



Surgical technique

Variability of Sagittal Plane Proximal Tibial Morphology and Its Effect on Stem Placement in Total Knee Arthroplasty

Eric S. Secrist, MD ^a, Taylor Rowe, BA ^b, Katherine K. Li, MD ^a, Thomas K. Fehring, MD ^{a, b, c, *}

^a Department of Orthopaedic Surgery Atrium Health/Atrium Musculoskeletal Institute, Charlotte, NC, USA

^b Research, OrthoCarolina Research Institute, Charlotte, NC, USA

^c Hip & Knee Center, OrthoCarolina, Charlotte, NC, USA

ARTICLE INFO

Article history:

Received 29 July 2021

Received in revised form

12 October 2021

Accepted 29 October 2021

Available online xxx

Keywords:

Total knee arthroplasty

Revision total knee arthroplasty

Stemmed implants

Tibia anatomy

Knee anatomy

Revision total knee stems offset

ABSTRACT

The tibial joint line is offset posteriorly relative to the tibial sagittal anatomic axis. This can have consequences when using stemmed implants during total knee arthroplasty. We retrospectively analyzed native knee lateral radiographs in 100 patients. The distance between the sagittal anatomic axis and the center of a simulated tibial resection was calculated as a percentage of overall tibial width. Analysis of 5 manufacturers' baseplates showed that the tibial stem attached on average 10% anterior to the midline. We measured the impingement point of a 12-mm-diameter stem starting from this position. The tibial joint surface was offset posteriorly from the anatomic axis in all patients by an average of 23.5% of the tibial width (range: 13.1%–33.2%). A 12-mm tibial stem would impinge within 40 mm in 2% (2/100) of patients and within 60 mm in 19% (19/100). There was a weak but statistically significant correlation between proximal tibial offset and distance to impingement. During total knee arthroplasty, the center of the cut tibia is offset posteriorly from the sagittal anatomic axis. In patients with high offset, tibial stem extensions can impinge against the posterior tibia, causing baseplate malpositioning, diminished cement mantle, or fracture.

© 2021 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Tibial stems are an important tool for complex total knee arthroplasty (TKA). Stem extensions are routinely utilized in revision TKA when proximal tibial bone is compromised as they significantly reduce compressive and shear forces on proximal tibial cancellous bone [1]. They are increasingly utilized in obese patients [2] to minimize the risk of catastrophic varus collapse associated with unstemmed implants [3]. Stemmed implants can also improve stability in patients with osteopenia or severe coronal plane deformities [4]. In revision surgery, outcomes are similar when either cementless or cemented stems are used in aseptic

revision TKA [5]. However, because it is important for cementless stems to engage the diaphysis for success, variation in tibial bone morphology must be recognized in preoperative planning.

It is well recognized by cementless stem users that valgus bowing of the tibia in the coronal plane requires recognition and technical judgment to avoid an insertional fracture or malpositioning at the joint line [1]. In such situations, offset stems can be used to avoid medial overhang if a canal-filling, diaphyseal-engaging cementless stem is used. Alternatively, a shorter cemented construct could be utilized to allow a non–canal-filling technique and avoid medial overhang. In either construct, recognition of tibial bone abnormalities is essential for avoiding insertional complications. While this valgus bowing of the tibia is commonly recognized by surgeons treating complex problems requiring stem extensions, the sagittal plane morphology of the proximal tibia is also an important consideration during the placement of a stemmed TKA implant. The impact of this variability in sagittal plane morphology has not been previously described.

The tibial diaphysis is triangularly shaped and relatively short, generally extending for approximately 6 cm [2]. While the anatomic axis is consistently centered over the ankle in the sagittal

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to <https://doi.org/10.1016/j.artd.2021.10.018>.

* Corresponding author. 2001 Vail Ave, Suite 200a, Charlotte, NC 28207, USA. Tel.: +1 704 323 2564.

