

Original Research Article

MORPHOMETRIC ASSESSMENT OF MEDIAL AND LATERAL POSTERIOR TIBIAL PLATEAU SLOPE: A STUDY OF DRY AND CADAVERIC TIBIAE

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ABSTRACT

Background: Posterior tibial slope is an important sagittal plane parameter of proximal tibial morphology, and it is useful for knee biomechanics, anterior cruciate ligament function, tibial osteotomy (high), unicompartmental knee arthroplasty and complete knee arthroplasty. Posterior tibial slope reported value was varied according to population, sex, imaging modality and anatomical reference axis used for measurement. Posterior tibial slope was assessed by using lateral radiographs in most of the conventional studies and commonly represent the tibial plateau as a single surface, even though the medial and lateral plateaus have distinct morphology. This study assessed and compared the medial and lateral posterior tibial plateau slopes in dry tibiae and cadaveric tibiae and to evaluate their relationship with laterality, gender and tibial length.

Materials and Methods: An observational prospective anatomical study was done in Department of Anatomy along with the collaboration of Department of Orthopaedic, King George's Medical University, Lucknow, Uttar Pradesh, India; and was conducted from April 2019 to September 2020, and it included 401 intact, ossified completely dry tibiae and 30 tibiae taken from 15 freshly formalin preserved cadavers. Posterior tibial slope of medial and lateral tibial plateaus was measured by using goniometer and for this anterior cortical line of the tibial shaft was taken as the reference axis. Statistical analysis was performed by using Jamovi 2.7.31. Mean and standard deviation were calculated; Student's t-test and paired t-test were used for comparison while Pearson correlation was used to know the relationship between tibial length and posterior tibial slope.

Results: The mean medial posterior tibial slope (PTS) was $16.02 \pm 2.71^\circ$ on left and $16.11 \pm 3.14^\circ$ on right while the lateral PTS was $12.01 \pm 3.09^\circ$ and $11.93 \pm 2.97^\circ$, respectively for dry tibiae. No significant differences were observed between left and right sides for medial PTS ($p = 0.748$) and lateral PTS ($p = 0.773$). Medial PTS was significantly greater than lateral PTS on both sides and in overall dry bone sample; the overall mean differences were calculated as $4.09 \pm 2.47^\circ$ ($p < 0.001$). Medial PTS was $14.69 \pm 1.21^\circ$ and $14.83 \pm 1.52^\circ$ for left and right respectively whereas lateral PTS was $10.93 \pm 1.97^\circ$ and $11.00 \pm 2.08^\circ$, respectively in cadaveric tibiae. Side-to-side differences was not significant, and the medial PTS was significantly greater than lateral PTS in the total cadaveric sample, as well as among females and males. Gender wise differences in medial PTS and lateral PTS were not significant statistically. Tibial length of dry bone or cadaveric tibiae showed no significant correlation with lateral and medial PTS.

Conclusion: There is Consistent medial-lateral asymmetry of PTS and medial plateau showing greater posterior slope than the lateral plateau in dry and cadaveric tibiae, demonstrated in this study. PTS was not influenced by laterality and gender; Pts was not related significantly to overall tibial length.

Findings in this respective study highlight that medial and lateral tibial slopes should be considered separately and it not represented by a single generalized PTS value.

Keywords: Posterior tibial slope, Medial tibial plateau, Lateral tibial plateau, Tibia, Dry bone, Cadaver.

