Maximizing Tibial Coverage Is Detrimental to Proper Rotational Alignment

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Abstract

Background Traditionally, the placement of the tibial component in total knee arthroplasty (TKA) has focused on maximizing coverage of the tibial surface. However, the degree to which maximal coverage affects correct rotational placement of symmetric and asymmetric tibial components has not been well defined and might represent an implant design issue worthy of further inquiry.

Questions/purposes Using four commercially available tibial components (two symmetric, two asymmetric), we sought to determine (1) the overall amount of malrotation that would occur if components were placed for maximal tibial coverage; and (2) whether the asymmetric designs would result in less malrotation than the symmetric designs when placed for maximal coverage in a computer model using CT reconstructions.

Methods CT reconstructions of 30 tibial specimens were used to generate three-dimensional tibia reconstructions

with attention to the tibial anatomic axis, the tibial tubercle, and the resected tibial surface. Using strict criteria, four commercially available tibial designs (two symmetric, two asymmetric) were placed on the resected tibial surface. The resulting component rotation was examined.

Results Among all four designs, 70% of all tibial components placed in orientation maximizing fit to resection surface were internally malrotated (average 9°). The asymmetric designs had fewer cases of malrotation (28% and 52% for the two asymmetric designs, 100% and 96% for the two symmetric designs; $p < 0.001$) and less malrotation on average (2° and 5° for the asymmetric designs, 14° for both symmetric designs; $p < 0.001$).

Conclusions Maximizing tibial coverage resulted in implant malrotation in a large percentage of cases. Given similar amounts of tibial coverage, correct rotational positioning was more likely to occur with the asymmetric designs. **Clinical Relevance** Malrotation of components is an important cause of failure in TKA. Priority should be given to correct tibial rotational positioning. This study suggested that it is easier to balance rotation and coverage with asymmetric tibial baseplates; clinical research will need to determine whether the observed difference affects patellar tracking, loosening rates, or the likelihood of revisions after TKA.

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Introduction

Tibial component rotation in TKA is critically important [4, 7–10, 15, 16]. Malrotated components can cause pain and/or compromised motion because of patellar maltracking and flexion-extension gap mismatch [2, 7, 23]. Function, patient satisfaction, and implant durability depend, to a large degree, on proper placement of TKA components [4, 11, 17, 22].

Although there are multiple anatomic references for rotational alignment of the femur, the bony references for the asymmetric proximal tibia vary and are not as well defined but include the tibial tubercle and the posterior axis of the tibia [1, 2, 5, 7, 8, 10, 12–14, 23, 24]. Other described references, which cannot be easily identified at the time of surgery, are the geometric center of each plateau, the kinematic axis, and the femoral epicondylar axis [5].

Traditionally, maximizing tibial coverage has been proposed to provide increased fixation by improving load transfer from the implant to the proximal tibia to avoid subsidence and/or loosening [6, 11, 16, 18]. However, tibial coverage rarely exceeds 78%, and several authors have proposed a minimum of 75% coverage for adequate fixation; however, this is based on mechanical data, and the degree to which this is clinically relevant is unknown [3].

The desirable functional rotation of the tray does not necessarily correspond with the orientation of the resected proximal tibia, and the direction of maximum mediolateral symmetry of the resected tibial surface may be internally rotated with respect to the plane of flexion-extension of the knee [12, 16]. To overcome this challenge, some designs include asymmetric trays with different components for right and left tibias. However, because tibial morphology is known to be variable, and because implants are supplied in a finite array of sizes, it is not known if the adoption of asymmetry makes a substantial improvement in minimizing the tradeoff between coverage and rotation during placement of the tibial tray.

Because tray position affects rotation and coverage differently, this study was performed to determine how coverage of the resected tibial surface affects rotational alignment of symmetric and asymmetric tibial components. Using four commercially available tibial components (two symmetric, two asymmetric; Fig. 1), we sought to determine (1) the overall amount of malrotation that would occur if components were placed for maximal tibial coverage; and (2) whether the asymmetric designs would result in less malrotation than the symmetric designs when placed for maximal coverage in a computer model using CT reconstructions.

Materials and Methods

Computer models of 30 tibias were selected from a large collection of CT reconstructions consisting of 0.65-mm thick contiguous CT slices. Three-dimensional (3-D) reconstructions of the tibia were prepared using specialized image processing software (Materialise, Leuven, Belgium), resulting in solid models of each bone with a dimensional accuracy of approximately 0.2 mm. Using the CT reconstructions, the following landmarks and axis were identified

Fig. 1 The four tibial component designs and their respected rotational axes used in this study.

for each specimen in a 3-D scanning software package (INUS Technology, Seoul, Korea).

Ten axial sections of the tibial shaft were taken at 5-mm increments from 50 mm to 100 mm below the anteromedial aspect of the tibial plateau. The anatomic tibial axis was defined as the line of best fit to the calculated centroids of these 10 axial slices.

The lowest point on the medial side of the tibial plateau was identified. A plane with a posterior slope of 5° to the anatomic tibial axis was used to slice the tibia 5 mm below the lowest point on the subchondral surface of the medial plateau to simulate the osteotomy. The resulting surface was defined as the resected tibial plateau or resection plane.

