Total knee arthroplasty: posterior tibial slope influences the size but not the rotational alignment of the tibial component

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Received: 22 October 2019 / Accepted: 21 January 2020 / Published online: 6 February 2020
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Abstract

Purpose The reasons leading to rotational tibial malalignment in total knee arthroplasties (TKAs) remain unclear. A previous cadaver study has shown an increase in internal rotation of the anatomical tibial axis (ATA) after the tibial cut. This study investigates the influence of tibial slope on the ATA and the size of the resected tibial surface.

Methods CT scans of 20 cadaver knees were orientated in a standardized coordinate system and used to determine the position of the centres of rotation of the medial and lateral tibial articular surfaces and, hence, of the ATA, after a virtual resection of 6 mm with 0°, 3.5°, 7° and 10° slope, respectively. Furthermore, at each slope, the radii of the medial and lateral tibial articular surfaces after resection were calculated.

Results Compared to resection of 6 mm with 0° slope, a slope of 3.5° resulted in a mean external rotation of the ATA of 0.9° (SD, 1.5°; \(P = 0.025\)). A slope of 7° resulted in a mean external rotation of the ATA of 1.0° (SD 2.0°; \(P = 0.030\)) and a slope of 10° had no influence on the rotation of the ATA. The radii of the medial and lateral articular surfaces of the cut tibiae were larger than those of the uncut tibia \((P < 0.001)\).

Conclusion Differences in the posterior tibial slope should not contribute to a rotational malalignment when using the ATA to align the prosthetic tibial plateau. Although statistically significant, the change in ATA with increasing slope was negligible.

Keywords Total knee replacement · Total knee arthroplasty · Anatomical tibial axis · Tibial component alignment · Tibial component malrotation

Introduction

Internal rotation error of the tibial component in total knee arthroplasty (TKA) has been linked to polyethylene wear, prosthesis loosening, stiffness and pain, and also negatively influences patellofemoral kinematics [8, 14, 24]. The two most common techniques for determining rotational alignment in TKAs are the measured resection and the gap balancing techniques [5]. In the measured resection technique, anatomical landmarks are used as references for a correct tibial cut and rotational placement of the implant. Although several landmarks have been proposed (either isolated or in combination), to date none of these has been widely accepted. The most frequently used landmarks include the medial edge or the medial third of the tibial tuberosity [7, 11, 28], the posterior cruciate ligament attachment, the posterior...
tibial condylar line [11, 15, 16], the transverse axis of the tibia, the patellar tendon [1, 2, 15, 16], the malleolar axis [2, 7, 15, 16], the sulcus of the intercondylar eminences [7], and the second metatarsal [28]. The rotational alignment of the tibial component on the resected tibial surface is determined by considering the surface landmarks and the contour of the medial and lateral tibial condyles. According to the principle of best fit and coverage of the resected bone surface, the surgeon places the tibial component centred between the anterior and posterior condylar margins on the medial tibial plateau [10]. However, this could be misleading because the position of the centres of the medial and lateral articular surfaces does not remain stationary after the tibial resection is performed. For instance, a cadaver study has reported an anterior shift of the centre of the lateral articular surface at the level of the resection relative to the original joint line [10]. This is in agreement with a further cadaver study showing that maximizing tibial coverage could lead to an internal malrotation [20]. Although the asymmetric designs are less likely to be affected, internal rotation error is probable at both symmetric and asymmetric tibial designs [20]. However, to date, the influence of tibial slope on the internal rotation error possibly introduced by this technique has not been investigated.

Rotation of the tibia surface can be determined by the anatomical tibial axis (ATA) defined as the perpendicular line at the mid-point of the line connecting the medial and lateral condylar centres [6]. Placing the tibial component following the principle of best fit and coverage will result in orientation of the component along the ATA. An anterior shift of the lateral condylar centre would result in an internal rotation of the ATA at the level of the resection relative to the original joint line [10] and may be responsible for an internal rotation malpositioning of the tibial component.

