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Extreme Variability in Posterior Slope of The Proximal Tibia: Measurements on 2,395 CT Scans of Patients Undergoing UKA?

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Abstract

Data regarding the posterior slope of the tibia (PTS) is limited and sometimes conflicting. The purpose of this study was to determine the native posterior tibial slope in patients undergoing a medial or lateral UKA. A retrospective review was performed on 2,395 CT scans in patients indicated for UKA, and the PTS of the osteoarthritic compartment was measured relative to a plane set perpendicular to the sagittal, tibial mechanical axis. The mean pre-operative PTS in patients undergoing medial UKA was 6.8° ± 3.3°, with 34.3% between 4° to 7°. The mean pre-operative PTS in patients undergoing lateral UKA was 8.0° ± 3.3°, with 27.5% between 4° to 7°. If attempting to recreate a patient's pre-operative tibial slope, a routine target of 5° to 7° will produce a posterior slope less than the patient's native anatomy in 47% of patients undergoing UKA. This is the first, large CT-based review of posterior slope variation of the proximal tibia in patients undergoing UKA.

Keywords

unicondylar; knee; arthroplasty; posterior slope

Introduction

The degree of posterior tibial slope (PTS) greatly influences the kinematics of the knee and is known to be an important factor in sagittal plane stability and tibial translation with weight bearing (1-3). PTS effects knee stability, the maximal flexion achieved, the resting position of the joint, and the tension placed on the crucial ligaments of the knee (2-8). Additionally, in the setting of knee arthroplasty and high tibial osteotomy, the amount of PTS effects balance of the flexion and extension gaps, and cartilage and implant pressures (3, 4, 8, 9).

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Over the past decade, the number of unicompartmental knee arthroplasties (UKA) performed has increased by 30%, as numerous studies have demonstrated shorter hospital stays, decreased perioperative morbidity, faster functional recovery, increased range of motion (ROM), and improved knee kinematics versus total knee arthroplasty (TKA) (10-12). However, UKA is a more technically challenging procedure than TKA, as retention of the anterior and posterior cruciate ligaments requires more accurate re-creation of the patient's preoperative, anatomic PTS. When performing a UKA the posterior tibial slope is commonly altered based on implant design and surgical technique, with many surgeons routinely targeting a PTS of 5°-7°. Proper understanding of a patient's native preoperative slope may improve the targets for proper reconstruction during UKA.

Historically, tibial slope has been measured on plain radiographs, but the accuracy of these measurements is questionable since the medial and lateral tibial plateaus are superimposed on a lateral projection of the knee (1-3, 13, 14). Recently, magnetic resonance imaging (MRI) has been used as a means to determine the medial and lateral posterior slope (1, 3, 13, 15), however the accuracy of these studies are limited as the whole length of the tibia, and thus its true mechanical axis was not available.

Current data on the PTS of the normal knee demonstrates a wide range of values, with a reported range of −3° to 10° for the medial tibial slope and 0° to14° for the lateral tibial slope (13). However, whether significant differences exist between the PTS of the medial and lateral tibial plateaus remains controversial. Hashemi et al., in a MRI study of 55 knees found that lateral compartments had steeper slopes than medial compartments (13). However, Haddad et al., in a MRI study of 143 knees found no difference between the PTS of the medial and lateral compartments (1).

These conflicting conclusions and the possibility that there is a significant difference between the PTS of the medial and lateral tibial plateaus warrant further investigation. In addition, the aforementioned assessments of PTS have been performed on healthy controls, and thus preoperative measurements on diseased tibia have yet to be reported. To date, no large-scale review of computed tomography (CT) scans of both diseased and healthy knees have been performed to determine the PTS of the medial and lateral tibial plateaus. The purpose of this study was to accurately determine the preoperative posterior tibial slope of a large population of patients undergoing medial or lateral UKA.

Materials and Methods

The institutional review board approved this study protocol prior to its initiation. A retrospective review was performed on 2,395 CT scans that were acquired during the design phase for a patient-specific UKA implant (ConforMIS iUni®, Bedford, MA). The participant cohort included 2,031 knees undergoing medial UKA and 364 knees undergoing lateral UKA. All patients had a primary preoperative diagnosis of isolated, unicompartmental osteoarthritis. Patients with a diagnosis of avascular necrosis and post-traumatic arthritis were not included. CT scans were obtained prior to surgery and included the hip center, ankle center, and knee joint. Following the acquisition of the CT scan, a three-dimensional

(3-D) model was generated for the knee joint (Figure 1). Measurements of the posterior slope of the medial or lateral compartments were performed using the 3-D model.

