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Original Research

Radiographic Cone Zone Classification of Metaphyseal Cone Fixation in Revision Total Knee Arthroplasty

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ABSTRACT

Background: No objective radiographic scoring system exists to classify metaphyseal cone stability. Our purpose was to create a novel, systematic method to radiographically evaluate metaphyseal cone fixation based on radiographic findings suggestive of cone stability.

Methods: A retrospective analysis was conducted of revision total knee arthroplasty patients (6/2015-12/2017) using porous titanium femoral or tibial metaphyseal cones in conjunction with short cemented stems (50 mm-75 mm). Minimum follow-up was 2 years. Survivorship free of aseptic loosening and reoperation, as well as radiographic evaluation using a novel cone zone scoring system were analyzed.

Results: Forty-nine revision total knee arthroplasties were included in the study (12 femoral, 48 tibial cones), the majority, performed for aseptic loosening (25/49, 51%). Median follow-up was 39 months (range 25-58). Using the radiographic cone zone scoring method, >90% of all femoral cones were classified as likely stable or stable with strong, statistically significant intraclass correlations between all 3 reviewers. Similarly, >97% of all tibial cones were classified as likely stable or stable, with moderate, statistically significant intraclass correlations between all 3 reviewers. Only 1 femoral and 1 tibial cone were considered at risk of loosening. The study sample demonstrated 100% survivorship free of revision for aseptic loosening without evidence of radiographic loosening in any case.

Conclusions: Using a novel systematic cone zone scoring and classification method, the overwhelming majority of femoral and tibial cones were classified as likely stable or stable, with no identified cases of aseptic loosening or related revision. Further studies are needed to validate this objective classification method.

Introduction

Significant femoral and tibial bone loss during revision total knee arthroplasty (rTKA) is not uncommon and poses a risk for inadequate metaphyseal fixation, threatening successful long-term survivorship [1,2]. Supplemental metaphyseal fixation, through metaphyseal sleeves and highly porous tantalum or titanium metaphyseal cones, can achieve long-term biologic osseointegration. Thus, these strategies are commonly employed to enhance metaphyseal fixation in rTKA [3,4]. Diagnostic, organized, and rational scoring of defects and/or radiographic abnormalities associated with rTKA have improved the ability to quantify the magnitude of and decide on appropriate treatments for these challenging problems.

Current evidence on the use of porous metal cones in rTKA demonstrates excellent survivorship in midterm follow-up [5-10]. However, basic radiographic evaluation within these studies has identified some cases with radiolucent lines and apparent loosening of metaphyseal cones [7,9]. While radiographic classification scoring systems (Radiographic Knee Society Score) exist for stemmed rTKA constructs without cones [11,12], there is no current

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existing radiographic scoring system to systematically evaluate the stability and fixation of metaphyseal cones. Such a classification system could be useful in allowing clinicians to radiographically evaluate and predict revision construct stability in an objective manner, as well as offering researchers a tool to systematically record radiographic outcomes of metaphyseal cones.

The primary aim of this study was to create a novel, systematic method to radiographically evaluate metaphyseal cone fixation based on radiographic findings suggestive of cone stability. Based on currently existing literature on cone survivorship, we hypothesize that the majority of the cones in this study would be classified as stable.

Material and methods

Study design and patient selection

An institutional review board-approved retrospective cross-sectional study was performed on patients who underwent rTKA, performed using a 3-D printed porous titanium femoral or tibial metaphyseal cone along with a short cemented stem (50-75 mm) between June 1, 2015, and December 31, 2017, at a single, high-volume, tertiary referral hip and knee specialty practice. Forty-nine rTKAs with minimum 2-year follow-up (median follow-up was 39 months [range 25-58 months]) were reviewed for radiographic evaluation of initial and postoperative films.

