Original Research Article

ANTHROPOMETRIC MEASUREMENTS OF THE PROXIMAL TIBIA IN DRY BONES AND CADAVERS: A MORPHOMETRIC STUDY IN A NORTH INDIAN POPULATION

Arun Kumar[1], Arjit Gangwar[2], Rahul Kapoor[3]

[1]*Assistant Professor, Department of Anatomy, Autonomous State Medical College, Pilibhit, Uttar Pradesh, India*
[2]*Assistant Professor, Department of Anatomy, Government Medical College, Budaun, Uttar Pradesh, India*
[3]*Assistant Professor, Department of Orthopaedic, Rama Medical College, Kanpur, Uttar Pradesh, India*

Received : *02/08/2026*
Received in revised form : *28/08/2026*
Accepted : *10/09/2026*

Corresponding Author:
Dr. Arun Kumar,
Assistant Professor, Department of Anatomy, Autonomous State Medical College, Pilibhit, Uttar Pradesh, India.

DOI: 10.70034/ijmedph.2026.3.748

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (3); 4852-4859

ABSTRACT

Background: The morphology of the proximal tibia differs between populations and as according to sex and laterality. For better understanding the morphology of knee correct anthropometric information of the proximal tibia is required and this information is also important for many of the orthopaedic procedures that involve the knee. Many of the previous studies have reported differences in dimensions of upper end of tibia among different populations, by using techniques such as radiography, computed tomography or magnetic resonance imaging. The present study done in dry bones and cadavers to evaluate the anthropometric measurements of the upper end of tibia by direct measurement.

Materials and Methods: This observational prospective study was conducted from April 2019 to September 2020 in the Department of Anatomy in collaboration with the Department of Orthopaedics, King George's Medical University, Lucknow, Uttar Pradesh, India. A total of 401 randomly selected intact and completely ossified dry tibiae of unknown age, sex and stature were studied comprising 206 left and 195 right tibiae along with this 15 formalin preserved cadavers (8 males and 7 females) were also taken in study and both tibiae measured. Length of tibia, anteroposterior and transverse dimensions of the medial and lateral condyles, anterior and posterior intercondylar measurements, anteroposterior and transverse dimensions of the intercondylar area, and bicondylar width were measured. For measuring these measurements directly digital Vernier caliper and osetometric board were used. Statistical analysis was done by using Jamovi version 2.7.31. Student's t-test, paired t-test and Pearson correlation were used during analysis of data of this study.

Results: Among 401 dry tibiae, 206 (51.4%) were of left side and 195 (48.6%) were of right side. Higher value for length of tibia and most of the linear measurements showed by dry tibiae of right side. Statistical significance among right-left differences were observed for tibial length, anteroposterior diameters of superior articular surface of medial condyle (AP-MC), anteroposterior measurement of superior articular surface of lateral condyle (AP-LC), anteroposterior measurement of intercondylar area (AP-IC), transverse diameter of superior articular surface of medial condyle (T-MC), transverse measurement of superior articular surface of lateral condyle (T-LC), transverse measurement of intercondylar area anterior end [T-IC(A)], transverse measurement of intercondylar area middle narrow part [T-IC(M)], transverse measurement of intercondylar area posterior end [T-IC(P)] and anteroposterior measurement of anterior intercondylar area (APIC-A) whereas anteroposterior measurement of posterior intercondylar area (APIC-P) and bicondylar width (BCW) were not significantly different. Linear measurements were high in male in comparison to female, statistically significant sex differences were seen with tibial length, AP-MC, AP-LC, AP-IC, T-LC, T-IC(A), APIC-A, APIC-P and BCW in cadaveric tibiae.

Conclusion: This study provides direct anthropometric measurements of the upper end of tibia from dry bones and cadavers from a North India population. The study demonstrates differences in dimension of upper end of tibia according to laterality in dry tibiae and as per sex in the cadaveric sample.

Keywords: Upper end of tibia, anthropometry, dry bone, cadavers, North India population.

