



Novel metaphyseal porous titanium cones allow favorable outcomes in revision total knee arthroplasty

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Abstract

Introduction Loosening and migration are common modes of aseptic failure following complex revision total knee arthroplasty (rTKA). Metaphyseal cones allow surgeons to negotiate the loss of femoral and tibial bone stock while obtaining stable bony fixation. This study examines the mid-term functional and radiographic outcomes in patients undergoing rTKA utilizing a novel metaphyseal cone system with stems of variable length and fixation methods.

Methods This two-center retrospective study examined all patients who underwent rTKA with a novel porous, titanium tibial or femoral cone in combination with a stem of variable length and fixation who had a minimum follow-up of 2-years. Outcome analysis was separated into tibial and femoral cones as well as the stem fixation method (hybrid vs. fully cemented).

Results Overall, 123 patients who received 156 cone implants were included (74 [60.2%] tibial only, 16 [13.0%] femoral only, and 33 [26.8%] simultaneous tibial and femoral) with a mean follow-up of 2.76 ± 0.66 years. At 2-years of follow-up the total cohort demonstrated 94.3% freedom from all-cause re-revisions, 97.6% freedom from aseptic re-revisions, and 99.4% of radiographic cone osteointegration. All-cause revision rates did not differ between stem fixation techniques in both the tibial and femoral cone groups.

Conclusion The use of a novel porous titanium femoral and tibial metaphyseal cones combined with stems in patients with moderate to severe bone defects undergoing complex revision total knee arthroplasty confers excellent results independent of stem fixation technique.

Level of evidence IV, case series.

Keywords Total knee arthroplasty · Revision total knee arthroplasty · Subsidence · Cone · Hybrid fixation · Cement

Introduction

The volume of revision total knee arthroplasty (rTKA) cases will continue to rise as primary TKA increases and risk factors for revision, such as obesity and old age, become

increasingly more common in those with previous primary TKAs [1]. The most frequently reported causes of TKA failure include aseptic loosening, infection, instability, and polyethylene wear [2–4]. Mechanical aseptic loosening often results in subsidence, described as the downward migration or “sinking” of all or part of the tibial prosthesis, often requiring revision due to altered knee mechanics [1, 2]. Bone loss is present to some degree in all revision TKA secondary to implant removal and resultant bone resection. This challenge can be addressed using different techniques and implants; however, the optimal approach has not yet been identified because of insufficient long-term data [5].

Three anatomical zones around the femur and tibia are available to support revision implants (joint surface or epiphysis, metaphysis, and diaphysis). Solid fixation in two of the three zones is critical to achieving long-term durability of revision TKA constructs [2]. Given this, numerous

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augmentation strategies have been developed to offset the bone loss and to restore the structural support and kinematic functionality of the knee. These constructs include traditional allografts and modular components, such as metaphyseal cones and sleeves, which were developed to fill larger femoral and tibial bone defects [3–5]. To achieve metaphyseal fixation, cones are a viable alternative to structural allografts, as these augments can provide excellent osteointegration and freedom from aseptic loosening [6–8].

Stems, on the other hand, can achieve diaphyseal fixation while bypassing bony defects and unloading compromised epiphyseal and metaphyseal zones [9]. Different stems lengths and fixation methods can be utilized in rTKA. Historically, long press-fit stems have been preferred to optimize the implant alignment and offload the metaphysis. However, pain that rises by stress between the tip of the stem and the host bone has been reported [10]. Recent studies reported that the use of metaphyseal cones with short, cemented stems had a similar survival rate with better functional outcomes compared with the use of cones and long uncemented stems [11, 12]. Therefore, the biomechanical efficacy of the cementation technique, when combined with metaphyseal cones, remains unclear.

Given this, the purpose of the study was to compare the functional outcomes and survival of rTKA using a novel titanium cone design with stems of variable length and fixation at a minimum of a 2-year follow-up.

Methods

This two-center institution, multi-surgeon, retrospective study examined all patients undergoing rTKA who received a porous, titanium tibial or femoral cone at two large institutions. Porous titanium metaphyseal cones were used to augment reconstruction in cases with severe tibial and/or femoral bone defects during rTKA with Anderson Orthopedic Research Institute bone loss classification ≥ 2 [13]. The Legion Cone System (Smith&Nephew, Memphis, TN) was FDA approved on January 2017 and integrated for use in revision TKA in both centers in June 2017. After

institutional review board approval, electronic medical records (EMR) from two independent health systems were reviewed to identify all revision total knee arthroplasties performed between July 2017 to April 2019. Data were collected and analyzed starting September 1st 2021. Inclusion criteria for this study were: patients who were 18 years or older who underwent revision TKA using Legion Cone System (Smith&Nephew, Memphis, TN). Exclusion criteria included: primary TKA cases, patients with pathologic lesions in the affected knee, and patients with less than 2-year follow-up since the index rTKA procedure. Of the 207 patients identified, seven primary TKA were excluded, two cases for pathologic lesions in the affected knee and 75 that did not complete a 2-year minimum follow-up. Patients who died with the implant in situ and patients who lost to follow-up were considered censored at the date of death and last follow-up, respectively. Finally, 123 patients met the inclusion criteria to be included for analysis. All patients that underwent rTKA with a tibial cone were paced in the tibial cone cohort, and all patients that underwent rTKA with a femoral cone were paced in the femoral cone cohort.