INTRODUCTION

Posterior tibial slope (PTS) is an important morphological factor of proximal tibia. The tibial longitudinal axis and superior articular surface of tibial plateau are not oriented in perpendicular manner but slopes posteriorly. Sagittal plane geometry of the knee contributed by this inclination and it further influences tibiofemoral translation, ligament loading and knee kinematics. So, the total knee arthroplasty (TKA), unicompartmental knee arthroplasty, high tibial osteotomy and anterior cruciate ligament (ACL) reconstruction are highly relevant to changes in PTS. The magnitude of PTS varies significantly among individuals and populations. Brazier et al. compared six radiographic methods in healthy knees and showed that the measured slope depends on anatomical reference axis used and there was difference of 5° when same tibial plateau was measured against different reference axis.^[1] Chiu et al. went through 25 pairs of Chinese cadaveric tibia for studying posterior slope of tibial plateau and reported posterior slope of medial plateau and of lateral plateau was 14.8° and 11.8° respectively and so it hints that two tibial plateaus cannot be considered a single planar surface.^[2] Clinical importance of PTS can be showed in biomechanical and clinical studies. Giffin et al. did an experimental study by altering the posterior tibial slope and showed changes in anterior tibial translation and knee kinematics, and so it indicate that PTS is not simply an anatomical measurement but it is an major determinant of knee mechanics.^[3] Fening et al. investigated the effect of modifying PTS on strain of ACL and kinematics of knee in a cadaveric study of human, supporting biomechanical relevance regarding sagittal tibial geometry.^[4] Hashemi et al. stated that combination of increased posterior directed tibial plateau slope and shallow medial tibial plateau depth was risk factor for ACL injury susceptibility and this is irrespective of gender.^[5] Haddad et al. measured PTS for medial and lateral plateau by using magnetic resonance imaging (MRI) in 143 knees and reported.^[5,7] was mean medial slope and.^[5,6] was mean lateral slope and the difference was significant between the medial and lateral PTS in the Asian patients on comparison with other ethnic groups.^[6] Yoo et al. compared five anatomical axes with a proposed mechanical axis and further stated that the measured medial tibial slope varied as per reference used and so this highlight that there is not any single universally accepted anatomical reference for PTS measurement.^[7] de Boer et al. assess inter-individual variation among posterior slope in the knee joint by doing in vitro

study and stated the presence of considerable inter-individual variation among posterior slope.^[8] Bisicchia et al. studied 581 radiographs of knees and reported the presence of significant differences in PTS between different ethnic groups (white and black subjects) whereas the difference among gender were conflicting and tibial proximal anatomical axis methods was recommended for evaluation of PTS.^[9] Webb et al. concluded that an increased PTS is associated with increase chances of further ACL injury after ACL reconstruction and the risk become more pronounced among those individuals having $PTS \geq 12^\circ$.^[10] Nelitz et al. by using human cadaveric knees examined different PTS values and reported that increase PTS alter the tibial rotation ability without increasing ACL strain.^[11] Mohanty et al. stated on the basis of their study that there is positive correlation between metaphyseal-diaphyseal angle and PTS in Indians and the metaphyseal-diaphyseal angle is an independent factor, it affects accuracy of extramedullary jigs in TKA.^[12] Waiwaiole et al. studied relation between ACL injury and PTS with respect to sex, age and race and further demonstrated that age and lateral PTS had statistically significant relation with ACL injury while the remaining medial PTS, sex and race were not significant predictors of ACL injury.^[13] Overall, it can be stated that PTS varies according to individuals, populations, reference axis and measurement technique and there can be different slopes of medial and lateral tibial plateaus. There are many of studies available which are based on radiographs, Computed tomography (CT) and MRI.

This present study was undertaken to directly measure the tibial plateau slopes- medial and lateral in dry and cadaveric tibiae using a standardized anatomical reference, that was anterior tibial cortex.

MATERIALS AND METHODS

Study design and setting: An observational prospective anatomical study was conducted in Department of Anatomy along with the collaboration of Department of Orthopaedics, King George's Medical University, Lucknow, Uttar Pradesh, India. Study was done from April 2019 to September 2020. Ethical approval was taken from Institutional Ethics Committee (IEC) of King George's Medical University, Lucknow, Uttar Pradesh, India; vide letter number 1507/Ethics/2019, Ref. code 98th ECM II B- Thesis/P6.

Study material

There were two components of this study: Dry-bone study – 401 intact, ossified completely dry tibiae were included and of these 206 were of left side and

195 of right side. Age, gender and stature of the individuals from whom the bones were taken were unknown. The bone was selected from Department of Anatomy, King George's Medical University, Lucknow.

