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Normal anatomical variations of tibial plateau geometry in Indian population: a magnetic resonance image-based study

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ABSTRACT

Background: Geometry of tibial plateau characterized by its medial tibial plateau slope (MTS), lateral tibial plateau slope (LTS), depth of concavity of medial tibial plateau (CMT), convexity of lateral tibial plateau on sagittal section and coronal tibial plateau slope (CTS) on coronal section of tibia.
Methods: 500 subjects (male-250, female-250) were included in the study. Various tibial slopes of each subject were measured using magnetic resonance image (MRI) of knee joint. Data was analysed using appropriate statistical analysis.
Results: When considering male and female one group (total population) mean (±SD) of MTS, LTS, CMT, CTS were 7.73 ± 3.20^0, 4.68 ± 2.75^0, 2.56±0.56 mm and 2.61 ± 2.15^0 respectively. In male population mean (±SD) of MTS, LTS, CMT, CTS were 6.94 ± 3.2^0, 3.77 ± 1.85^0, 2.7±0.55 mm, 3.06 ± 2.39^0 respectively. In female population population mean (±SD) of MTS, LTS, CMT, CTS were 9.28 ± 2.65^0, 6.45 ± 3.36^0, 2.28±0.48 mm, 1.75 ± 1.24^0 respectively. Over all MTS and LTS was poorly correlated (r=0.43). Female had significant steeper MTS (p=0.013) and LTS (p=0.001) but had less CTS (p=0.04) and shallow CMT (p=0.012) compared to male.
Conclusions: Knowledge of this study could be used in different operative orthopaedic procedures (like knee arthroplasty, high tibial osteotomy, tibial plateau fracture fixation), non-contact ACL injury risk assessment.

Keywords: Geometry of tibial plateau, Various slopes, Total knee replacement

INTRODUCTION

The geometry of the tibial plateau is complex and asymmetric. It is characterized by its anterior to postero-inferior medial tibial plateau slope (MTS), lateral tibial plateau slope (LTS), lateral to medial coronal tibial plateau slope (CTS), depth of concavity of medial tibial plateau (CMT), and convexity of lateral tibial plateau.[1] Most important character of tibial plateau geometry is its posterior tibial slope (PTS). Posterior tibial slope is defined as the angle between the perpendicular to the middle part of the diaphysis of the tibia and the line representing the posterior inclination of the tibial plateau.[2] PTS is divided into MTS and LTS. As MTS and LTS are different PTS is not uniform.[1,3-5]

The posterior tibial slope varies widely.[3,6,7] PTS increases with age.[8] PTS is steeper in people who has squatting habit.[9] PTS is steeper in female compared to male.[,3,7] According to some studies PTS is same in both male and female.[10,11] PTS is steeper in the patients who has osteoarthritis of knee.[12]

Tibial plateau slopes, MTS and LTS, independently are important determinants of knee biomechanics.[2,13-15] Steeper medial tibial plateau slope, lateral tibial plateau slope and shallower medial tibial plateau depth has also been recognized as a risk factors for anterior cruciate ligament injury.[5,16-18] Geometry of tibial plateau considered during alignment of the knee prosthesis in sagittal plane during total knee arthroplasty (TKA).[12,19,20]

Increase tibial plateau slope may increase the postoperative range of flexion.[12,21] High tibial osteotomy done for surgical correction of deformities of the knee joint may cause an unintended change in the tibial plateau slope.[22] The aims of the study was to provide reference values of the tibial plateau slope and depth of concavity of medial tibial plateau in normal Indian population. In the present study we measured MTS and LTS separately, using conventional MRI of knee joint. Besides with this MRI of knee we were able to CTS, CMT, and convexity of lateral tibial plateau. Tibial plateau geometry is complex and three dimensional. With the help of MRI, we can measure MTS, LTS, CTS and concavity of medial tibial plateau. By radiograph we can't measure all these variables so in our study we used MRI knee to explore the tibial plateau geometry.

The following benefits could be gained for the treatment of the population of this society: (1) Modification of knee prosthesis sizing/geometry for Indian population. (2) Modification of some surgical procedures of knee joint (like knee arthroplasty, high tibial osteotomies) for Indian population. (3) Assessment of risk regarding non-contact anterior cruciate ligament (ACL) injury. (4) Radiological study to modify techniques for assessment of knee joints in patients with different tibial plateau angle.