Data search

The EMRs were reviewed for demographic data, including patient age, gender, BMI, American Society of Anesthesiologists (ASA) Classification, and smoking status. Surgical characteristics were collected from a review of operative reports, including operative time, bone loss, revision indication, implant constraint, stem length, coupler use, revised components, and femoral and tibial cone use. Tibial and femoral-sided bone loss was categorized per the Anderson Orthopaedic Research Institute bone defect classification on the basis of intraoperative assessment and preoperative X-ray findings [13, 14] (Table 1). Perioperative and clinical outcomes, such as operative time, hospital length of stay (LOS), 90-day readmissions, were also collected for this analysis. Re-revision including incidence, indications and cone explanation data was obtained from surgeries that were performed solely in the participating centers. Functional outcomes measured by knee flexion were collected

Table 1 Bone loss in all included patients as per Anderson Orthopedic Research Institute (AORI) Classification

Tibial			Femoral		
AORI tibial classification	All patients (<i>n</i> = 123)	Cones (<i>n</i> = 107)	AORI femoral classification	All patients (<i>n</i> = 123)	Cones (<i>n</i> = 49)
T1	13 (10.5%)	0 (0.0%)	F1	44 (35.7%)	0 (0.0%)
T2A	41 (33.3%)	37 (34.5%)	F2A	27 (21.9%)	1 (2.0%)
T2B	37 (30.0%)	37 (34.5%)	F2B	21 (17.0%)	21 (42.9%)
T3	33 (26.8%)	33 (30.8%)	F3	27 (21.9%)	27 (55.1%)

AORI Anderson Orthopedic Research Institute

from preoperative and the most recent postoperative reports. Re-revision surgery was defined as any case in which the femoral, tibial, polyethylene liner or all components were explanted or exchanged. LOS was evaluated in days spent in the hospital following surgery, and surgical time was derived by calculating the time difference between the initial skin incision and skin closure.

Radiographic follow-up and analysis

All patients were followed postoperatively at various time points, including 2 weeks, 6 weeks, 3 months, 6 months, 1 year and 2-year postoperatively. At the 2-year follow-up visit, patients were instructed to come for a follow-up visit should any symptoms occur or per surgeon request on a case to case basis. Thus some patients have longer follow-up visits which are reported in the figures. Pre and post-operative knee range of motion as well as knee stability were evaluated by the operating surgeon. Immediate postoperative anteroposterior and lateral knee radiographs were made and analyzed along with radiographs made at three months, twelve months, and annually thereafter. All radiographs were assessed by 2 orthopedic surgeons who did not perform the surgery. The radiographic assessment was performed based on the Knee Society total knee arthroplasty radiographic evaluation system for long-stemmed revision prostheses of the latest follow-up radiograph [15]. The interface between the cone and the host bone was also assessed for initial and progressive radiolucency as well as areas of initial radiolucency that had not changed or resolved with continued follow-up. As described by Fehring et al., femoral implants were classified as stable (≤ 8 radiolucencies), closely observe (9 to 19), or loose (≥ 20 radiolucencies).

Tibial implants were classified as stable (≤ 9 radiolucencies), closely observe (10 to 22), and loose (≥ 23 radiolucencies) [16].

Surgical technique

All procedures were performed by fellowship-trained, high-volume arthroplasty surgeons at their respective institutions. All patients underwent rTKA through the medial parapatellar approach. After explantation of the necessary components, the degree of femoral and tibial bone loss was assessed and a determination was made regarding the need for a metaphyseal cone by the operating surgeon. Porous metaphyseal titanium cones were utilized in all patients in this cohort. Decision regarding the type of fixation in the revised femoral and tibial components (hybrid vs fully cemented) and degree of constraint in polyethylene liner or use of hinge was made at the discretion of the operating surgeon based on patient-specific bone quality and morphology. In the hybrid cementation technique, cement was applied to the bone surface, metaphyseal bone, and the implant but avoiding cement on the majority of the stem (press fit stem) (Fig. 1) [17]. In the cemented technique, cement was applied to the bony surface and pressurized in the canal with a cement plug [18].

Statistical analysis

Binary variables were created to identify patients with femoral and tibial cones, and within those groups, patients with hybrid or fully cemented stems. Study participants' demographic and clinical baseline characteristics were described as means with standard deviations (SD) for continuous