Cadaveric study – 15 freshly formalin preserved cadavers were taken and among this 8 were male and 7 were female and both tibiae were examined from each cadaver; that means total 30 cadaveric tibiae.

Inclusion and exclusion criteria

Freshly formalin preserved cadaveric component, normal intact dry tibia bones of both sexes and intact proximal tibial articular surface for direct measurements were included in this study; whereas deformed, distorted, damaged upper end of tibia, traumatic accidental cadavers and osteophytes surrounding the upper end of tibia cut surface in cadavers were excluded from study.

Instruments: Digital Vernier caliper, osteometric board, measuring ruler, protractor/goniometer, marker/pencil, standard dissection instruments were used while conducting this study.

Measurement of PTS: The PTS was measured directly on dry tibiae and exposed cadaveric tibial plateaus. As the reference anterior cortical line was used. Along the anterior cortex of middle portion of tibial shaft, a straight line was drawn and extended proximally, further for each plateau and another line was made tangentially along the articular surface by joining most anterior point and posterior point of medial or lateral tibial plateau. Another third line which was perpendicular was made to the anterior cortical line at its intersection with plateau tangent. Between this perpendicular line and tangent to the tibial plateau an angle is formed, and it was recorded as the PTS. Medial posterior tibial slope (PTS-M) and lateral posterior tibial slope (PTS-L) was done

measured separately. This same method was used for dry bone and cadaveric specimens.

Cadaveric dissection: Fifteen cadavers were positioned in supine position, and a midline anterior skin incision of approximately 12-15 cm was made over the knee with horizontal extensions at both ends, further the skin flaps were reflected, and excision of ligamentum patellae was done. The knee was flexed to 90 degrees. The menisci were removed and knee joint was exposed, further ACL was cut at its tibial attachment to expose medial tibial plateau, lateral tibial plateau and intercondylar area. PTS-M and PTS-L were measured by using the same method applied for dry bone component.

Statistical analysis: Data were entered and analysed by using Jamovi 2.7.31. Mean $\pm$ Standard deviation (SD) was used to express the continuous variables whereas to compare two independent means Student's t-test was used. Paired t-test for within specimen comparisons of medial and lateral. Pearson correlation coefficient was used to access relation between tibial length and PTS. Statistically significant was considered if p-value of <0.05 .

RESULTS

Total 431 tibiae were examined; 401 were dry tibiae (195 of right and 206 of left) and 30 were cadaveric tibiae (15 of right and 15 of left).

Dry tibiae: Laterality wise comparison of PTS in dry tibiae was done and the calculated mean medial PTS was $16.02 \pm 2.71^\circ$ on the left and $16.11 \pm 3.14^\circ$ on right and the differences was not significant statistically ($t = -0.32$, $p = 0.75$) whereas the mean lateral PTS was also differed in left and right while the differences ($t = 0.28$, $p = 0.77$) was not statistically significant. [Table 1]

Table 1: Laterality wise comparison of PTS in dry tibiae

Characteristic	Left (n = 206) Mean (SD)	Right (n = 195) Mean (SD)	t-value		p-value
PTS-M	16.02 (2.71)	16.11 (3.14)	-0.32		0.75
PTS-L	12.01 (3.09)	11.93 (2.97)	0.28		0.77

{Values expressed in Mean (SD) and p-value for laterality for comparison obtained by independent sample Student t-test}

PTS-M was consistently greater than PTS-L and the mean differences between both in overall samples ($n = 401$) was $4.09 \pm 2.47^\circ$ ($t = 33.22$, $p = <0.001$) and

the medial plateau demonstrated a significantly greater posterior slope than the lateral plateau in left and right dry tibiae. [Table 2]

Table 2: Difference between PTS-M and PTS-L in dry tibiae

Comparison	Groups	Mean differences	SD	95% CI		t-value	p-value
				Lower	Upper		
PTS-M & PTS-L	Left (n=206)	4.01	2.33	3.69	4.33	24.63	<0.001
	Right (n=195)	4.19	2.6	3.82	4.56	22.45	<0.001
	Total (n=401)	4.09	2.47	3.85	4.34	33.22	<0.001

