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Original Research

Short- and Mid-term Radiographic Outcomes of Ream-then-broaching Metaphyseal Cones During Revision Total Knee Arthroplasty

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ABSTRACT

Background: The purpose of this study is to assess the short- and mid-term radiographic outcomes of a ream-then-broach metaphyseal cone design for revision total knee arthroplasty (rTKA).
Methods: A retrospective, multicenter analysis of rTKA patients utilizing femoral and/or tibial metaphyseal cone placement from January 2017 to July 2022 was performed. Assessment of radiolucency was performed utilizing a novel "cones score" for radiolucency for tibial and femoral cones.
Results: Sixty-four rTKAs (23 femoral and 59 tibial cones) with short-term follow-up (12-24 months) and 80 rTKA (24 femoral and 76 tibial cones) with mid-term follow-up (>24 months) were assessed. No intraoperative complications were reported. No cases of cone or stem aseptic loosening were observed. The cones scoring system had a significantly strong intraclass correlation between the 3 reviewers ($P < .001$). Of tibial cones, 96.6% and 96.1% had no change in cones scoring at short- and mid-term follow-ups, respectively. Of femoral cones, 87.0% and 100% had no change in cones scoring at short- and mid-term follow-ups, respectively. All tibial and femoral implants were deemed radiographically stable at last radiographic follow-up.
Conclusions: The utilization of a ream-then-broach metaphyseal cones demonstrated excellent radiographic stability at short- and mid-term follow-ups. The use of this method has minimal risk of intraoperative or short-term failures. Surgeons should be familiar with this type of cone implantation system.

Introduction

With an expected increase in primary total knee arthroplasty (TKA) over the next decade, there will naturally be a corresponding rise in revision total knee arthroplasty (rTKA). Stable initial fixation and proper implant alignment are the goals of revision surgery [1]. Successful rTKA relies on appropriate management of bone loss to prevent premature revision implant failure [2,3]. A reliable rTKA construct should aim to achieve fixation of at least 2 of 3 anatomical zones: (1) epiphysis, (2) metaphysis, and (3) diaphysis [2]. While the robust use of diaphyseal engaging stems, designed to bypass bone defects and reduce implant stress, has effectively led to an increased rate of implant survivorship, poor metaphyseal engagement remains a significant concern that can lead to aseptic loosening and subsequent failure [4,5]. With the development of metaphyseal cones, shorter revision constructs may achieve similar longevity to longer diaphyseal engaging constructs [6].

Recently, there has been an increased interest in the use of metaphyseal-engaging porous implants such as cones and sleeves. While sleeves can adequately address metaphyseal bone loss, they are coupled to the stem, which dictates the final position of the implant. Conversely, metaphyseal cones are placed independently of the implant and stem, which may address the metaphyseal defects more efficiently.

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While techniques that involve reaming prior to cone insertion have been studied, the use of a broaching system has been previously avoided due to concerns about imposing iatrogenic fractures in the sclerotic metaphyseal bone [7,8]. Nevertheless, recently developed ream-then-broaching metaphyseal cones have gained popularity as they potentially provide a more reliable and congruent bone preparation. One potential concern for ream-only cones is early micromotion that may lead to fibrous fixation of the surrounding bone and possible failure of the revision construct [7,9,10]. Currently, literature regarding clinical outcomes of these newer ream-then-broach cone designs is limited [7,9]. The purpose of this investigation is to assess the rates of short- and mid-term postoperative radiolucency for patients who underwent rTKA using a single metaphyseal cone design that utilizes a ream-then-broach technique.

Material and methods

Study design and patient population

This investigation was a retrospective cross-sectional study of patients >18 years of age who underwent rTKA with placement of a metaphyseal cone utilizing a Smith & Nephew (Memphis, TN) ream-then-broach design from January 2017 to July 2022. This multicenter study was conducted across 3 high-volume hip and knee specialty institutions. All surgeries were performed by fellowship-trained arthroplasty surgeons experienced in complex revisions. Both short (25 mm) and long (40 mm) tibial cones, as well as laterality-specific femoral cones, were included in this study.