INTRODUCTION

The tibia is a primary structural constituent of the modified hinge joint, and it lies medial to fibula; its shaft is triangular in sections, and its expanded proximal end consist of tibial tuberosity, medial and lateral condylar area which is separated by intercondylar area. The upper end of tibia serves as a critical component of the knee complex because it articulates directly with the femoral condyles to form tibiofemoral joint and it also contributes to transmission of body weight from the femur bone (above) to the talus bone of foot (below). By using direct anatomical measurements as well as radiography, computed tomography (CT) and magnetic resonance imaging (MRI) techniques anthropometric measurements of the upper end of tibia have been investigated. Westrich et al. evaluated proximal tibial anatomy using resection specimens and demonstrated differences between medial and lateral tibial plateau dimensions.[1] Uehara et al. measure the proximal tibial dimensions in 80 Japanese patients, who were undergoing total knee arthroplasty (TKA) and reported population specific measurements pertinent to tibial component design.[2] Hitt et al. collected morphological data from the distal part of femur, proximal part of tibia and patella from 337 knees and reported for tibial aspect ratio from data that a higher ratio for smaller knees and proportionally lower ratio for larger knees, gender differences in the morphological data were also seen across variable tibial aspects ratio.[3] Studies in Asian populations have also demonstrated that there is presence of differences in morphology of upper end of tibia. Kwak et al. conducted anthropometric analysis by using 3-dimensional CT measurements of cut surface of upper end of tibia in 200 knees of Korean cadavers and reported the presence of differences between measured dimensions of proximal tibia and commercially available symmetric tibial components.[4] Surendran et al. evaluated anthropometry of medial condyle of tibia for designing the tibial component in unicondylar knee arthroplasty among Korean population.[5] Cheng et al. conducted a 3-dimenison morphometry of knee to design TKA among Chinese population and reported variation between proximal tibial dimensions and conventional knee prostheses.[6] Regional variation in the morphology of upper end of tibia has been reported by Indian studies. Gandhi et al. reported significant sex related differences in the measured parameters on doing morphometric analysis of proximal tibia among fifty male and fifty female and.[7] Murlimanju et al. conducted a study on 73 dry cadaveric tibiae to evaluate morphometry of lateral and medial tibial plateau in South Indian population and reported differences between measurements of both plateau.[8] Zalawadia et al. did morphometric study of proximal tibia on 120 dry tibia of known gender in Gujarat region and reported all take five different parameters was larger significantly in male than females.[9]

Based on indirect techniques such as CT, MRI and radiography there were various studies and so, this present study was undertaken to record direct anthropometric measurements of the proximal tibia in dry bones and cadavers from North India population.

MATERIALS AND METHODS

Study design and setting: An observational prospective study conducted in the Department of Anatomy in collaboration with the Department of Orthopaedics, King George's Medical University, Lucknow, Uttar Pradesh, India from April 2019 to September 2020.

Ethical clearance: The approval for the study was obtained from the Institutional Ethical Committee of King George's Medical University, UP, Lucknow, vide letter number 1507/Ethics/2019, Ref. code 98th ECM II B- Thesis/P6.

Sample size and Sampling technique: This study was conducted on two different groups of samples: dry tibiae and human cadavers.

Dry bone study: A total of 401 intact, ossified completely dry tibiae were included and of these totals, 206 were left sided and remaining 195 were right sided. The dry tibiae were selected randomly from Osteology Laboratory of the Department of Anatomy, King George's Medical University, Lucknow and the age, sex and stature of the individuals from whom the bones were obtained were unknown.

Cadaveric study: 15 freshly formalin preserved cadavers including 8 males and 7 females and both right tibia and left tibia of each cadaver were examined. Overall, that means measurement of 30 tibiae.

Inclusion and Exclusion criteria

Freshly formalin preserved cadavers and normal dry tibia bones of both sexes 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.

Data collection: From 410 dry tibiae and 15 freshly formalin preserved cadavers' data were collected.

Instruments were used: Digital Vernier caliper, osteometric board, measuring rulers, protractor, goniometer, marker pen, pencil, white paper and instruments for dissection.

Anthropometric measurements: Direct measurements were done to record all the linear measurements. Tibial length was measured by using osetometric board from the highest point of the intercondylar eminence to the tip of medial malleolus. Anteroposterior diameter of medial condyle (AP-MC) is the maximum distance between the anterior and posterior borders of the superior articular surface of the medial condyle, the anterior most and posterior most points were identified and the distance between these points was measured using a Vernier caliper. Transverse diameter of medial condyle (T-MC), maximum transverse diameter of the superior articular surface of the medial condyle was measured between the medial most and lateral most points of the articular surface. Anteroposterior diameter of lateral condyle (AP-LC) was measured as maximum distance between anterior and posterior borders of superior articular surface of the lateral condyle. Transverse diameter of lateral condyle (T-LC) was measured between the medial-most and lateral-most points of the superior articular surface. Anteroposterior diameter of intercondylar area (AP-IC) was the maximum distance between the anterior and posterior borders of the intercondylar area was measured. Transverse diameter of intercondylar area (T-IC) was measured at anterior level [T-IC (A)], middle/narrowest level [T-IC (M)] and posterior level [T-IC (P)] and at each level the maximum transverse distance between the medial and lateral borders of the intercondylar area was measured. Anteroposterior measurement of anterior intercondylar area (APIC-A) was measured from anterior border of intercondylar area to a line join the intercondylar eminence. Anteroposterior measurement of posterior intercondylar area (APIC-P) was measured between the line joins the intercondylar eminence and posterior border of intercondylar area. Bicondylar width (BCW) was defined as maximum mediolateral length of the upper end of the tibia and was measured from medial most point of superior articular surface of the medial condyle to the lateral most point of the superior articular surface of the lateral condyle.

