

Reviews

Short-Term Survivorship of 3D-Printed Titanium Metaphyseal Cones in Revision Total Knee Arthroplasty: A Systematic Review.

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Background

Several studies have evaluated the outcomes of tantalum cones in revision knee arthroplasty with moderate-to-severe metaphyseal bone defects. However, recent innovations have led to the development of 3-D printed titanium cones to better adapt to host bone, there remains no consensus on their overall performance.

Objective

We therefore performed a systematic review of the literature to examine short-term survivorship and complication rates of their usage in revision TKAs.

Methods

A systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. A comprehensive search of PubMed, MEDLINE, EMBASE, and the Cochrane Database of Systematic Reviews was conducted for English articles using various combinations of keywords.

Results

In all, 7 articles met the inclusion criteria. A total of 687 cones were implanted in 557 revision TKAs. The all-cause revision-free survivorship of the implants was 95.3% (26 revisions), and of the cones was 95.5% (31 cones revised) at mean 24 months follow-up. The cones revision-free survivorship from aseptic loosening was 99.7%. The overall complication rate was 19.7% with infection as the most common complications observed and the most frequent reason for revision with an incidence of 10.4% and 4.1%, respectively. Overall, functional outcomes improved as documented by postoperative knee scores.

Conclusion

3-D printed metal cones represent a reliable option in metaphyseal bone defects reconstruction that provides high fixation, good short-term survivorship, and complications rates in line with similar devices. In addition, they are associated with lower intraoperative complications, and higher survivorship from aseptic loosening.

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INTRODUCTION

Total knee arthroplasty (TKA) is one of the most effective and successful orthopedic surgical procedures, with a projected yearly volume of 1.5 million cases by 2050.¹ Along with the increasing primary TKAs performed, the number of revisions will also rise over the next years.^{1,2} Femoral and tibial bone defects represent a frequent complication that can compromise the reconstruction and fixation in revision TKA, resulting in a challenging problem for the orthopedic surgeon.³ In fact, solid fixation of the implants is crucial to allow early rehabilitation and weight-bearing while providing long-term survivorship of the construct.⁴

According to the current knowledge, the treatment algorithm for mild to moderate bone defects (Anderson Orthopedic Reconstruction Institute⁵ types 1, 2A, and most 2B) has been widely approved using cement augmentation, morselized cancellous bone graft, structural grafts, or modular metallic augments, while the treatment of severe bone defects (severe types 2B and 3) is still under debate even though metaphyseal cones and sleeves have recently gained rapid diffusion.⁵⁻⁸ Tantalum cones have been introduced over a decade ago and to date they have shown excellent mid-term outcomes,⁹ however, there is still a lack of evidence on their survivorship in the long-term despite the described results seem to be promising.¹⁰ Although the encouraging results, there remain some limitations related to their fitting into the metaphyseal host bone considering the size and geometry of the metal cone, and of the bone defect, as well as the potentially more demanding surgical technique compared with conventional reconstruction options.¹¹

To overcome these, novel 3-D printed metaphyseal cones have been developed based on large CT databases to identify the ideal shape and location that allows optimum bone coverage and support. These new devices have shown comparable biomechanical stability when compared with tantalum cones¹² and excellent short-term outcomes providing exceptional metaphyseal fixation.¹³⁻¹⁶ However, there remains no consensus on the overall performance of these novel cones, we, therefore, performed a systematic review of the literature in order to examine the short-term survivorship and complication rate of 3D-printed titanium cones. Specifically, we aimed to examine (1) what is the overall survivorship after their usage in revision TKA? (2) what is the cumulative incidence of failure due to aseptic loosening of the device? (3) do 3D-printed titanium cones provide adequate implant survivorship and fixation in line with tantalum cones for the management of moderate-to-severe bone loss in revision TKA?