Initially, data were collected for all qualifying cases, irrespective of time for follow-up. Subsequently, patients with insufficient radiographic follow-up (<24 months) were contacted to obtain recent radiographs. Ultimately, all patients who did not have radiographic follow-up beyond 12 months from the procedure were excluded, and those with postoperative radiographs within 12-24 months were included in a separate short-term follow-up cohort. Any reoperation or implant revision was documented.

Table 1
Patients' demographic and clinical characteristics.

Variables	Short-term follow-up (12-24 months) N= 64	Mid-term follow-up (>24 months) N = 80
Mean follow-up ± SD	15.6 ± 3.7	35.7 ± 12.1 (24-73)
Age (y), median ± SD	68.0 ± 8.068 (41-83)	65.50 ± 0.968 (46-86)
Gender		
Male	28 (43.8%)	31 (38.8%)
Female	36 (56.3%)	49 (61.3%)
Body mass index, median ± SD	31.95 ± 7.59 (22.79-56.01)	31.77 ± 7.15 (19.70-47.55)
Race		
White	50 (78.1%)	68 (85.0%)
Black	12 (18.8%)	9 (11.3%)
Other	2 (3.1%)	3 (3.8%)
ASA class		
1	4 (6.3%)	10 (12.5%)
2	15 (23.4%)	26 (32.5%)
3	43 (67.2%)	43 (53.8%)
4	2 (3.1%)	1 (1.3%)
Smoker		
Never	37 (57.8%)	47 (58.8%)
Current	9 (14.1%)	10 (12.5%)
Former	18 (28.1%)	23 (28.7%)

ASA, American Society of Anesthesiologists.

Patient characteristics and study variables

Patient age, sex, race, American Society of Anesthesiologists classification, and smoking status were recorded. Characteristics of the revision included the laterality of the implant revised, previous revisions, institution, indication for the revision, operative time, components replaced, and the type of cone inserted (femoral cone, short tibial cone, and long tibial cone) (Tables 1 and 2).

Surgical technique

Preparation of the tibial and femoral metaphyseal cone(s) was carried out according to the recommended surgical technique guide Smith & Nephew (Memphis, TN). All cones were press fit while all the revision implants and stems were fully cemented (Fig. 1).

The "cones score"

To best quantify radiographic evidence of implant loosening, a novel "cones score" was developed for the purposes of this study. Since the cones are placed independently of the revision implants, the authors believe a score assessing cone stability independent from the revision implants is warranted. Currently, there are no standardized metrics for the assessment of postoperative radiolucency for rTKA with metaphyseal cones. A recent study by Behery et al conceptualized a score to evaluate loosening and lucency around metaphyseal cones, but this has not yet been validated [11]. We propose a slightly different categorization system for evidence of cone failure.

The "cones score" is the summation of areas of lucency around the periphery of the cone based on anteroposterior and lateral radiographs. There are 8 zones for the tibia cone and 7 for the

Table 2
Characteristics of revision total knee arthroplasty with ream-then-broaching metaphyseal cones.

Variables	Short-term follow-up (12-24 months) N= 64	Mid-term follow-up (>24 months) N = 80
Implant revised		
R TKA	28 (43.8%)	41 (51.3%)
L TKA	35 (54.7%)	36 (45.0%)
R UKA	1 (1.6%)	1 (1.3%)
L UKA	-	2 (2.5%)
Previously revised TKA	0 (0.0%)	0 (0.0%)
Institution		
A	24 (37.5%)	24 (30.0%)
B	15 (23.4%)	29 (36.3%)
C	25 (39.1%)	27 (33.8%)
Revision indication		
Mechanical complications	31 (48.4%)	57 (71.3%)
Instability	21 (32.8%)	15 (18.8%)
Infection	8 (12.5%)	6 (7.5%)
Arthritis progression (UKA)	1 (1.6%)	2 (2.5%)
Dislocation	2 (3.1%)	0 (0.0%)
Arthrofibrosis	1 (1.6%)	0 (0.0%)
Operative time (min), median ± SD	163.0 ± 61.5 (61.0-332.0)	157.0 ± 63.0 (62.0-372.0)
Component changed		
Femur and tibia	49 (76.6%)	61 (76.3%)
Tibia only	10 (15.6%)	15 (18.8%)
Femur only	5 (7.8%)	4 (5.0%)
Femoral cone	23 (35.9%)	24 (30.0%)
Tibial cones	59 (92.2%)	76 (95.0%)
Short tibial cone	53 (82.8%)	65 (81.3%)
Long tibial cone	6 (9.4%)	11 (13.8%)

UKA, unicompartmental knee arthroplasty.