Radiographic review

Complete radiographic evaluation is comprised of initial and final postoperative radiographs with an anteroposterior (AP) and lateral view that completely capture the implant and host bone interface, except for the implant-bone interface obscured by the anterior flange of the femoral component on the AP view. Initial postoperative and the most recent knee AP and lateral and merchant plain radiographs were compared and evaluated for signs of loosening including subsidence, implant migration, and the development of radiolucent lines that did not previously exist immediately following rTKA. If the radiolucent lines were present immediately postoperatively, they could be explained by bone loss and lack of contact at the time of surgery. Constructs not including a cone were not included in this analysis.

A cone zone radiographic scoring system was created to specifically classify metaphyseal cone stability. In a manner similar to zone classification by the Radiographic Knee Society Scoring [11], femoral and tibial cones were divided into radiographic zones. Femoral cones were divided into 6 or 8 zones, depending on whether the distal medial and lateral borders of the cone were obscured from visualization on the AP view by the anterior flange of the femoral component (Fig. 1a-c). This was done in order to allow complete assessment of femoral cones that are placed in conjunction with a distal femoral replacement or potted more proximally than the anterior flange of the femoral component (Fig. 1c). If an 8-zone division was used in those rare circumstances, on the AP view, distally, the medial/lateral zones were numbered 1 and 2, while the proximal medial/lateral zones were numbered 3 and 4, respectively. On the lateral view, distally, anterior/posterior were numbered 5, 6, and proximally 7, 8, respectively. Tibial cones were divided into 8 zones on both AP and lateral views (Fig. 1a-c). There is no currently available evidence on the amount of cone contact and ingrowth necessary for overall stability of the construct. However, given the tendency for metaphyseal cones to achieve spot welds and stable ingrowth in areas of contact with host bone despite lacking contact in other zones, the scoring system was devised with points assigned to positive findings that may indicate ingrowth and solid fixation. For each given zone, a maximum of 1 point is assigned upon the presence of any of the following 3 positive findings: a) bony apposition to the cone; b) absence of radiolucent line or progressive radiolucent line measured and compared to the immediate postoperative radiographs using a radiographic ruler; and c) the presence of a spot weld (Fig. 2).

The sum of the scores from all zones for either a femoral or tibial cone were classified as follows, based on author consensus for scoring cutoff values:

Femoral cones (6 or 8 zones):

1. Stable: Positive finding in 4 or more of 6 zones (or 6 or more of 8).
2. Likely stable, warrants observation: Positive finding in 3 zones out of 6 (or 4-5 out of 8).
3. At-risk: Positive finding in only 1-2 out of 6 zones (or 1-3 out of 8).

Tibia (8 zones)

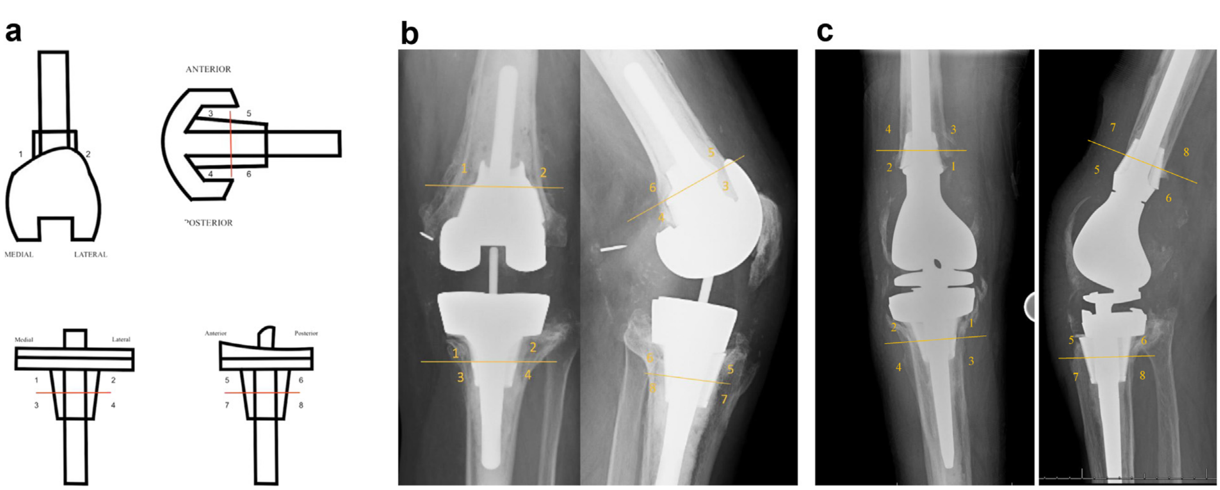

Figure 1. (a) Cone radiographic scoring zones for femoral and tibial cones demonstrated schematically. (b and c) Cone radiographic scoring zones for femoral and tibial cones demonstrated on plain films.