MATERIALS AND METHODS

SEARCH STRATEGY

This search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.¹⁷ The US National Library of Medicine (PubMed/MEDLINE), EMBASE, and the Cochrane Database of Systematic Reviews were queried for publications utiliz-

ing various combinations of the search terms “total knee arthroplasty”, “TKA”, “revision”, “bone defect”, “bone loss”, “reconstruction”, “metal cones”, “metaphyseal fixation”, “3D-printed”, “highly-porous cones”, “titanium cones”, and “metaphyseal cones,” in combination with the Boolean operators (AND, OR, *) since the inception of database to June 2021. No limit was set with regard to the year of publication. Two authors (F.M. and V.D.M.) independently conducted all the searches and screened the titles and abstracts to identify relevant studies. Differences were resolved by consulting a third senior reviewer (I.D.M.). Only abstracts that evaluated the survivorship of metaphyseal 3D-printed titanium cones following revision TKA were reviewed. If the title and abstract of each study contained insufficient information, the full manuscript was reviewed. An additional search was conducted by screening the references list of each selected article, as well as the available grey literature at our institution.

INCLUSION AND EXCLUSION CRITERIA

Inclusion criteria were any original study in which a metaphyseal 3D-printed titanium cone was used in revision TKA to address metaphyseal moderate-to-severe bone loss and provide implant fixation. Implant survivorship was reported, postoperative complications were reported, and clinical outcomes were reported using validated patient-reported scales. Exclusion criteria were case reports, surgical technique reports, review articles, expert opinions, letters to editors, biomechanical reports, instructional course lectures, studies on animals, cadaver or in vitro investigations, book chapters, abstracts from scientific meetings, unpublished reports, studies with less than 10 knees, studies with a mean follow-up of less than 1 year, studies using the same database, and studies written in a non-English language. If a duplicate population was noticed, the study with the longer mean follow-up was included to avoid including the same patients twice.

DATA EXTRACTION AND COLLECTION

Two independent reviewers (F.M. and V.D.M.) separately examined all the identified studies and extracted data. During the initial review of the data, the following information was collected for each study: title, first author, year of publication, study design, number of patients, patients died and lost at follow-up, age of patients, length of follow-up, indication for index surgery, bone loss classification, degree of the bone defect, type of cone used, number of cones used, complication types, reoperations for any reason, implant loosening, deep infections, and patient-reported outcomes. The level of evidence analysis was determined using the Oxford Centre for Evidence-Based Medicine Levels of Evidence (LoE).¹⁸ Selective reporting bias was not included in this analysis.

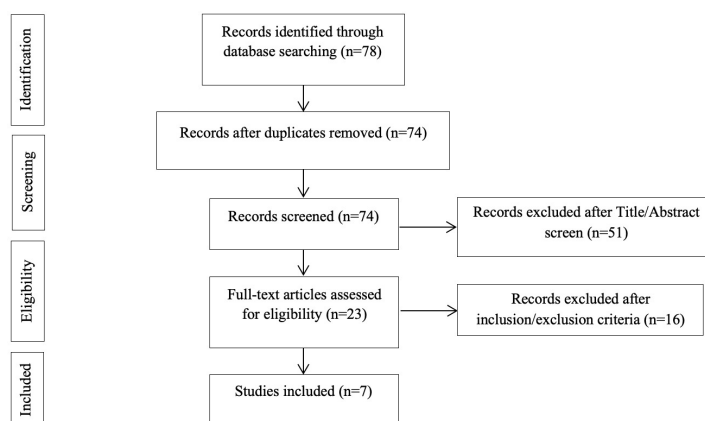


Figure 1. PRISMA flow diagram outlining the systematic review process.

RESULTS

STUDY SELECTION

The search resulted in 78 abstracts that were examined (Figure 1). Following the elimination of duplicate articles, predetermined inclusion and exclusion criteria were applied. In total, 7 articles met the inclusion criteria and were included in the final analysis (Table 1).^{11,13,15,16,19-21} Consensus on which articles would be analyzed in the present study was achieved by discussion between the reviewers based on the predetermined inclusion and exclusion criteria described above. There were no LoE I and II studies available for inclusion. The studies included one prospective LoE III,¹⁹ and six LoE IV studies according to Oxford Centre for Evidence-based Medicine Level of Evidence.^{11,13,15,16,18,20,21} Given the overall lack of level I and II studies, a meta-analysis was not conducted.