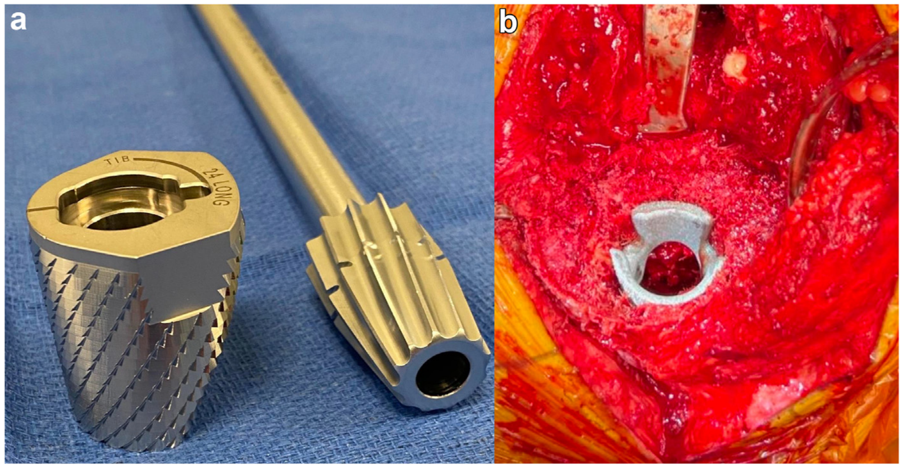

Figure 1. The ream and broach implant. (a) Example of the Smith & Nephew reamer (right) and broach (left) used during metaphyseal bone preparation. (b) Intraoperative view of an implanted tibial metaphyseal cone after reaming and broaching. Note the intimate fit of the cone with the host bone. Reaming enlarges the metaphyseal bone, while broaching compacts the remaining cancellous bone into a shape that helps create a bony shelf, supporting the cone and increasing the surface area contact between the bone and the cone implant.

femoral cone. Each radiographic zone, as outlined in Figure 2, represents 1 point in the cones score. For zones 1, 4, and 6 on the femoral cone and zones 1, 3, 5, and 7 on the tibial cone, the interpretation also included any change in position of the intramedullary (IM) stem or the prosthesis, which may indicate loosening. Any radiolucency greater than 1 mm or change in IM stem alignment in each radiographic location of concern resulted in a deduction of the corresponding point for that subjected zone. A perfect score is 7 points for the femur and 8 points for the tibia. This scoring system provides a systematic approach to quantifying radiolucency around the periphery of the cone. The cones score was calculated for each patient on their initial postoperative radiograph and compared to their most recent follow-up films. The senior author for each institution independently reviewed and