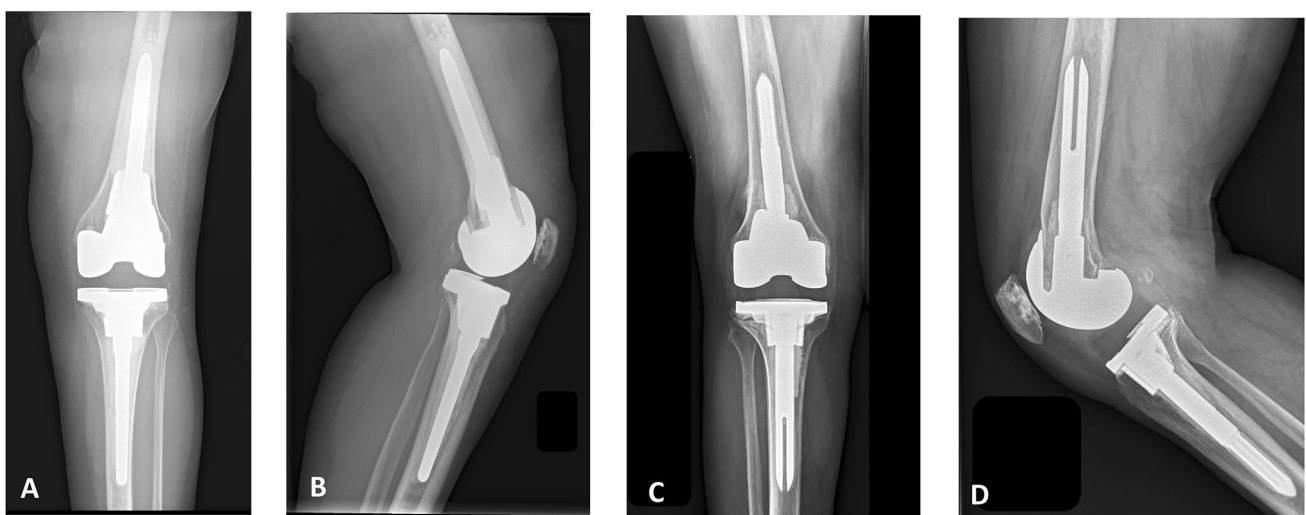


Fig. 1 **A** (anterior–posterior X-ray) and **B** (lateral X-ray) rTKA with fully cemented femoral and tibial cones and stems. **C** (anterior–posterior X-ray) and **D** (lateral X-ray) rTKA with using hybrid cemented tibial cone with press-fit stem components

variables and frequencies with percentages for categorical variables. Survivorship was analyzed and presented graphically by using the Kaplan–Meier (KM) method. Differences in survivorship outcomes between groups were calculated using the log-rank test. Outcomes and survivorship data were calculated using the time of the latest follow-up. Following the patients' 2-year follow-up visit, they are instructed to come in for a follow-up visit should any symptoms or complications occur or per surgeon's request on a case to case basis. Hence, the number of patients at risk was low after 3-year follow-up. Given this, KM plots were truncated at the 3-year follow-up point.

A multivariable binary logistic regression analysis was performed to control for the effect of confounding variables on outcomes. A p -value of less than 0.05 was considered statistically significant. All statistical analysis was performed using IBM SPSS software (IBM-SPSS-version 26, Armonk, NY, USA).

Results

Total cohort

Overall, 123 patients were included in this analysis who received 156 cone implants (74 [60.2%] tibial only, 16 [13.0%] femoral only, and 33 [26.8%] simultaneous tibial and femoral) with a mean follow-up of 2.76 ± 0.66 years. The mean age was 66.1 ± 8.2 years (Table 2).

The most common revision indications included aseptic loosening (58 cases [47.2%]), periprosthetic infection (PJI) (33 cases [26.8%]), and instability (20 cases [16.3%]). (Table 3). Surgical time did not differ between stem fixation methods both in the tibial and femoral groups. Sixteen (13.0%) rTKAs underwent re-revision surgery: 9 for PJI (eight acute and one chronic), three for instability, two for aseptic loosening, one for periprosthetic fracture, and one for liner failure. Notably, ten (62.5%) of the 16 re-revisions were liner exchanges (seven [43.8%] for acute PJI, and three [18.8%] for instability). At the most recent follow-up, knee flexion improved from 101.39 ± 15.58 degrees pre-operatively to 111.19 ± 16.19 degrees post-operatively ($p < 0.001$). At the most recent radiographic follow-up, one (0.6%) tibial cone with a fully cemented stem had evidence of subsidence. For the entire cohort, freedom from all-cause re-revision was 94.3%, freedom from aseptic re-revision was 97.6%, and freedom from re-revision due to aseptic loosening was 99.4% at 2-year (Fig. 2).

Tibial cones

The indications for revision did not significantly differ between groups ($p = 0.599$). The proportion of surgeries

Table 2 Demographic characteristics of included patients

	Overall ($n = 123$)
Male no. (%)	53 (43.1)
Age (years)	66.1 ± 8.2
BMI (kg/m^2)	32.1 ± 6.3
Race no. (%)	
White	90 (73.2)
African American	22 (17.9)
Asian	0 (0.0)
Other	11 (8.9)
ASA classification no. (%)	
1	5 (4.1)
2	86 (69.9)
3	32 (26.0)
4	0 (0.0)
Smoking status no. (%)	
Current	6 (4.9)
Former	26 (21.1)
Never	91 (74.0)

ASA American Society of Anesthesiologists, BMI body mass index, kg kilograms, m meter, no. number

performed as index revisions (51.8% vs. 29.4, $p = 0.019$) and with long stems (92.9% vs 43.1%, $p < 0.001$) was higher in the hybrid cementation group. All-cause re-revision rates ($p = 0.428$) and indications ($p = 0.502$) did not differ between cohorts (Table 3).

In multivariate regression, all included baseline or surgical characteristics were not significantly associated with higher all-cause re-revision rates (Table 4). Eleven (10.3%) patients required re-revisions. Of these, four (3.7%) tibial cones were removed. In the hybrid group, three cones were explanted; one due to instability in which the entire construct was changed to a hinged design, one due to aseptic loosening of the tibial baseplate, and one due to PJI. In the cemented group, one cone was explanted due to the aseptic loosening of both the tibial base plate and the cone. Freedom from all-cause re-revision was 96.3% at 2-year (Fig. 3). Patients in the fully cemented group had numerically higher freedom from all-cause re-revision compared to the hybrid group at 2-year (98.0% vs 94.2%, $p = 0.312$) (Fig. 3). Freedom from tibial cone explanation due to aseptic loosening was 100% at 2-year (Fig. 5).

