



## Evaluation of the posterior tibial slope on MR images in different population groups using the tibial proximal anatomical axis

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Study performed at Whipps Cross University Hospital, London, U.K.

**We measured the posterior tibial slope for the medial and lateral tibial plateau separately in MR images of 143 knees (71 women, 72 men) and compared the measurements between genders and different ethnic groups.**

**For the whole population the mean medial slope was 5.7° and the mean lateral slope 5.6°. There was a significant difference between the medial and lateral posterior tibial slope in the Asian patients compared with other ethnic groups ( $p < 0.001$ ).**

**We have shown that measurement of the posterior tibial slope (PTS) could be reliably performed on MR images, revealing a gender difference. These findings might have clinical relevance when performing reconstructive surgery at the knee in determining ideal placement of the tibial component.**

**Keywords :** posterior tibial slope ; MRI ; gender ; race ; knee.

the posterior tibial slope helps stabilising knees which are posterior cruciate ligament (PCL) deficient. In total knee replacement (TKR) the PTS plays a key role in knee movements in the sagittal plane in and achieving optimum knee flexion. Malviya *et al* (22) and Bellemans *et al* (1) reported the importance of the tibial slope in predicting maximum knee flexion and Lombardi *et al* (21) identified its relevance in balancing the flexion and extension gaps. In addition, PTS has an important influence on the extension force of the quadriceps muscle after TKR (25) and satisfactory outcome after unicondylar knee replacement (15). TKR aims to restore the mechanical axis of the natural knee joint but surgeons are aware of the variability in the anatomy between patients.

### INTRODUCTION

The posterior tibial slope (PTS) plays a very important role in the kinematics and biomechanics of the knee joint. Shelburne *et al* (27) showed that increased PTS increased the tibial shear force and anterior tibial translation at the knee which is particularly important in individuals undergoing proximal tibial osteotomy (6). Increased medial PTS has been reported to be associated with anterior cruciate ligament (ACL) injuries in teenagers (33) and adults (2,30). According to Giffin *et al* (11) increasing

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The PTS has been measured previously from plain radiographs (3,23) but the accuracy of these measurements has been questioned because the medial and lateral slopes are superimposed on the lateral projection (14). The PTS has been reported in the range from  $0^\circ$  to  $18^\circ$  in radiological and MRI studies (10,14). In a recent MRI study with separate measurement of the PTS for medial and lateral plateaux, the mean posterior slope was higher in the lateral plateau, and higher in females than males ( $7^\circ$  vs  $5.9^\circ$  in females and  $5.4^\circ$  vs  $3.7^\circ$  in males) (14). Utzschneider *et al* (31) studied 14 knees from seven cadavers and showed that measurement from a short lateral radiograph of medial and lateral slopes had good correlation with CT/MRI measurements. An MRI measurement study of the PTS compared with traditional radiographic measurements found the PTS was  $3.4^\circ$  less on MRI scans but there was good correlation between the two methods (16). These studies (14,17,31) were based on relatively small number of measurements and did not consider the variations that might exist in the different ethnic groups.

We are unaware of any previous investigation of the PTS in large numbers where separate assessments of the medial and lateral slopes have been examined with reference to the ethnicity of the patients. The aim of our study was to perform MRI based measurement of the medial and lateral tibial slopes and assess whether there is significant difference in the measurements with regards to gender and ethnicity.