E-mail address: Thomas.Fehring@orthocarolina.com

<https://doi.org/10.1016/j.artd.2021.10.018>

2352-3441/© 2021 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

plane [3], this is not the case at the knee where the sagittal joint center is posterior to the anatomic axis. This mismatch is one reason why Herzog curves are incorporated into the design of intramedullary nails utilized for fixation of tibia fractures [4]. This posterior offset of the proximal tibia relative to the diaphysis can influence the trajectory of a tibial stem in a similar fashion to an intramedullary nail. In patients with significant posterior offset at the joint line, this can cause the stem to impinge on the posterior tibial cortex, potentially leading to an insertional fracture. In cases where a cemented stem is used, it can lead to a diminished posterior cement mantle (Figs. 1 and 2). When an uncemented diaphyseal-engaging stem is used, it can lead to significant anterior overhang (Fig. 2a and b). Adding posterior slope to the tibial cut can mitigate some of these problems, although such an adjustment can effect flexion stability. Another strategy to avoid anterior overhang with diaphyseal-engaging press-fit stems is the use of an offset stem. Recognition of this problematic morphology preoperatively would allow surgeons to plan appropriately to address it.

In our practice we have noticed several cases where a long tibial stem contacted the posterior cortex during a complex primary or a revision TKA. In this study, we sought to define the normal amount of posterior offset of the tibial center at the cut surface for a TKA relative to the diaphyseal anatomic axis. We also sought to define the amount of posterior proximal tibial offset which would cause issues with impingement on the posterior cortex. Our hypothesis was that the distance between the anatomic axis of the tibia and the joint center would be clinically insignificant in most patients but that in a certain subset of patients, posterior offset in the sagittal plane would result in posterior cortical impingement with potential negative consequences when using a stemmed tibial implant.

Material and methods

We reviewed a series of consecutive patients presenting to a single arthroplasty surgeon's clinic (TKF) with a primary complaint of knee pain during 2019–2020. Patients were included if they had an appropriate lateral knee radiograph available for review. Radiographs had to be performed before TKA, include a marker ball, and have appropriate rotation. Patients with abnormal fibular overlap with the proximal tibia or malrotation of the femoral condyles on the lateral radiograph were excluded. Patients were also excluded if they had any history of tibial fracture or tibial osteotomy or any known neuromuscular or metabolic bone disorders.

Posterior proximal tibial offset was calculated for each patient as the difference between the diaphyseal sagittal plane anatomic axis of the tibia and the center of the tibia at the cut surface for a standard TKA (Fig. 3 and b). All measurements were obtained using TraumaCad® software. The sagittal diaphyseal anatomic axis was estimated by a line bisecting the center of the tibia at the most distal point visible on the lateral knee radiograph and the distal extent of the tibial tubercle (line CD). A line was then drawn to simulate a resection which was perpendicular to the anatomic axis and intersected the posterior-superior apex of the tibia (line AB). We simulated a resection which would be perpendicular to the mechanical axis of the tibia because revision TKA incorporating long tibial stems is most often used with posterior-stabilized components designed to be implanted with neutral tibial slope [5]. This was intended to simulate the minimum resection necessary to achieve a flat surface on which to seat a tibial baseplate on the proximal tibia. The center point of this cut surface was defined (line EF), and the percentage of posterior tibial offset was calculated as the difference between the anatomic axis and the center of the cut tibial surface as a percentage of overall tibial width (CE/AB).



Figure 1. Postoperative radiograph after primary TKA with a 14 × 30 stem which led to posterior impingement and a diminished cement mantle. Preoperative native knee posterior proximal tibial offset was 28.3%, and a stem was used due to obesity.