Cadaveric procedure: Fifteen cadavers were positioned in supine position and a midline vertical skin incision approximately 12-15 cm long was made over anterior aspect of the knee with horizontal extensions at both ends, further the skin flaps were reflected to expose knee region. After excision of ligamentum flavum the knee was flexed to 90°. The knee joint was exposed and the menisci were removed, further the anterior cruciate ligament (ACL) was cut at its tibial attachment to expose medial and lateral tibial plateaus and intercondylar area. The linear measurements of the medial and lateral plateaus were done by using the same measurement methods used for the dry bone study, while similar method also applied for measuring the intercondylar area. The length of tibia was measured by extending the knee and the distance from the highest point of the intercondylar eminence to the tip of the medial malleolus was measured.

Statistical Analysis: Statistical analysis was performed by using Jamovi, version 2.7.31. The results were reported as number, percentage (%) and mean ± standard deviation (SD). Student's t test was used for comparing two means whereas paired t test was used for paired comparisons. Pearson correlation was used to check the correlation between tibial length and other measurements.

Pearson correlation coefficients were classified as:

$r < 0.3$: - weak or no correlation
$r = 0.3$-0.5: - mild correlation
$r = 0.5$-0.7: - moderate correlation
$r = 0.7$-0.9: - strong correlation
$r > 0.9$: - very strong to perfect correlation

The level of significance reported as:

$p > 0.05$: - not significant
$p < 0.05$: - significant
$p < 0.01$: - highly significant
$p < 0.001$: - very highly significant.

RESULTS

A total 431 tibiae were included in this study; in that 401 were dry, intact, completely ossified tibia bone [206 (51.4%) of left side and 195 (48.6%) of right side] and 30 cadaveric tibiae from 15 cadavers [15 (50%) of left and 15 (50%) of right – side]. Among 15 cadavers 8 were males and 7 were females. Overall, 221 (51.3%) were left tibiae and 210 (48.7%) were right tibiae.

Dry bone anthropometric measurements: The laterality wise distribution of the linear anthropometric measurements of the upper end of tibia was assessed. The mean values of AP-MC, T-MC, AP-LC, T-LC, AP-IC, T-IC(A), T-IC(M), T-IC(P), APIC-A and BCW were high for the right side in comparison to left side whereas APIC-P was slightly high for the left side and the differences between right and left sides were significant statistically for AP-MC, T-MC, AP-LC, T-LC, AP-IC, T-IC(A), T-IC(M), T-IC(P) and APIC-A; while APIC-P and BCW were not statistically significant. [Table 1]

The anteroposterior dimensions of the medial condyle were greater than lateral condyle in both right and left sided dry tibiae; the mean difference between AP-MC and AP-LC was 5.48 ± 2.72 mm on the left side and 5.82 ± 3.31 mm on the right side and these differences were statistically significant for both sides and also for the overall sample ($p < 0.001$). The transverse dimensions of the medial condyle were smaller than lateral condyle; the mean differences were -1.10 ± 3.19 mm on the left side and -0.19 ± 3.31 mm on the right side, and these differences were also statistically significant for both sides along with for overall sample (p <0.001). [Table 2]

Table 1: Laterality wise comparison of linear anthropometric measurements of dry tibiae