Using the ankle center, the mechanical axis (MA) of the tibia was first established in both the coronal and sagittal planes (Figure 2). A resection plane was then set at 90° to the mechanical axis of the tibia. Definition of the perpendicular plane was performed while standardizing the rotation of the tibia along the longitudinal axis of the leg, by ensuring that the fibular head was located at the posterior aspect of the tibia (2). The participant's slope was defined as the patient's natural anterior/posterior (A/P) slope, measured as a line tangent to the most prominent aspects of the anterior and posterior cortices of the involved compartment. The angle between the patient's natural slope and the perpendicular plane was measured and defined as the patient's medial or lateral slope angle (Figure 3). For convention, a positive value corresponded with a posterior tibial slope, while a negative value corresponded with an anterior tibial slope. For all patients in this cohort, the posterior tibial slope of the affected, osteoarthritic compartment was measured. In a subset of 116 UKA patients, the PTS of both the affected and non-affected tibial compartments were measured. The goal of this subset was to compare the mean PTS of the medial and lateral compartments when they are “diseased” versus “healthy.”

Statistical Analysis

All data was collected and analyzed using Microsoft Excel software (Microsoft Corporation, Redmond, WA, USA). Measurements of the PTS for the medial and lateral compartments were reported using the mean, standard deviation, and range. Statistical comparisons for the PTS between the medial and lateral compartments, and between the affected and nonaffected compartments were performed using an unpaired, Student's two-tailed t-test with a statistical significance set at a p-value of <0.05.

Results

In 2,031 knees undergoing medial UKA the mean preoperative posterior slope was 6.8° ± 3.3° and ranged from −9.6° to 16.8°. The largest number of knees (696, 34.3%) had a preoperative posterior slope between 4° and 7°. 430 knees (21.2%) had a preoperative posterior slope between 0° and 4°, 545 knees (26.8%) were between 7° and 10°, and 360 knees (17.7%) had a preoperative posterior slope of greater than 10°. Thirteen (0.6%) knees had an anterior tibial slope. Overall, 44.5% of patients undergoing a medial UKA possessed a preoperative posterior slope of the medial compartment of >7°.

In 364 knees undergoing lateral UKA the mean preoperative posterior slope was 8.0° (SD 3.3) and ranged from −5.6° to 16.9°. The largest number of knees (118, 32.4%) had a preoperative posterior slope between 7° and 10°. Forty-three knees (11.8%) had preoperative posterior slopes between 0° and 4°, 100 knees (27.5%) were between 4° and 7°, and 103 knees (28.3%) had a pre-operative posterior slope of greater than 10°. Only one knee (0.3%) had an anterior tibial slope. Overall, 60.7% of patients undergoing a lateral UKA possessed a preoperative posterior slope of the lateral compartment of >7°. The mean preoperative PTS of the lateral compartment was significantly greater than that of the medial compartment ($p<0.001$).

In the subset of 116 patients in which the PTS was recorded for both the affected and non-affected compartments, 106 underwent a medial UKA and 10 underwent a lateral UKA. In patients where the medial compartment was the affected compartment (n=106), the mean medial PTS was 6.7° ± 3.0° (range −2.5° to 14.0°) versus 9.5° ± 4.3° (range 4.7° to 15.8°) when the medial compartment was unaffected (n=10; patients undergoing lateral UKA). This difference reached statistical significance (p=0.01) and suggests flattening of the PTS or increased anterior wear with medial compartment disease. In patients where the lateral compartment was the affected compartment (n=10), the mean lateral PTS was 7.9° ± 3.7° (range 1.8° to 15.8°) versus 6.8° ± 3.2° (range −0.9° to 13.3°) when the lateral compartment was unaffected (n=106; patients undergoing medial UKA). This suggests an increase in PTS and posterior wear with lateral compartment disease, although this difference did not reach statistical significance (p=0.3).

The PTS distribution of the affected tibial compartment data in both the medial and lateral UKA cohort of this subset was comparable to that seen in the entire cohort of 2031 medial and 364 lateral UKAs. For the unaffected lateral compartment (n=106), there were an equal number of subjects with a pre-operative slope between 4°-7° and between 7°-10°, which represented the largest number of knees (34 each group, 32.1%). 20 knees (18.9%) had a preoperative posterior slope between 0° and 4°, 17 knees (16.0%) were >10°, and 1 knee (0.9%) had an anterior tibial slope (Table 1). For the unaffected medial compartment (n=10), none of the subjects had a tibial slope less than 4°, while the corresponding percentages for a PTS between 4°-7°, 7°-10° and >10° were 40%, 10% and 50% respectively (Table 2).