Tibial baseplates for TKA systems which incorporate long stems were obtained from 5 companies. These stems were analyzed photographically to determine the position of the center of the stem in the sagittal plane. This was defined as the distance from the most anterior point of the baseplate to the center of the stem housing as a percentage of the total width of the baseplate in the

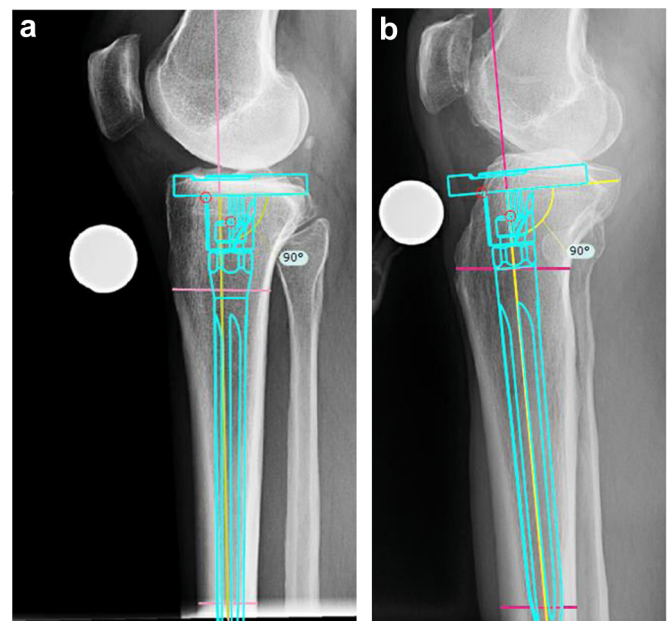


Figure 2. Templating of a long-stemmed tibial implant in a patient with the lowest (13.1%, a) and highest (33.2%, b) posterior proximal tibial offset seen in the patients in this study. Both cases are templated for a Stryker triathlon universal baseplate with a diaphyseal-engaging stem.

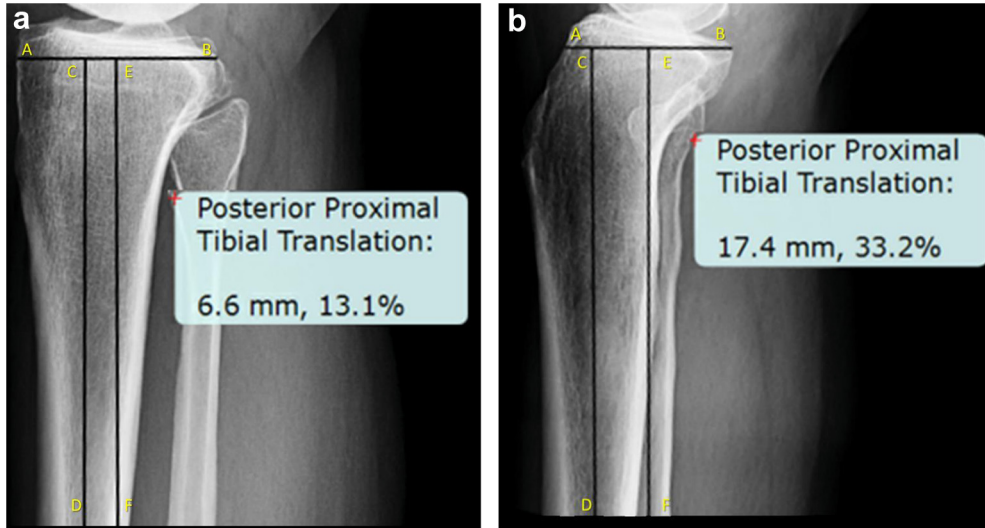


Figure 3. Representative radiographs demonstrating the method utilized for calculating posterior proximal tibial offset in a patient with the lowest posterior proximal tibial offset (6.6 mm, 13.1% of overall tibial width, a) and highest posterior proximal tibial offset (17.4 mm, 33.2% of overall tibial width, b).

sagittal plane. This method of calculation was validated by comparing the results with published literature from one company. Another company confirmed the accuracy of our calculations by verifying them against their proprietary internal specifications. Table 1 depicts these photographic measurements as well as the stem options for the respective companies.