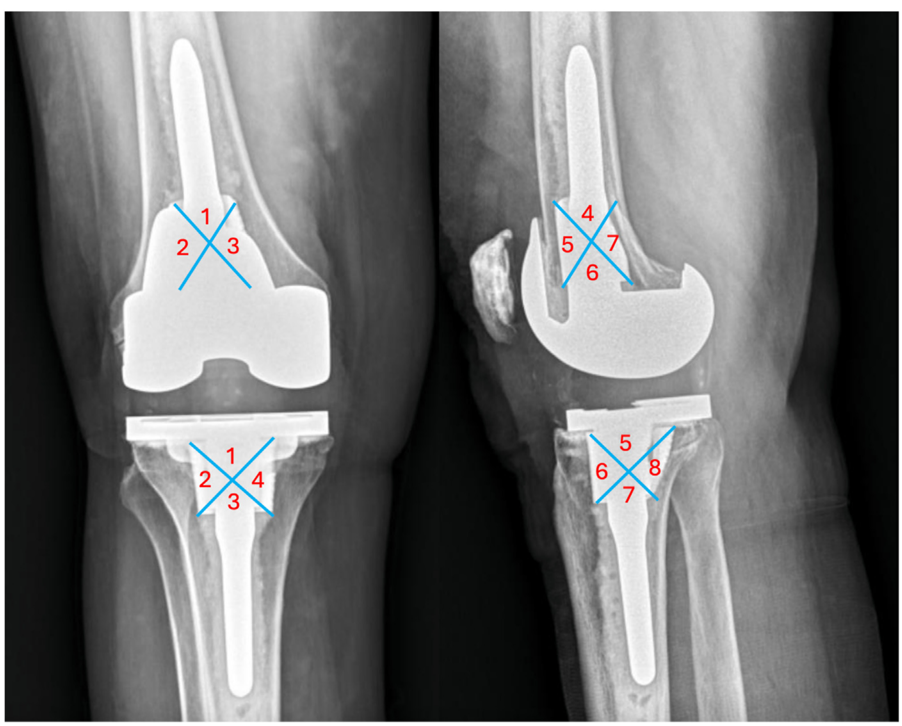

Figure 2. The cones score. The “cones score” for the tibial cone assesses the radiolucency around the periphery of the cone in zones 2, 4, 6, and 8. Zones 1, 3, 5, and 7 evaluate the cement mantle and the position of the intramedullary (IM) stem. Changes in stem position within these cones may indicate potential failure of the revision tibial construct. For the femoral cone, the scoring is based on 7 zones because the distal-most aspect of the cone cannot be assessed on the anteroposterior (AP) view due to overlap with the femoral implant. In this case, zones 1, 4, and 6 are used to identify potential loosening of the IM stem, while zones 2, 3, 5, and 7 assess radiolucency around the periphery of the cone.

recorded their cones score for their respected patients. Subsequently, all pooled scores were reviewed and confirmed by each instuition's most senior surgeon.

The interobserver reliability of the scoring system was assessed by 2 independent senior arthroplasty surgeons who scored 30 randomly selected cases. An intraclass correlation test was then used to analyze the interrater reliability between the respective senior authors and independent reviewers.

Data analyses

All analyses were conducted using SPSS Statistics 27.0.1 (IBM Corporation, Armonk, NY). The analysis was stratified by the follow-up cohort. Descriptive statistics were performed for patient demographics, preoperative characteristics, surgical characteristics, and cone scores. The change in cones scores was calculated by subtracting the final postoperative follow-up score from the initial postoperative score. Spearman's intraclass correlation coefficient was used to assess radiographic interrater reliability. A P-value of <0.05 was considered significant.

This retrospective study was institutional review board-approved (Marshall University Institutional Review Board, Huntington, WV; Application number: 1897509-3). The procedures were followed in accordance with the committee's standards. Due to the retrospective nature of this study, a waiver of consent was obtained from the board.

Results

A total of 280 patients who underwent rTKA with either femoral or tibial metaphyseal cones using a ream-then-broach technique were retrospectively reviewed across the 3 institutions for this study. As depicted in Figure 3, 136 patients were excluded from the final analysis due to either insufficient radiographic follow-up, revision unrelated to the stability of the implant, and death within 2 years of surgery for reasons unrelated to the procedure.

Of the 144 patients included in the study, 64 patients (23 with femoral and 59 with tibial cones) had short-term follow-up within 12-24 months (mean: 15.6 ± 3.7 months) and 80 patients (24 with femoral cones and 76 with tibial cones) had mid-term follow-up of more than 24 months (mean: 35.7 ± 12.1 months, range: 24-73 months) (Table 1). None of the patients included in the short-term follow-up cohort were included in the mid-term follow-up analysis. Using the senior authors' scoring as a reference, there was strong, statistically significant interclass correlation of the cones score with those of the 2 independent reviewers (Spearman's coefficient 0.93, $P < .001$ and .78, $P < .001$).