Discussion

Posterior tibial slope plays a key role in knee kinematics and biomechanics, as greater PTS increases the tibial shear force and anterior translation of the knee, affects knee flexion, and has been shown to the influence the outcomes of UKA (2, 8, 16, 17). In a review of 99 UKAs with a mean follow-up of 16 years, Hernigou et al. noted a significant linear relationship between anterior tibial translation and PTS, with increased PTS associated with an increased rate of ACL rupture and implant loosening (2). Prior studies have assessed the native preoperative tibial slope of patients using plain radiographs or MRI, however these studies have been limited by the questionable accuracy of plain radiographic measurements, lack of PTS assessment relative to the mechanical axis of the tibia, and inclusion of only healthy controls(1-3, 13). Despite the known importance of PTS on knee kinematics and UKA outcomes, little data exists assessing the preoperative PTS in a large cohort of patients with osteoarthritis undergoing a medial or lateral UKA. Furthermore, no large-scale review of CT scans for measurement of the PTS using the true, tibial mechanical axis has been performed. Therefore, the purpose of this study was to accurately determine the preoperative PTS of a large population of patients undergoing medial or lateral UKA using computed tomography. This study demonstrates marked variability of the PTS with 44.5% of medial plateaus and 60.7% of lateral plateaus having greater than 7° of posterior slope preoperatively, with a range of 26.4° and 22.5° in the medial and lateral compartments, respectively.

This study had several limitations that are important to recognize when interpreting our data. First, measurement of the PTS of both the medial and lateral compartments were not performed in all knees, which would have provided further data comparing the affected and nonaffected compartments of a large cohort of patients. However, as CT scans were being performed during the design phase of a specific UKA implant, only the affected compartment was routinely being assessed. Second, demographic data regarding patient gender, age, height, weight, body mass index, and ethnicity were not available for review, and unfortunately correlations between these factors and PTS were not delineated. Third, intra- and inter-observer measurements for our measurement technique were not performed. However, this technique and the use of CT scans to measure posterior slope has previously been described by Utzschneider et al., who demonstrated high intra- and inter-observer correlations using this method (3). Lastly, while the importance of understanding a patient's native, preoperative PTS could influence targets for reconstruction during UKA, CT scans are not routinely used as a preoperative assessment tool, thus limiting the applicability of our results. Furthermore, our study is solely a report on the variability of tibial anatomy in patients undergoing UKA, and thus no firm conclusions can be drawn regarding surgical technique or the clinical outcomes of altering a patient's PTS.

Haddad et al. performed a MRI assessment of 143 healthy knees, and found no significant difference between the medial (5.7° ± 3.8°) and lateral compartments (5.6° ± 4.2°) for posterior tibial slope. However, in contrast, Hashemi et al. performed a MRI assessment of PTS in 55 healthy patients, and noted a significant difference between the medial (5.0 ± 3.2°; range −3° to 10°) and lateral compartments (6.4° ± 3.0°; range 0° to 14°) for tibial slope (13). Our findings were consistent with these results as we found the lateral compartment (8.0° ± 3.3°; range −5.6° to 16.9°) to have a significantly greater PTS than the medial compartment (6.8° ± 3.3°; range −9.6° to 16.8°), however patients in our cohort demonstrated a much greater range of values versus patients in the aforementioned study. The differences in our study compared to the prior MRI reviews can be attributed to several factors, including our inclusion of osteoarthritic patients indicated for unicompartmental knee arthroplasty (versus healthy knees), and utilization of CT scans with PTS measurements performed relative to the tibial mechanical axis (versus the anatomic axis).

Therefore, while uncertainty remains regarding the presence of significant differences in PTS between the medial and lateral compartments in healthy knees, the results of our study provide important insight into the anatomy of osteoarthritic knees undergoing UKA. Furthermore, the results of our subset of patients where the PTS was measured in both the affected and nonaffected compartments suggest that medial compartment disease is commonly associated with increased anterior wear and flattening of the PTS, while lateral compartment disease is commonly associated with posterior wear and an increase in PTS. Weidow et al. assessed the morphologic changes of cartilage wear in 42 patients undergoing total knee arthroplasty, and noted an increased amount of anterior tibial wear in patients with predominantly medial compartment OA, and posterior tibial wear in patients with predominantly lateral compartment OA (18). Thus, our study demonstrated similar findings.