The average position of the center of the tibial baseplate in the sagittal plane for those 5 companies was 10% anterior to the midline, or at the 40% mark in the anterior-posterior plane (Table 1). Based on this, we measured the point at which a 12-mm tibial stem would impinge against the posterior endosteal surface of the tibia if stems of varying lengths were used. We did this by extending a line parallel to the sagittal anatomic axis from a point 6 mm posterior to the 40% position at the resected tibial surface and measuring the distance at which it intersected the posterior endosteal cortex. This 6-mm measurement was chosen to simulate the posterior half of a 12-mm-diameter stem extension. This

diameter was chosen to simulate an average-sized stem based on our review of stem size options from 5 companies which make revision tibial baseplate sets.

Demographic data were obtained on all patients included in the study from a registry. Institutional review board approval was obtained before the initiation of the study. All data were input using RedCap [6], and analysis was performed using Microsoft Excel and SAS v. 9.4 (SAS Institute, Cary, North Carolina, USA). Normality testing was performed on all numeric data. No power analysis was performed as we did not perform any comparative analyses in this study.

Results

One hundred thirty-one patients were reviewed for this study. There were 31 patients excluded. One patient had undergone a prior tibial tubercle osteotomy, one had had a prior tibial fracture, and the other 29 lacked appropriate preoperative radiographs for

Table 1
Tibial stem positioning in the sagittal plane and stem length options among varying total knee arthroplasty manufacturers.

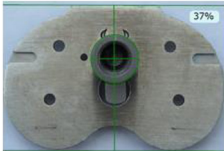
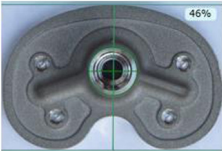

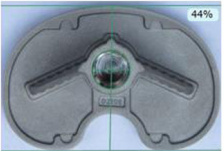
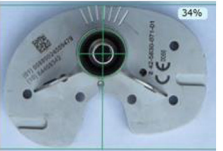
Tibial baseplate	 37%	 46%	 39%	 44%	 34%
Stem position within tibial baseplate in sagittal plane (percentage)	37%	46%	39%	44%	34%
Stem length options (mm)	80 mm, 120 mm	30 mm, 50 mm, 60 mm, 110 mm, 160 mm	50 mm, 90 mm, 130 mm, 190 mm, 250 mm	50 mm, 100 mm, 150 mm	30 mm, 75 mm, 135 mm, 175 mm
Optional couplers (mm)	40 mm offset coupler	25 mm offset coupler	30 mm offset coupler	25 mm offset coupler 25 mm, 50 mm straight adapter	None (separate offset stems available)
Posterior stem angulation (degrees)	0 degrees	2.5 degrees	0 degrees	0 degrees	0 degrees

Table 2
Demographics.

Age (in years) at evaluation, median (q1, q3)	68.0 (58.0, 74.5)
BMI, mean (\pm SD)	30.3 (5.9)
Height (in inches, \pm SD)	67.3 (3.9)
Sex, n (%)	
Female	57 (57.0%)
Male	43 (43.0%)
Ethnicity, n (%)	
Not Hispanic or Latino	97 (97.0%)
Hispanic or Latino	1 (1.0%)
Declined	1 (1.0%)
Unrecorded	1 (1.0%)
Race, n (%)	
Asian	1 (1.0%)
Black, African American	14 (14.0%)
White	81 (81.0%)
Declined	1 (1.0%)
Unknown	1 (1.0%)
Side, n (%)	
Right	51 (51.0%)
Left	49 (49.0%)

BMI, body mass index; SD, standard deviation.

review, because no preoperative radiographs were available, no marker ball was utilized, or the lateral radiograph was malrotated. Demographic data can be seen in [Table 2](#).

The average posterior offset distance between the anatomic axis of the tibia in the sagittal plane and the center of the cut tibial surface was 23.5% (standard deviation: 3.8%, range: 13.1%–33.2%) of the overall width of the tibia at that point. The distribution of percent offset between the anatomic axis and the center of a resected joint line can be seen in [Figure 5](#).