Femoral cones

The overall distribution of revision indications did not significantly differ between groups ($p = 0.129$), though the proportion of revisions performed for component malpositioning (12.5% vs. 0.0%, $p = 0.024$) was higher in the hybrid cementation group. All-cause re-revision rates ($p = 0.544$)

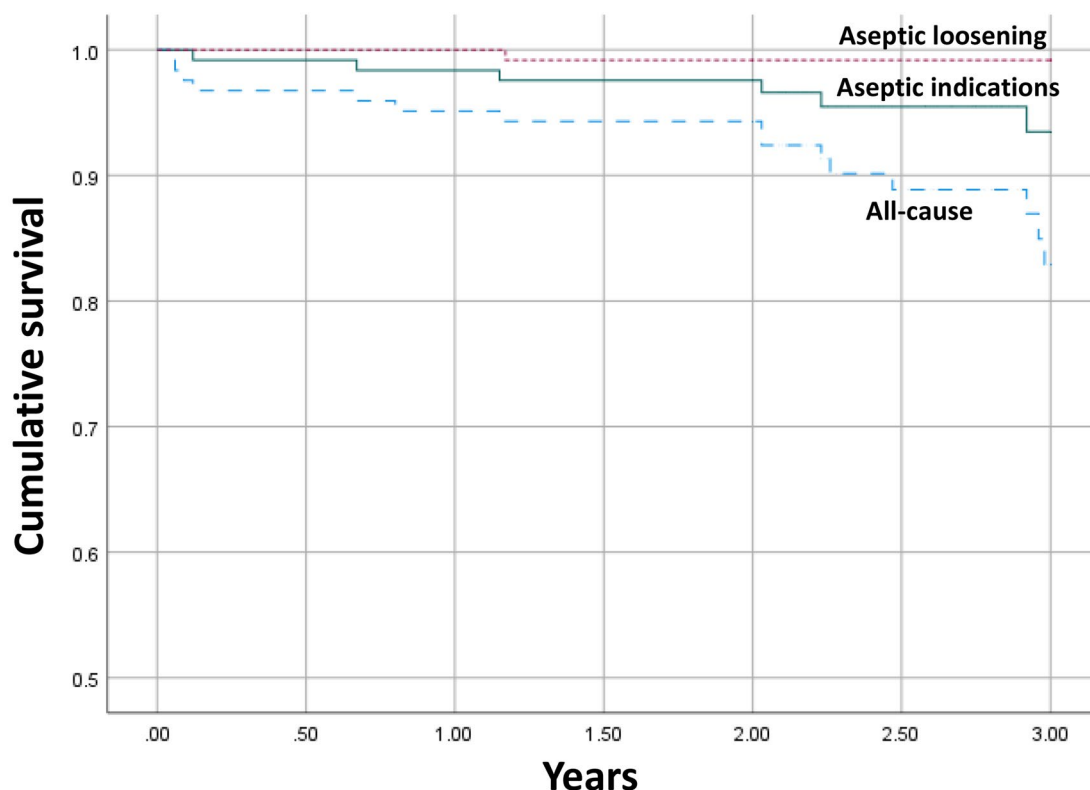
Table 3 Surgical characteristics of included patients

	Per patient				<i>P</i> -value	Femoral cones			
	Overall (<i>n</i> = 123)	Tibial cones Overall (<i>n</i> = 107)	Hybrid (<i>n</i> = 56)	Cemented (<i>n</i> = 51)		Overall (<i>n</i> = 49)	Hybrid (<i>n</i> = 8)	Cemented (<i>n</i> = 41)	<i>P</i> -value
Reason for revision no. (%)					0.599				0.129
Aseptic loosening	58 (47.2)	50 (46.7)	27 (48.2)	23 (45.1)	0.813	20 (40.8)	5 (62.5)	15 (36.6)	0.294
PJI	33 (26.8)	30 (28.0)	14 (25.0)	16 (31.4)	0.534	18 (36.7)	2 (25.0)	16 (39.0)	0.549
Instability	20 (16.3)	17 (15.9)	8 (14.3)	9 (17.6)	0.663	8 (16.3)	0 (0.0)	8 (19.5)	0.212
Arthrofibrosis	7 (5.7)	7 (6.5)	5 (8.9)	2 (3.9)	0.312	1 (2.0)	0 (0.0)	1 (2.4)	0.659
Component malpositioning	2 (1.6)	1 (0.9)	1 (1.8)	0 (0.0)	0.340	1 (2.0)	1 (12.5)	0 (0.0)	0.024
Fracture	2 (1.6)	1 (0.9)	0 (0.0)	1 (2.0)	0.295	1 (2.0)	0 (0.0)	1 (2.4)	0.659
Pain	1 (0.8)	1 (0.9)	1 (1.8)	0 (0.0)	0.340	0 (0.0)	0 (0.0)	0 (0.0)	n/a
Hinged implant no. (%)	40 (32.5)	32 (29.9)	6 (10.7)	26 (51.0)	< 0.001	26 (53.1)	2 (25.0)	24 (58.5)	0.082
Long stem no. (%)	83 (67.5)	74 (69.2)	52 (92.9)	22 (43.1)	< 0.001	33 (67.3)	7 (87.5)	26 (64.3)	0.184
Femoral cone no. (%)	49 (39.8)	33 (30.8)	9 (16.1)	24 (47.1)	0.004	–	–	–	–
Tibial cone no. (%)	107 (87.0)	–	–	–	–	33 (67.3)	6 (75.0)	27 (65.9)	0.773
First revision no. (%)	50 (40.7)	44 (41.1)	29 (51.8)	15 (29.4)	0.019	12 (24.5)	2 (25.0)	10 (24.4)	0.971
Operative time (minutes)	147.4 ± 33.5	147.6 ± 32.8	148.6 ± 33.7	146.6 ± 32.2	0.766	150.0 ± 31.7	153.5 ± 33.9	149.3 ± 31.7	0.734
LOS (days)	4.79 ± 3.83	4.50 ± 2.46	3.47 ± 2.00	5.63 ± 2.44	< 0.001	6.30 ± 5.23	4.66 ± 1.75	6.62 ± 5.63	0.336
90-day readmission no. (%)	13 (10.6)	11 (10.3)	8 (14.3)	3 (5.9)	0.153	6 (12.2)	2 (25.0)	4 (9.8)	0.229
All-cause re-revision no. (%)	16 (13.0)	11 (10.3)	7 (12.5)	4 (7.8)	0.428	10 (20.4)	1 (12.5)	9 (22.0)	0.544
Reasons for re-revision no. (%)					0.502				0.690
Aseptic loosening	2 (1.6)	2 (1.9)	2 (3.6)	0 (0.0)	0.177	0 (0.0)	0 (0.0)	0 (0.0)	n/a
PJI	9 (7.3)	6 (5.6)	3 (5.4)	3 (5.9)	0.909	6 (12.2)	1 (12.5)	5 (12.2)	0.982
Instability	3 (2.4)	2 (1.9)	1 (1.8)	1 (2.0)	0.947	3 (6.1)	0 (0.0)	3 (7.3)	0.444
Other	2 (1.6)	1 (0.9)	1 (1.8)	0 (0.0)	0.340	1 (2.0)	0 (0.0)	1 (2.4)	0.659
All-cause cone explanation	5 (4.1)	4 (3.7)	3 (5.4)	1 (2.0)	0.355	1 (2.0)	0 (0.0)	1 (2.4)	0.659

