Total Knee Arthroplasty: Influence of Increasing the Posterior Tibial Slope on the Rotational Alignment and the Size of the Tibial Component

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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, 25]. 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, 12, 29], the posterior cruciate ligament attachment, the posterior tibial condylar line [12, 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 [29]. 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 centered between the anterior and posterior condylar margins on the medial tibial plateau [11]. However, this could be misleading because the position of the centers of the medial and lateral articular surfaces do not remain stationary after the tibia resection is performed. For instance, a cadaver study has reported an anterior shift of the center of the lateral articular surface at the level of the resection relative to the original joint line [11]. This is in agreement with a further cadaver study showing that maximizing tibial coverage could lead to an internal malrotation [21]. Although the asymmetric designs are less likely to be affected, internal rotation error is probable at both symmetric and asymmetric tibial designs [21]. 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 centers [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 center would result in an internal rotation of the ATA at the level of the resection relative to the original ATA [11] 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, 27], to date the slope to be targeted intraoperatively is still under discussion. In TKA, a neutral tibial slope (0°) leads to restricted flexion [27], and a greater posterior tibial slope correlates with greater postoperative flexion [4, 17, 20]. Posterior tibial slope is also believed to reduce ligament tension and hence reduce the incidence of component loosening [27]. Moreover, an excessive posterior tibial slope can lead to anterior dislocation of the tibia and alter the biomechanics of the knee [27]. Regarding prosthetic design, slightly greater posterior tibial slopes have been suggested for cruciate retaining prostheses compared to posterior stabilized prostheses [28]. 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[31]. 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 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 … degrees , a mechanical varus or valgus alignment of more than 10°, severe arthritis (Kellgren-Lawrence Grade 3 or 4 [18]) and trochlea dysplasia grade B, 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 (15.2) kg).

Computer tomography (CT) scans of each cadaver knee were obtained. Imaging and data import was 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 analyzed using the visualization software VG Studio Max 2.1.1 (Volume Graphics, Heidelberg, Germany) facilitating high precision measurements using CT-based coordinate measurement technology [23].

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. [13] and McPherson et al. [22] as used in a previous study [11]. Two-dimensional reconstructions of the data sets in the sagittal, frontal and transverse planes as well as a 3-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 center (FFC) on the posterior femoral condyle. In the sagittal plane, the tibial reference points (TRP) were determined [7]. The TRP 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 region of interest to achieve an unobstructed view on the uncut proximal tibial joint surface.

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 [26], and a virtual cut of 6 mm has already been used successfully in the same standardized system in a previous study [11]. The best-fit circle [6] and the rotation center of the medial and lateral articular surfaces were defined in each resected surface. The centers 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 center. The line connecting the medial and lateral center and the corresponding ATA were drawn (Fig 2).

For each knee, the angle between the line connecting the medial and lateral articular surface centers and the X-axis and hence the angle between the ATA and the X-axis were 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 Friedmann 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, Amonk, NY, USA).

A systematic review by Panni et al. [24] 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° [30]. Therefore, an internal rotation of less than 3° was considered not clinically relevant.

Results

For a 6mm 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=.n.s) 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).

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 revision of TKAs [3, 19]. 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 [11] 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, no 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 were 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 ATA as rotational reference 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 [21], it is also important for asymmetric designs of tibial components in TKA.

The size of the medial and lateral articular surfaces in the cut tibiae were 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 [10]. A smaller tibial component would mainly have contact with the cancellous bone of the cut surface associated with a high risk of subsiding. 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 [10]. 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. Due to ethical reasons, the experiments were limited to 20 cadaver knees and all knees were non-arthritic. However, the small variability in results between specimen suggests that these results can be generalized. Virtual 6mm 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 principal of maximal coverage remains a major consideration when choosing the size of the tibial component in TKA.

Figure captions

Fig 1 A virtual bone resection of 6 mm was performed with a slope of 0° (blue), 3.5° (yellow), 7° (red) and 10 ° (green).