If a 12 mm stem was inserted at the average sagittal plane position of the tibial baseplates we analyzed, the majority of patients would impinge against the posterior endosteal surface between 60 and 80 mm (59%). However, 19% of patients would impinge with a 60-mm stem and 2% would impinge with a 40-mm stem ([Fig. 4](#)).

The shortest distance to impingement was 33.7 mm, and the longest distance to impingement was 128 mm ([Figs. 5a, b and 6](#)).

There was a weak but statistically significant correlation (Adj. $R^2 = 0.322$, $P < .001$) between the percentage of posterior offset between the center of the resected joint surface and the estimated impingement point for a 12-mm tibial stem inserted 10% anterior to the center of the resected joint line (ie, at the 40% mark in the anterior-posterior plane) ([Fig. 6](#)).

Discussion

We have demonstrated the variability of sagittal plane morphology of the proximal tibia as well as its potential impact on stem placement during TKA. Tibial stems are an important tool for revision TKA [7] and complex primary TKA in obese patients [8] or patients with severe preoperative deformities [9]. In this study, a 60-mm-long stem with a diameter of 12 mm would impinge against the posterior endosteal surface in 19% of patients. In 2% of patients, a stem only 40-mm long would have impinged against the endosteal surface. This impingement could create a stress riser leading to either insertional or postoperative fracture. It could also tilt the tibial baseplate into inappropriate tibial slope, which could interfere with flexion gap balancing. Finally, intersection with the endosteal surface could result in a diminished posterior cement mantle if a cemented stem is used or increased anterior overhang of the baseplate relative to the anterior cortex of the proximal tibia if a canal-filling, diaphyseal-engaging stem is used.

This study has limitations. It lacks clinical correlates, as it was based on preoperative radiographs of the native knee in patients who did not eventually undergo TKA which incorporated a long stem. We therefore cannot address the clinical prevalence of issues arising from the mismatch of tibial stems and the joint center during placement of a stemmed TKA in this purely radiographic analysis. It was based on plain film radiographs, and although we did control for quality of the radiographs and eliminated 22% of the

