the development of a multitude of techniques aimed at restoring physical and functional integrity of the knee [13, 18, 19, 25]. For severe, segmental, type 2 or type 3 defects according to AORI classification [9], structural grafts, metal or tantalum augments, tantalum cones, and special prostheses have been advocated [19, 29–31].

Structural allografts are characterized by well-documented disadvantages: possible fracture, unpredictability of integration, theoretical possibility of viral disease transmission, availability [1, 4, 7, 33]. Another disadvantage is the meticulous preparation required to maximize surface contact between allograft and host bone interfaces [7, 8].

Modular metal augmentation offers several advantages as compared to allografts: extensive modularity, quick and easy use, and large availability. Moreover, metal augmentation requires minimal bone resection, presents excellent biomechanical properties and allows immediate mobilization and loading [15, 20]. Augmentation is

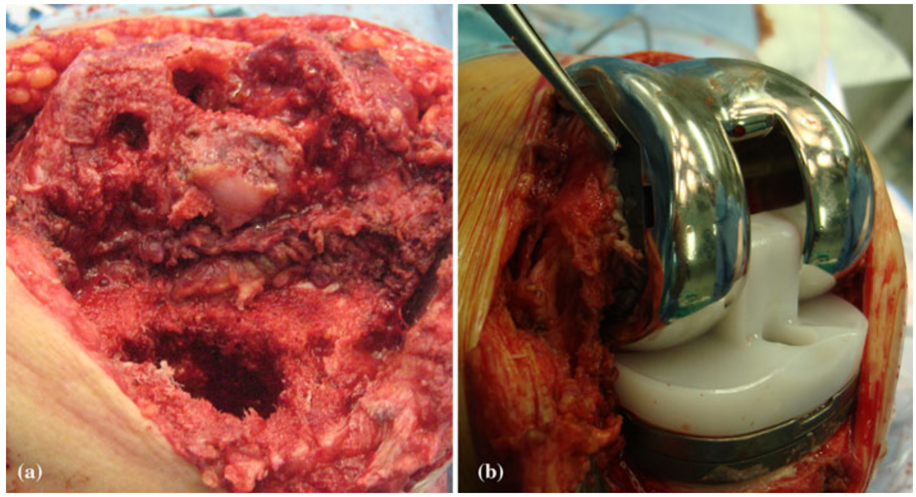

Fig. 1 Segmental femoral and tibial defects (**a**) were managed with metal augments both on the femur and on the tibia (**b**) to ensure stable bone–prosthesis interface that otherwise would not be possible

generally indicated when 40 % or more of the bone–implant interface is unsupported by host bone, resulting in an inability to achieve stability of the trial implants [6] (Fig. 1). Tibial augments can assist the surgeon to recreate a flat platform, restore anatomic joint line and balance extension and flexion spaces (Fig. 2). Posterior femoral augmentation can assist the surgeon in restoring antero-posterior dimension (therefore impacting flexion gap), while distal femoral augmentation is useful in re-establishing the anatomic joint line (therefore impacting extension gap).

Trabecular tantalum augmentation has been proposed to restore the structural stability of the proximal tibial and/or distal femur metaphyses with severe defects [16, 17, 21] (Fig. 3). Physical, structural and biomechanical properties of porous tantalum provide an increased potential for bony ingrowth, which may prove extremely beneficial for younger patients [3, 22].

Modular stems can provide correct component position, enhance fixation and decrease stress at the bone–implant interface in the presence of severe bone loss [2, 5, 23]. Offset stems can assist with implant alignment when the metaphyseal bone may not be directly centred over the diaphysis [26, 28] (Fig. 4).

Concerns exist about the use of modular augmentation related to potential mid-term bone loss and fretting, or dissociation of the modular components. Purpose of this study was to determine whether the use of modular augmentation to reconstruct severe bone defects (1) significantly increased clinical and functional outcomes, (2) caused radiolucency or osteolysis and (3) affected mid-term survivorship of the revision total knee arthroplasties. The hypothesis was that modular augmentation provides stable and durable component fixation, therefore favouring a good survivorship of the knee revisions.