While the physiological posterior tibial slope ranges from 4° to 10° [4, 26], to date, the slope to be targeted intraoperatively is still under discussion. In TKA, a neutral tibial slope (0°) leads to restricted flexion [26], and a greater posterior tibial slope correlates with greater postoperative flexion [4, 17, 19]. Posterior tibial slope is also believed to reduce ligament tension and hence reduce the incidence of component loosening [26]. Moreover, an excessive posterior tibial slope can lead to anterior dislocation of the tibia and alter the biomechanics of the knee [26]. Regarding prosthetic design, slightly greater posterior tibial slopes have been suggested for cruciate retaining prostheses compared to posterior stabilized prostheses [27]. While it is clear that a complete absence of a slope and an excessive slope should be avoided, there is no widely accepted opinion on the optimal slope. Posterior tibial slopes from 0° to 10° or the restoration of the anatomical slope of each individual patient have been suggested [30]. Moreover, although the influence of tibial slope on postoperative flexion and stability of the knee joint has been extensively researched, to date, the influence of tibial slope on the rotational alignment of the tibial component has not been examined.

The primary aim of this study was to investigate the influence of tibial slope on ATA orientation and hence the rotational alignment of the prosthetic tibial plateau. The first hypothesis of this study was that the orientation of the ATA would differ between cuts performed with different slopes. The secondary aim of this study was to investigate the influence of the tibial cut and different slopes on the size of the resected tibial surface and hence of the prosthetic tibial plateau. The second hypothesis was that the resected tibial surface would be larger than that of the native tibial plateau.

Materials and methods

This study was approved by the regional review board (Ethikkommission beider Basel, IRB approval number: EKBB 32/11). Forty knees of 20 cadavers of the anatomy course of our institute were accessed clinically as well as with full leg radiographs and CT scans for possible inclusion. Exclusion criteria were scars around the knee, flexion contracture more than 15° degrees, a mechanical varus or valgus alignment of more than 10°, severe arthritis (Kellgren–Lawrence Grade 3 or 4 [17]) and trochlea dysplasia grade C, or D according to Dejour [9]. Of 40 knees screened, 20 met the inclusion criteria and were included in this study [11 left and 9 right knees; 4 male and 8 female donors; mean (standard deviation); age 85 (10.9) years; body height 1.62 (0.11) m; body mass 63.4 (15.2) kg].

Computer tomography (CT) scans of each cadaver knee were obtained. Imaging and data import were performed with a helical GE Lightspeed 16-row CT scanner (General Electric Healthcare Corporation, Waukesha, WI, USA; 120 kV, slice thickness 0.625 mm, voxel depth 0.5 mm, voxel height 0.283 mm and voxel width 0.283 mm). The Digital Imaging and Communications in Medicine (DICOM, Rosslyn, VA, USA) data were analysed using the visualization software VG Studio Max 2.1.1 (Volume Graphics, Heidelberg, Germany) facilitating high-precision measurements using CT-based coordinate measurement technology [22].

The surface data of each knee specimen were oriented into a standardized coordinate system. The system was based on the reports of Grood et al. [12] and McPherson et al. [21] as used in a previous study [10]. Two-dimensional reconstructions of the data sets in the sagittal, frontal and transverse planes as well as a three-dimensional reconstruction of the entire data volume per knee and axes were selected for monitor display. The transverse flexion axis was determined by measuring movements of the flexion facet centre (FFC) on the posterior femoral condyle. In the sagittal plane, the tibial reference points (TRP) were determined [7]. The TRP

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is the intersection between the three spatial axes at the most distal edge of the posterior tibia. The FFC and TRP span the frontal plane. The coordinate system was established from the frontal plane (primary reference), the axis through the FFC (secondary reference) and the TRP as the origin (tertiary reference). After constructing the coordinate system, the tibia was isolated by defining it as a region of interest to achieve an unobstructed view on the uncut proximal tibial joint surface.

The coronal tibial alignment of the native tibiae was documented by measuring the tibial mechanical angle (TMA) defined as the angle between the tibial mechanical axis and a tangent to the proximal tibial joint surface [13]. Values under 90° indicate a mechanical varus.