Characteristic	Left (n = 206) Mean (SD)	Right (n = 195) Mean (SD)	t-value	p-value
Tibial length	357.86 (25.82)	364.21 (21.80)	-2.654	0.008
AP-MC	41.51 (3.76)	42.60 (3.78)	-2.894	0.004
T-MC	28.87 (3.46)	29.77 (3.10)	-2.754	0.006
AP-LC	36.02 (3.18)	36.78 (3.51)	-2.257	0.025
T-LC	29.96 (3.12)	30.68 (3.38)	-2.207	0.028
AP-IC	45.34 (4.31)	46.51 (3.66)	-2.925	0.003
T-IC(A)	27.48 (3.68)	28.50 (5.16)	-2.274	0.025
T-IC(M)	10.94 (1.86)	11.32 (1.90)	-2.025	0.044
T-IC(P)	15.81 (2.74)	16.70 (2.72)	-3.259	0.001
APIC-A	26.27 (3.40)	27.57 (3.06)	-4.017	<0.001
APIC-P	19.34 (2.17)	19.07 (1.87)	1.342	0.18
BCW	69.18 (5.51)	69.77 (8.28)	-0.847	0.4

{mm (millimetre) was the metric unit used for all length measured; Mean (SD) was calculated and p-value for laterality comparisons were obtained by using an independent-sample Student's t-test}

Table 2: Comparison of medial and lateral condylar dimensions in dry tibiae

Comparison	Group	Mean difference ± SD (mm)	95% Confidence Interval		t-value	p-value
			Lower	Upper		
AP-MC and AP-LC	Left (n = 206)	5.48 ± 2.72	5.11	5.86	28.9	<0.001
	Right (n = 195)	5.82 ± 3.31	5.35	6.29	24.5	<0.001
	Overall (n = 401)	5.65 ± 3.02	5.35	5.94	37.4	<0.001
T-MC and T-LC	Left (n = 206)	-1.10 ± 3.19	-1.53	-0.66	-4.9	<0.001
	Right (n = 195)	-0.91 ± 3.31	-1.37	-0.44	-3.8	<0.001
	Overall (n = 401)	-1.00 ± 3.25	-1.32	-0.69	-6.1	<0.001

{Mean differences were calculated as medial minus lateral measurement; positive value indicates greater medial measurement while negative indicate greater lateral measurement. Paired Student's t-test was used}

Positive correlations were observed between tibial length and all other measured lengths of upper end of tibia; correlation coefficients ranged from 0.124 for T-IC(P) to 0.539 for AP-LC and the strongest correlation were observed for AP-LC (r = 0.539), AP-IC (r = 0.530), AP-MC (r = 0.523), T-LC (r = 0.442), BCW (r = 0.432), T-MC (r = 0.426), APIC-A (r = 0.422) and the correlations for T-IC(M) (r = 0.174) and T-IC(P) (r = 0.124) were smaller. All measured parameters were statistically significant. [Table 3]

Table 3: Correlation of tibial length with other measured parameters of dry tibiae

Parameters	Pearson Correlation coefficient (r)	Level of correlation	p-value	Significance level
AP-MC	0.523	Moderate	<0.001	Very Highly significant
AP-LC	0.539	Moderate	<0.001	Very Highly significant
AP-IC	0.530	Moderate	<0.001	Very Highly significant
T-MC	0.426	Mild	<0.001	Very Highly significant
T-LC	0.442	Mild	<0.001	Very Highly significant
T-IC(A)	0.368	Mild	<0.001	Very Highly significant
T-IC(M)	0.174	Weak	0.007	Highly significant
T-IC(P)	0.124	Weak	0.013	Significant
APIC-A	0.422	Mild	<0.001	Very Highly significant
APIC-P	0.368	Mild	<0.001	Very Highly significant
BCW	0.432	Mild	<0.001	Very Highly significant

{Pearson correlation was calculated using total tibial length}

Cadaveric anthropometric measurements: The gender wise comparison of linear anthropometric measurements of cadaveric tibiae showed mean values were greater in male tibiae than female tibiae. The mean tibial length was 340.75 ± 10.71 mm in female tibiae while in male it was 384.55 ± 7.33 mm and differences were statistically significant (p <0.001). Among other parameters AP-MC, T-MC, AP-LC, T-LC, AP-IC, T-IC(A), APIC-A, APIC-P and BCW were having gender wise differences statistically significant whereas remaining parameters like T-MC, T-IC(M) and T-IC(P) were no statistically significant gender wise differences. {Table 4}

Table 4: Gender-wise comparison of linear anthropometric measurements in cadaveric tibiae

Characteristic	Female (n = 14) Mean (SD)	Male (n = 16) Mean (SD)	t-value	p-value
Tibial length	340.75 (10.71)	384.55 (7.33)	-13.213	<0.001
AP-MC	41.95 (4.92)	46.87 (3.12)	-3.31	0.004
T-MC	30.14 (4.10)	32.39 (3.82)	-1.556	0.13