DEMOGRAPHIC DATA

Seven studies on 3D-printed^{11,13,15,16,19-21} metaphyseal metal cones were included for analysis. A total of 557 knees (687 cones) with a mean age ranging from 62 to 71 years, were included in the analysis. The mean follow-up was 24.2 months (range, 14-30 months). Six studies reported on the gender of the patients (543 patients)^{11,13,15,16,19,20} including 298 females (54.9%) and 223 males (45.1%). Three studies (212 knees) reported on the mean number of surgical procedures before index revision^{11,13,21} with a mean number of 2.5 (range, 1-4.2 procedures). Prosthetic joint infections (PJI) represented 36.6% (204 of 557 knees) of all revision TKAs with cones in these series. A 2-stage revision was always performed in case of PJI. An aseptic revision was the indication in 65.1% of the cases (363 knees). Among them, aseptic loosening was reported as the cause in 180 knees (49.5% of the aseptic revisions), followed by knee instability in 57 knees (15.7% of the aseptic revisions). (Table 1) A total of 687 cones were implanted during the surgical procedures in order to fill the metaphyseal bone defects. The metaphyseal portions of the implants were cemented

to the internal surface of the metal cones in every case. Five studies (487 knees) reported the type of prosthetic implant used,^{11,15,16,19,20} condylar constrained knee (CCK) implant was used in 61.8% of the revisions (301 knees), followed by a rotating hinge knee (RHK) in 22.8% of the cases (111 knees), and posterior stabilized knee (PS) in 13.9% (68 knees). Further details are addressed in Table 2.

CONES

Overall, 687 metal cones were implanted. All studies^{11,13,15,16,19-21} reported on 3D-printed titanium cones. Overall, 522 metal cones were used for tibial metaphyseal bone defects (75.9%), while 165 metal cones were used for femoral defects (24%). Six studies reported when the metal cones were used on both sides (657 cones),^{11,13,15,16,20,21} with 166 cones used on both sides (25.3%). (Table 2)

REOPERATIONS AND REVISIONS

Overall, 31 cones were revised either for septic or aseptic reasons (4.5%, 31 of 687 cones). 29 metal cones were revised in case of periprosthetic joint infection (PJI, 4.2%), while 2 cones were revised for aseptic loosening (0.3%). The rate of intraoperative cone-related fracture rate was 0.9% (6 of 687 cones).

The overall reoperations rate was 17.8% (99 of 557 knees). The all-cause revision-free survivorship of the prosthetic implant was 95.3% (531 of 557 knees) at a mean follow-up of 24 months (range 14-30 months). Complications were reported in 19.7% of the cases (110 of 557 knees). Infection was the most common reason for reoperation and revision with an incidence of 10.4% (58 of 557 knees) and 4% (23 of 557 knees), respectively. Debridement, antibiotics, and implant retention was performed in 35 cases (DAIR; 35 of 557 knees, 6.3%). Reoperations for other reasons were reported in 5.6% (31 of 557 knees) of the cases including 9 irrigation and debridement (I&D) for superficial wound problems (1.6%), 7 manipulations under anesthesia (MUA, 1.2%), and arthroscopic lysis of adherence for knee

stiffness in 4 cases (0.7%). Further information is addressed in [Table 3](#).

INFECTION

Infection was the most frequent complication observed. In total, the incidence of infection was 10.4% (58 of 557 knees). All the patients that developed either a superficial or deep infection required subsequent surgery. Among them, 23 required an implant revision (39.7%), and 35 underwent a DAIR with the substitution of the polyethylene insert (60.3%). It was not possible to discriminate among the infections how many were recurrent, due to the lack of information.