METHODS

This is an observational correlation study. Data was collected from 500 subjects (250 male and 250 female) who were attended in a tertiary care hospital for minor knee problems from Jan 2011 to Jan 2014. Mean age of subjects were 32.96 years (Range 25-42 years). Subjects with minor knee problem (mild soft tissue injury, superficial bruise etc.) were included in the study. Patients with history of any old or new tibial plateau fracture, osteoarthritis of knee, operations of knee, and any congenital anomaly of tibia excluded from the study. All measurements were done by annotation tools on soft copy of T1 weighted (TE) sagittal and coronal magnetic resonance imaging scans of the tibiofemoral joint of the selected subjects. All MRI done on the same 1.5 Tesla machine. We used methods proposed by Hashemi et al for measurement of medial, lateral and coronal tibial plateau slope and depth of concavity of medial tibial plateau.[1]

First the dorsal aspect of the tibial plateau was identified. In this transverse image, the coronal plane that passed closest to the centroid of the tibial plateau was identified. Next, the orientation of the longitudinal axis of the tibia, in the coronal plane, was determined. This was done by determining the midpoint of the medial-to-lateral width of the tibia at two points located approximately 4 to 5 cm apart and as distally in the image as possible. The extended line L connecting the two midpoints represents the longitudinal (or diaphyseal) axis of the tibia in the coronal plane (Figure 1). The coronal slope of the tibial plateau (the coronal tibial slope) was then measured as the angle between a line (OA) joining the peak points on the medial and lateral aspects of the plateau and the line (OP) perpendicular to the longitudinal axis L (Figure 2).

A similar approach was followed to determine the sagittal slopes of the medial and lateral tibial plateaus. In mid sagittal section of tibia, the longitudinal (or diaphyseal) axis of the tibia L was constructed (Figure 3). This was done by determining the midpoint of the anterior-to-posterior width of the tibia at two points located approximately 4 to 5 cm apart and as distally in the image as possible then these two mid points were connected.

The diaphyseal axis was then reproduced in the middle of medial tibial plateau on sagittal plane. The peak anterior and posterior points on the medial tibial plateau were identified. The slope of the line (OA) extending through these two points represented the medial tibial slope, and it was measured with respect to the axis (OP) perpendicular to the longitudinal axis (Figure 4). A similar approach was used to determine the lateral tibial slope (Figure 5). The depth of the concavity of the medial aspect of the tibial plateau was measured by drawing a line (AB) connecting the superior and inferior crests of the tibial plateau in the same plane in which the medial tibial slope was measured. A line parallel to this line (CD) was then drawn tangential to the lowest point of the concavity, representing the lowest boundary of the subchondral bone. The perpendicular distance (EF) between the two lines was then measured and was used to represent the depth of concavity of the medial tibial plateau (Figure 6). More or less flat articular surface (AB) was found on lateral tibial plateau (Figure 7) but we could not able to measure the magnitude of convexity.

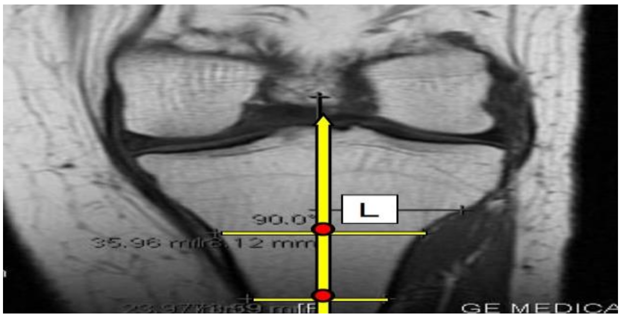

Figure 1: Longitudinal axis of the tibia in the coronal plane (L).

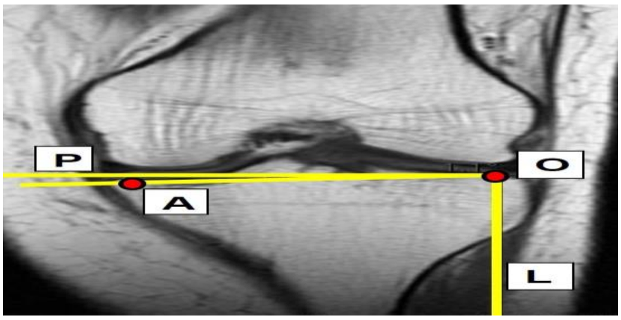

Figure 2: Coronal tibial plateau slope (POA).