AP-LC	36.42 (3.59)	39.56 (2.56)	-2.786	0.012
T-LC	29.42 (3.23)	33.08 (2.99)	-3.22	0.003
AP-IC	43.37 (5.29)	50.18 (2.67)	-4.542	<0.001
T-IC(A)	23.26 (2.39)	26.79 (3.67)	-3.076	0.004
T-IC(M)	9.89 (1.74)	10.64 (1.08)	-1.455	0.17
T-IC(P)	16.83 (3.26)	17.61 (2.04)	-0.791	0.45
APIC-A	24.45 (3.67)	29.74 (2.40)	-4.728	<0.001
APIC-P	19.22 (1.74)	20.90 (2.02)	-2.433	0.02
BCW	67.36 (3.83)	77.63 (4.06)	-7.102	<0.001

{Mean ± SD were calculated; p-value were obtained using an independent sample Student's t-test}

On laterality wise comparison of 30 cadaveric tibiae; the mean tibial length was 363.44 ± 24.47 mm on left and 364.78 ± 24.24 mm on right side with no statistically significant difference (p = 0.172) while other linear anthropometric measurements were also showing no statistically significant difference between left and right cadaveric tibiae. [Table 5]

Table 5: Laterality wise comparison of various linear anthropometric measurements of cadaveric tibiae

Characteristic	Left (n = 15) Mean (SD)	Right (n = 15) Mean (SD)	t-value	p-value
Tibial length	363.44 (24.47)	364.78 (24.24)	-0.151	0.88
AP-MC	44.72 (4.78)	44.43 (4.78)	0.1611	0.87
T-MC	31.68 (4.05)	31.00 (4.16)	0.4487	0.66
AP-LC	37.99 (3.45)	38.20 (3.52)	-0.164	0.87
T-LC	31.80 (3.60)	30.95 (3.61)	0.6511	0.52
AP-IC	47.21 (5.27)	46.80 (5.52)	0.2093	0.84
T-IC(A)	25.53 (3.74)	24.75 (3.47)	0.5861	0.56
T-IC(M)	10.45 (1.52)	10.13 (1.41)	0.5805	0.57
T-IC(P)	17.19 (2.60)	17.31 (2.81)	-0.1194	0.91
APIC-A	27.04 (3.87)	27.49 (4.31)	-0.3006	0.77
APIC-P	20.53 (1.88)	19.70 (2.20)	1.1142	0.27
BCW	72.94 (6.64)	72.73 (6.58)	0.087	0.93

{Values are expressed in Mean (SD); independent samples Student's t-test was used to compare left and right sides}

The anteroposterior dimensions of medial condyle were greater in comparison to lateral in both left and right-side cadaveric tibiae; the mean difference between AP-MC and AP-LC in left and right side were 6.72 ± 3.95 mm and 6.23 ± 4.07 mm respectively whereas the overall mean difference was 6.48 ± 3.95 mm and was statistically significant (p = <0.001). The mean difference between T-MC and T-LC was -0.13 ± 2.78 mm on left and 0.06 ± 2.93 mm on right while the overall mean difference was -0.03 ± 2.80 mm and it was not statistically significant (p = 0.949). [Table 6]

Table 6: Comparison of medial and lateral condylar dimensions in cadaveric tibiae

Comparison	Group	Mean difference ± SD	95% CI		t-value	p-value
			Lower	Upper		
AP-MC & AP-LC	Left (n=15)	6.72 ± 3.95	4.54	8.91	6.593	<0.001
	Right (n=15)	6.23 ± 4.07	3.98	8.49	5.932	<0.001
	Overall (n=30)	6.48 ± 3.95	5.01	7.95	8.987	<0.001
T-MC & T-LC	Left (n=15)	-0.13 ± 2.78	-1.66	1.41	-0.175	0.864
	Right (n=15)	0.06 ± 2.93	-1.56	1.68	0.078	0.939
	Overall (n=30)	-0.03 ± 2.80	-1.08	1.01	-0.064	0.949

{Mean differences were calculated by medial minus lateral measurement and paired Student's t-test was used}

The correlation coefficients ranged from r = 0.060 for T-IC(P) to r = 0.791 for BCW; while the significant positive correlations were seen for AP-MC, AP-IC, T-MC, T-LC, T-IC(A), APIC-A, APIC-P and BCW; whereas T-IC(M) and T-IC(P) were not statistically significant. [Table 7]

Table 7: Correlation of tibial length with other measured parameter of cadaveric tibiae