Virtual bone resections of 6 mm were performed with 0°, 3.5°, 7° and 10° slope, respectively (Fig. 1). A tibial resection of 6 mm is in accordance with the average required resection for TKA [25], and a virtual cut of 6 mm has already been used successfully in the same standardized system in a previous study [10]. The best-fit circle [6] and the rotation centre of the medial and lateral articular surfaces were defined in each resected surface. The centres of the medial and lateral articular surfaces were obtained by calculating the root mean square of the error for the best-fit circle [6] (Fig. 2). The coordinates in the sagittal (y), frontal (x), and axial (z) planes were calculated for each circle centre. The line connecting the medial and lateral centres and the corresponding ATA were drawn (Fig. 2).

For each knee, the angle between the line connecting the medial and lateral articular surface centres and the X axis and hence the angle between the ATA and the X axis was calculated for each slope. The angle of the cut surfaces with 0° slope was then subtracted from the angle of the cut surface at the other slopes. Positive values indicate an external rotation and negative results an internal rotation of the ATA at each slope compared to the cut surface at 0°. The radii of the medial and lateral articular circle were determined at each slope and compared to those of the 0° slope and to those of the uncut tibia. The mean and standard deviation of these angle differences and of the radii and surfaces were calculated.

The Friedman test was used to compare multiple cuts and the Wilcoxon signed-rank test to compare pairs of cuts. Non-parametric tests were chosen because of the small sample size. The significance level was set a priori to \( P < 0.05 \) for single comparisons and to \( P < 0.01 \) for multiple comparisons. The statistical analysis was performed in SPSS Version 22 (IBM, Armonk, NY, USA).

A formal sample size was not performed. Different conditions were compared within specimen, and the non-parametric Friedman test is a conservative statistical test for detecting differences between conditions. Hence, the methodology was appropriate and justifiable for answering the research question. The method of best-fit circle is an automated method that does not depend on the tester. Therefore, a formal test–retest reliability assessment was not necessary. Angles are computed to 1/100°.

A systematic review by Panni et al. [23] concluded that an internal rotation > 10° represents a significant risk factor for pain and inferior functional outcomes after TKA. The lowest amount of internal rotation reported to correlate with poorer results after TKA is 3° [29]. Therefore, an internal rotation of less than 3° was considered not clinically relevant.
Results

In the native tibiae, the mean TMA was 87.6° (SD 1.5°). For a 6-mm resection, a posterior tibial slope of 3.5° resulted in a mean external rotation of the ATA of 0.9° (SD 1.5°; \( P = 0.025 \)) compared to a tibial slope of 0°. A slope of 7° resulted in a mean external rotation of the ATA of 1.0° (SD 2.0°; \( P = 0.030 \)) and a slope of 10° did not lead to a rotation of the ATA (mean internal rotation of 0.1°; SD 2.3°; \( P = \text{ns} \)) compared to a tibial slope of 0°.

In all resected surfaces and in the native tibiae, the medial articular surface was larger than the lateral (\( P < 0.001 \)). Furthermore, the radii of the medial and lateral articular surfaces of the cut tibiae were larger than those of the native tibiae (\( P < 0.001 \)). The radius of the medial circle was increased at all cuts (+28.1% at 0° slope; +26.6% at 3.5° slope; +25.1% at 7° slope; and +24.3% at 10° slope) compared to the native tibia. Similarly, the radius of the lateral articular surface increased by 27.8% at 0° slope, 27.8% at 3.5° slope, 26.5% at 7° slope and 22.1% at 10° slope compared to the native tibia (Fig. 3).

Moreover, comparison between the different slopes revealed that the radius of the medial circle decreased significantly (\( P < 0.05 \)) with increasing slope. Compared to the 0° tibial slope, the medial radius for the 3.5°, 7° and 10° posterior slopes was reduced by 1.2%, 2.3% and 2.9%, respectively. The radius of the lateral circle decreased significantly (\( P < 0.05 \)) only when increasing the slope from 3.5° to 7° and from 7° to 10°. The surface of the 3.5° slope was comparable and those of the 7° and 10° slope were 1.0% and 4.4% reduced, respectively, compared to the 0° tibial slope (Fig. 4).