Figure 2. Lateral view of a tibial cone and short cemented stem construct demonstrating spot welding, a positive finding in zone 6 of the tibial cone (arrow).

1. Stable: Positive finding in 6 or more of 8 zones.
2. Likely stable, warrants observation: Positive finding in 4-5 zones out of 8.
3. At-risk: Positive finding in only 1-3 out of 8 zones on both views.

The radiographic review was performed by 3 different authors (only 1 of whom was the treating surgeon for a subset of these patients), who were blinded to the patient identifiers and clinical outcomes to allow for interrater reliability analysis, using the most senior author's scoring as a reference score.

Statistical analysis

Spearman's intraclass correlation was used to analyze interrater reliability between radiographic scores between the 3 authors. *P*-value of < .05 was considered statistically significant. Statistical Analysis Software (SAS) version 9.4 was used for analysis.

Results

Forty-six cases involved both component revisions, while there were only 2 isolated tibial revisions and 1 isolated femoral revision. Cones placed in the tibia were used in almost all cases (48/49, 98%), and cones placed in the femur were used in only 12 cases (24%).

Using the radiographic cone zone score, 11 of 12 femoral cones were categorized as stable or likely stable with scores by all 3 reviewers, with only 1 femoral cone considered at risk of loosening by all 3 authors (Table 1). Using the most senior surgeon's scoring as the reference score (Reviewer #3), there was a statistically significant, strong intraclass correlation with the other 2 reviewers (Spearman's coefficient 0.96, $P < .001$ and Spearman's coefficient 0.78, $P = .003$). Similarly, at least 90% of all 48 tibial cones were considered stable by all 3 reviewers. Only 1 tibial cone was considered at risk of loosening by the senior author but was considered as likely stable by the other 2 reviewers. The intraclass correlations between the 2 additional reviewers and the most senior surgeon's scoring were at least moderate and both statistically significant (Spearman's coefficients of 0.82 and 0.55, $P < .001$ for both). While there were frequent positive findings suggestive of cone ingrowth as defined in this study, only 2 tibial cones demonstrated clear radiographic "spot welds".

Consistent with the findings using the radiographic cone zone score, there were no identified cases of radiographic or clinical aseptic loosening with the use of metaphyseal cones in this study. A total of 7 (14%) cases required reoperation, 4 of which were for infection (3 of which were polyethylene liner exchanges and 1 superficial wound debridement), 1 for extensor mechanism reconstruction without component revision, and 1 bearing exchange for arthrofibrosis. There was only one revision, for aseptic loosening of a stemmed femoral component without a cone (to a cone and cemented stem construct), alongside a tibial component with a cone and short cemented stem that was well fixed at the time of reoperation.

Discussion

Based on the novel radiographic cone zone scoring method, nearly all femoral and tibial cones were classified as radiographically stable or likely stable. There were no identified cases of aseptic

Table 1
Radiographic cone zone classification of all metaphyseal cones in the study sample.