Parameters	Pearson correlation coefficient (r)	Level of correlation	p-value	Significance level
AP-MC	0.580	Moderate	<0.001	Very highly significant
AP-LC	0.436	Mild	0.436	Not significant
AP-IC	0.727	Strong	<0.001	Very highly significant
T-MC	0.372	Mild	0.043	Significant
T-LC	0.587	Moderate	<0.001	Very highly significant
T-IC(A)	0.442	Mild	0.014	Significant
T-IC(M)	0.309	Mild	0.096	Not significant
T-IC(P)	0.060	Weak	0.752	Not significant
APIC-A	0.689	Moderate	<0.001	Very highly significant
APIC-P	0.525	Moderate	0.003	Very highly significant
BCW	0.791	Strong	<0.001	Very highly significant

{Pearson correlation was calculated by using total tibial length}.

DISCUSSION

The present study evaluated the linear anthropometry of the upper end of tibia by using direct measurements of 401 dry tibiae and 30 cadaveric tibiae and the main outcome was that several proximal tibial dimensions were different between right and left side of dry bone sample, the anteroposterior dimensions of medial condyle was greater than lateral condyle, male cadaveric tibiae were larger than female tibiae for most of the measured parameters and the tibial length was showing positive correlation with majority of upper end of tibial measurements.

The mean AP-MC in the present dry bone sample was measured 41.51 ± 3.76 mm on the left and 42.60 ± 3.78 mm on the right while AP-LC was 36.02 ± 3.18 mm and 36.78 ± 3.51 mm, respectively; medial condyle was consistently larger than the lateral condyle in the anteroposterior direction and this finding is consistent with established asymmetry of tibial plateau. Murlimanju et al. reported AP length of medial plateau was 39.8 ± 3.8 mm and of lateral plateau was 33.6 ± 3.7 mm with the lateral plateau significantly smaller than medial in a study of 73 dry South India tibiae.[8] Bhadoria et al. reported greater AP and transverse dimensions of medial condyle of tibia in comparison to lateral condyle among North Indian population.[10] Anteroposterior dimension of medial condyle was greater than lateral in both left and right dry tibiae and in the cadaveric tibiae; whereas in transverse dimensions T-MC was significantly smaller than T-LC in dry tibiae while the transverse medial-lateral differences were not significant statistically in cadaveric tibiae. Studies using three-dimensional reconstruction and imaging have also showed presence of substantial asymmetry of upper end of tibia. Cheng et al. demonstrated substantial variation in proximal tibial dimensions and showed morphology of upper end of tibia changes with sex and overall size.[6] Nakamura et al. demonstrated changes in AP, ML and medial to lateral AP relationships at different levels of upper end tibial resection.[11] Several parameters in this study were significantly larger on the right side like-AP-MC, T-MC, AP-LC, T-LC, T-IC(A), T-IC(M), T-IC(P), APIC-A while the other two APIC-P and BCW did not significantly differ between sides. Murlimanju et al. showed no significant right-left differences for most of measured plateau parameters in South Indian dry tibiae aside from lateral plateau length 8. In cadaveric tibiae, none of the laterality comparisons reached statistical significance. Male cadaveric tibiae had greater mean values for all measured linear parameters in comparison to female cadaveric tibiae; statistical significant differences were seen among tibial length, AP-MC, AP-LC, T-LC, AP-IC, T-IC(A), APIC-A, APIC-P and BCW whereas T-MC, T-IC(M) AND T-IC(P) showed no statistically significant differences. The difference in tibial length, mean of 340.75 ± 10.71 mm in female tibiae and 384.55 ± 7.33 mm in male tibiae while for BCW 67.36 ± 3.83 mm in females and 77.63 ± 4.06 mm in males. Lucena-dos-Santos et al. reported significantly greater values for all ten measured proximal tibia measurements in males in comparison to females including medial and lateral condylar and intercondylar measurements among 60 pairs of adult tibiae.[12] Gandhi et al. demonstrated significant gender differences across measurements of proximal tibia in their North Indian sample.[7] Korean MRI-based morphometric analysis showed significant large upper end of tibia dimensions in men and difference in tibial aspect ratio between male and female.[13] Yang et al. reported significant gender related differences among ML, AP, medial AP and lateral AP dimensions of the upper end of tibia in Chinese knees.[14] Wise et al. on statistical shape analysis demonstrated significant gender associated differences in upper end of tibial shape after adjusting demographic factors.[15] The gender linked differences was seen in this cadaveric related sample study, therefore need of broader literature. In intercondylar dimensions of dry tibiae, the right side showed significantly greater value for AP-IC, T-IC(A), T-IC(M), T-IC(P) and APIC-A while APIC-P was not differed significantly. Zheng et al. showed substantial variability in morphology and position of soft tissue insertion on tibial plateau by using three-dimensional models of cadaveric tibiae and founded these relation could not always predicted adequately from single tibial dimensions.[16] The tibial length showed positive correlation with all measured proximal tibial parameters in dry bone sample and the strongest were seen with AP-LC, AP-IC, AP-MC, T-LC, BCW, T-MC, APIC-A, T-IC(A) and APIC-P whereas T-IC(M) and T-IC(P) had weaker correlation; while in cadaveric tibiae positive correlations were seen for all measured parameters and overall strongest was showed by BCW ($r = 0.791$). The relation between overall bone size and upper end of tibia dimensions is consistent with morphometric studies and demonstrating that size is one of the important components of proximal tibial variation because here finding in this study indicated larger tibiae having larger proximal tibial dimensions. Dai et al. did comprehensive assessment of 347 digital tibial models and reported that dominant source of morphological variation was overall size and it was contributed by asymmetry and aspect-ratio differences.[17]

