

Tibial metaphyseal cones combined with short stems perform as well as long stems in revision total knee arthroplasty

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Introduction

Total knee arthroplasty (TKA) is a common procedure with good long-term survivorship.¹ As more TKA procedures are being performed, on a younger patient population, the number of revision total knee arthroplasty (rTKA) procedures is naturally set to increase.² Large osseous defects in the tibia, and their adverse impacts on fixation, are a common and challenging problem encountered during rTKA.³ Bone loss can be stratified using the Anderson Orthopaedic Research Institute (AORI) bone loss classification system.⁴ In large osseous defects (AORI II or III), solid fixation onto both the metaphysis and diaphysis is required for reliable fixation.^{5,6}

Trabecular metal (TM) tantalum cones (Zimmer, Warsaw, IN, USA) are one option for establishing metaphyseal (zone 2)

Abstract

Backgrounds: There is uncertainty around optimal tibial stem length in revision total knee arthroplasty (rTKA) utilizing a tibial trabecular metal (TM) cone. The purpose of this study was to compare: (1) functional outcomes, (2) radiographic outcomes and (3) implant survivorship in rTKA utilizing TM cones combined with either short stems (SS) or long stems (LS) at minimum 2 years follow-up.

Methods: In this retrospective, multi-centre study, patients undergoing rTKA utilizing a TM cone between 2008 and 2019 were included. Patients were divided into: SS group (no diaphyseal engagement), and LS group (diaphyseal engagement). All relevant clinical charts and post-operative radiographs were examined. Oxford Knee Score (OKS) and EuroQoL-5D (EQ-5D-5L) data were collected at most recent follow-up.

Results: In total, 44 patients were included: 18 in the SS group and 26 in the LS group. The mean time of follow-up was 4.0 years. Failure free survival was 94.4% for the SS group and 92.3% for the LS group. All failures were for prosthetic joint infections managed with debridement, antibiotics, and implant retention. At most recent follow-up, 3 patients demonstrated radiographic signs of lucency (1 SS 2 LS, $P = 1$) and the mean OKS were 37 ± 4 and 36 ± 6 ($P = 0.73$) in the SS and LS groups, respectively.

Conclusion: Tibial SS combined with TM cones performed as well as LS in rTKA at minimum 2 years follow-up. A tibial SS in combination with a TM cone is a reliable technique to achieve stable and durable fixation in rTKA.

fixation in the presence of large osseous defects.^{7–9} *In vitro* studies have reported favourable mechanical and osteoinductive properties, demonstrating the potential to provide short-term support and long-term fixation.^{10,11} Several clinical studies have evaluated this technology with good implant survivorship and favourable short- and medium-term functional and radiological outcomes.^{9,12}

Diaphyseal (zone 3) fixation in rTKA is usually established using stems.¹³ Stems can be broadly classified as short or long. Short stems (SS) are cemented into the metaphysis and proximal diaphysis whereas long stems (LS) directly engage the diaphysis. Traditionally, long stems have been used in the context of severe bone loss to offload the deficient metaphyseal bone and improve implant alignment. However, long stem use is associated with end of stem pain and stress shielding.¹⁴ Computational and cadaveric

biomechanical studies have indicated that long stems may not be necessary alongside a TM cone, even when large osseous defects are present.¹⁵ Recent clinical studies comparing SS and LS use alongside TM cones further support this idea.^{16–18}

The purpose of this study was to evaluate: (1) survivorship, (2) functional outcomes and (3) radiographic outcomes in this series of rTKAs utilizing tibial TM cones with SS or LS with a minimum of 2 years follow-up.

Materials and methods

This study was carried out with ethical approval from the Auckland Human Research Ethics Committee (AHREC, AH0045), along with locality approval in all institutions from which data was collected.