CLINICAL SCORES

Among the included studies, four studies recorded the preoperative and postoperative Knee Society Score (KSS).^{11,13,15,19} The average KSS improved from a preoperative mean of 38.5 points (poor, range 1-51 points) to a follow-up mean of 88.3 points (good, range 80-106). The average KSS function improved from a preoperative mean of 25.3 points (poor, range 2.5-48 points) to a follow-up mean of 61.5 (fair, range 55-69).^{15,19} One study¹⁹ reported the functional outcomes based on the Western Ontario and McMaster Universities scores with an improvement from a preoperative mean of 32.3 points (range, 19-46 points) to a follow-up mean of 14.1 points (range, 0-42 points). One study (95 knees)¹⁶ used the Knee Injury and Osteoarthritis Outcome Score Jr (KOOS) and reported an improvement from 44.4 preoperatively to 59.4 points at final follow-up. ([Table 4](#))

RADIOGRAPHIC OUTCOMES

Five studies reported on the radiographic outcomes regarding metal cones integration and radiolucent lines (456 cones).^{11,13,16,20,21} Overall, 98.7% of the cones (450 of 456 cones) were considered well-fixed and osseointegrated, six cones were considered radiographically loose with progressive radiolucent lines at the cone-bone interface (1.3%), and one cone was considered with fibrous ingrowth with nonprogressive radiolucent lines at the cone-bone interface (0.2%).

DISCUSSION

The usage of 3D-printed titanium metaphyseal cones is progressively increasing in revision TKA with moderate-to-severe bone defects considering their relatively easy surgical technique and promising short-term survivorship suggesting a notable solution that provides durable fixation. According to this systematic review the overall cones' revision rate was 4.5% (31 of 687 cones) with an incidence of cone's revision due to aseptic loosening of 0.3% (2 cones) at a mean follow-up of 24.2 months.

Considering that the population of TKA patients has changed deeply in the last decades, shifting towards younger and more active patients, the number of revisions is increasing considerably.² Multiple techniques have been

described to reconstruct moderate-to-severe metaphyseal bone defects including cement, morselized/structural bone graft, metal wedges and augments, metaphyseal cones or stepped sleeves, and custom or hinged tumor prostheses.^{8,22-25} Despite that, no consensus has been reached yet on the best reconstruction option for moderate-to-severe metaphyseal bone defects, even though metal cones have shown excellent survivorship at medium-term follow-up.^{26,27} Metaphyseal porous cones have been used to reconstruct large metaphyseal bone defects while providing restoration of the joint line, implant fixation with osseous integration, and offloading axial forces away from the epiphyseal zone of fixation to metaphyseal and diaphyseal fixation zones.²⁸ However, when tantalum cones were introduced, they were associated with multiple disadvantages such as quite large size and hand preparation of the bone bed, opposing their large diffusion. In order to bypass these problems, 3D-printed titanium cones have been developed with an easier surgical technique while providing equivalent or better biomechanical stability and early survivorship.^{11-13,15} Our review of the literature suggests that 3D-printed titanium cones are an effective way to manage moderate-to-severe metaphyseal bone defects in revision TKA.

The all-cause revision-free survivorship of implants after cones implantation was 95.3% at a mean follow-up of 24 months, in line with the current literature on revision TKAs (5-to-6% at 5 years follow-up).^{29,30} The overall complication rate, including revision surgery, was high at 19.7% (110 of 557 knees), particularly when compared with short-term outcomes of revision TKA with mild bone loss.²⁹⁻³¹ Among them, infection was the most common complication that required a reoperation (10.4%, 58 of 557 knees), and that required a subsequent re-revision of the prosthetic implant (4.1%, 23 of 557 knees) associated with a cone revision rate of 4.2% (29 of 687 cones) due to septic reasons, in line with the current literature on revision arthroplasty.^{32,33} Due to a lack of information, it was not possible to stratify how many of these cones were intraoperatively well-fixed or loose at the time of the 2-stage re-revision. Among the cases that required subsequent surgery for infection, almost 60% (35 of 58 infected knees) of them underwent DAIR, suggesting the intent to leave the re-revision as the last option due to the considerably increased complexity of the surgical technique. In fact, the revision of the previously implanted cones, and management of the subsequent bone defect in order to re-establish a well-fixed construct may be a considerably challenging procedure. Despite the multiple advantages of metal cones when compared with conventional reconstruction techniques including shorter operative times, avoided the risk of disease transmission associated with bone graft, and excellent initial fixation, one clear disadvantage may be the complexity of removing well-integrated metal cones in circumstances such as PJI recurrency.³⁴ Other complications that required subsequent surgery were reported in 5.6% of the cases (31 of 557 knees). The most frequent surgical procedure was I&D, performed in case of superficial wound complications and it was noted in 1.6% of the cases (9 knees), followed by MUA