LOS length of stay, *no.* number, *PJI* periprosthetic joint infection

and indications ($p = 0.690$) did not differ between cohorts. In multivariate regression, all included baseline and surgical characteristics were not associated with higher all-cause re-revision rates (Table 4). Ten (20.4%) patients required

re-revisions. Of these, one (2%) cone from the cemented group was removed due to a periprosthetic fracture in which the entire femoral component was replaced. Freedom from all-cause re-revision was 89.8% at 2-year (Fig. 4).



No. at Risk							
All-cause	123	119	117	116	116	68	40
Aseptic	123	122	121	120	120	70	42
Aseptic Loosening	123	123	123	122	122	75	45

Fig. 2 Kaplan–Meier survivorship analysis for freedom from all-cause re-revision and aseptic re-revision for all included patients. 2-year: All-cause: 94.3%, Aseptic: 97.6%, Aseptic Loosening: 99.4%. 3-year: All-cause: 82.9%, Aseptic: 93.5%, Aseptic Loosening: 99.4%

No differences in freedom from all-cause re-revision were found between the cemented and hybrid subgroups at 2-year (92.5% vs 85.7%, $p=0.539$). Freedom from the explanation of femoral cones due to aseptic loosening was 100% at 2-year (Fig. 5).

Discussion

In this study, we evaluated 123 rTKAs using 156 novel porous titanium metaphyseal cones with stems of variable length and fixation methods at a minimum of 2 years of follow-up. Our main findings at 2-years minimum follow-up included: (1) 94.3% freedom from all-cause re-revisions and 97.6% freedom from aseptic re-revisions; (2) excellent cone radiographic osteointegration (99.4%); (3) all-cause cone implant survivorship of 96.8%; and (4) all-cause re-revision rates did not differ between stem cementation techniques.

As the incidence of revision TKA continues to increase, implants and techniques to address commonly encountered challenges during revision surgery have become increasingly important [19]. One of the main challenges of rTKA remains the management of bone loss and long-term fixation, as this is a major risk factor for aseptic loosening after rTKA [20]. Cones and other metaphyseal augment systems were developed as a viable alternative to traditional allograft to address moderate tibial and femoral metaphyseal defects (AORI II and III) and to achieve improved long-term implant fixation [2, 19–23].

Previous studies reported excellent outcomes in rTKA using metaphyseal cones. All-cause re-revision rates varied from 86.0–95.4% [6, 8, 24], and multiple analyses reported 100% freedom from aseptic loosening [6, 11, 24]. Similar to these studies, our investigation demonstrated a high all-cause re-revision-free survivorship and excellent freedom from aseptic loosening. Notably, the majority of re-revisions in our cohort were related to PJI. Given that 30.8% of the

Table 4 Binary logistic regression for baseline characteristics associated with re-revision after index rTKA (values reported as unstandardized beta [95% confidence interval])

	Tibial cones (<i>n</i> = 107)		Femoral cones (<i>n</i> = 49)	
	All-cause re-revision	<i>P</i> -value	All-cause re-revision	<i>P</i> -value
Hinged articulation	3.33 (0.45–24.64)	0.239	0.57 (0.06–5.86)	0.634
Cemented (vs. hybrid) Stem	0.45 (0.05–4.16)	0.446	5.93 (0.35–99.76)	0.217
Long (vs. short) stem	6.80 (0.56–83.27)	0.134	5.10 (0.44–58.83)	0.191
First revision	0.57 (0.07–4.45)	0.592	0.39 (0.01–17.90)	0.631
Revision indication				
Aseptic loosening	–	–	–	–
PJI	1.60 (0.20–12.64)	0.656	1.24 (0.11–13.89)	0.861
Instability	0.71 (0.05–9.74)	0.795	0.43 (0.01–25.39)	0.686
Other	–	–	–	–
Age	0.98 (0.87–1.09)	0.666	0.96 (0.83–1.12)	0.598
Male	3.07 (0.48–19.69)	0.237	2.31 (0.28–19.04)	0.436
BMI	1.07 (0.94–1.21)	0.330	1.15 (0.94–1.40)	0.172
Race				
White	–	–	–	–
African American	0.98 (0.14–6.70)	0.981	0.48 (0.01–16.42)	0.686
Other	–	–	2.47 (0.02–250.00)	0.702
ASA classification	0.29 (0.06–1.61)	0.160	1.23 (0.07–23.07)	0.890
Smoking status				
Current	6.61 (0.38–115.50)	0.195	–	–
Former	2.47 (0.31–19.61)	0.392	4.76 (0.23–97.94)	0.312
Never	–	–	–	–

ASA American Society of Anesthesiologists, BMI Body mass index, PJI periprosthetic joint infection

patients who underwent index revision surgery had a history of PJI, these findings are not surprising and consistent with previously reported re-revision rates for PJI in complex patients undergoing revision TKA [25, 26]. Previous literature reported cone osteointegration rates of 98–100% at a minimum follow-up of 2 years [27, 28]. Our cohort had a single case of cone aseptic loosening, which coincides with these studies to validate the efficacy of this novel porous cone design.