Materials and methods

From 2003 to 2007, 38 consecutive revision knee arthroplasties in 38 patients were carried out by senior surgeon (A.S.P.) at our institution. The indications for the revision procedure included second-stage revision for the treatment for deep infection (16 patients), aseptic loosening of at least one of the components (11 patients), severe osteolysis

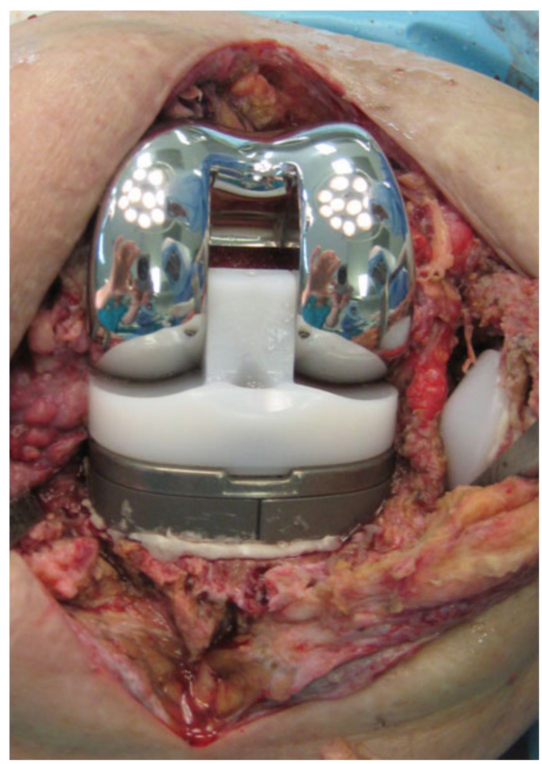

Fig. 2 Full tibial wedges can be used to substitute for extensive cortical bone loss and to elevate the tibial base plate

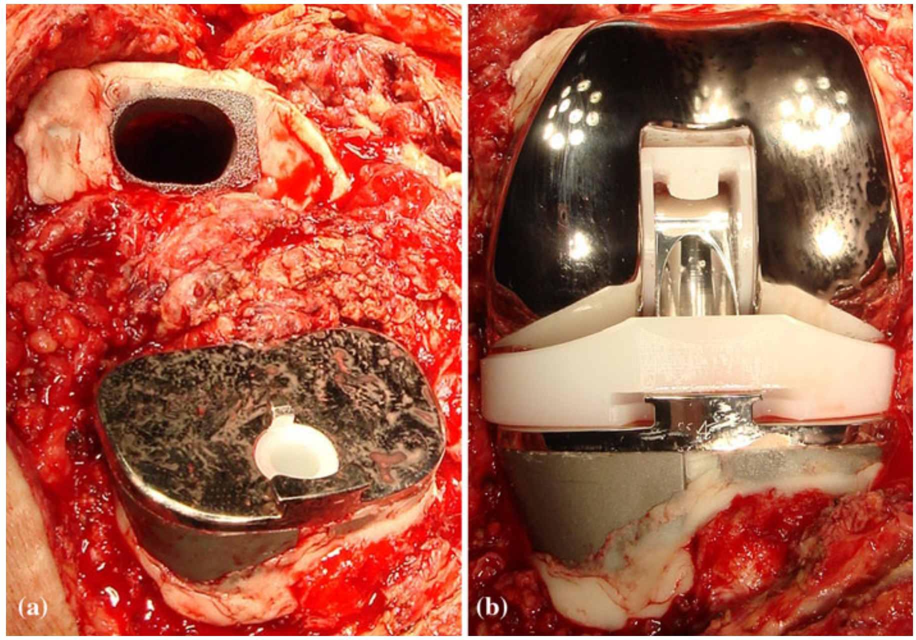

Fig. 3 Massive defects may require extensive reconstructive constructs which include highly porous tantalum metaphyseal cones (**a**, **b**). Tantalum cones were designed to prevent the incidence of non-union and resorption associated with bulk allograft reconstructions

around a well-fixed prosthesis (7 patients), pain (2 patients) and severe knee instability (2 patients).

The study group included 24 women and 14 men. At the time of knee revision surgery, the median patient age was 75 (65–84) years, and the median body mass index (BMI) was 27.3 (24.2–32.3) kg/m^2. The median follow-up was 7 (4.5–9) years.

Removed knee arthroplasties were as follows: postero-stabilized (25 implants), cruciate-retaining (7 implants), semiconstrained (3 implants), medial unicompartmental (2 implants) and hinged (1 implant). Bone deficiency encountered during the revision procedure was categorized according to the AORI bone defect classification system [9]. Thirty-six knees (36/38 or 94.7 %) had an AORI bone defect classification of type 2, and eight knees (8/38 or 21 %) had an AORI bone defect classification of type 3.