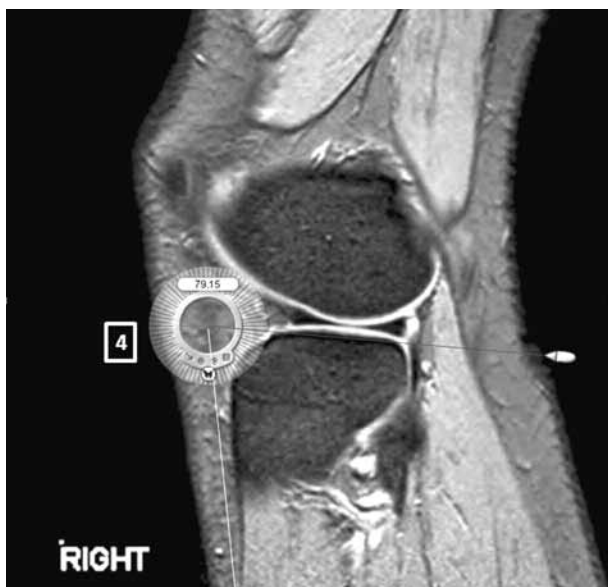
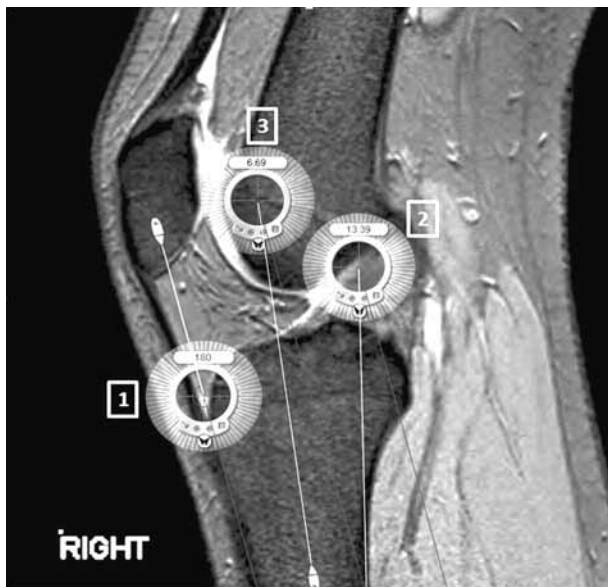
## MATERIALS AND METHODS

We reviewed MRIs of 148 knees (148 patients) performed to investigate soft tissue pathology at the knee. All the MRIs were reported by a radiologist. A total of five cases were excluded, three due to osteoarthritic changes with cartilage wear, osteophyte formation and joint subluxation, one had a fracture and one had deformity. This left 143 knee MRIs for inclusion in the study. Of the included MRIs, 71 were from female and 72 were from male subjects. The mean age of the patients was 42 years (13 to 87). With regards to ethnicity this was taken from the patient's self-applied classification in their hospital registration documents. The distribution was as follows : 59 white, 39 Afro-European/Afro-Caribbean,

37 Asian (Indian, Pakistani, and Bangladeshi), seven mixed and one not stated.

The T1 weighted MR scan pictures were retrieved from our Picture Archive Communication System (PACS) database. Three images of the sagittal plane MRI scan were chosen for measurements in this study. The midline image was chosen (Fig. 1) from the centre of the tibial plateau at the site of insertion of the posterior cruciate ligament. In this view both cruciate ligaments and the curves in anterior and posterior proximal tibial cortices were visible. The medial and lateral images were chosen from the centres of medial and lateral tibial plateaux respectively. In the medial and lateral views, the horns of each meniscus were viewed as small triangles. The three images were grouped together and saved anonymously in a single Powerpoint slide (Microsoft, Redmond, Washington, USA). The grouped images were reviewed for measurements. All measurements were made by one single observer (BH) who was blinded to details such as the age, gender and diagnoses.

The posterior slope was measured between the tibial proximal anatomical axis (TPAA) and the slopes on the tibial plateaux on the medial as well as lateral side. The angles were measured using the Screen Protractor free-ware (Informer Technologies Inc., Dallas, TX, USA). The protractor has two arms and a central circular measurement guide. The protractor is transparent and can be easily moved between the images whilst maintaining the alignment of its arms. It gives instant decimal readings to  $0.01^\circ$ . The measurements were recorded to one tenth of a degree. To measure the tibial slope, one arm of the protractor was aligned along the TPAA. The TPAA was chosen as the line bisecting the angle made between the anterior and posterior tibial cortices in the proximal tibia. To achieve this, one arm of the protractor is placed along the anterior cortex of the tibia (Fig. 1). Without moving the former the whole protractor is moved posteriorly and the second arm is aligned with the posterior cortex of the proximal tibia (Fig. 2). At this point the protractor would give the reading (x) of the angle between the anterior and posterior cortices of the proximal tibia (Fig. 2). The second arm would then be moved by  $(x/2)$  degrees towards the first arm so it would be parallel with the line bisecting the angle between the anterior and posterior cortices of the proximal tibia, i.e. the TPAA. By moving the whole protractor to the other images, one would then align the second ray to the uppermost surface of the bony edges at the anterior and posterior extremes of the lateral and the medial plateaux. This would give the reading for the PTS in the medial and lateral tibial plateaux. This method circumvents the issue of the sagittal topography