{Mean difference along with SD was calculated; CI = confidence interval; paired t-test was used}

In dry tibiae, the PTS-M and PTS-L both were showing weak or no correlation with tibial length and neither was significant statistically. [Table 3]

Table 3: Correlation between tibial length and PTS in dry tibiae

Parameters	Pearson correlation coefficient (r)	Level of correlation	p-value	Significance level
PTS-M	0.004	Weak or No correlation	0.943	Not significant
PTS-L	0.059	Weak or No correlation	0.237	Not significant

{r, Pearson correlation coefficient was calculated to check strength and direction of association}

Cadaveric tibiae: The mean PTS-M in female was higher than male and the difference were not statistically significant (p is 0.062), and the mean

PTS-L was also not significant statistically among male and female (p = 0.716) in cadaveric tibiae. [Table 4]

Table 4: Gender wise comparison of PTS in cadaveric tibiae

Characteristic	Female (n=14) Mean (SD)	Male (n= 16) Mean (SD)	t-value	p-value
PTS-M	15.25 (1.44)	14.33 (1.15)	1.946	0.067
PTS-L	10.82 (2.17)	11.09 (1.88)	-0.368	0.72

{Values expressed in Mean (SD) and p-value for gender wise comparison obtained by Student's t-test} Laterality wise comparison done in cadaveric tibiae and the calculated mean PTS-M was $14.69 \pm 1.21^\circ$ on left and $14.83 \pm 1.52^\circ$ on right whereas the mean

PTS-L was $10.93 \pm 1.97^\circ$ on left and $11.00 \pm 2.08^\circ$ on right; while both were not demonstrated a statistically significant side to side difference. {Table 5}

Table 5: Laterality wise comparison of PTS in cadaveric tibiae

Characteristic	Left (n = 15) Mean (SD)	Right (n = 15) Mean (SD)	t-value	p-value
PTS-M	14.69 (1.21)	14.83 (1.52)	-0.293	0.77
PTS-L	10.93 (1.97)	11.00 (2.08)	-0.090	0.93

{Values expressed in Mean (SD) and p-value for laterality for comparison obtained by independent sample Student t-test}

The medial plateau in cadaveric tibiae showed a significantly greater posterior slope than lateral plateau while the mean difference $\pm$ SD for overall

sample (n = 30) was $3.79 \pm 1.38^\circ$ and p = <0.001. [Table 6]

Table 6: Difference between PTS-M and PTS-L in cadaveric tibiae

Comparison	Group	Mean difference	SD	95% CI		t-value	p-value
				Lower	Upper		
PTS-M & PTS-L	Left (n=15)	3.75	1.51	2.92	4.59	9.62	<0.001
	Right (n=15)	3.83	1.28	3.13	4.54	11.6	<0.001
	Total (n=30)	3.79	1.38	3.28	4.31	15.1	<0.001

{Values represent the mean difference $\pm$ SD between medial and lateral PTS-M and PTS-L; CI, confidence interval; paired t-test was applied}

In cadaveric tibiae, PTS-M and tibial length showed mild negative correlation (r = -0.422, p = 0.019) while it was statistically significant; whereas PTS-L

and tibial length showed moderate correlation (r = 0.633, p <0.001) and was very highly significant. [Table 7].

Table 7: Correlation between tibial length and PTS in cadaveric tibiae

Parameters	Pearson correlation coefficient (r)	Level of correlation	p-value	Significance level
PTS-M	-0.422	Mild Negative	0.019	Significant
PTS-L	0.633	Moderate	<0.001	Very highly significant

{r, Pearson correlation coefficient was calculated to check strength and direction of association}

DISCUSSION

The present study examined 401 dry tibiae and 30 cadaveric tibiae separately for assessing PTS-M and PTS-L and the main finding of the study was that the PTS-M was greater significantly than lateral slope in dry as well as cadaveric tibiae. The overall medial-lateral difference was $4.09 \pm 2.47^\circ$ (p <0.001) in dry tibiae whereas it was $3.79 \pm 1.38^\circ$ (p <0.001) in cadaveric tibiae. PTS-M and PTS-L was showed no significant with tibial length in dry tibiae.