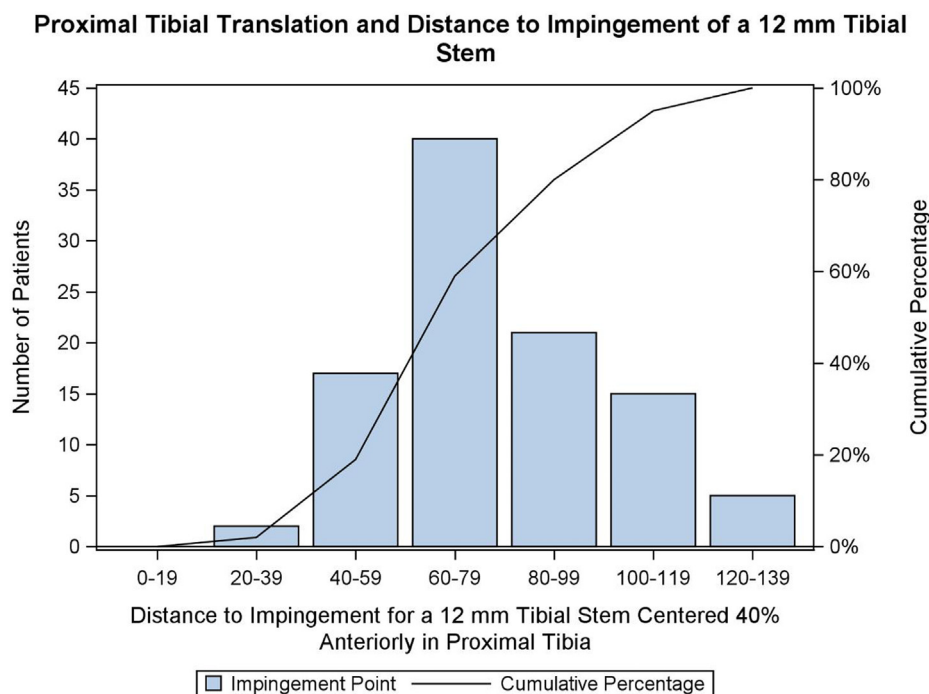


Figure 4. Calculated length at which a 12-mm-diameter stem centered 40% anteriorly in the proximal tibia would impinge against the posterior endosteal tibial surface.

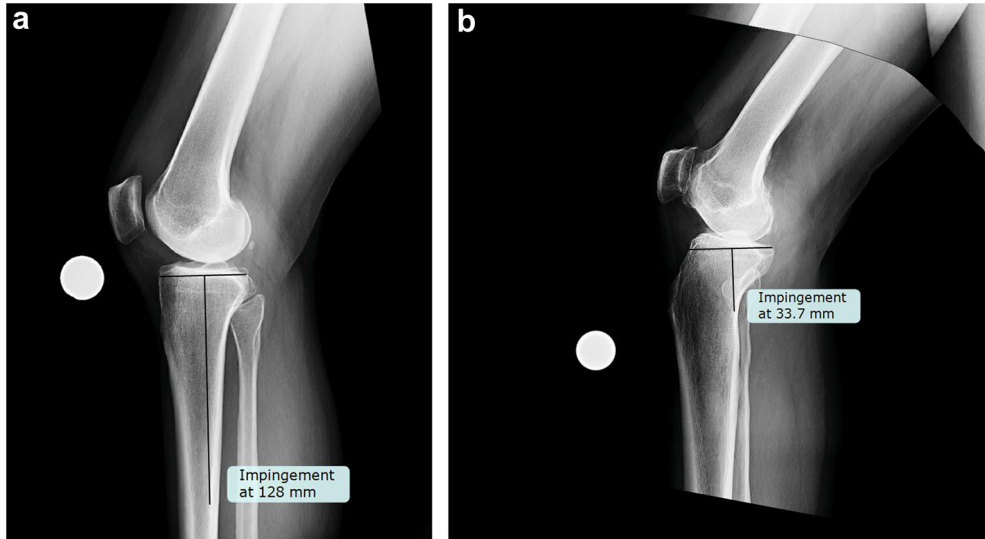


Figure 5. Representative radiographs demonstrating the method utilized for calculating the impingement point for the patient with the lowest (a) and highest (b) posterior proximal tibial offset. The impingement point was calculated as a line parallel to the sagittal axis, beginning from a point 6 mm posterior to the 40% mark in the resected tibia. This was chosen to simulate the posterior half of a 12-mm stem.

patients based on poor radiographic quality, a CT analysis would have provided more reliable results. Our study population selected for patients with painful knees presenting to an arthroplasty surgeon and may not necessarily represent population-wide norms. Our methodology for measurement of the distance between the anatomic axis of the tibia and the center of a tibial resection was a novel method which has not been utilized in previous studies. Our study population was not racially diverse, which could be relevant as 3 previous studies have demonstrated increased variability in tibial morphology in patients of Asian descent [10–12] and there

was only one patient who self-reported as Asian in this study. Replication of this study methodology in a more diverse ethnic population could yield significantly different results than what we have reported here. We chose to analyze the depth at which a 12-mm stem would impinge; however, the diameter of the stem would effect this distance, as thinner stems would impinge lower and thicker stems would impinge higher within the tibia. Additionally, all of our resections were based off of native knee radiographs, while in the revision setting, preexisting resections result in increased bone loss and could result in earlier impingement.