All patients who underwent rTKA at four tertiary public hospitals between January 2008 and July 2019 were identified using theatre and discharge codes. Operative notes and post-operative x-rays of the identified procedures were examined and those utilizing a tibial tantalum cone (Trabecular Metal; Zimmer, Warsaw, Indiana) were included in the study. The exclusion criteria were cones implanted alongside a primary TKA, or the absence of two-years of clinical follow-up. Two patients lacked two-year follow-up without known complications or reoperation;

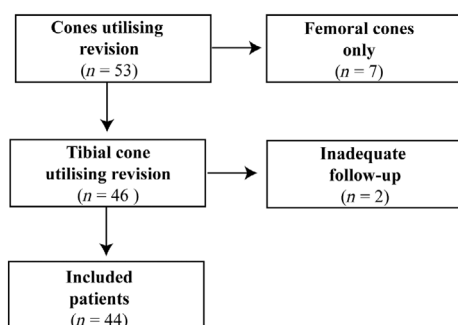


Fig. 1. Participant flow chart.

Fig. 2. Representative X-rays of two different rTKA reconstructions. (a) Tibial-sided TM cone with LS. (b) Tibial-sided TM cone with SS. TM, trabecular metal; SS, short stem; LS, long stem.



one died for reasons unrelated to his surgery and one was lost to follow-up. A total of 44 participants were included in our study (Fig. 1).

Study participants were separated into two groups based on whether their tibial implant stem extension was of substantial length to reach the diaphysis (Fig. 2). This was assessed on post-operative x-rays. A total of 26 patients had tibial stems reaching the diaphysis and were placed in the LS group and 18 patients had tibial stems that did not reach the diaphysis and were placed in the SS group. The mean follow-up time of the included study cohort was 4.0 ± 1.8 years (range, 2.1–12.1 years).

All patients were followed using electronic hospital records and radiographs. Patient pre-operative characteristics are summarized in Table 1. No significant difference in any baseline parameter was observed between the two groups. The indications for the index revision were aseptic in 35 patients (80%) and septic in 9 patients (20%) (Fig. 3). Septic rTKAs were all performed as part of a two-stage procedure.

Surgical technique

All procedures were performed by fellowship-trained arthroplasty surgeons experienced in complex rTKAs. The surgical technique used to implant tantalum cones in our cohort closely resembled that described in previous studies.⁷ The choice of stem type (SS or LS) was based on individual surgeon preference. Bone defects in all revised tibias were classified as AORI II or higher.² All cases used antibiotic-loaded cement. All short stems were fully cemented. Of the long stems, 5 were fully cemented, and the others utilized a hybrid fixation technique. Surgical characteristics are summarized in Table 2.

Clinical, functional and radiographic evaluation

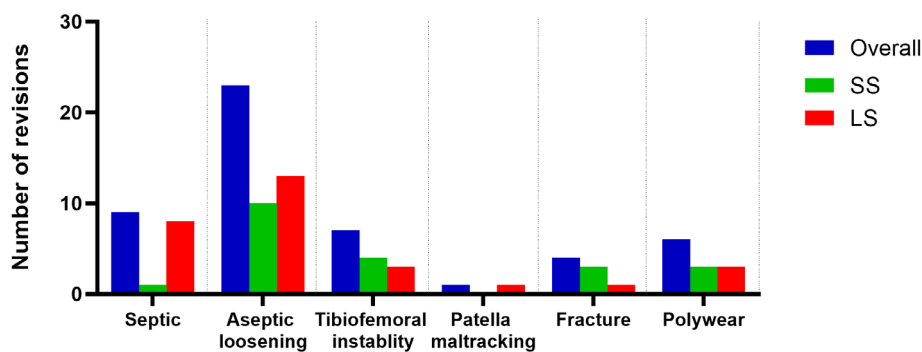
Patients were routinely seen 2 weeks post-operatively for a wound check, followed by clinic review and X-ray at 6 weeks, then 6 months, and annually thereafter. If any concerns were identified, more frequent follow-up appointments were scheduled as required. Information regarding complications, reoperations and revisions