**Figs. 1 to 3.** — The five sequential steps in measurement of the PTS on the medial and lateral sides are shown. Note that after the first arm is aligned with the anterior cortex of the tibia, its alignment is not changed until the second arm is parallel to the PTTA (steps 1 to 3 in figure 1). Then the second arm remains in position and the first arm is aligned with the most superior aspects of lateral and medial tibial slopes (steps 4 and 5 in figures 2 and 3).

of the articular surfaces of the tibial condyles (20). The measurements were documented in an Excel Microsoft® 2010 spreadsheet. The demographic data including age, gender and ethnicity were also collated.

### Statistical analysis

The data were then analysed using the Statistical Package for the Social Sciences (SPSS) software to calculate the mean and standard deviation (SD) for all the angles. Our data had a normal distribution as checked by histogram and normal Q-Q plot graphs so we used

parametric tests to compare means. Student's paired t-test was used to determine whether the differences were significant for medial versus lateral tibial slope in each individual and the Student's unpaired t-test was used for female versus male individuals. Analysis of Variance (ANOVA) was used to assess differences for the ethnic groups (White, Asian, Afro-Caribbean / Afro-European). For the ANOVA test the Levene's Homogeneity of variance test was used to ensure that the variances in the groups are equal. A p-value < 0.05 was considered statistically significant for all tests.

The intraclass correlation coefficient (28) (ICC) was used to assess the inter-observer and intra-observer reliability. The measurements were then repeated for 19 random samples after three months by the same author (BH) and another author (SK) to assess for inter-observer and intra-observer reliability. A separate sample of 20 cases were re-measured and compared with the original series by another author (KM). An ICC of < 0.20 was considered poor agreement, an ICC of 0.20 to 0.40 fair agreement, 0.40 to 0.60 moderate agreement, 0.60 to 0.80 good agreement and 0.80 to 1.00 very good agreement.

Table I. — Demographics, results of the medial and lateral PTS measurements and statistical analysis

	No	Age Mean, (SD)	Medial PTS Mean, (SD)	Lateral PTS Mean, (SD)	P Value Med/Lat
Sex*					
Male	72	37, (16.7)	5.1, (3.7)	4.8, (4.2)	0.67 <sup>a</sup>
Female	71	47, (14.1)	6.3, (3.9)	6.3, (4.0)	0.92 <sup>a</sup>
P Value Female vs. Male			0.049 <sup>b</sup>	0.041 <sup>b</sup>	
Race*					
White	59	45, (16.5)	4.2, (3.7)	4.4, (4.2)	0.78 <sup>a</sup>
Asian	37	40, (16.8)	7.9, (3.3)	8.1, (4.0)	0.86 <sup>a</sup>
Afro-Caribbean/European	39	41, (15.2)	6.0, (3.3)	4.6, (4.2)	0.09 <sup>a</sup>
P Value compare 3 groups			< 0.001 <sup>c</sup>	< 0.001 <sup>c</sup>	

<sup>a</sup> = Paired student's t test, <sup>b</sup> = Independent student's test, <sup>c</sup> = ANOVA, No : Number, Med : medial, Lat : lateral, \*8 individuals were from other ethnicities, hence the discrepancy in total numbers.

## RESULTS

The ICC measurements found the intra-observer reliability for the angles obtained by repeated measurements in 19 random images was 0.79 for the medial side and 0.85 for the lateral side, indicating good and very good agreement respectively.

The inter-observer reliability for the measurements assessed for the same 19 re-measurements by BH and SK produced an ICC of 0.81 medially and 0.83 laterally. Inter-observer reliability comparing the 20 patients re-measured (KM vs BH) had an ICC of 0.88 medially and 0.80 laterally.

The mean medial slope was 5.7° (standard deviation (SD) 3.83) and the mean lateral slope 5.6° (SD 4.17) for the total population. Results for different subgroups and the relevant p values are summarized in table I.