Prostheses implanted at revision included the NexGen Legacy Constrained Condylar Knee (LCCK, Zimmer, Warsaw, IN, USA) in 31 patients, the NexGen Rotating Hinge Knee (RHK, Zimmer, Warsaw, IN, USA) in 5 patients and the NexGen Legacy Posterior Stabilized Knee (LPS, Zimmer, Warsaw, IN, USA) in 2 patients with revision of medial unicompartmental arthroplasty. "Condylar constrained knee" (CCK) prostheses are semiconstrained implants which represent an excellent alternative to the hinged prostheses. CCK implants are characterized by a large and long tibial post which engages in the large, deep intercondylar cam of the femoral component, thus ensuring medio-lateral and rotational stability.

Type 1 defects were managed with cement and morselized autografts. Type 2 and 3 defects were treated with metal augments, tantalum cones and modular cementless stems. In particular, tantalum cones were used only for the management of type 3 defects.

All data were prospectively collected. Clinical and radiographic evaluation was performed preoperatively and at post-revision intervals of 3 months, 6 months, 1 year and yearly thereafter. Patients were assessed clinically using the International Knee Society (IKS) knee and function scores and the Hospital for Special Surgery (HSS) knee score; median knee flexion was reported.

Radiographic assessment, including weight-bearing anteroposterior, lateral and Merchant views, was completed for all 38 patients to evaluate the presence of radiolucencies and osteolysis. The presence and location of radiolucent lines were assessed according to a previously reported modification [24] of the Knee Society total knee arthroplasty radiographic evaluation system [10] for long-stemmed revision prostheses. Moreover, radiolucencies were described as none, incomplete or complete. An osteolytic lesion was recorded according to size as none, minimal (0.5 × 0.5 cm) or greater than 2 cm.

Statistical analysis

Patient demographics were described using medians and ranges. Improvements relative to the median IKS knee and function scores, HSS knee score and median knee flexion were analysed using a Student's t test. The degree of statistical significance was defined as $p < 0.05$.

Fig. 4 Offset stems can avoid medio-lateral or anteroposterior component overhang and coronal or sagittal malalignment of the prosthetic components. This radiograph shows a CCK revision with a 9-year follow-up

Results

Constraint choice of the revision prosthesis depended on the state of collateral ligaments and other peripheral knee stabilizers and on the severity of bone loss. A postero-stabilized implant (NexGen LPS) was sufficient in only 2 knees, whereas 31 knees required a semiconstrained implant (NexGen LCCK) and 5 knees required a rotating hinged prosthesis (NexGen RHK).

Table 1 shows specific devices used for the management, respectively, of the tibial and femoral bone defects (Table 1). In particular, tantalum cones were used in 7 of 8 knees with type 3 defect: 4 cones were used on the femoral side, and 5 cones were on the tibial side.

The median IKS knee and function scores and HSS score were 34 (15–58), 19.5 (13–39) and 30 (24–60) points, respectively, before the operation, and 78 (49–97), 76 (58–90) and 80.5 (64–98) points ($p < 0.001$) at the latest follow-up evaluation. The median knee flexion increased from 82° (31°–110°) preoperatively to 116° (100°–129°) ($p < 0.01$) at the final follow-up.

Table 1 Devices used for the management of the bone defects

Option	Tibial side	Femoral side
Cement	7	9
Autograft	2	1
Allograft	0	0
Wedges	2	–
Blocks	38	46
Cones	5	4
Stems	38	36

Clinical outcomes of the patients revised for deep infection (16 patients) and those revised for aseptic loosening and severe osteolysis (18 patients) were considered too. At the final follow-up, the median IKS knee and function scores and HSS score were 77.5 (51–93), 76 (58–87) and 82 (65–93) points for the septic group, respectively, and 80.5 (49–96), 77 (60–89) and 83.5 (67–96) points for the aseptic group, respectively: these differences were not significant (n.s.). The median knee flexion was 123° (108°–127°) in the aseptic group and 105° (100°–112°) in the septic group ($p < 0.01$).