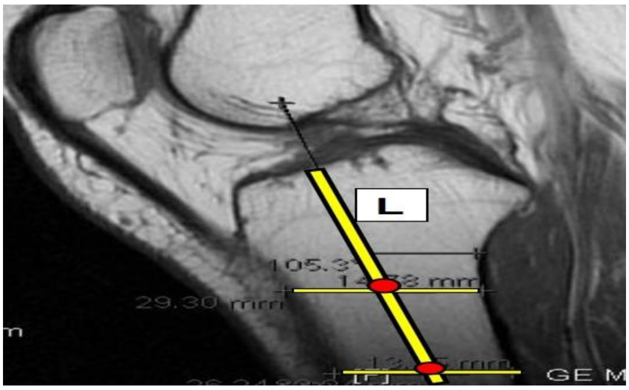

Figure 3: Longitudinal axis of the tibia on mid sagittal section (L).

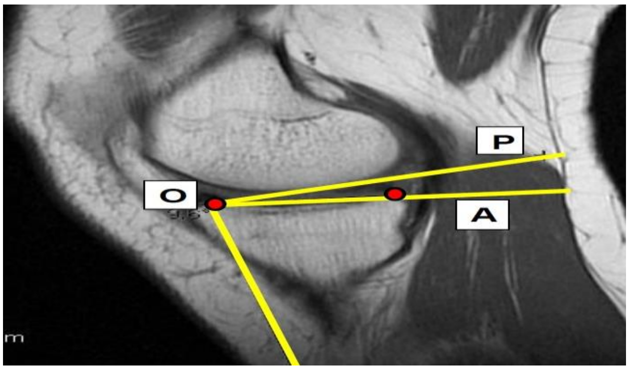

Figure 4: Medial tibial plateau slope (POA).

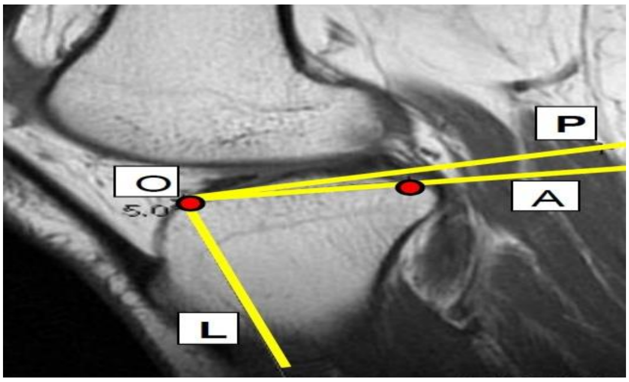

Figure 5: Lateral tibial plateau slope (POA).

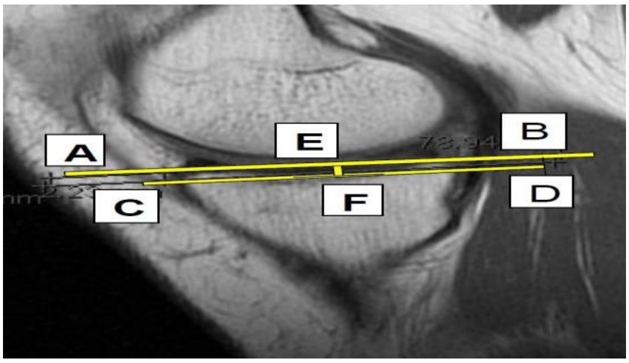

Figure 6: Concavity of the medial tibial plateau (EF).

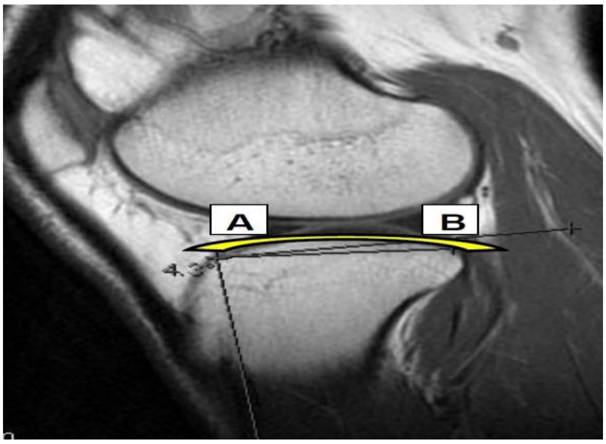

Figure 7: Convexity of the lateral tibial plateau (AB).