### Gender Variation

The mean PTS was higher in females than in males both on the medial (6.3°, SD 3.9 vs. 5.1°, SD 3.7) and the lateral (6.3°, SD 4.0 vs 4.8°, SD 4.2) sides.

A statistically significant difference was noted between females and males for both the medial tibial slope (t-test, p = 0.049) and the lateral tibial slope (t-test, p = 0.041) with females having a higher

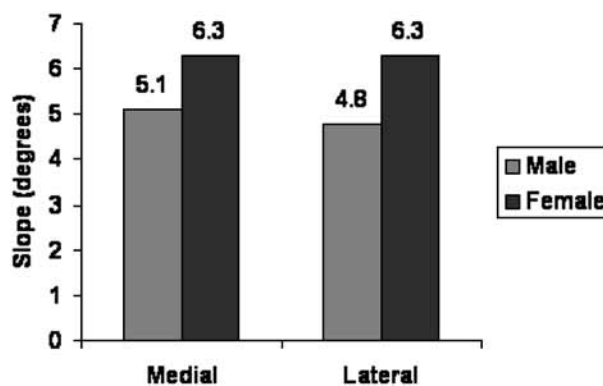


Fig. 4. — A column chart comparing the PTS in the medial and lateral tibial slopes in the female and male groups. The mean values are displayed for each analysis.

mean medial and lateral tibial slope angle compared with males. There was no significant difference between the medial tibial slope and lateral tibial slope measurements in females (t-test, p = 0.92) or males (t-test, p = 0.67). The results are also shown in figure 4.

### Ethnic variation

There was no statistically significant difference between the medial and lateral tibial slopes for any of the ethnic cohorts. The results for measurements and p values are summarized in table I.

Table II. — Results of post hoc Bonferroni analysis for lateral and medial PTS measurements in different ethnic groups

		Mean difference	Std. error	P value	95% confidence intervals	
					Lower bound	Upper bound
Lateral PTS	White vs. Asian	-3.629	0.831	< 0.001	-5.64	-1.61
	White vs. Afro-Caribbean/European	-0.186	0.818	1	-2.17	1.79
	Asian vs. Afro-Caribbean/European	3.442	0.910	0.001	1.23	5.64
Medial PTS	White vs. Asian	-3.669	0.737	< 0.001	-5.45	-1.88
	White vs. Afro-Caribbean/European	1.870	0.807	0.066	-3.82	.086
	Asian vs. Afro-Caribbean/European	-1.798	0.725	0.043	.0390	3.55

Std. = Standard, PTS = Posterior tibial slope.

ANOVA test between ethnic groups showed a significant difference between the groups for medial and lateral PTS ( $p$ -values < 0.001). The post-hoc Bonferroni test results are summarized in table II. The most striking difference was the steeper medial PTS in the Asian population with little difference between the white and Afro-Caribbean / Afro-European cohort. The comparison of the results is also shown in figure 5.

Eight individuals were from other ethnic groups. They were included in the gender variation calculations but not in the ethnic calculations.

## DISCUSSION

The posterior tibial slope has mainly been assessed previously on plain radiographs. Brazier *et al* (3) described the different anatomical axes against which the PTS could be measured. The lines included the tibial proximal anatomical axis (TPAA); tibial shaft anatomical axis (TSAA); posterior tibial cortex (PTC); fibular proximal anatomical axis (FPAA); fibular shaft axis (FSA); anterior tibial cortex (ATC). They concluded that among the proximal axes, the TPAA and PTC gave higher reliability. Paley *et al* (26) measured the posterior proximal tibial angle (PPTA) on 16 AP and lateral radiographs that included the femur and tibia in one film. They quoted an average of  $9^\circ$  (SD 3.5).