Table 1. Study Characteristics and Patients Demographics

Study (year)	Type of study (LoE)	No. of knees	Follow-Up (months)	Mean Age (years)	Female/male	Previous Surgery	Indication
Anderson et al (2021)	Retrospective (IV)	95	15.6	62.3	48/47	N/A	PJI: 39 AL: 28 Instability: 9 Other: 19
Cherny et al (2021)	Prospective (III)	31	24	63 (34-86)	21/10	N/A	AL: 18 PJI: 11 Periprosthetic fracture: 2
Chalmers (2021)	Retrospective (IV)	163	30 (24-48)	67 (48-86)	88/75	N/A	AL: 75 PJI: 46 Instability: 24 Other: 18
Remily et al (2021)	Retrospective (IV)	54	30 (24-42)	65 (45-92)	27/27	4.2 (1-14)	PJI: 30 AL: 11 Instability: 6 Other: 7
England et al (2021)	Retrospective (IV)	16	14 (2-44)	71 (49-92)	N/A	1 (1-5)	PJI: 8 Other: 8
Tetreault et al (2020)	Retrospective (IV)	142	29 (24-43)	66 (44-88)	76/63	2.4 (1-8)	PJI: 54 AL: 48 Instability: 18 Others: 23
Denehy et al (2019)	Retrospective (IV)	56	27 (24-34)	66 (32-84)	38/24	N/A	Aseptic: 49 PJI: 13
Total.		557	24.2 (14-30)	65.8 (62.3-83)	298/223	2.5 (1-4.2)	PJI: 204 Aseptic: 363 AL: 180 Instability: 57

N/A Not Available; LoE Level of Evidence; PJI Periprosthetic Joint Infection; AL Aseptic Loosening

Table 2. Type and Number of Cones, Knee Prosthetic Implant

Study (year)	Type of Cones	Commercial Brand of Cones	Number of Cones	Femoral Cones	Tibial Cones	Tibial-Femoral Cones	Place of Cones	Type of Implant
Anderson et al (2021)	3-D printed	N/A	126	37	89	62	N/A	52 PS 19 CCK 24 RHK
Cherny et al (2021)	3-D printed	Endoprint Innovation and Technology Company (Endoprint ITK LLC, Moscow, RU) and LOGEEKS DM (Logix LLC, Novosibirsk, RU)	35	15	20	N/A	16 metaphyseal, 11 femoral diaphyseal, 8 tibial diaphyseal	16 RHK 15 CCK
Chalmers (2021)	3-D printed	(Stryker, Mahwah, NJ, USA)	163	0	147 symmetric 16 asymmetric	0	N/A	5 PS 106 CCK 52 RHK
Remily et al (2021)	3-D printed	N/A	68	15	53	14	N/A	N/A
England et al (2021)	3-D printed	(Implantcast GmbH, Buxtehude, DE)	16	0	16	0	N/A	N/A
Tetreault et al (2020)	3-D printed	(Stryker, Mahwah, NJ, USA)	202	68	134	60	N/A	11 PS 99 CCK 19 RHK 12 DFA 1 TFA
Denehy et al (2019)	3-D printed	(Stryker, Mahwah, NJ, USA)	77	30	47	30	N/A	62 CCK 15 Other
Total.			687	165	522	166	-	68 PS, 301 CCK, 111 RHK, 12 DFA, 1 TFA, 15 Others

RHK Rotating Hinge Knee; CCK Constrained Condylar Knee; PS Posterior Stabilized; DFA Distal Femoral Arthroplasty; TFA Total Femoral Arthroplasty