Medial PTS greater than lateral PTS in this study indicates that the two tibial plateaus do not form identical sagittal surfaces. Weinberg et al. according to their study, reported that tibial slope-medial is greater than tibial slope-lateral and also demonstrated presence of individual based variability.^[14] Ho et al. did 3-dimensional CT study in 100 knees and concluded that medial slope and lateral slope differ as per taken anatomical references, and that is the reason that tibial plateau should not necessarily be represented by a single sagittal angle as changing anatomical reference considerably alter measurement of medial slope and lateral slope.^[15] Karimi et al.

evaluated tibial slope- medial and as well as lateral, further examined its relation with demography and tibial morphological variables; and this study laid down the importance of treating medial and lateral slopes as separate anatomical parameters.^[16] This study showed no relationship of tibial length with PTS-M and PTS-L in dry tibiae; whereas in cadaveric tibiae showed inverse correlation between tibial length and PTS-M (r is -0.422, p is 0.019) and the correlation between tibial length and PTS-L (r = 0.633, p <0.001) was moderate; while both reached to statistical significance. There were no significant right and left differences identified for medial as well as lateral PTS in dry or cadaveric tibiae. No significant difference in tibial plateau slope between right and left side reported by Medda et al. in their study among adult Eastern Indian population.^[17] PTS-M was high in females ($15.25 \pm 1.44^\circ$) than males ($14.33 \pm 1.15^\circ$) while PTS-L was slightly high among males ($11.09 \pm 1.88^\circ$) than females ($10.82 \pm 2.17^\circ$); and neither one was statistically significant. Weinberg et al. identified significant sex related differences in both medial as well as lateral tibial slope in their study.^[14] Pangaud et al. concluded in their study after examine and measuring lower limb alignment and PTS based on CT in 378 patients and reported that PTS varied as per ethnicity and sex, while the magnitude and direction of the effect also varied between global, medial as well as lateral measurements.^[18] PTS shapes tibiofemoral translation and kinematics of knee; it is pertinent to ACL reconstruction, arthroplasty of knee and tibial osteotomy (high). Bates et al. did a cadaveric robotic study to investigate knees with varying tibial slopes during simulated athletic movements and showed the existence of relation between tibial slope and sagittal and frontal plane joint loading.^[19] Dai et al. conducted a cadaveric validation study of cruciate retaining TKA and showed that with changing of the reconstructed PTS, knee kinematics got influenced; this denotes the importance of sagittal tibial geometry in arthroplasty.^[20]

Overall, this respective study showed that the PTS-M was greater significantly than the PTS-L in dry as well as cadaveric tibiae; whereas the PTS-M and PTS-L does not show significant correlation with tibial length in dry tibiae. So, these findings indicate the importance of assessment of medial as well as lateral PTS separately and then further interpret the measurements as per the reference axis used.

Strengths: Assessment of medial as well as lateral PTS in a large sample of 401 dry tibiae and 30 tibiae from freshly preserved cadavers is one of the major strengths of the study. Reference axis for direct measurement was used anterior tibial cortex, and it also allowed side specific comparison and assessment of medial-lateral differences. Skeletal and cadaveric specimens provide important anatomical information for understanding variations in PTS.

Limitations: There was lack of information about sex, age, stature and clinical history in dry bone sample whereas the cadaveric samples were small.

Measurements were done manually so, it may lead to observer related measurement error. Assessment of functional, clinical and radiological outcomes were not done in this study, so the findings cannot be directly inferred to surgical decision making or postoperative results. Relation with tibial length were nonsignificant and it should be interpreted carefully.

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CONCLUSION

There is Consistent medial-lateral asymmetry of PTS and medial plateau showing greater posterior slope than the lateral plateau in dry and cadaveric tibiae, demonstrated in this study. PTS was not influenced by laterality and gender; Pts was not related significantly to overall tibial length. Findings in this respective study highlight that medial and lateral tibial slopes should be considered separately and it not represented by a single generalized PTS value

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