Axial sections of the tibial tubercle were taken at 1-mm increments. A line was drawn connecting the most lateral and most medial aspects of the tibial tubercle at any level. This line was projected to the tibial resection plane. Once this line was divided into three sections, the point between the most medial and middle section (the medial one-sixth) was identified. A line was constructed from this point to the center point of the posterior cruciate ligament recess of the tibial plateau. This line was defined as the tibial rotational axis (Fig. 2).

The implant axis was determined for each of the implant designs. For the symmetric implants (designated S1 and S2), the axis was generated by creating a line between the two most posterior points of the component. The AP axis of the implant was orthogonal to the posterior axis and was generated by creating a perpendicular line to the midpoint of this axis. For the asymmetric components (designated A1 and A2), based on the reference provided by the manufacturer, the mediolateral direction of the axis was defined (Fig. 1).

Three observers (SM, SI, KA) with significant experience in TKA directed the sizing and position of each tibial

tray on each of the tibias and reached a consensus opinion concerning the placement providing optimal coverage, provided that (1) the largest component was used without cortical overhang; and (2) the component was placed in the most central position possible on the resection surface, thereby equalizing as much as possible the uncovered area in both the mediolateral and AP directions.

After computer implantation, the rotational orientation of each component was measured with respect to the midline of the medial third of the tibial tubercle (Fig. 2). The areas of the tibial component and resected surface were calculated using the reverse engineering program RapidForm 2006 (RapidForm, Lakewood, CO, USA). We divided the area of the tibial component by the area of the resected surface to determine percent of coverage.

Four tibial tray designs were selected from commercially available systems and converted into CAD models by reverse engineering.

The tibial rotational axis was compared with the resulting rotational axis of the virtually implanted tibial

components. Correct rotational alignment was defined as the implant axis being within $\pm 5^\circ$ of deviation from the axis of neutral tibial rotational; otherwise, the tibial component was considered malrotated. Statistical analyses of the experimental data were performed using Statview 5.0 (SAS Institute, Chicago, IL, USA). Statistical significance was set at $p < 0.05$. Mean values and SDs were calculated for each implant type.

Analysis of the implantation data was performed using random effects repeated-measures analysis of variance (ANOVA). If the results of the ANOVA test revealed a statistically significant difference ($p < 0.05$) between groups for a given variable (eg, rotational alignment), a comparison of each pair was performed using Fisher's least significant difference. This analysis allows for examination and comparison of all four designs with respect to the occurrence and severity of malrotation.

Results

When placed for maximal tibial coverage, 70% of the tibial components were internally malrotated. Averaging all four designs, malrotation was $9^\circ \pm 7^\circ$ of internal rotation when coverage was maximized (Table 1). When the tibial components were placed in the orientation that maximized coverage of the resection surface, the average tibial coverage achieved across all specimens and implants was $82\% \pm 4\%$, ranging from $79\% \pm 3\%$ (Tray S1) to $82\% \pm 3\%$ (Tray A2).

Use of the asymmetric components resulted in less frequent and less severe malrotation. Placement of component A1 resulted in 28% of trays malrotated, and component A2 had 52% of components malrotated, whereas the symmetric components were malrotated 100% (S1) and 96% (S2) of the time ($p < 0.001$; Fig. 3). Asymmetric components demonstrated less severe malrotation than symmetric components when placed for maximum coverage. Component A1 demonstrated a mean of $2^\circ \pm 5^\circ$ of malrotation, A2 a mean of $5^\circ \pm 5^\circ$, and S1 and S2 both had a mean of $14^\circ \pm 5^\circ$ ($p < 0.001$).

Fig. 2 Tibial base plate placed on the proximal tibia. The rotational axis of the tibia is marked by the straight line and the rotational axis of the component is depicted by the arrow. The angle between these two axes represents the degree of malrotation.

Table 1. The mean $\pm$ SD of percent coverage, percent malrotation, and degree of malrotation tabulated according to tibial design and for the four designs together (average)

Design	Percent coverage	Percent malrotation	Degree of malrotation (range)
A1	$81\% \pm 4\%$	28%	2° (–6 to 12)
A2	$82\% \pm 3\%$	52%	5° (–8 to 12)
S1	$79\% \pm 3\%$	100%	14° (6 to 23)
S2	$81\% \pm 4\%$	96%	14° (5 to 18)
Average	$81\% \pm 4\%$	70%	9°

$p < 0.001$ asymmetric (A1, A2) versus symmetric (S1, S2) degree of malrotation; $p < 0.001$ asymmetric (A1, A2) versus symmetric (S1, S2) percent of malrotation.

Fig. 3 The degree of malrotation versus percent coverage for each specimen according to implant design. Note that nearly all of the symmetric designs and some of the asymmetric designs do not fall within the $\pm 5^\circ$ acceptable range.