Table 3. Complications and Reoperations in 3D-printed Cones Revision TKA

Study (year)	No. of knees	Complications (rate)	Reoperations (rate)	Revisions (rate)	Cones Revised (rate)	AL cones (Rate)	Infection (Rate)	Reoperations for Other Reasons (Rate)
Anderson et al (2021)	95	12	9	2	4	0	6 [2 revision, 4 DAIR]	6 [3 ORIF, 3 MUA]
Cherny et al (2021)	31	0	0	0	0	0	0	0
Chalmers (2021)	163	25	23	6	6	0 (0%)	16 [6 revision, 10 DAIR]	7 [2 extensor mechanism reconstruction, 2 I&D, 2 ORIF femoral, 1 arthroscopy - stiffness]
Remily et al (2021)	54	18	18	7	81	1	14 [6 revision, 8 DAIR]	3 [1 femoral component loose, 1 periprosthetic fx - total femur, 1 arthroscopy - stiffness]
England et al (2021)	16	3	3	1	1	0 (0%)	2 [1 revision, 1 DAIR]	1 [femoral component loose]
Tetreault et al (2020)	142	38	32	5	5	1	10 [3 revision, 7 DAIR]	11 [7 I&D, 4 MUA]
Denehy et al (2019)	56	14	14	5	7	0	10 [5 revision, 5 DAIR]	4 [1 instability, 1 extensor mechanism reconstruction, 2 arthroscopy - stiffness]
Total	557	110 (19.7%)	99 (17.8%)	26 (4.7%)	31/687 (4.5%)	2/687 (0.3%)	58 (10.4%) [23 revision, 35 DAIR]	31 (5.6%) [9 I&D, 7 MUA, 4 arthroscopy, 3 extensor mechanism, 5 ORIF, 2 femoral component loose, 1 TFA]

Fx fracture; PJI Periprosthetic Joint Infection; AL Aseptic Loosening; ORIF Open Reduction Internal Fixation; DAIR Debridement Antibiotics Implant Retention; I&D Irrigation and Debridement; MUA Manipulation Under Anesthesia; TFA Total Femur Arthroplasty

Table 4. Clinical and Radiographic Outcomes

Study	Pre-operative Clinical	Postoperative Clinical	Radiographic analysis
Anderson et al (2021)	KOOS Jr 44.4±17.1	59.4±17	126/126 cones osseointegrated
Cherny et al (2021)	KSS 1 (-15-14) KSSk -1.5 (-15-11) KSSf 2.5 (0-10) WOMAC 32.3 (19-46)	KSS 105.9 (95-155) KSSk 50.9 (43-55) KSSf 55 (40-100) WOMAC 14.1 (0-42)	N/A
Chalmers (2021)	N/A	N/A	140 pts @ 20.4 months 1 cone fibrous ingrowth 2 cones radiographically loose
Remily et al (2021)	KSS 52	KSS 80.4	52 pts 1 radiographically loose
England et al (2021)	N/A	N/A	100% ingrowth
Tetreault et al (2020)	KSS 50 (0-94)	87 (72-94)	119/122 cones osseointegrated 3/122 radiographically loose
Denehy et al (2019)	KSS 51 KSSf 48	KSS 80 KSSf 68	N/A
Total.	KSS 38.5 (1-51) KSSf 25.3 (2.5-48)	KSS 88.3 (80-106) KSSf 61.5 (55-68)	6/456 radiographically loose (1.3%) 1/456 fibrous ingrowth (0.2%)

N/A Not Available; KSS Knee Society Score; KSSf Knee Society Function Score; WOMAC Western Ontario and McMaster Universities

for knee stiffness in 1.2% (7 knees), and arthroscopic lysis of adherence in 0.7% (4 knees).

Overall, 31 cones were revised either for septic or aseptic reasons (4.5%, 31 of 687 cones) with only two cones (of 687, 0.3%) clearly documented as being revised for aseptic loosening at the cone-bone interface, suggesting fixation survivorship from aseptic loosening of 99.7% at 24 months follow up. In addition, according to the available radiographic results, 98.7% of the implanted cones (450 of 456 cones) were considered well-fixed at final follow-up, while only 1.3% were considered radiographically loose (6 cones) with progressive radiolucent lines at the cone-bone interface. If we combine the cones revised for aseptic loosening (2 cones) and the cones radiographically loose (6 cones), the overall survivorship from aseptic loosening at short-term follow-up would be 98.8%, comparing favorably with the aseptic survivorship reported by Zanirato et al³³ (97.3%) at mean 36 months follow-up on general metaphyseal metal cones in revision TKA. However, a complete radiographic analysis is available only on 66% of the cones (456 of 703), and the systematic review available in the literature reported the combined results of conventional and 3-D printed cones, suggesting that a clear comparison between the two devices is, to date, still not possible. Nevertheless, the reported results indicate a notable fixation provided by 3-D printed titanium and custom-made cones at short-term follow-up.