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**Fig. 3** The radii of the medial and lateral articular surfaces in the native joint as well as in the cut tibiae for different slopes. In all cut tibiae, the radii were larger than the ones of the native tibiae (\( P < 0.001 \)), and the medial radius was larger as the lateral (\( P < 0.001 \))

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**Fig. 4** The radii of the medial and lateral articular surfaces relative to those of the native joint (\( y = 0 \) mm). The radius of the medial circle decreased significantly (\( P < 0.05 \)) with increasing slope, while the radius of the lateral circle decreased significantly (\( P < 0.05 \)) only when increasing the slope from 3.5° to 7° and from 7° to 10°.
Discussion

The most important finding of this study was the absence of a clinically notable influence of posterior tibial slope on the ATA and the presence of a clear influence on the size of the resected tibial surface when comparing the cut surfaces to the native tibial surfaces.

Internal rotation has been shown to be the most common rotational malalignment in the revision of TKAs [3, 18]. Using the anterior and posterior contours of the resected tibial condyles as reference points and following the best fit and coverage principle, the surgeon aligns the tibial component to the ATA. A previous cadaver study has already identified an internal rotation of the ATA on the cut tibia [10] compared to the native tibia as a possible explanation of an internal tibial rotation malalignment. Correspondingly, Incavo et al. [16] proposed a slight external rotation of the tibial component to improve patella kinematics and reduce complications. A further internal rotation of the ATA with increasing slope would imply that the surgeon should consider placing the tibial component even more externally rotated relative to the ATA to avoid malalignment. However, to date the influence of a greater posterior tibial slope on the rotation of the ATA had not been investigated.

In the present study, a notable influence of increasing posterior tibial slope on the rotation of the ATA was observed. Although statistically significant, the amount of the internal rotation observed compared to the native joint was well below the defined level of clinical relevance (3°). Hence, the results suggest that the observed differences should not have any consequence in the considerations of the surgeon when implanting the prosthetic tibial plateau. These results are clinically relevant for surgeons taking the best fit and coverage principle for placing tibial components in TKA because they rule out the possibility that a greater posterior tibial slope may lead to malrotation. While this finding is particularly relevant when using symmetric tibial designs, because these designs have been shown to be more affected from tibial rotational error when maximizing coverage [20], it is also important for asymmetric designs of tibial components in TKA.

This study was conducted on isolated tibiae. Virtual cuts of the tibias alone were performed. Therefore, the hip knee angle (angle between the mechanical axis of the femur and the tibia) [13] of the cadavers should not have an influence on the results. The TMA values showed a great homogeneity among the cadavers. Therefore, although the TMA has been reported to have a great variability [13], it should not influence the results of this study.

The size of the medial and lateral articular surfaces in the cut tibiae was larger than those of the native tibiae. If the size of the prosthetic tibia plateau is chosen according to the best coverage principal, the resulting tibiofemoral contact areas of the cut tibiae at all slopes are larger than that of the native tibia. Although based on this finding, using smaller tibial components may be indicated, maximizing the tibial coverage by choosing the largest tibial plateau fitting the cut tibial surface is believed to be crucial for optimal TKA outcome [9]. A smaller tibial component would mainly have contact with the cancellous bone of the cut surface associated with a high risk of subsidence. Hence, the results of this study do not particularly change the way of decision-making when choosing the size of the tibial plateau. Yet, in cases where no implant size perfectly fits the cut tibia, the surgeon must choose between an underhanging component risking a component subsidence and other associated complications or an overhanging component risking soft tissue irritation and worse postoperative outcome [9]. Hence, understanding the differences in size of the tibial cut surface and the native surface is important.