Femoral cones

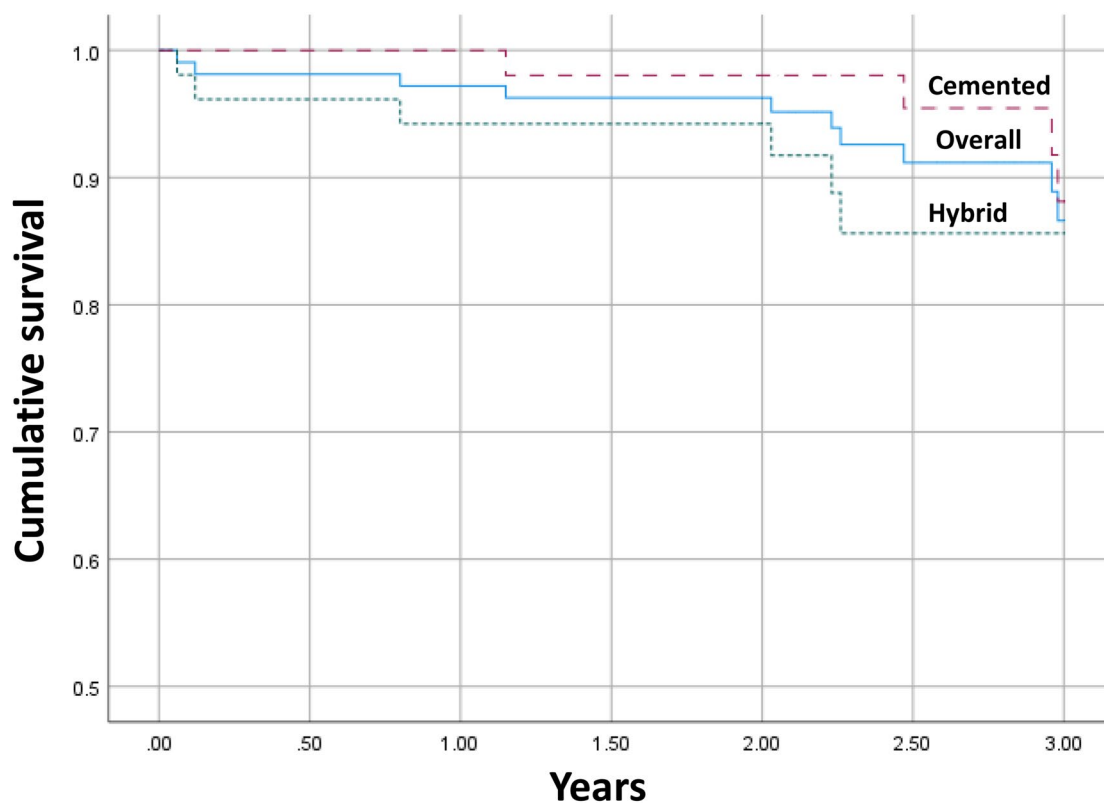
Majority of studies evaluating cones in rTKA present data about tibial cones [8, 21, 29, 30]. There is a paucity of data in the literature about the outcomes of femoral cones. In a cohort of 159 rTKA with trabecular metal femoral cones, Potter et al. reported 96% freedom from aseptic loosening and 84% freedom from all-cause cone explanations in 5-year follow-up time. Importantly, they did not specify the use of tibial or femoral cones in their cohort. Another study which included 68 3D-printed titanium femoral cones, demonstrated 95.6% freedom from aseptic loosening at the latest follow-up [8]. Our femoral cohort demonstrated similar rates of freedom from aseptic loosening at the latest follow-up. Finally, Tetraulet et al. reported two (2.9%) intraoperative fractures that have occurred when impacting the cone to the

femur metaphysis. Our study reported no events of intraoperative fractures.

Stem fixation

Although stems improve mechanical stability, the optimal indications, proper lengths, diameters, and appropriate fixation methods for these constructs remain controversial [9]. There are two traditional stem fixation methods, including hybrid cementation with a cementless press-fit stem and total cementation [10]. In a meta-analysis comparing cemented and cementless stem fixation in revision TKA, Wang et al. found similar outcomes between groups [18]. Moreover, in a randomized trial, Kosse et al. found no differences in radiographic stability and patient-reported functional outcomes when comparing cemented and press-fit stems in patients with mild to moderate bone loss in rTKA at 6.5 years of follow-up [31]. Hence, the superior fixation method remains uncertain.