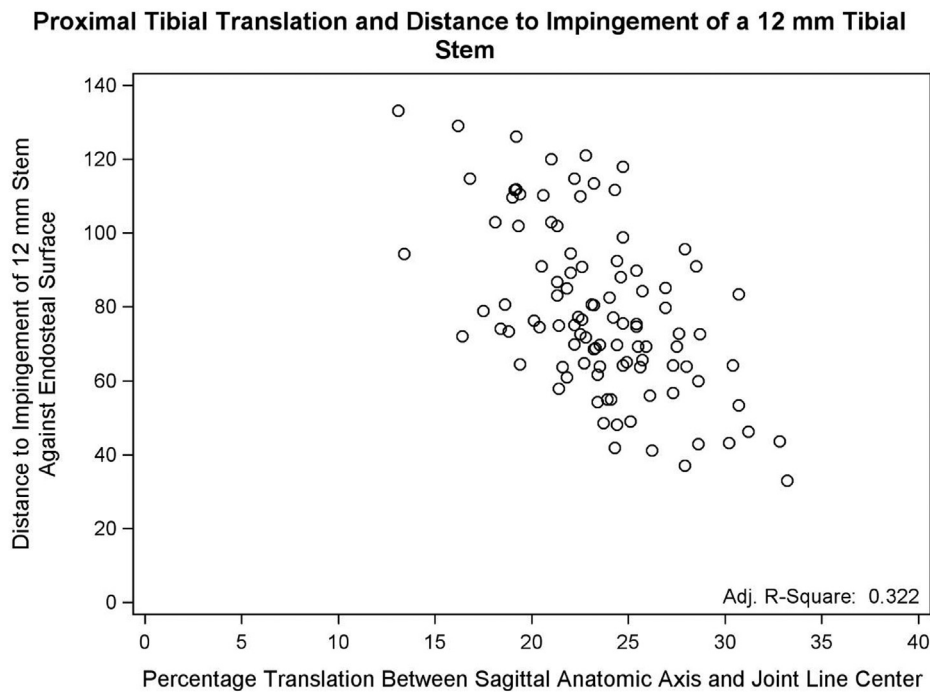


Figure 6. Relationship between proximal tibial posterior offset and the distance to impingement of a 12-mm stem positioned 10% anterior to the center of the resected joint line in the sagittal plane (ie, the 40% mark in the anterior-posterior plane).



Figure 7. Primary TKA in which additional tibial slope was added to avoid posterior impingement after preoperative recognition of high proximal tibial offset. Preoperative native knee posterior proximal tibial offset was 29.7%.

Finally, this study only analyzed the sagittal plane morphology on lateral radiographs, meaning we cannot comment on the incidence of coronal plane malalignment.

The most relevant literature on the relationship of the tibial diaphysis to the proximal tibia comes from an autopsy study published in 1995 which involved performing axial CT scans of the proximal tibia after placing a straight rod in 10 cadaver tibias. This allowed the examiners to calculate the relative position of the tibial diaphysis compared with the joint line. That study found that the tibial anatomic axis was anterior to the plateau center in 9 of 10 specimens, ranging from 15 mm anterior to 1.5 mm posterior to the center of the joint line [2]. These results are similar to those reported here, as the anatomic axis was anterior to the plateau center in all 100 patients.

This is the first study to correlate the sagittal plane morphology of the proximal tibia with potential issues during insertion of stemmed TKA implants. This is only a concern among patients with above-average posterior offset of the proximal tibia. There are several strategies that could be utilized to avoid the issues caused by this impingement. Cemented non–canal-filling stems can be utilized to allow slightly asymmetric positioning within the canal. Posterior slope can be increased with the downside of effecting flexion/extension gap balancing (Fig. 7). Offset stems allow baseplates to be positioned posteriorly relative to the center of the diaphyseal anatomic axis; however, if an offset stem is utilized with cement proximal to the offset junction, extraction can be extremely challenging. Finally, a shorter stem can be used (Fig. 8).

Overall, we have demonstrated the potential for issues related to stem impingement in patients with a proximal tibial joint line which is posteriorly offset relative to the diaphyseal anatomic axis.