Outcome	Sample
Femoral cones	N = 12
Cone zone score classification	
Stable (≥ 4 out of 6, or ≥ 6 out of 8)	Reviewer 1: 7 (58%), Reviewer 2: 4 (34%), Reviewer 3: 6 (50%)
Likely stable (3 out of 6, or 4-5 out of 8)	Reviewer 1: 4 (34%), Reviewer 2: 7 (58%), Reviewer 3: 5 (42%)
At-risk (≤ 2 out of 6, or ≤ 3 out of 8)	Reviewer 1: 1 (8%), Reviewer 2: 1 (8%), Reviewer 3: 1 (8%)
Tibial cones	N = 48
Cone zone score classification	
Stable (≥ 6 out of 8)	Reviewer 1: 44 (92%), Reviewer 2: 43 (90%), Reviewer 3: 45 (94%)
Likely stable (4-5 out of 8)	Reviewer 1: 4 (8%), Reviewer 2: 5 (10%), Reviewer 3: 2 (4%)
At-risk (≤ 3 out of 8)	Reviewer 1: 0 (0%), Reviewer 2: 0 (0%), Reviewer 3: 1 (2%)

Reviewer 3 scores (senior author) were considered the reference category.

loosening or revisions for aseptic loosening of any of the cones in this study.

Using the created radiographic scoring system, only 1 femoral and 1 tibial cone were classified as "at risk", with frequently reported positive radiographic findings on the majority of femoral and tibial cones to indicate possible cone ingrowth. This radiographic scoring method was created given the current lack of a published systematic method to evaluate cone stability radiographically. This could be a potentially useful tool for clinicians in the radiographical diagnosis of aseptic loosening, particularly in constructs with existing stem radiolucent lines, which are not uncommon with cementless stems. Furthermore, this scoring method may be used to systematically assess and document the radiographic outcome of cone constructs with cemented or cementless stems for research analysis. Given no cases of aseptic loosening of the revision constructs in this study, further studies are needed to validate this scoring method and correlate the categories of radiographic stability to intraoperative findings. Furthermore, while the early and midterm radiographic appearance of these cone constructs is promising, long-term radiographic evaluation is needed.

With minimum 2-year follow-up, there were no identified cases of aseptic loosening of any cone used in this study. Although the reoperation rate was 14% in this study, the majority of reoperations were for prosthetic joint infections. There was only one revision, which was required for a stemmed femoral component without a cone. This is noteworthy despite the moderate use of varus-valgus constrained bearings as well as a few hinged-bearing TKAs in this study. Similar excellent survivorship, with only one confirmed case of aseptic loosening, was demonstrated in a recent retrospective study on 60 rTKAs using the same-design cones but in conjunction with either cementless or cemented stems of various lengths [9]. Furthermore, a recent retrospective comparative study demonstrated excellent and identical all-cause survivorship of trabecular metal cones with short cemented stems compared with longer cemented or cementless stems used with rotating hinge TKA [8]. Two comprehensive systematic reviews estimated the rate of aseptic loosening of cone constructs at 1.7%-2.2% [3,13]. However, there was considerable heterogeneity in the types of cones used, stem fixation, and the degree of bone loss. The lack of early aseptic failures in this study is encouraging, but long-term follow-up studies are required to confirm this finding.

Limitations

There are some shortcomings to this study that should be considered. These include the retrospective design, the limited sample size, and the proportion of patients lost to follow-up with <2 years of clinical follow-up, despite repeated attempts to contact these patients and incentives to return for follow-up. Additionally, there is no variable capturing the degree of bone loss encountered during revision. Furthermore, the novel cone zone scoring method requires further validation in conjunction with clinical outcomes of loosening based on future studies, given the lack of any cases of aseptic loosening in this series of rTKAs. Due to the lack of radiographic loosening cases within this cohort, this validation is important before the scoring system may be widely used for clinical application. Furthermore, despite radiologic and clinical lack of evidence for cone failure, it is still possible for a cone to lack osseointegration and therefore be loose by definition, even if the overall construct is indeed stable through cement fixation. This would not be captured by the proposed classification system and is an inherent limitation to radiographic assessment of these constructs. Finally, there was some heterogeneity in the use of constrained bearings as well as the use of different rTKA implants.

Conclusions

Durable metaphyseal fixation has evolved as a guiding principle in rTKA. Using a novel systematic cone zone scoring and classification method for the radiographic evaluation of metaphyseal cones, the overwhelming majority of femoral and tibial cones were classified as likely stable or stable, with no identified cases of aseptic loosening or related revision. Further studies are needed to validate this objective classification method in predicting cases of aseptic loosening.