Discussion

Although TKA continues to have high success rates, rotational alignment is still a problem, as seen in CT and retrieval studies [10, 21]. It has been shown that 15% to 19% of patients undergoing TKA are not completely satisfied with the function of their joint [4, 17, 19, 20]. We believe inadvertent internal rotation of the tibial tray, in an effort to increase tibial bone coverage, may be part of this problem and thus sought to evaluate the influence of component design (symmetric versus asymmetric components) on rotation.

Proper rotation of the tibial component is a basic principle of TKA, and this goal may conflict with maximizing tibial coverage, as we have previously considered [12]. However, multiple recent publications demonstrate that internal tibial component rotation still occurs and is a source of failure in TKA [3, 6, 17, 18]. Correct rotation can be achieved using symmetric or asymmetric components, but the extent of coverage (especially posteromedial) may vary depending on component design.

This study has several limitations. There are varying opinions on what landmarks to use when assessing component alignment; this is especially true when discussing the tibia. We chose the middle of the medial one-third of the tubercle (medial one-sixth), because it was easily reproducible in the laboratory and can also easily be used in the operating room. The tibial tubercle has been shown in multiple studies to be the most reproducible clinical landmark in terms of tibial tray rotation [5, 8]. Importantly, although there are many options for alignment, the medial one-sixth of the tibial tubercle rotational axis is within 5° of the kinematic axis of the knee and the femoral epicondylar axis, both of which compare favorably with multiple other anatomic

landmarks [5]. A second limitation is the elimination of any surgeon discretion on the rotational position. We used strict parameters to guide component placement, specifically that the tray had equal amounts of bone circumferentially and that no cortical overhang was permitted. In reality, during surgery, the surgeon can make small adjustments to improve rotational position but may also incorrectly make adjustments to inadvertently worsen internal rotation. Another potential limitation of the study is that we did not measure intra- and interobserver variability but rather used a consensus of three knowledgeable observers with strict guidelines for component placement. We believe this is satisfactory for this study because this involves minimal interpretation by the observers. We were not asking the observers to place the component in correct rotation, but to place the largest component allowed by the guidelines in measuring the result of rotation.

These results demonstrate that the practice of implanting tibial trays in the orientation that maximizes fit and coverage of the exposed tibial bone leads to malrotation of the implant in internal rotation in a majority of cases. Tibial tray rotational positioning has an important relationship to tibial coverage. In our study, regardless of component design, when coverage was optimized, most (70%) of the components were malrotated. We believe this helps to explain why TKA revisions for malrotation have been reported in the last decade [3–5, 10, 22]. Malrotation of components has been shown to cause many issues [4, 10, 11, 24]. Berger and Rubash reported that internal rotation of the tibial component from 3° to 8° correlated with patellar subluxation, whereas internal rotation of 7° to 17° correlated with findings of patellar dislocation or patellar prosthesis failure [4]. Our data offer little improvement over coverage values reported over two decades ago, suggesting that contemporary implant designs have not solved this problem [14]. There is also literature to demonstrate that accepting some uncovered posterior medial tibial bone aids in the proper rotational positioning of the tibial component [12]. There is a lack of data to support the concern that decreased tibial coverage is the cause of tibial subsidence and several long-term studies report very low rates of tibial loosening [3, 11, 16]. Nonetheless, we still encounter many failed TKAs because coverage has been maximized at the expense of proper rotation.

We also found that asymmetric components had significantly fewer cases of internal malrotation as well as lesser amounts of malrotation (Table 1). We evaluated only four different designs of tibial trays for this study. Although there are more than four trays on the market, the goal of the study was not to identify a quality about a specific tray, but rather to illuminate the idea that coverage and rotation are closely linked. Whereas maximizing coverage resulted in a high likelihood of malrotation, the asymmetric trays performed

significantly better than the symmetric trays. Coverage is important, but rotation must be taken into account and given priority. To properly rotate the tray with current designs, especially symmetric designs, tibial coverage may need to be decreased. Bonnin et al. [7] noted that correct positioning of the tibial component requires that two criteria be fulfilled simultaneously; first, implant rotation ensuring optimal knee kinematics and second, optimized prosthetic coverage ensuring uniform load transfer. The concern that too little coverage causes an increase in stress of the tibia-implant interface has not been shown to decrease the success of implants, unless coverage was less than 75% [3, 11, 16, 18]. No tray in this study had less than 74% coverage.

This study suggests that when a tibial tray design is chosen for maximal coverage, it has a high probability of being internally rotated. Several solutions exist for this problem; most simply, surgeons can accept some uncovered proximal tibial bone and select the rotational vector at the medial one-sixth of the tibial tubercle. Other options include (1) tibial polyethylene inserts designed with 5° to 10° more of external rotation to use with existing base plates; (2) redesign of the angle of the tibial base plates so that the locking mechanism is externally rotated compared with the shape of the tray; and (3) new tibial designs with a more anatomic shape with the rotational vector directed at the medial one-sixth of the tibial tubercle. Future research and continuing surveillance of clinical practice will show whether placement of the tibial component can be standardized using anatomic landmarks and improved implant designs or whether new approaches are needed to match tibial rotation to the demands of each patient's individual knee anatomy.

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