The most common indications for revision between both short- and mid-term groups were mechanical complications, instability, and infection (Table 2). The majority of short-term and mid-term patients underwent both femoral and tibial component exchange (76.6% and 76.3%, respectively) with placement of a tibial cone (92.0% and 95.0%, respectively). No intraoperative fractures were documented in this study. Tibial cones were not utilized in revisions involving size 3 or smaller tibial baseplates due to fracture concerns, as the smallest diameter cone is 18 mm. In these cases, longer IM stems were used to achieve stability. Femoral cones were used less frequently due to adequate remaining bone stock after implant removal and appropriate augmentation (35.9% and 30.0% in short- and mid-term cohorts, respectively).

At the time of the last follow-up, there were no occurrences of revisions due to implant instability or loosening among patients available to review. The average immediate postoperative tibial cones score was 8.0 for the short-term cohort and 7.9 for the mid-term cohort (Table 3). At short-term follow-up, 96.6% of patients had no changes in their tibial cones score, while 1 patient had a decreased score from 8 to 6. For the mid-term follow-up, 96.1% of patients maintained their tibial cone score. Two patients had a decrease of 3 points (2.6%), and 1 patient had a decrease of 2 points (1.3%). All tibial implants were deemed radiographically stable, and no changes in stem position were noted.

All femoral cones had a perfect score of 7 in the immediate postoperative period. In the short-term follow-up cohort, 87.0% of patients had no changes in their femoral cone score, while all mid-term follow-up patients maintained a perfect score. Of the 3 cases with decreased scores, 2 (8.7%) decreased by 1 point, and 1 (4.3%)

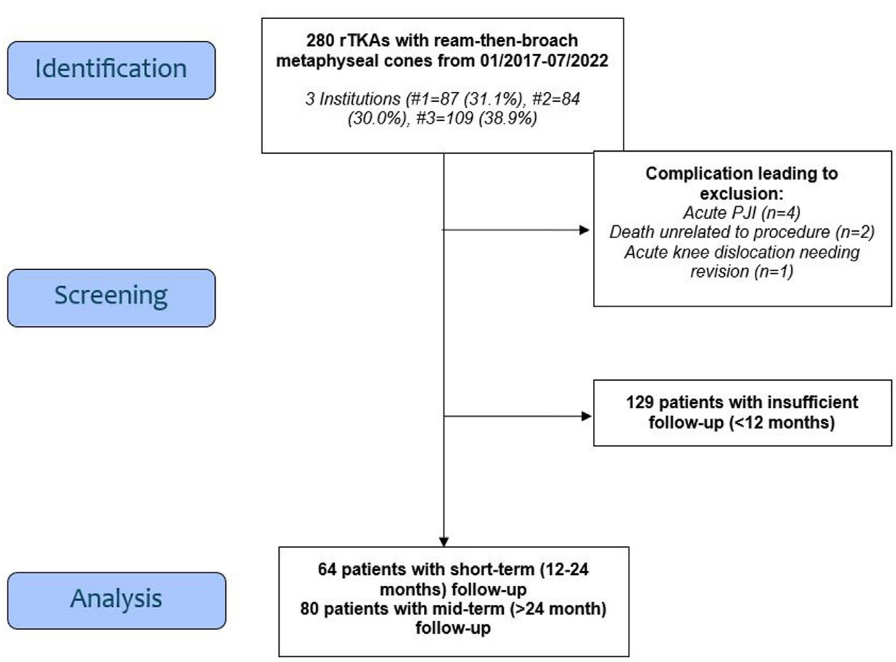

Figure 3. Patient flow chart. Demonstration of case selection for the study. Ultimately, 144 cases were selected, 64 with short-term outcomes and 80 with mid-term outcomes. PJI, periprosthetic joint infection.

Table 3
Short-term and mid-term changes in cones scoring with ream-then-broaching metaphyseal cones.