Strengths and limitations

The strength of this study is the systematic and standardized investigation of different posterior tibial slopes and the effects on the ATA and the size of the resected tibial surface. A formal sample size calculation was not performed. For ethical reasons and due to lack of further cadaver availability, the sample size was limited to 20 cadaver knees and all knees were non-arthritic. However, the small variability in results between specimens suggests that these results can be generalized. Virtual 6-mm resections of the tibiae were performed. Results may vary slightly when resections are performed physically and in different sizes. Nonetheless, the results provide important information for surgeons performing TKAs.

Conclusion

Differences in tibial slope—and hence also slight slope inaccuracies in performing tibia cuts during surgery—do not notably influence the rotation of the tibial component in TKAs. These results are relevant when placing the tibial component following the principle of best fit and coverage. Furthermore, the results of this study show that the size of the cut tibial surface is larger than the native articular surface. However, the principle of maximal coverage remains a major consideration when choosing the size of the tibial component in TKA.
Author contributions PI participated in the data analysis and wrote the manuscript; VK conducted the experiments and revised the manuscript. (*PI and VK contributed equally to this work). AM analysed and interpreted the data and was a major contributor to the writing of the manuscript. MM was responsible for the conduct of the experiments and reviewed the manuscript. AMN participated in the conduct of the experiments and the data analysis; he also reviewed and edited the manuscript. All authors read and approved the final manuscript. All authors had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Funding No external funding was used for this study.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval This study was approved by the regional review board (Ethikkommission beider Basel, IRB Approval number: EKBB 32/11). All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee.

Informed consent For cadaver studies informed consent is not required.