Final results were also analysed dividing the patients into two subgroups: patients with BMI < 30 kg/m^2 at surgery (27 patients) and patients with BMI ≥ 30 kg/m^2 at surgery (11 patients). Patients with BMI < 30 kg/m^2 presented clinical and functional scores significantly higher than patients with BMI ≥ 30 kg/m^2. In particular, the median IKS knee and function scores and HSS score were 82 (54–95), 81.5 (64–90) and 83.5 (69–96) points in the patients with BMI < 30 kg/m^2, respectively, and 76.5 (49–90), 69 (58–89) and 75 (62–88) points in the patients with BMI ≥ 30 kg/m^2 ($p < 0.01$) at the final follow-up. The median knee flexion was 118.5° (102°–129°) in the patients with BMI < 30 kg/m^2 and 106° (100°–123°) in the patients with BMI ≥ 30 kg/m^2, but this difference was not significant (n.s.).

Re-operation was necessary in 3 (7.9 %) patients. One patient with a Legacy Constrained Condylar Knee prosthesis presented knee instability, caused by a probably underestimated complete lesion of medial stabilizers of the knee, and was revised using a one-stage reimplantation with an RHK prosthesis. Two other patients, both with a Legacy Constrained Condylar Knee prosthesis, presented recurrence of infection. One of these two patients required a knee arthrodesis because of a multidrug-resistant *Pseudomonas aeruginosa* infection. The other patient with infection recurrence by methicillin-resistant *Staphylococcus aureus* was revised through a two-stage reimplantation with an RHK prosthesis. All three patients had not presented any problems related to modular augmentation components before the re-operation.

Radiographic results

In two (5.2 %) cases, 12 months after surgery, anteroposterior radiographs revealed radiolucent lines (incomplete and less than 1 mm) around the tibial component, at the bone–cement interface. These radiolucent lines were not progressive at further follow-up intervals, nor associated with subsidence of the tibial platform. In both cases, the radiolucency was observed next to the medial tibial block of a Legacy Constrained Condylar Knee prosthesis. Two femora had minimal osteolysis without clinical or scintigraphic evidence of aseptic loosening.

All metal augments (except two medial tibial blocks as previously mentioned) and all tantalum cones appeared well fixed radiographically at the final follow-up, with no evidence of complications related to the modular augmentation. In particular, on the immediate postoperative radiographs, all nine porous cones appeared to be closely apposed to the adjacent host bone of the proximal tibial and distal femoral metaphysis. No radiolucencies were observed between the cones and adjacent bone at the final follow-up, and this finding was considered evidence of osseointegration.

Discussion

The most important finding of the present study was that 38 knee revisions were satisfactorily managed with metal augments, tantalum cones and stem extension. No allograft was used. The median follow-up was 7 years, therefore supporting the hypothesis that modular augmentation could provide stable and durable revision total knee arthroplasties.

At the latest follow-up, IKS and HSS scores and knee flexion were significantly improved. No significant differences were found between septic and aseptic patients in terms of clinical and functional scores, whereas the septic group presented significant lower range of motion probably due to a major incidence of arthrofibrosis caused by multiple surgeries for eradicating infection. On the contrary, obesity significantly affected clinical and functional scores that were lower in patients with BMI $\geq$ 30 kg/m^2, while no significant differences were found in terms of median knee flexion in patients with BMI $<$ or $\geq$ 30 kg/m^2. Hardeman et al. [14] also found that the cause of index failure did not have a significant effect on the clinical and functional outcome after revision and that the reason for index failure had no influence on the incidence of failure after revision TKA. However, they reported worse results for early (<2 years) revisions that were mostly performed for infection and instability.

Because of the low number (five) of hinged prostheses implanted in this series, no comparison was made between hinged and semiconstrained implants. However, Fuchs et al. [11] reported a statistically significant difference in flexion range of motion between hinged and non-hinged designs (96.5° vs. 107.5°) but not in HSS, KSS, VAS, Tegner activity score or patella score.

The three failures of this series were due to the recurrence of infection in two patients and instability in another patient (probably determined by an underestimated severe ligamentous injury). All three patients had not presented any problems related to modular augmentation components before the re-operation. In all patients, radiographs revealed neither complete or progressive radiolucencies nor signs of significant osteolysis, dissociation or mechanical failure of metal augments and tantalum cones at the final follow-up.