Variables	Short-term follow-up (12-24 months) N = 64	Mid-term follow-up (>24 months) N = 80
Femur	N = 23	N = 24
Initial postoperative cones score, mean ± SD	7.0 ± 0.0 (7.0-7.0)	7.0 ± 0.0 (7.0-7.0)
Cones score at last follow-up, median ± SD	6.8 ± 0.48 (7.0-5.0)	7.0 ± 0.0 (7.0-7.0)
Change in cones score		
0	20 (87.0%)	24 (100%)
1	2 (8.7%)	-
2	1 (4.3%)	-
Tibia	N = 59	N = 76
Initial postoperative cones score, mean ± SD	8.0 ± 0.0 (8.0-8.0)	7.9 ± 0.23 (6.0-8.0)
Cones score at last follow-up, median ± SD	7.9 ± 0.29 (8.0-6.0)	7.8 ± 0.58 (5.0-8.0)
Change in cones score		
0	57 (96.6%)	73 (96.1%)
1	1 (1.7%)	0 (0.0%)
2	1 (1.7%)	1 (1.3%)
3	-	2 (2.6%)

decreased by 2 points. All femoral implants were deemed radiographically stable at final follow-up, and no changes in stem position were noted.

Discussion

In this investigation, we demonstrated excellent short-term and mid-term radiographic success with the implementation of a ream-then-broach metaphyseal cone system. At mid-term follow-up, 96.1% of tibial cones and 100% of femoral cones showed no evidence of radiolucency. In our study, more tibial cones were placed compared to femoral cones in both short-term and mid-term cohorts. Notably, there were no documented cases of aseptic loosening requiring revision at mid-term follow-up. The estimated mid-term revision rate for aseptic loosening per metaphyseal cone is 1.7%, and the overall mid-term aseptic survivorship rate for rTKA is approximately 97.3% [12,13]. While a large-scale comparative study is warranted, our findings suggest that ream-then-broaching cones are effective in enhancing stable biological fixation at the metaphysis.

Previously, broaching during sclerotic metaphyseal bone preparation was avoided due to the theoretical risk of iatrogenic fracture. As a result, much of the current literature on metaphyseal cones is based on techniques that are often tedious and imprecise, such as the free-handed burring technique. However, broaching may offer the additional benefit of precise bone preparation, potentially leading to more congruent initial implant placement to encourage early biologic fixation. To our knowledge, this is the first multicenter study assessing mid-term radiographic outcomes of ream-then-broach metaphyseal cones utilizing a novel scoring system to evaluate radiographic loosening and failure. A recent single-institution study by Behery et al included a novel cone scoring system but evaluated only 49 rTKAs [11]. Our study introduces a slightly different scoring system that accounts for changes in stem position as well as lucency around the cones. Additionally, our study utilized second-generation ream-then-broach cone designs.

No cases of intraoperative fracture during the implementation of a metaphyseal cone with broaching were documented in this study. Current literature estimates the rate of intraoperative fracture during metaphyseal cone preparation at approximately 1.2% [13]. In a review of 142 rTKAs with metaphyseal cones, Tetreault et al reported 3 incidents of intraoperative fracture using a ream-only technique [7]. Similarly, Behery et al in their study utilizing a ream-only technique reported no intraoperative fractures [8]. The authors suggested that the absence of intraoperative fracture was due to avoiding the use of a broach in metaphyseal bone preparation. A broach may allow the surgeon to better modulate the forces applied to the bone during preparation. Our study suggests that broaching after preparing the metaphyseal bone with a reamer may not significantly increase the risk of intraoperative fractures.

Currently, there are no standardized methods for assessing radiographic loosening in cone and sleeve constructs. While many contemporary studies have attempted to evaluate cone constructs using general rTKA scoring systems, such as the Knee Society Radiographic scoring system [14], we believe that a thorough radiographic assessment of rTKAs with metaphyseal cones should specifically examine the zones around the cone implants, as these are placed separately from the revision implants. Inspired by aspects of the Knee Society Radiographic scoring system, our novel cones score utilizes a similar zonal classification system to assess radiolucent lines as well as any IM stem angulation in zones where the assessment of radiolucency around the cone was not feasible due to implant overlap. The cones scoring system demonstrated strong interrater reliability in this current study. While further studies are needed to validate the cones score, we suggest that future research on radiographic assessment of rTKAs with metaphyseal cones use a system specifically targeting the areas around the cone implants, such as our proposed cone score.