This study is the first to review PTS and its variability using CT scans relative to the tibial mechanical axis in a large cohort of patients presenting with unicompartmental disease. Our results demonstrate that routinely targeting a 5°-7° posterior slope in UKA will create a posterior slope less than a patient's native anatomy in 47% of patients. This brings into question what the appropriate “target” for PTS should be for patients undergoing UKA, and whether this slope should be altered for each patient based on their preoperative anatomy. While a routine target of 5°-7° PTS may fail to recreate a patient's native anatomy in a large percentage of patients, Hernigou et al. noted that placing >7° of PTS may have negative consequences in UKA (2). However, one limitation of that study is that each patient's preoperative PTS was unknown, and thus the change in PTS after undergoing UKA was unknown. For example, failures attributed to a PTS of >7° could possibly have been in patients with very minimal PTS preoperatively, which was significantly increased after undergoing UKA, causing abnormal stresses of the anterior cruciate ligament in that particular patient. Thus, the absolute PTS value postoperatively may not be as significant as the actual change in PTS. This study demonstrates a wide variability of PTS in patients undergoing UKA, and future directions must focus on the impact of altering a patient's native PTS on the clinical outcomes following UKA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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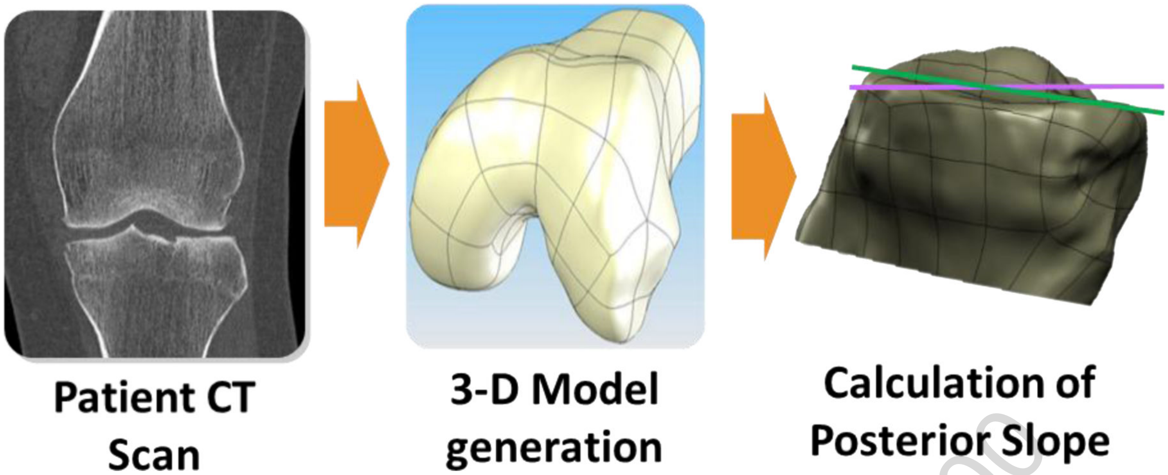

Figure 1.
Overview of the process of developing a 3-D model and calculation of the posterior slope based on a preoperative CT scan.