Fig 2 The best-fit circle [6] as well as the rotation center of the medial and lateral articular surfaces defined in each of the resected surfaces (here shown: a cut with 0° slope). The anatomical tibial axis (ATA) is defined as the perpendicular at the mid-point of the line joining the medial and the lateral condylar centers (red arrow). Placing the tibial component following the principle of best fit and coverage will result in orientation of the component along the ATA. A rotation of the ATA at different slopes could result in a rotational malalignment

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 ($P<0.001$).

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°-10°.

Conflict of Interest

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

Authors Contribution

PI participated in the data analysis wrote the manuscript, VK conducted the experiments and revised the manuscript. (* PI and VK contributed equally to this work). AM analyzed and interpreted the data and was a major contributor in the writing of the manuscript. MM is was responsible for the conduction of the experiments and reviewed the manuscript. AMN participated in the conduction 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.

List of Abbreviations

ATA Anatomical tibial axis
TKA Total knee arthroplasty
FFC Flexion facet centre
TRP Tibial reference points

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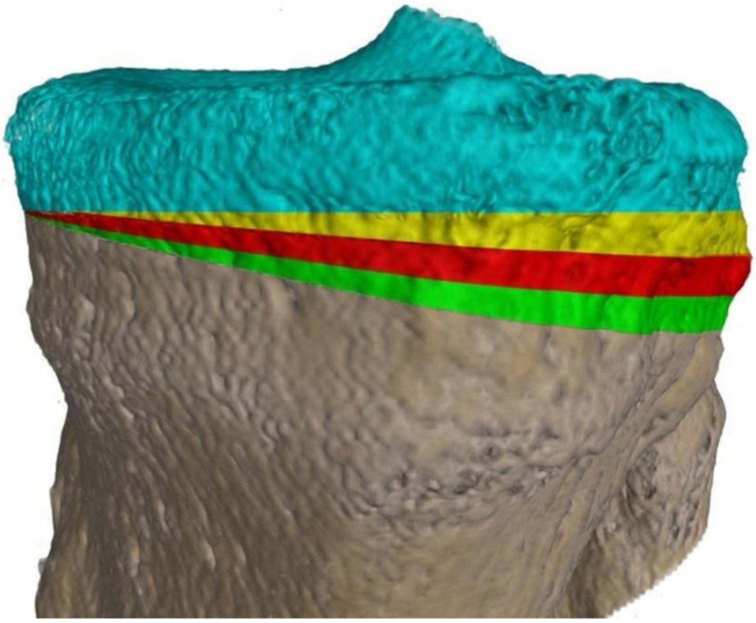
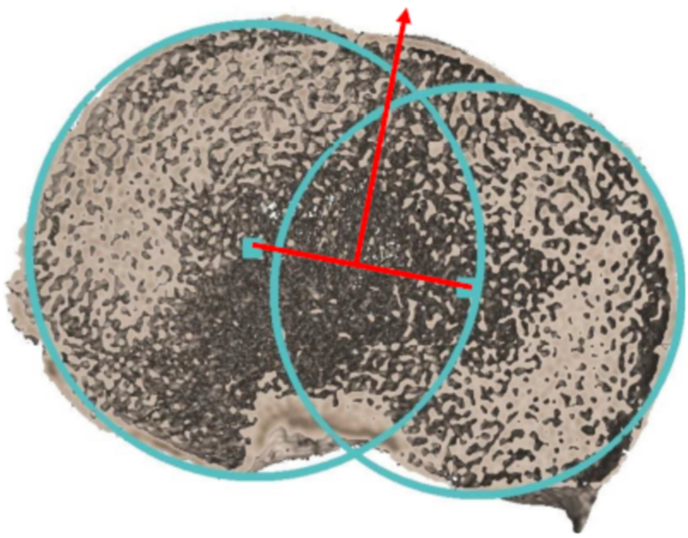
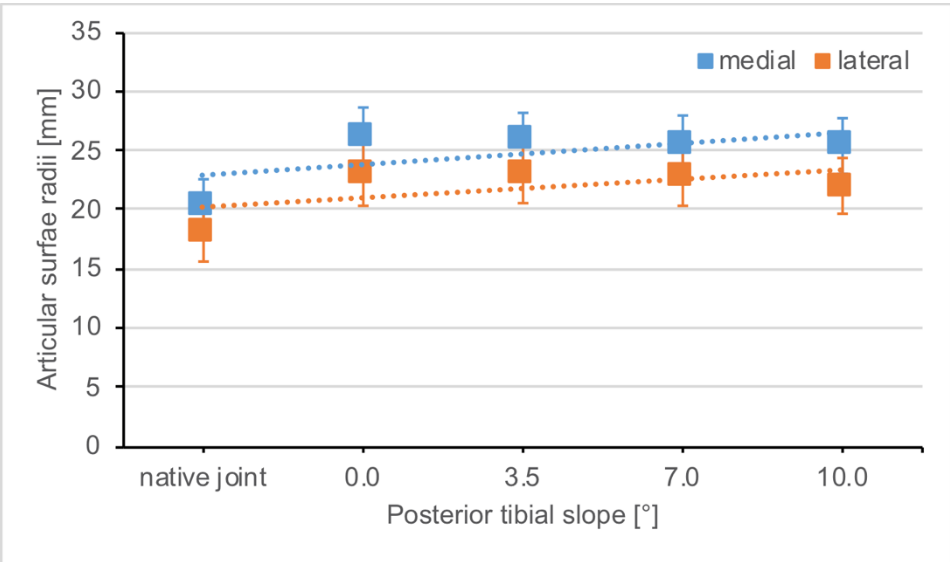
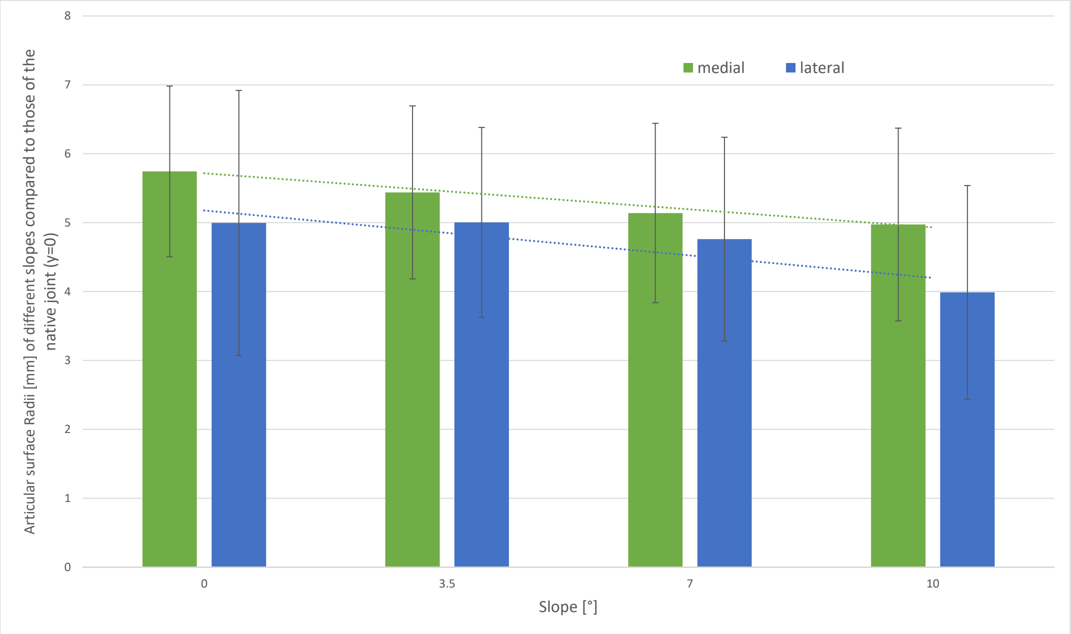






medial
lateral
Articular surfae radii [mm]
35
30
25
20
15
10
5
0
native joint
0.0
3.5
7.0
10.0
Posterior tibial slope [°]



medial
lateral
Articular surface Radii [mm] of different slopes compared to those of the native joint (y=0)
8
7
6
5
4
3
2
1
0
0
3.5
7
10
Slope [°]

353