This study has several limitations that should be carefully considered. Despite extensive efforts to minimize patient attrition, the study experienced a high rate of inadequate postoperative follow-up, which limits our ability to assess mid-term outcomes. This may be attributed to the socioeconomic status of the patient populations of the institutions included, located in medically underserved areas with high rates of follow-up attrition and long travel distances from patient residencies to the nearest academic centers. Additionally, the lack of a control group means that the data from this study is purely descriptive, preventing us from demonstrating the superiority of the ream-then-broach technique compared to other cone and sleeve systems. As the primary goal of this study was to investigate radiographic evidence of loosening, functional or patient-reported outcomes were not collected, which may limit the clinical interpretation of our findings. However, since no reoperations were performed for aseptic loosening or cone failure, it can be inferred that the implants in this population were clinically stable. Furthermore, the degree of metaphyseal bone defect was not quantified, and the decision to use a metaphyseal cone was based solely on surgeon discretion rather than a standardized metric. Finally, while the novel cones score intuitively appears to be a useful marker for radiolucency, further studies are needed to correlate the cones score with clinically loose components and the risk of revision. Given the lack of available data on the cones score, we are unable to determine what score would be a cutoff for loosening. Furthermore, assessment of radiolucency in certain zones in our scoring system can be limited by prosthesis and stem overlap. However, these zones were included to account for potential gapping or angulation change at the cone or prosthesis, which would suggest loosening. Readers should interpret the implications of our cone score with caution.

Future studies are warranted to evaluate the long-term longevity of metaphyseal cones using a multicenter, high-volume approach. Additionally, there is limited evidence comparing ream-only to ream-then-broach cone techniques. We hypothesize that broaching creates a more congruent surface for implant integration, potentially offering more immediate stability and reducing micromotion, which may improve long-term mechanical outcomes. Future studies utilizing advanced imaging modalities to assess early osseointegration between different implant designs are needed to explore this hypothesis.

Conclusions

This is the first multicenter investigation to assess the radiographic survivorship of ream-then-broach metaphyseal cones. Our results demonstrate excellent radiographic outcomes at both short- and mid-term follow-up. Given the importance of maximizing metaphyseal fixation during rTKA, we suggest that surgeons consider ream-then-broaching metaphyseal cone implants for patients with significant bone defects, as broaching may provide a more congruent and reliable metaphyseal preparation. However, a formal comparative study with clinical outcome data is warranted to confirm these findings. The novel idea of a “cones score” may provide a more uniform manner for surgeons to evaluate the stability of these implants, but future research is necessary.

Conflicts of interest

M. Bullock is a speaker bureau and paid consultant of Smith & Nephew; has stock options in Stryker and Smith & Nephew; is an editorial board member of the Journal of Arthroplasty and Arthroplasty Today; and is a board member of the West Virginia Orthopaedic Society and AAHKS Digital Health and Social Media Committee. A. Ong receives royalties/financial/material support from Smith & Nephew; is a paid consultant for Stryker and Smith & Nephew; and is a guest reviewer of the Journal of Arthroplasty. J. Shields is a paid consultant of Smith and Nephew and Arthromeda; receives research support from Smith and Nephew; is an editorial board member of HSS Journal Board and Chair of AAOS Social Media Ambassadors; and is a member of Knee Advisory Board of Smith and Nephew. R. Lutz is the Chair of the AAOS Resident Assembly Education Committee. All other authors declare no potential conflicts of interest.

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CRediT authorship contribution statement

Aria Darbandi: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andrew Schaver:** Writing – review & editing, Data curation, Conceptualization. **Micah MacAskill:** Writing – review & editing, Methodology, Conceptualization. **Rex Lutz:** Writing – review & editing, Methodology, Data curation. **Amira Scaramella:** Methodology, Investigation, Data curation. **Christian Sangio:** Writing – review & editing, Investigation, Data curation. **John Shields:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **Alvin Ong:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Matthew Bullock:** Writing – review & editing, Supervision, Project administration, Investigation, Formal analysis, Conceptualization.

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