As previously mentioned, this study may support the hypothesis that modular augmentation (metal and tantalum) could result highly effective in managing severe (type 2 and 3) knee periprosthetic bone defects and provide stable and durable component fixation, therefore favouring a good survivorship of the knee joint reconstructions. Haas et al. [12] reported an 8-year survivorship of 83 % on 67 knee revisions for aseptic indications, performed with the use of metal wedges and augments, and not cemented stems. Werle et al. [32] assessed the use of large (30 mm) metal distal femoral augments to compensate for severe bone deficiencies in revision TKA. HSS scores, IKS scores and range of motion improved after implantation of femoral components with 30-mm distal femoral augments. There was no radiographic evidence of loosening, and no implants had been revised at mean 37-month follow-up. Patel et al. [27] described the results of type 2 bone defects treated with modular metal augments in 79 revision total knee arthroplasties. The survival of the components was 92 % at 11 years. The presence of non-progressive radiolucent lines around the augment in 14 % of knees was not associated with poorer knee scores, the range of movement, survival of the component or the type of insert which was used.

Metal augmentation and tantalum cones may simplify the surgical technique of knee reconstruction, making it more reproducible, because of their extensive modularity, quick and easy use, and large availability. Moreover, modular augmentation may considerably shorten operative times with a potential decrease in complications and, above all, infection [4, 8, 19]. Finally, modular augments and tantalum cones, with their excellent biomechanical properties, could provide a well-functioning and durable knee joint reconstruction also in the presence of severe large bone defects. In a biomechanical analysis, Toms et al. [31] compared four methods in treating segmental medial T2A defects: mesh repair with the use of a stainless steel mesh, cement repair, bag repair with the use of a polyester mesh bag filled with compacted morselized bone graft and augment repair. Using metal augments gave the highest initial stability.

Meneghini et al. [22] reported on porous tantalum metaphyseal cones for the treatment for large tibial bone loss at the time of 15 revision total knee arthroplasties. Eight knees had a type 3 defect, and seven knees had a type 2B defect. The patients were followed up for an average of 34 months. Overall, the average Knee Society clinical scores improved from 52 points preoperatively to 85 points at the final follow-up. At the last follow-up evaluation, all fifteen porous metaphyseal cones showed evidence of osseointegration with reactive osseous trabeculation at points of contact with the tibia. There was no evidence of loosening or migration of any of these tibial reconstructions at the time of final follow-up. Three knees presented incomplete, stable and non-progressive radiolucencies.

Howard et al. [16] recently reported on tantalum cones for the treatment for severe femoral type 3 bone loss at the time of 24 knee revisions. The patients were followed up for an average of 33 months. Overall, the average Knee Society clinical score improved from 55 points preoperatively to 81 points at the time of the latest follow-up. All femoral cones appeared well fixed radiographically, with no evidence of complications related to the cones.

Modular augmentation may significantly reduce the need for allografting, whose limitations and complications appear to limit the long-term success of the revision TKA. In fact, concerns exist about the long-term results of structural allografts because of their inherent complications, namely graft non-union, collapse and resorption [33]. One report [4] described sixty-six structural allografts used in 52 revisions. Twelve knees (23 %) had a re-revision at a mean of 70.7 months. The allografts were retained in only two of these patients, and the survival rate for all allografts was 72 % at 10 years. In a retrospective study, Bauman et al. [1] reviewed 65 revisions in which large bone defects were managed with bulk allografts. They reported a 10-year revision survivorship of 76 %. Sixteen patients (22.8 %) had failed reconstructions, with 8 of 16 as a result of allograft failure and 3 as a result of failure of a component unsupported by an allograft.

The main limitation of this study was that a non-randomized case series was presented. Although 38 knee revisions were included in a prospective study, results were not compared with any control group. Moreover, patients and respective outcomes were not matched based on their age or the type of implanted prosthesis because of the low number (five) of hinged devices implanted in this series.

However, the clinical relevance of the present study was to show how modular augmentation could manage severe knee periprosthetic bone defects without needing allografting, whose limitations and complications appear to limit the long-term success of the revision TKA [1, 4, 33]. Because of their extensive modularity, quick and easy use, large availability, excellent biomechanical properties and potential decrease in complications [4, 8, 19], metal augmentation and tantalum cones could provide well-functioning and durable revision total knee arthroplasties.

Conclusions

In this study, metal augments, tantalum cones and modular stem extension were used to manage severe femoral and tibial defects during revision TKA. Clinical and functional scores significantly improved, whereas no radiologic evidence of complications related to the metal augments and tantalum cones occurred at the final follow-up. The cause of revision (septic or aseptic) did not significantly affect clinical and functional outcomes, whereas obesity significantly decreased clinical and functional scores at the last follow-up.

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Conflict of interest None.

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