The differences between the measurements of tibiae in this study and those reported in other populations reflects the population dependent morphological nature of proximal tibial. Moghtadaei et al. did study on Iranian population and reported significant gender related differences in upper end of tibial dimensions and existence of asymmetry between medial and lateral anteroposterior dimensions.[18] Small proximal tibial dimensions in females and asymmetry between medial and lateral AP dimensions was also shown in MRI-based study of Iranian knees.[19] Miyatake et al. did intraoperative analysis of 703 knees in 566 Japanese patients and showed the importance of matching tibial component to the actual resected tibial morphology.[20] Hafez et al. did study on Arabian knees likewise and showed population specific AP and ML dimensions and compared these measurements with available implant dimensions.[21] Shah et al. demonstrated on the basis of their MRI based study that asymmetric tibial trays achieved greater tibial coverage than symmetric designs and that coverage varied according to sex.[22] Anthropometry of proximal tibia is of great importance clinically and relevant to the total knee arthroplasty.

Strength: The main strength of this study is its large dry bone sample of 401 tibiae, and it allows detail assessment of multiple proximal tibial dimensions, there was also cadaveric components included which provided additional information. Direct anthropometric measurements of proximal tibia rather than dependency on radiography or other imaging techniques, multiple dimensions of the medial and lateral condyles and intercondylar region were evaluated was also one of the strengths of this study. The study examined laterality, gender related differences in cadaveric tibiae, condylar differences between medial and lateral and correlation of tibial length with other measured parameters and these all provides multidimensional information of proximal tibia morphology. Use of clearly defined anatomical landmarks and standardized measurement provide an informative anatomical dataset that can be used for comparison with other morphometric studies.

Limitation: The dry bones were taken from single institutional osteology collection; along with this the age, gender and stature were unknown so age and gender specific analysis could not be performed on dry bones sample. The cadaveric samples were small, only 15 and so it limits precision and generalizability. This study was also conducted at a single centre and for this reason the findings may not represent the entire Indian population. Measurements were performed on the intact proximal tibial articular surface. The dry bone and cadaveric tibiae differ in demographic availability and sample structure, and so comparison will be inappropriate.

CONCLUSION

This respective study demonstrates considerable measurable variation in linear anthropometry of the upper end of tibia. Several dimensions differed significantly between the right and left sides while the medial condyle showed greater anteroposterior dimension than the lateral condyle in dry tibiae. Male dimensions were consistently greater than female dimensions for all measured parameters, all gender wise differences not reached to statistical significance and even the laterality differences were not significant statistically in cadaveric tibiae. Tibial length showed positive correlation with most of the proximal tibial dimensions and so it shows relation between overall tibial size and proximal morphology. The finding supports asymmetric and population dependent nature of upper end of tibia anatomy and provide direct morphometric data from an Indian sample. These measurements may serve as anatomical reference data for further studies of morphology regarding upper end of tibia and for investigation in terms of implant size and design; nevertheless, direct application of measurements for implant selection requires correlation with standardized resection surface and clinical studies.

Acknowledgement: The authors acknowledge the Department of Anatomy, King George's Medical University, Lucknow, Uttar Pradesh, India for providing access to the osteology laboratory, cadaveric material and institutional facilities required for the study. The authors also acknowledge the Department of Orthopaedics, King George's Medical University, Lucknow, Uttar Pradesh, India for its academic and clinical collaboration. The authors are grateful to the technical and supporting staff of the Department of Anatomy for their assistance in specimen preparation and measurement procedures.