All data was analysed using sstatistical version 6 (Tulsa, Oklahoma: StatSoft Inc., 2001) software. Mean, median, range and standard deviation of the MTS, LTS, CMT, CTS were calculated for male, female and the entire population and Kolmogorov-Smirnov test was done to assess whether data was normally distributed or not. Paired student t tests were done to tests for differences between MTS and LTS within individual subject. Student unpaired t tests were done to compare the values of MTS, LTS, CMT and CTS between male and female. Finally, correlation tests were performed to determine the strength of the linear relationship between MTS and LTS, MTS and CTS, LTS and CTS. For all analysis $p<0.05$ was set to be significant.

RESULTS

All measurements of tibial plateau geometry (MTS, LTS, CMT) were taken by three different authors, it was found that there was high inter class correlation coefficient (ICC=0.986), values measured by the senior surgeon were included in the present study.

Mean age of male and female subjects are 31.30±9.40 years and 33.12±13 years respectively. When considering male and female one group (total population) mean MTS, LTS, CMT, CTS were 7.73^0, 4.68^0, 2.56 mm and 2.61^0 respectively. In male population mean MTS, LTS, CMT, CTS were 6.94^0, 3.77^0, 2.7 mm, 3.06^0 respectively. In female population population mean MTS, LTS, CMT, CTS were 9.28^0, 6.45^0, 2.28 mm, 1.75^0 respectively. Descriptive statistics of numerical variables of tibial plateau are summarized in Table 1. Correlation test showed that MTS and LTS, MTS and CTS, LTS and CTS were poorly correlated in pooled population with r value 0.43, -0.01, -0.03 respectively. Similar, results were found in male and female subjects. MTS and LTS was different within each sex group and this was statistically significant ($p<0.05$). Female had significant steeper MTS ($p=0.013$) and LTS ($p=0.001$) but had less CTS ($p=0.04$) and shallow CMT ($p=0.012$) compared to male. Statistically significant tests were summarized in Table 3. Lateral tibial plateau is convex overall but its articular surface is flat.

Table 1: Descriptive statistics of numerical variables of male, female and total population.

Variables	MTS (^{0})	CMT (mm)	LTS (^{0})	CTS (^{0})
Total population (n=500)				
Mean	7.73	2.56	4.68	2.61
Median	7.55	2.51	3.9	1.9
Minimum	0.7	1.68	1.4	0.19
Maximum	13.9	3.71	14.5	10.3
Lower quartile	5.7	2.22	2.7	1.1
Upper quartile	9.6	2.81	6.5	3.5
Std. Dev.	3.204	0.561	2.757	2.152
Standard error	0.453	0.079	0.39	0.304
Male population (n=250)				
Mean	6.94	2.7	3.77	3.06
Median	6.9	2.79	3.4	2.5
Minimum	0.7	1.68	1.4	0.19
Maximum	13.9	3.71	8.6	10.3
Lower quartile	4.5	2.3	2.3	1.1
Upper quartile	8.8	2.85	4.7	4.6
Std. Dev.	3.205	0.553	1.859	2.392
Standard error	0.558	0.096	0.324	0.416
Female population (n=250)				
Mean	9.28	2.28	6.45	1.75
Median	9.5	2.29	6.6	1.5
Minimum	4.2	1.7	2.7	0.4
Maximum	13.4	3.63	14.5	5.1
Lower quartile	7.01	1.95	3.4	0.9
Upper quartile	10.15	2.41	8.1	1.9
Std. Dev.	2.657	0.483	3.364	1.24
Standard error	0.644	0.117	0.816	0.301

Table 2: Comparison of numerical variables of tibial plateau geometry between male and female gender student's unpaired t test.

Variables	Mean	Mean	T value	df	P	Valid n	Valid n	SD	SD
	Male	Female				Male	Female	Male	Female
MTS	6.94	9.28	-2.58	48	0.013*	250	250	3.205	2.657
CMT	2.7	2.28	2.615	48	0.012*	250	250	0.553	0.483
LTS	3.77	6.45	-3.645	48	0.001*	250	250	1.859	3.364
CTS	3.06	1.75	2.111	48	0.04*	250	250	2.392	1.24

*Statistically significant.

Table 3: Results of similar study.