More recently, some studies have used CT/MRI scan images for measuring the slope on medial and lateral sides separately (14,17,31). Whilst Hashemi *et al* (14) in their MRI study used the traditional methods used for plain radiographic measurements,

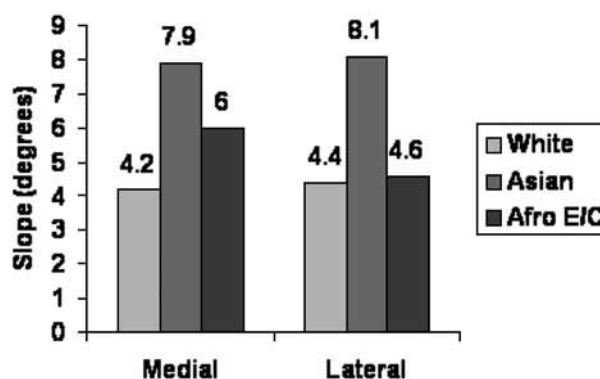


Fig. 5. — A column chart comparing mean medial and lateral tibial slope angles in the White, Asian and Afro-European / Afro-Caribbean (Afro E/C) ethnic groups.

Hudek *et al* (17) used a new system for finding the TPAA. It has been recognised that measurement of the PTS on lateral radiographs is not sufficiently accurate due to superimposition of the two slopes (14).

Ideally one would like to measure the PTS against the anatomical axis of the tibia, firstly because the final aim of knee procedures is to restore the ideal biomechanics and secondly, the tibial proximal anatomical axis does not exactly match the mechanical axis of the tibia. Hudek *et al* (17) found that their MRI measurement underestimated the PTS when they compared it against their radiological measurements. This might be due to the differences between these two axes. Thirdly, at least theoretically, the larger the distance between the two points increases the accuracy in measurement

of the angle. In the study by Brazier *et al* (3) good correlation was shown among the measurements using tibial proximal anatomical axis (TPAA), posterior tibial cortex (PTC) lines and tibial shaft anatomical axis (TSAA).

The limiting factor in measuring our MR images was that the whole length of the tibia was not available. This deficiency has been noted previously (17). For greater accuracy, study of full length MRI or CT scans of the tibia would be required. Nevertheless, the method we used was easy and reproducible as shown by the good and excellent agreement for the ICCs.

We have found that the PTS referenced from the TPAA is steeper in females by a mean of  $1.2^\circ$  ( $p = 0.05$ ) medially and a mean of  $1.4^\circ$  ( $p = 0.04$ ) laterally. This is consistent with the findings of Hashemi *et al* (14). The increased PTS in certain populations might be associated with increased stress on the ACL. Injuries of the ACL have been found to be up to nine times more common among female athletes (4,32) and they are more susceptible to non-contact ACL injuries. A recent report, without assessing the influence of gender, has also confirmed a greater incidence of ACL rupture when the PTS angle is increased (29).

There has been a recent trend towards gender specific TKR mainly focusing on anatomical differences of the distal femur. It has been suggested that the anterolateral and anteromedial aspects of the femur are less prominent and the mediolateral/anteroposterior ratio is lower in women (5,12,13). The relevance of these differences in the clinical setting has been debated in studies where gender specific knee replacement was compared with unisex knee replacement (7,18,19,24). However, our findings and those of Hashemi *et al* (14) would suggest that if a TKR needs to be specific for gender, then the position of the tibial component needs also to be suitably matched. However, Hashemi *et al* (14) did not investigate the relationship of PTS to racial type.

de Boer *et al* (8) undertook a non-imaging laboratory study of the PTS using a purpose made measuring tool to examine 61 male and 44 female cadaver tibiae which had been stripped of all soft-tissue. They found an ethnic variation for the PTS

( $p = 0.001$ ) but not for gender ( $p = 0.091$ ). Their findings might be a reflection of their methodology. A radiological study performed by a single observer on 212 lateral tibial radiographs acquired from six Nigerian hospitals measured the PTS with reference to the ATC finding a mean PTS of  $12.3^\circ$  (9). Those authors attempted to make racial comparisons with published literature which had identified their comparator groups by nationality rather than race and cited only one of their three reference papers. Accordingly we are unable to comment on the veracity of their work. We found that Caucasians had the least PTS, followed by Afro-Europeans / Afro-Caribbean patients, with the PTS in our Asian population being approximately  $4^\circ$  greater than in Caucasians ( $p < 0.001$ ).

In conclusion, using MR images and using the TPAA as the reference to measure the PTS, we have shown that there are significant differences between individuals related to ethnicity and gender. These differences should receive due consideration when undertaking TKR on diverse populations.

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