References

1. Akagi M, Mori S, Nishimura S, Nishimura A, Asano T, Hamanshi C (2005) Variability of extraarticular tibial rotation references for total knee arthroplasty. Clin Orthop Relat Res. https://doi.org/10.1097/01.blo.0000160027.52481.32172-176
2. Akagi M, Oh M, Nonaka T, Tsujimoto H, Asano T, Hamanshi C (2004) An anteroposterior axis of the tibia for total knee arthroplasty. Clin Orthop Relat Res. https://doi.org/10.1097/00003086-200403000-00030213-219
3. Bedard M, Vince KG, Redfern J, Collen SR (2011) Internal rotation of the tibial component is frequent in stiff total knee arthroplasty. Clin Orthop Relat Res 469:2346–2355
4. Blemmens J, Robijns F, Duerinckx J, Banks S, Vandenneucker H (2005) The influence of tibial slope on maximal flexion after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 13:193–196
5. Cheriyan JJ, Kapadia BH, Banerjee S, Jauregui JJ, Issa K, Mont MA (2014) Mechanical, anatomical, and kinematic axis in TKA: concepts and practical applications. Curr Rev Musculoskelet Med 7:89–95
6. Cobb JP, Dixon H, Dandachi W, Inanpour F (2008) The anatomical tibial axis: reliable rotational orientation in knee replacement. J Bone Joint Surg Br 90:1032–1038
7. Dalury DF (2001) Observations of the proximal tibia in total knee arthroplasty. Clin Orthop Relat Res. https://doi.org/10.1097/00003086-200108000-00021150-155
8. Dalury DF, Pomeroy DL, Gorab RS, Adams MJ (2013) Why are total knee arthroplasties being revised? J Arthroplasty 28:120–121
9. Erkocak OF, Kucukdurmaz F, Sayar S, Erdil ME, Ceylan HH, Tuncay I (2016) Anthropometric measurements of tibial plateau and correlation with the current tibial implants. Knee Surg Sports Traumatol Arthrosc 24:2990–2997
10. Forster-Horvath C, Kremo V, Muller-Gerbl M, Nowakowski AM (2015) Using the anatomical tibial axis for total knee arthroplasty alignment may lead to an internal rotation error. Int Orthop 39:2347–2353
11. Graw BP, Harris AH, Tripuraneri KR, Giori NJ (2010) Rotational references for total knee arthroplasty tibial components change with level of resection. Clin Orthop Relat Res 468:2734–2738
12. Grood ES, Suntay WJ (1983) A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. J Biomech Eng 105:136–144
13. Hess S, Moser LB, Amsler F, Behrend H, Hirschmann MT (2019) Highly variable coronal tibial and femoral alignment in osteoarthritic knees: a systematic review. Knee Surg Sports Traumatol Arthrosc 27:1368–1377
14. Hutter EE, Granger JF, Beal MD, Sistom RA (2013) Is there a gold standard for TKA tibial component rotational alignment? Clin Orthop Relat Res 471:1646–1653
15. Ikeuchi M, Yamanaka N, Okanoue Y, Ueta E, Tani T (2007) Determining the rotational alignment of the tibial component at total knee replacement: a comparison of two techniques. J Bone Jt Surg Br 89:45–49
16. Incavo SJ, Coughlin KM, Pappas C, Beynnon BD (2003) Anatomic rotational relationships of the proximal tibia, distal femur, and patella: implications for rotational alignment in total knee arthroplasty. J Arthroplasty 18:643–648
17. Kim JH (2013) Effect of posterior femoral condylar offset and posterior tibial slope on maximal flexion angle of the knee in posterior cruciate ligament sacrificing total knee arthroplasty. Knee Surg Relat Res 25:54–59
18. Lakstein D, Zarrabian M, Kosashvili Y, Safir O, Gross AE, Backstein D (2010) Revision total knee arthroplasty for component malrotation is highly beneficial: a case control study. J Arthroplasty 25:1047–1052
19. Malviya A, Lingard EA, Weir DJ, Deegan DJ (2009) Predicting range of movement after knee replacement: the importance of posterior condylar offset and tibial slope. Knee Surg Sports Traumatol Arthrosc 17:491–498
20. Martin S, Saurez A, Ismaily S, Ashfaq K, Noble P, Incavo SJ (2014) Maximizing tibial coverage is detrimental to proper rotational alignment. Clin Orthop Relat Res 472:121–125
21. McPherson A, Karrholm J, Piniskerova V, Sosna A, Martelli S (2005) Imaging knee position using MRI, RSA/CT and 3D digitisation. J Biomech 38:263–268
22. Nowakowski AM, Muller-Gerbl M, Valderrabano V (2012) Assessment of knee implant alignment using coordinate measurement on three-dimensional computed tomography reconstructions. Surg Innov 19:375–384
23. Panni AS, Ascione F, Rossini M, Braile A, Corona K, Vasso M et al (2018) Tibial internal rotation negatively affects clinical outcomes in total knee arthroplasty: a systematic review. Knee Surg Sports Traumatol Arthrosc 26:1636–1644
24. Petersen W, Rembitzki IV, Bruggemann GP, Ellermann A, Best R, Koppenburg AG et al (2014) Anterior knee pain after total knee arthroplasty: a comparison of two techniques. J Bone Joint Surg Am 96:1021–1029
25. Schnurr C, Csecsei G, Nessler J, Eysel P, Konig DP (2011) How much tibial resection is required in total knee arthroplasty? Int Orthop 35:989–994
26. Seo SS, Kim CW, Kim JH, Min YK (2013) Clinical results associated with changes of posterior tibial slope in total knee arthroplasty. Knee Surg Relat Res 25:25–29
27. Sierra RJ, Berry DJ (2008) Surgical technique differences between posterior-substituting and cruciate-retaining total knee arthroplasty. J Arthroplast 23:20–23
28. Sistom RA, Goodman SB, Patel JJ, Delp SL, Giori NJ (2006) The high variability of tibial rotational alignment in total knee arthroplasty. Clin Orthop Relat Res 452:65–69
29. Thielemann FW, Konstantinids L, Herget GW, Knothe D, Helwig P, Sudkamp NP et al (2016) Effect of rotational component alignment on clinical outcome 5 to 7 years after TKA with the columbus knee system. Orthopedics 39:S50–55

30. Wittenberg S, Sentuerk U, Renner L, Weynandt C, Perka CF, Gwinner C (2019) Importance of the tibial slope in knee arthroplasty. Der Orthop. https://doi.org/10.1007/s00132-019-03777-8

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