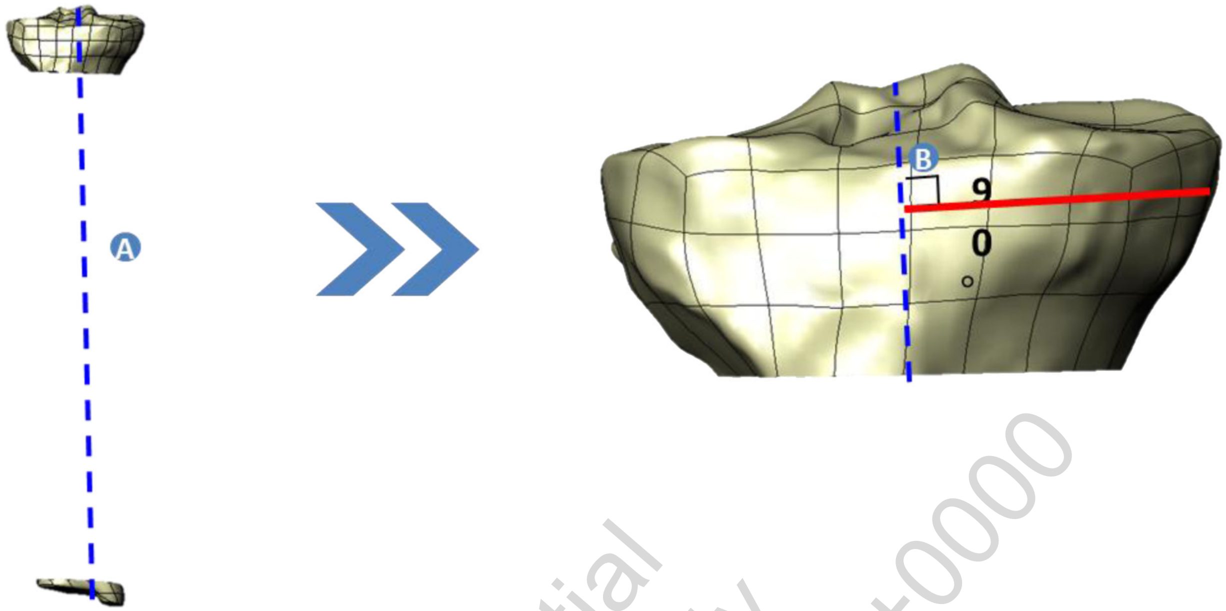

Figure 2.
Use of the ankle center to establish the tibial mechanical axis and creation of a plane perpendicular to the axis.

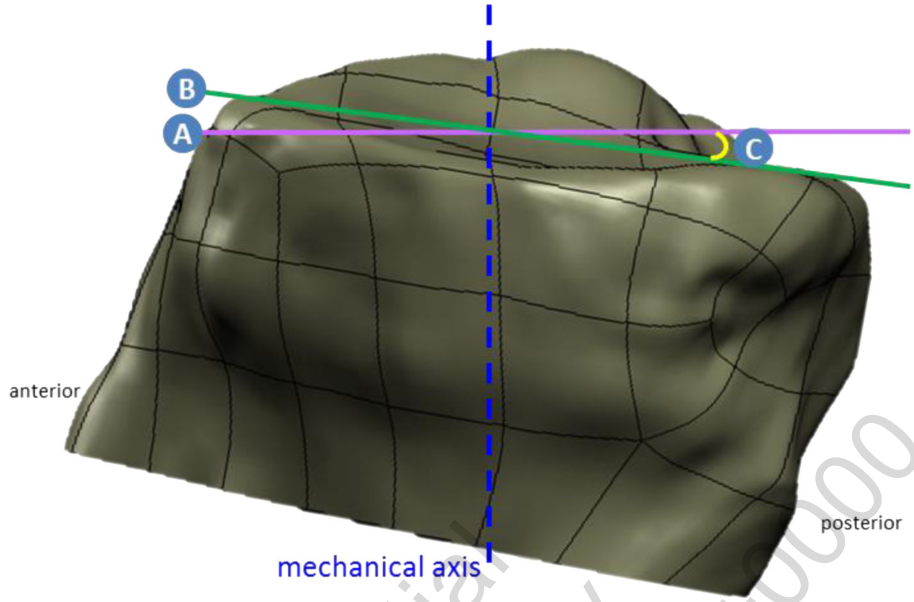

Figure 3.
Sagittal view of a 3D model of knee. The angle between the patient's natural slope (green line) and the perpendicular plane (purple line) defined the posterior tibial slope of the compartment.

Table 1

Summary of the posterior tibial slope of the lateral compartment in subset of 116 patients.

Range	Lateral Compartment Affected (n=10) N (%)	Lateral Compartment Unaffected (n=106) N(%)
0-4°	1 (10.0%)	20 (18.9%)
4-7°	3 (30.0%)	34 (32.1%)
7-10°	4 (40.0%)	34 (32.1%)
> 10°	2 (20.0%)	17 (16.0%)
Anterior Slope	0 (0%)	1 (0.9%)

Table 2

Summary of the posterior tibial slope of the medial compartment in subset of 116 patients.

Range	Medial Compartment Affected (n=106) N (%)	Medial Compartment Unaffected (n=10) N (%)
0-4°	16 (15.1%)	0 (0%)
4-7°	39 (36.8%)	0 (0%)
7-10°	34 (32.1%)	4 (40%)
> 10°	15 (14.2%)	1 (10%)
Anterior Slope	2 (1.9%)	5 (50%)