Despite the abundant literature comparing short cemented versus long uncemented stems in rTKA, limited literature is available examining stem fixation types with the use of metaphyseal cones [6, 8, 11]. In a retrospective cohort of 202 cones with fully cemented and hybrid fixation, Tetraulet et al. reported 100% survivorship of cones for aseptic loosening, 98% all-cause cone revision survival, and 90%



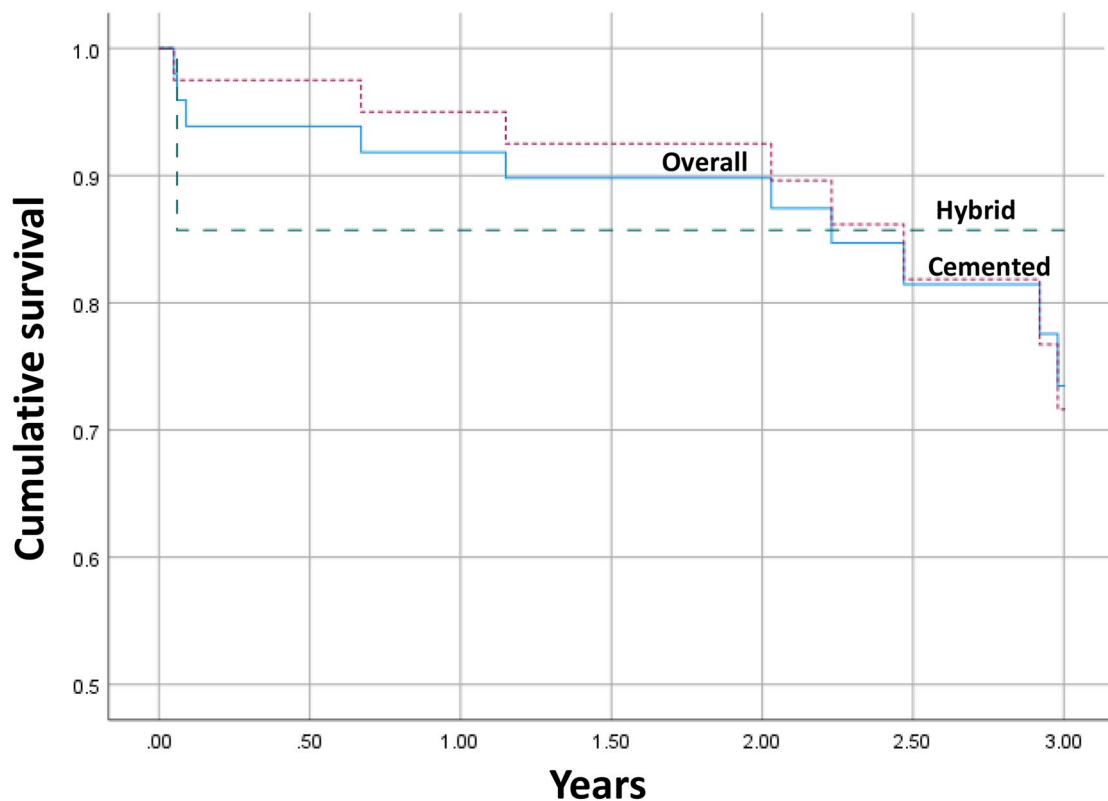
No. at Risk							
All-cause	107	105	104	104	104	64	37
Cement	51	51	51	50	50	37	24
Hybrid	56	54	53	53	53	28	17

Fig. 3 Kaplan–Meier survivorship analysis for freedom from all-cause re-revision in patients with tibial cones. 2-year Overall: 96.3%. 3-year Overall: 86.6%. 2-year: Cemented: 98.0% vs. Hybrid: 94.2%, $p=0.312$. 3-year: Cemented: 88.1% vs. Hybrid: 85.6%, $p=0.570$

freedom from re-revision at 2.4 years of follow-up [8]. However, no comparison of the stem fixation methods was made. In agreement with Kosse et al., our study found no differences in freedom from all-cause re-revision between the hybrid and fully cemented stem groups. In a computational study investigating whether fully cemented stems are required to augment metaphyseal cones in rTKA, Xie et al. compared different stem lengths and found that the highest micromotion was observed at the tip of a long stem, however, the motion was too small to effect osseointegration. In a small cohort of rTKA patients with rotating hinge implants comparing tibial cones with either short cemented stems or long press-fit stems, Jacquet et al. demonstrated that short cemented tibial stems combined with trabecular metal cones confer similar survivorship and better functional outcomes at a minimum of 5 years of follow-up [11]. In agreement with Jacquet et al., our tibial cohort demonstrated similar freedom from re-revisions and aseptic loosening. However, we found that the fully cemented stem-group had numerically

superior freedom from all-cause re-revision compared to the hybrid group at latest follow-up. While abundant literature was published about outcomes of different cone designs, heterogeneity of surgical characteristics restricts the generalization of the results for other cone designs. Number of previous revisions to the same knee, different articulation designs and the use of stems of different fixation methods and lengths highly vary between each revision case.

Our study found a higher proportion of prior multiple revisions to the ipsilateral knee in the tibial cemented group. This finding is not surprising since multiple revisions might lead to higher metaphyseal bone loss that require bypassing the defect using fully cemented stems [9]. Interestingly, our regression model did not find lower re-revision risk for patients with index revisions suggesting that the use of cones with stems of different fixation methods provides a rigid structure in the present of moderate to severe bone loss in rTKA.