Study		MTS (^{0})	LTS (^{0})	CTS (^{0})	CMT (mm)
Stijak et al[16]	T (N=33)	6.6±3.2	4.4±2.3	NA	NA
Hashemi et al[1] (MRI)	F (N=33)	5.9±3	7±3.1	2.5±1.9	2.7±0.76
	M (N=22)	3.7±3.1	5.4±2.8	3.5±1.9	3.1±0.99
	T (55)	5.02±3.2	6.38±3.04	NA	NA
Hudek et al (MRI)	F (N=55)	4.9	5.7	NA	NA
	M (N=55)	3	4	NA	NA
	T (110)	4.1±2.8	4.9±3.2	NA	NA
Khan et al[5] (MRI)	F (19)	4.17±3.12	3.67±2.54	NA	1.94±0.64
	M (32)	4.17±2.38	2.04±2.28	NA	2.4±0.78
	T (51)	4.81±2.55	2.65±2.48	NA	2.23±0.75
Present study (MRI)	F (250)	9.28±2.65	6.45±3.36	1.75±1.24	2.28±0.48
	M (250)	6.94±3.2	3.77±1.85	3.06±2.39	2.7±0.55
	T (500)	7.73±3.2	4.68±2.75	2.61±2.15	2.56±0.56

*Study based on Lateral Radiograph.

DISCUSSION

Jae et al showed that mean value of tibial plateau slope differed significantly as the reference axis of the tibia changed.[23] However according to Brazier et al the mean value of slope measured by different methods are strongly correlated.[24] The reference axis in the present study is proximal tibial anatomical axis.[1,4] In the present study MTS of the female (MTS=9.28±2.65^0) is greater than the male (MTS=6.94±3.2^0) and the difference is statistically significant (p=0.013) similarly LTS of the female (LTS=6.45±3.36^0) is greater than the male (LTS=3.77±1.85^0) this difference is statistically significant (p=0.001).

In the present study CTS of the male (CTS=3.06±2.39^0) is greater than the female (CTS=1.75±1.24^0) and the difference is statistically significant (p=0.04) which is similar to the study of Hashemi and Khattak et al.[1,3]

According to Hashemi and Khan et al the concavity of medial tibial plateau (CMT) of the male is greater than the female similar results were observed in the present study.[1,5] The results of similar type of studies using conventional MRI and same reference axis were summarized in Table 3.

There were several limitations of the present study. MRI measurements are subject to observer inconsistencies, landmark identification, and image clarity concerns. Further studies regarding other anatomical aspects of the knee such as the medio-lateral and antero-posterior dimensions of the tibia are needed to complete our knowledge regarding the anatomical variations of the tibial plateau geometry in the Indian population.

The risk factors of non-contact ACL injury are multifactorial. Biomechanical study showed increasing slope of the tibial plateau caused increasing stresses on the anterior cruciate ligament during compressive load on knee joint as in standing and walking. Concavity of medial tibial plateau also prevents anterior tibial translation during standing and walking. So, Individuals with a shallower medial tibial depth of concavity, while having increased posteriorly directed slope of their tibial plateau, were at increased risk of suffering an non-contact anterior cruciate ligament injury compared with those with decreased posterior slope and increased medial tibial depth.[5,18] Furthermore, these relationships were different between men and women.[18] From the present study it was found that female had steeper medial and lateral tibial plateau slope but shallower medial tibial plateau compared to male. So female is more susceptible to non-contact ACL injury compared to male. Modification of radiological technique (tibial plateau view) on the basis of tibial plateau slope has been described for diagnosis and measurement of displacement of tibial plateau fracture Moore et al and for assessment of tibiofemoral osteoarthritic changes Sanshiro et al.[6]

CONCLUSION

Subject to subject differences in terms of medial tibial plateau slope, lateral tibial plateau slope, coronal tibial plateau slope and concavity of medial tibial plateau in Indian population could be help in constructing more subject specific implant in total knee replacement for Indian patients. Furthermore, during total knee replacement attempts to place the prosthetic tibial component at a specific slope that reproduces the original compartmental slope of the subject would help in more post-operative range of movement and less implant loosening. From the present study it was found that coronal tibial plateau slope of male was more than the female Indian population. This should be considered when performing TKA in Indian men, as it suggests that an anteroposterior cut of the distal femur should be in increased external rotation to achieve a rectangular flexion gap.

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