Table 1 Patient demographics, comorbidities and surgical history

Characteristic	Overall	SS	LL	P value
Sex[†]				
Female	30 (68%)	15 (83%)	15 (58%)	0.15
Male	14 (32%)	3 (17%)	11 (42%)	
Age (y)[‡]	70.4 (± 9.2)	68.25 (± 9.7)	71.8 (± 8.8)	0.22
Ethnicity[†]				
New Zealand European	24 (55%)	12 (66%)	12 (46%)	
Māori	5 (11%)	2 (11%)	3 (12%)	
Other	15 (34%)	4 (22%)	11 (42%)	
American Society of Anaesthesiologists (ASA) Physical Status rating[†]				
1	4 (9%)	2 (11%)	2 (8%)	0.93
2	24 (55%)	9 (50%)	15 (58%)	
3	16 (36%)	7 (39%)	9 (35%)	
BMI (kg/m²)[‡]	30.8 (± 5.8)	32.3 (± 6.9)	30.0 (± 5.0)	0.26
Diabetes[†]	10 (23%)	4 (22%)	6 (23%)	1
Rheumatoid arthritis[†]	5 (11%)	2 (11%)	3 (12%)	1
Immunocompromised at time of revision[†]	4 (9%)	2 (11%)	2 (8%)	1
Peripheral vascular disease[†]	2 (5%)	0 (0%)	2 (8%)	0.64
Current smoker[†]	4 (9%)	2 (11%)	2 (8%)	1
Follow-up (years)[‡]	4.0 (± 1.8)	3.8 (± 1.3)	4.2 (± 2.1)	0.48

[†]Values given as number of patients with the percentage in parenthesis.

[‡]Values given as the mean with the standard deviation in parenthesis.

**Fig. 3.** Indications for revision surgery.

was retrospectively obtained from clinic letters recorded during follow-up visits and from subsequent operation notes, clinical notes, and discharge summaries.

Failure was defined as any operation where the tibial component was explanted, whether for component loosening or deep infection. Deep infection which was not treated with surgical revision but where the patient was placed on lifelong suppressive antibiotics was also treated as a failure. Reoperation was defined as any open knee surgery not involving cone explanation.

Knee function was assessed post-operatively with the use of the Oxford Knee Score and the EQ-5D.^{19,20} OKS score and EQ-5D data were obtained via questionnaires sent prospectively through the mail. The 5-digit EQ-5D results were converted into a single summary index score (EQ-5D index score) using the commonly used UK EQ-5D Index Score.²¹

AP, lateral and patella views taken post-operatively at routine follow up were analysed for the presence of radiolucent lines and reactive trabeculation by two senior authors.

Statistical analysis

Failure, reoperation, and complication rates, as well as patient demographics and operative characteristics were investigated using SPSS 11.0 for Windows (IBM, Armonk, NY, USA), with statistical significance set at $P < 0.05$. Discrete data was assessed using the Chi-Squared test. Testing the normality of continuous data was undertaken using the Shapiro-Wilks Test, followed by either a Student's *t*-test (parametric) or Mann-Whitney *U* test (non-parametric). A Kaplan-Meier survivorship analysis was performed with the endpoint being failure as defined above.

Results

Survivorship

At last follow-up available, three knees (6.8%) required a reoperation (1 SS and 2 LS patients). The failure rate of the SS group at mean follow-up 3.8 years was 5.5%, and the failure rate of the

LS group at mean follow-up 4.2 years was 7.7%. While our study was underpowered for a formal non-inferiority analysis, in our small cohort, there were no statistically significant differences in failure rates ($P = 1$). Kaplan–Meier survival estimates (failure as endpoint) are presented in Figure 4.

Table 2 Surgical characteristics

Characteristic	SS	LS
Revised components[†]		
Tibial components alone	0 (0%)	1 (4%)
Both Femoral and tibial components	18 (100%)	25 (96%)
Femoral cone implanted [†]	5 (28%)	15 (58%)
Level of constraint[†]		
Posteriorly stabilized (PS)	8 (44%)	5 (19%)
Constrained condylar knee (CCK)	6 (33%)	20 (77%)
Rotating hinge (RH) [§]	4 (22%)	1 (4%)
Stem usage[†]		
Short stem	18 (41%)	
No stem extension	12 (67%)	
30 mm (stubby stem) extension	6 (33%)	
Long stem		26 (59%)
100 mm extension		16 (61%)
155 mm extension		10 (38%)
Long stem cementation[†]		
100 mm stem extension utilizing hybrid fixation		12 (46%)
100 mm extension fully cemented		4 (15%)
155 mm stem extension hybrid fixation		9 (35%)
155 mm stem extension fully cemented		1 (4%)

[†]Values given as number of implants with the percentage in parenthesis.
[§]All femoral tumour prosthesis.