No. at Risk							
All-cause	49	47	46	45	45	26	19
Cement	42	41	40	39	39	20	15
Hybrid	7	6	6	6	6	6	4

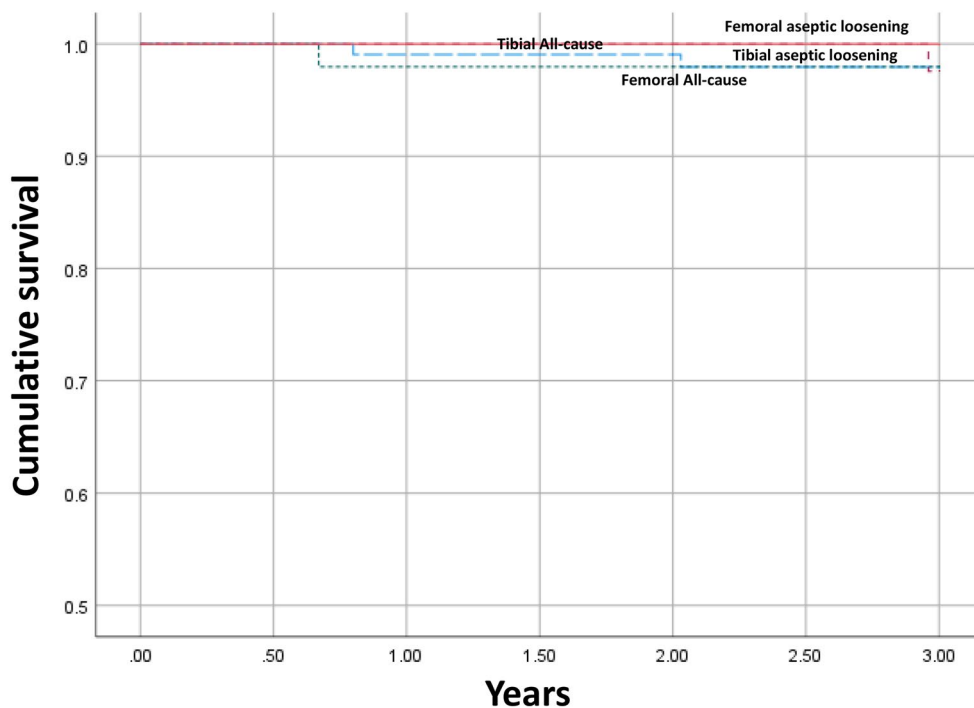
Fig. 4 Kaplan–Meier survivorship analysis for freedom from all-cause re-revision in patients with femoral cones. 2-year Overall: 89.8%. 3-year Overall: 73.5%. 2-year: Cemented: 92.5% vs. Hybrid: 85.7%, $p=0.539$. 3-year: Cemented: 71.6% vs. Hybrid: 85.7%, $p=0.866$

Our study results are novel since it is the first to report the use of a distinct regression model to account for patients' baseline and surgical characteristics for both femoral and tibial cones. Both tibial and femoral cones demonstrated similar rates of freedom from aseptic re-revisions and explantation. These findings add to the efficacy of this novel porous cone design that can be used safely for both tibial and femoral bone loss. Moreover, the similar outcomes of different stem fixation methods both for femoral and tibial cones enable surgeons to choose the best modality on a case-by-case basis after evaluating the patient bone morphology and quality both pre and intra-operatively.

Limitations

Our study does have limitations. Given its retrospective nature, the results may be impacted by potential confounding variables and biases. Additionally, our analysis focused solely on outcomes of rTKA using a single cone system,

so we were unable to compare this system to other cone systems. In the tibial cone cohort, a larger proportion of patients in the hybrid groups underwent their first revision surgery, contributing to selection bias. However, in multivariate regression, patients undergoing their first revision were not associated with lower re-revision rates. Overall, the number of included patients and outcomes event rates such as re-revisions that were examined in a binary logistic regression was too small to generate enough statistical power to yield statistical significance. Additionally, longer-term follow-up may be necessary to fully elucidate the effects of fixation selection on outcomes. Our analysis also may not have captured all revisions performed at outside institutions. While this raises the possibility that we underestimated the true revision rate, our findings are in line with previous studies, so missed cases were likely not to alter our findings. Finally, patient-reported outcomes questionnaires such as the Knee Society Score (KSS) and Knee Injury and Osteoarthritis Outcome Score (KOOS)



No. at Risk							
Tibial All-Cause	107	107	106	106	106	66	40
Femoral All-Cause	49	49	48	48	48	29	20
Tibial Aseptic Loosening	107	107	107	107	107	67	40
Femoral Aseptic Loosening	49	49	49	49	49	30	22

Fig. 5 Kaplan–Meier survivorship analysis for freedom from all-cause removal of cones. Tibial All-Cause Re-revision. 2-year: 99.1%, 3-year: 98.0%. Femoral All-Cause Re-revision. 2-year: 98.0%, 3-year:

98.0%. Tibial Aseptic Loosening Re-revision. 2-year: 100.0%, 3-year: 97.6%. Femoral Aseptic Loosening Re-revision. 2-year: 100.0%, 3-year: 100.0%

were not available for analysis for a sufficient number of patients in this cohort.

Future work should focus on identifying if there is a difference in postoperative stability and complications between different systems. Although the present study represents, to our knowledge, the largest series of patients undergoing rTKA with the use of porous titanium metaphyseal cones, further studies should work towards generating larger databases to generate greater statistical power and to enable comparison with other augmentation systems for bone loss during rTKA.

Conclusions

The use of novel porous titanium femoral and tibial metaphyseal cones combined with stems in patients with moderate to severe bone defects undergoing complex revision total knee arthroplasty confers excellent results independent of stem fixation technique.

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Declarations

Conflict of interest I.S, C.O, J.W, P.H J.R have nothing to disclose. G.VH reports being a paid consultant for Smith&Nephew. S.M reports being a paid consultant for Zimmer and Intelijoint. R.S reports IP royalties from Smith & Nephew, being paid consultant for Smith & Nephew, Intelijoint, have stock options from Intelijoint, Gauss Surgical and receives research support from Smith & Nephew and Intelijoint.

Ethical approval The present study was exempt from human-subjects review by our Institutional Review Board (IRB).

Informed consent N/A.

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