Figure 8. Revision TKA in which a shorter stem (14 mm × 30 mm) was selected to avoid insertional fracture after preoperative recognition of high proximal tibial offset. The stem has 2.5 degrees of posterior stem angulation, and the shorter stem still abutted the posterior cortex. Preoperative posterior proximal tibial offset measured 25.5%.

In this study, the center of the diaphyseal axis and the center of the resected tibia were not aligned in any of the patients in the sagittal plane. Awareness of this fact could encourage surgeons to incorporate analysis of lateral radiographs into preoperative planning and thereby mitigate the risk of complications related to the variability described here.

Conclusions

The sagittal plane morphology of the proximal tibia can influence stem placement during TKA. Here we have demonstrated that long tibial stems will impinge earlier in patients in whom the center of the proximal tibial joint line is offset posteriorly relative to the sagittal plane anatomic axis. If long tibial stems are placed in these patients, impingement against the posterior tibia can result in baseplate malpositioning, diminished cement mantle, or fracture. Recognition of this morphology preoperatively would allow surgeons to implement strategies to avoid these consequences.

Conflicts of interest

Thomas Fehring receives royalties from, is a paid consultant for, and receives research support as a principal investigator from DePuy and A Johnson & Johnson Company; the other authors declare no potential conflicts of interest.

References

- [1] Gobba MS, Chan N, Patel R, Noble PC, Incavo SJ. Tibial stems in revision total knee arthroplasty: is there an anatomic conflict? *J Arthroplasty* 2015;30(9):86.
- [2] Hicks CA, Noble P, Tullos H. The anatomy of the tibial intramedullary canal. *Clin Orthop Relat Res* 1995;(321):111.

- [3] Askam BM, Morin M, Roberts H, Macknet D, Wild JR, Karunakar MA. Defining the intramedullary axis of the distal tibia using CT. *Orthop Trauma Assoc 2019 Annu Conf*; 2019. Scientific Poster # 135.
- [4] Hiesterman TG, Shafiq BX, Cole PA. Intramedullary nailing of extraarticular proximal tibia fractures. *J Am Acad Orthop Surg* 2011;19(11):690.
- [5] Kannan A, O'Connell RS, Kalore N, Curtin BM, Hull JR, Jiranek WA. Revision TKA for flexion instability improves patient reported outcomes. *J Arthroplasty* 2015;30(5):818.
- [6] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42(2):377.
- [7] Edwards PK, Fehring TK, Hamilton WG, Perricelli B, Beaver WB, Odum SM. Are cementless stems more durable than cemented stems in two-stage revisions of infected total knee arthroplasties? *Clin Orthop Relat Res* 2014;472:206–11. <https://doi.org/10.1007/s11999-013-3139-8>. Springer New York LLC.
- [8] Gopalakrishnan A, Hedley AK, Kester MA. Magnitude of cement-device interfacial stresses with and without tibial stemming: impact of BMI. *J Knee Surg* 2011;24(1):3.
- [9] Easley ME, Insall JN, Scuderi GR, Bullek DD. Primary constrained condylar knee arthroplasty for the arthritic valgus knee. *Clin Orthop Relat Res* 2000:58–64. <https://doi.org/10.1097/00003086-200011000-00008>. Lippincott Williams and Wilkins.
- [10] Kwak D-S, Han CW, Han S-H. Tibial intramedullary canal axis and its influence on the intramedullary alignment system entry point in Koreans. *Anat Cell Biol* 2010;43(3):260.
- [11] Shao H, Chen C, Scholl D, Faizan A, Chen AF. Tibial shaft anatomy differs between Caucasians and East Asian individuals. *Knee Surg Sports Traumatol Arthrosc* 2018;26(9):2758.
- [12] Tang Q, Zhou Y, Yang D, Xu H, Liu Q. The offset of the tibial shaft from the tibial plateau in Chinese people. *J Bone Joint Surg Am* 2010;92(10):1981.