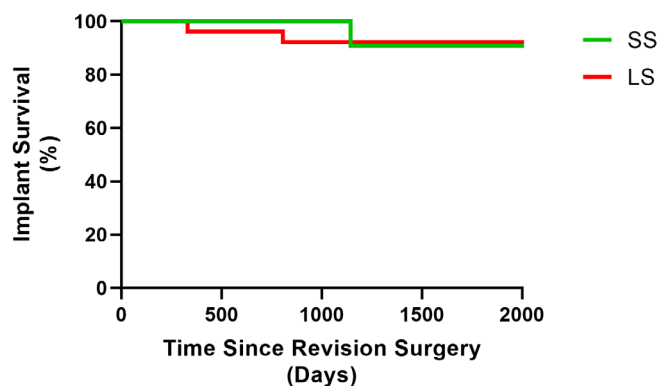


Fig. 4. Kaplan Meier survival curves for short stems (SS) and long stems (LS).

Table 3 Functional outcomes

Characteristic	Overall	SS	LL	<i>P</i> value
OKS[†]	36.6 (± 5.5)	37.1 (± 3.7)	36.3 (± 6.2)	0.73
EQ-5D-5L[†]	0.77 (± 0.13)	0.81 (± 0.16)	0.76 (± 0.11)	0.37
EQ-VAS[†]	66.3 (± 23.7)	64.4 (± 19.0)	67.2 (± 26.3)	0.79

[†]Values given as the mean with the standard deviation in parenthesis.

The causes for failure were chronic PJI for two patients in the LS group and late-onset PJI for one patient in the SS group. These were all treated with irrigation and debridement, polyethylene liner exchange with component retention, and lifelong antibiotic therapy. At the time of re-operation, all tibial implants were noted to be well fixed. Both LS failures had septic indications for their index revision surgery, while the SS failure was originally revised due to a periprosthetic fracture. There were no reoperations because of aseptic loosening. One patient, in the LS group experienced chronic end of stem pain that was managed non-operatively. Further, in the LS group, one patient experienced extensor mechanism failure managed conservatively with an extension brace.

Functional

Functional scores were available for 25 patients, 8/18 (44%) of the SS group and 17/28 (61%) of the LS group. The mean functional follow-up time was 4.5 years and 3.8 years mean follow-up in the SS and LS groups, respectively ($P = 0.28$). At most recent follow-up the mean OKS were 37 ± 4 and 36 ± 6 ($P = 0.73$) and the mean EQ-5D-5L Index Scores were 0.81 ± 0.16 and 0.76 ± 0.11 ($P = 0.37$) in the SS and LS groups, respectively. Functional outcomes are summarized in Table 3.

Radiographic

Immediate postoperative X-rays of all knees showed apposition between cone and metaphyseal bone. The mean radiographic follow-up was 2.0 years and 2.7 years follow-up in the SS and LS groups, respectively ($P = 0.43$). At the time of most recent radiographic follow-up all, one patient in the SS group and two patients in the LS group demonstrated non-progressive tibial radiolucent lines ($P = 1$). However, none of these patients were revised for component loosening.

Discussion

The main finding of this study was that the use of short stems combined with TM cones was not associated with increased failure rates compared with long stems and TM cones in rTKA with severe tibial bone loss at a minimum of 2 years follow-up.

Tibial bone loss in rTKA is diverse in aetiology and extent; its pattern is difficult to anticipate preoperatively and is often underestimated.^{22,23} Full assessment of the bone defect can only occur intraoperatively after the implant has been removed, however the surgical plan and fixation method should be determined beforehand. Unforeseen bone loss may complicate the initial surgical plan by making fixation with stems, modular augments, or small bone grafts

insufficient.^{13,24} Thus, there is a need for a robust and flexible supplementary fixation method that can be used on a large variety of bone defects. A variety of techniques are currently employed, with no clear consensus as to which method is the most efficacious.²⁵

Porous metaphyseal technologies, specifically TM cones and metaphyseal sleeves (MS) have emerged as a promising addition to the armamentarium of techniques used to address osseous defects in rTKA.^{26–28} Nonorganic and inert in nature, porous metaphyseal technologies eliminate the risks of disease transmission, resorption, or collapse. These implants possess a high friction coefficient which facilitates early mechanical stability, and are also highly porous, facilitating bone ingrowth and long-term biological fixation.^{9,12,29,30} The disadvantages of these technologies include the occasional need to remove viable bone to adapt residual anatomy, cost, and difficulty of removal during re-revision.