Regarding the complications related to these devices, the intraoperative cone related fracture rate was 0.9% (6 of 703 cones), comparing favorably with overall data reported on general cones (1.2% ± 4.8%),³³ suggesting that the easier bone preparation of the 3-D printed cones may lead to a lower rate of intraoperative complications and intraoperative fractures. In fact, with conventional metal cones, it may be necessary to remove more host bone in order to adapt the cone to the metaphyseal bone-bed to avoid size mismatch or cone-implant impingement that may com-

promise the final position and fixation of the component. However, this additional re-shaping of the host bone may additionally reduce the strength of the already damaged metaphyseal bone.

Metaphyseal metal cones in revision TKA are currently used in multiple settings, the most common indication is the management of moderate-to-severe bone loss after PJI in 37% of the cases (204 of 557 knees), followed by AL in 32% (180 knees), and instability in 10% (57 knees), in line with the current literature on revision TKA.^{33,35} In the case of bone loss reconstruction with 3-D printed or custom-made metal cones, according to this systematic review, a CCK implant was used in 61% of the revisions (301 of 487 knees), followed by RHK in 22% (111 knees), and PS in 13.9% (68 knees).³⁶⁻³⁸

Despite a relatively high rate of complications associated with metal cones for reconstruction of bone defects in revision TKA, patients showed considerable improvement in a variety of functional scores. Specifically, 3-D printed and custom-made metal cones were associated with an average improvement of 50 points in the KSS between preoperative and latest follow-up. On average, patients improved from “poor” health (mean preoperative KSS of 38.5) to “good” health (mean postoperative KSS of 88.3) at latest follow-up. In addition, KSS function score improved from a mean preoperative value of 25.3 (“poor”) to a mean value of 61.5 (“fair”) at final follow-up, suggesting that these devices remain an efficacious procedure and provide a reliable early fixation that allows the patient to rapidly rehabilitate, improving patient functionality and outcomes.

There were a variety of limitations in this study. First, we were limited by the quality of the original studies, the variability in inclusion criteria, and the definition of moderate-to-severe bone defects by the different authors, as well as the methods for reporting the evaluated variables, and the number of patients analyzed. Second, our methodology did not allow for the identification of unpublished litera-

ture on 3-D printed metal cones and is limited by potential publication bias. Third, several different outcome scores were used across the included studies to assess overall knee function. Fourth, larger multicenter studies that use similar outcome assessment measures would be helpful to better compare the results of conventional tantalum cones with 3-D printed titanium cones in order to evaluate outcomes and complications rates. Fifth, the indication of metal cones reconstruction and the bone defects classification was considered differently among the studies. Sixth, the number of previous surgical procedures before index revision was not reported by most of the studies

CONCLUSION

To date, given the reconstruction options available in case of moderate-to-severe metaphyseal bone defects in revision TKA, metal cones represent a valuable and reliable option that provides high fixation, and good short-to-midterm survivorship, and complications rates in line with the current literature. 3-D printed metal cones may be associated with lower intraoperative complications, and higher survivorship from aseptic loosening providing a reliable fixation, while being associated with similar infection and complications rates. However, further monitoring is necessary to better define if there is a difference between conventional tantalum cones and 3-D printed titanium

cones and to evaluate the mid-to-long term outcomes of this surgical device.

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CONTRIBUTIONS

FM, IDM: designing the work. FM, VDM, FM, SP, AS, ADF, VLV: acquisition and analysis of the data. FM: drafting the work. IDM, GM, GG: revised it critically for important intellectual content. IDM: final approval of the version to be published.

CONFLICT OF INTERESTS

The authors declare no potential conflict of interests.

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