CRediT authorship contribution statement

Omar A. Behery: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Elaine Shing:** Data curation, Writing – original draft, Writing – review & editing. **Ziqing Yu:** Formal analysis. **Bryan D. Springer:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Walter B. Beaver:** Supervision, Writing – original draft, Writing – review & editing. **Thomas K. Fehring:** Supervision, Writing – original draft, Writing – review & editing. **Jesse E. Otero:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflicts of interest

J. E. Otero is a paid consultant and receives research support from DePuy Synthes. T. K. Fehring is a paid consultant, receives research support, and receives royalties from DePuy. B. Springer receives royalties from Stryker and Osteoremedies; is a paid consultant for Stryker and Convatec; and is a board member of *American Joint Replacement Registry*, *International Congress for Joint Reconstruction*, and American Association of Hip and Knee Surgeons. W. Beaver receives royalties, is a paid consultant, presenter, contributes research support and has stock options from Stryker, provides research support for Depuy, Pacira and DonJoy and is a board member of ICJR and OrthoCarolina Research Institute. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101271.

References

[1] Kurtz SM, Ong KL, Lau E, Bozic KJ. Impact of the economic downturn on total joint replacement demand in the United States: updated projections to 2021. J Bone Joint Surg Am 2014;96:624–30.
[2] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89:780–5.
[3] Roach RP, Clair AJ, Behery OA, Thakkar SC, Iorio R, Deshmukh AJ. Aseptic loosening of porous metaphyseal sleeves and tantalum cones in revision total knee arthroplasty: a systematic review. J Knee Surg 2021;34:1033–41.
[4] Haidukewych GJ, Hanssen A, Jones RD. Metaphyseal fixation in revision total knee arthroplasty: indications and techniques. J Am Acad Orthop Surg 2011;19:311–8.
[5] Chalmers BP, Malfer CM, Mayman DJ, Westrich GH, Sculco PK, Bostrom MP, et al. Early survivorship of newly designed highly porous metaphyseal tibial cones in revision total knee arthroplasty. Arthroplast Today 2021;8:5–10.
[6] Potter 3rd GD, Abdel MP, Lewallen DG, Hanssen AD. Midterm results of porous tantalum femoral cones in revision total knee arthroplasty. J Bone Joint Surg Am 2016;98:1286–91.
[7] Kamath AF, Lewallen DG, Hanssen AD. Porous tantalum metaphyseal cones for severe tibial bone loss in revision knee arthroplasty: a five to nine-year follow-up. J Bone Joint Surg Am 2015;97:216–23.

[8] Jacquet C, Ros F, Guy S, Parratte S, Ollivier M, Argenson JN. Trabecular metal cones combined with short cemented stem allow favorable outcomes in aseptic revision total knee arthroplasty. J Arthroplasty 2021;36:657–63.
[9] Tetreault MW, Perry KI, Pagnano MW, Hanssen AD, Abdel MP. Excellent two-year survivorship of 3D-printed metaphyseal cones in revision total knee arthroplasty. Bone Joint J 2020;102-B(6_Supple_A):107–15.
[10] Anderson LA, Christie M, Blackburn BE, Mahan C, Earl C, Pelt CE, et al. 3D-printed titanium metaphyseal cones in revision total knee arthroplasty with cemented and cementless stems. Bone Joint J 2021;103-B(6 Supple A): 150–7.
[11] Ewald FC. The Knee Society total knee arthroplasty roentgenographic evaluation and scoring system. Clin Orthop Relat Res 1989:9–12.
[12] Fehring TK, Odum S, Olekson C, Griffin WL, Mason JB, McCoy TH. Stem fixation in revision total knee arthroplasty: a comparative analysis. Clin Orthop Relat Res 2003:217–24.
[13] Zanirato A, Formica M, Cavagnaro L, Divano S, Burastero G, Felli L. Metaphyseal cones and sleeves in revision total knee arthroplasty: two sides of the same coin? Complications, clinical and radiological results-a systematic review of the literature. Musculoskelet Surg 2020;104:25–35.