A systematic review of TM cone usage in rTKA conducted by Divano *et al.*²⁶ reported a revision rate of 8.2% at 3.6 year mean follow-up. Zanirato *et al.*²⁸ reported a similar revision rate of 7.7% at 3.6 years follow-up in their systematic review of TM cones. This study reports a 6.8% total failure rate observed at 4.0 years mean follow-up, with prosthetic joint infection being the sole cause of failure. MS show similarly promising results, with Chalmers *et al.*³¹ reporting a revision rate of only 2.5% at 3 years mean year follow-up. In a systematic review comparing the two techniques, Roach *et al.*³² found that the revision rate when using TM cones was twice as high compared with MS. However, the review conducted by Zanirato *et al.*²⁸ found an equivalent survival rate between the two techniques. No randomized studies have directly compared the two fixation methods.

The stable zone 2 fixation offered by these porous metaphyseal technologies may mean zone 3 fixation is less relevant and can be achieved with smaller stems.^{15,33–35} Though long stems can aid implant alignment, up to one in six patients report end of stem pain which can significantly decrease patient quality of life.^{13,36} The current literature surrounding optimal stem use in rTKA, let alone TM Cone utilizing rTKA, is poor.³⁷

MS implants without long stems have shown mixed results; Stefani *et al.*³⁸ and Fonesca *et al.*³⁹ reported favourable outcomes whereas Gøttsche *et al.*⁴⁰ encountered problems with implant malalignment. In contrast, TM cones without long stems have demonstrated consistently promising outcomes. Denehy *et al.*⁴¹ reported a failure rate of 9.8% at 2.2 years follow-up with no cases of aseptic failure in a cohort of short stemmed tibial prosthesis. Behery *et al.*¹⁸ reported a 14% reoperation rate at 3.3 years follow-up with no cases of aseptic loosening in a similar cohort. Jacquet *et al.*¹⁶ directly compared TM cone + SS and TM cone + LS in aseptic rTKA, finding equivalent survival rates between the two groups and superior functional outcomes in the TM cone + SS group. This study included 18 SS implants with a total failure rate of 5.5% and aseptic failure rate of 0% at 3.8 years follow-up. Our study also found equivalent functional and radiological outcomes between the SS and LS groups.

Limitations of this study include a small patient number and short follow-up time. However, this study included all operations utilizing a tibial TM cone which have occurred in the catchment area. Inherent bias when retrospectively reviewing data, although

care was taken to be systematic, is probable. Lack of preoperative functional scores limited our functional analysis and the conclusions thus drawn. Lastly, patients were sourced from multiple different centres to increase numbers, introducing confounding error when observing trends in performance.

Short tibial stems combined with TM cones provide comparable short- to mid-term fixation and function compared with long stems and TM cones in revision knee arthroplasties complicated by extensive bone loss. Further studies with longer follow-up are required to determine whether TM cones provide suitable long-term clinical, radiographic, and functional outcomes.

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Conflict of interest

The authors did not receive financial support from any organization for the submitted work. Jacob Munro has received a speaking fee from Zimmer Biomet and DePuy Synthes. All other authors have no conflicts of interest to declare that are relevant to the content of this article. The study has been performed in accordance with the ethical standards in the 1964 Declaration of Helsinki.

Author contributions

Bruno Batinica: Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; writing – original draft; writing – review and editing. **Scott M. Bolam:** Conceptualization; formal analysis; funding acquisition; investigation; methodology; writing – original draft; writing – review and editing. **Matt D’Arcy:** Conceptualization; data curation; formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Mark Zhu:** Conceptualization; formal analysis; funding acquisition; methodology; project administration; writing – original draft; writing – review and editing. **A. Paul Monk:** Conceptualization; methodology; project administration; supervision; writing – original draft; writing – review and editing. **Jacob T. Munro:** Conceptualization; methodology; project administration; supervision; writing – original draft; writing – review and editing.

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