REFERENCES

1. Westrich GH, Haas SB, Insall JN, Frachie A. Resection specimen analysis of proximal tibial anatomy based on 100 total knee arthroplasty specimens. J Arthroplasty. 1995;10(1):47-51. doi:10.1016/s0883-5403(05)80100-7
2. Uehara K, Kadoya Y, Kobayashi A, Ohashi H, Yamano Y. Anthropometry of the proximal tibia to design a total knee prosthesis for the Japanese population. J Arthroplasty. 2002;17(8):1028-1032. doi:10.1054/arth.2002.35790
3. Hitt K, Shurman JR, Greene K, et al. Anthropometric measurements of the human knee: correlation to the sizing of current knee arthroplasty systems. J Bone Joint Surg Am. 2003;85-A Suppl 4:115-122.
4. Kwak DS, Surendran S, Pengatteeri YH, et al. Morphometry of the proximal tibia to design the tibial component of total knee arthroplasty for the Korean population. The Knee. 2007;14(4):295-300. doi:10.1016/j.knee.2007.05.004
5. Surendran S, Kwak DS, Lee UY, et al. Anthropometry of the medial tibial condyle to design the tibial component for unicondylar knee arthroplasty for the Korean population. Knee Surg Sports Traumatol Arthrosc Off J ESSKA. 2007;15(4):436-442. doi:10.1007/s00167-006-0188-5
6. Cheng FB, Ji XF, Lai Y, et al. Three dimensional morphometry of the knee to design the total knee arthroplasty for Chinese population. The Knee. 2009;16(5):341-347. doi:10.1016/j.knee.2008.12.019
7. Gandhi S, Singla RK, Kullar JS, Suri RK, Mehta V. Morphometric analysis of upper end of tibia. J Clin Diagn Res JCDR. 2014;8(8):AC10-13. doi:10.7860/JCDR/2014/8973.4736
8. Murlimanju BV, Purushothama C, Srivastava A, et al. Anatomical morphometry of the tibial plateau in South Indian population. Ital J Anat Embryol. Published online 2016:258-264. doi:10.13128/IJAE-20275
9. Zalawadia AZ, M Patel S. MORPHOMETRIC STUDY OF UPPER END OF TIBIA IN GUJARAT REGION AND ITS CLINICAL IMPLICATION IN KNEE ARTHROPLASTY. Int J Anat Res. 2018;6(1.1):4871-4875. doi:10.16965/ijar.2017.493
10. Pooja B, Babita P, Sabita M. MORPHOMETRIC STUDY OF PROXIMAL END OF TIBIA WITH ITS CLINICAL IMPLICATIONS IN NORTH INDIAN POPULATION. J Evol Med Dent Sci. 2018;7(23):2801-2806. doi:10.14260/jemds/2018/632
11. Nakamura S, Morita Y, Ito H, Kuriyama S, Furu M, Matsuda S. Morphology of the Proximal Tibia at Different Levels of

Bone Resection in Japanese Knees. J Arthroplasty. 2015;30(12):2323-2327. doi:10.1016/j.arth.2015.05.056
12. Lucena-dos-Santos ERS, Albuquerque PPF de, Albuquerque PV de, et al. Determinación del Sexo Basada en la Evaluación Morfométrica de la Tibia Proximal. Int J Morphol. 2018;36(1):104-108. doi:10.4067/S0717-95022018000100104
13. Lim HC, Bae JH, Yoon JY, Kim SJ, Kim JG, Lee JM. Gender differences of the morphology of the distal femur and proximal tibia in a Korean population. The Knee. 2013;20(1):26-30. doi:10.1016/j.knee.2012.05.010
14. Yang B, Yu JK, Zheng ZZ, Lu ZH, Zhang JY, Cheng JH. Computed tomography morphometric study of gender differences in osteoarthritis proximal tibias. J Arthroplasty. 2013;28(7):1117-1120. doi:10.1016/j.arth.2012.07.036
15. Wise BL, Liu F, Kritikos L, et al. The association of distal femur and proximal tibia shape with sex: The Osteoarthritis Initiative. Semin Arthritis Rheum. 2016;46(1):20-26. doi:10.1016/j.semarthrit.2016.02.006
16. Zheng L, Harner CD, Zhang X. The Morphometry of Soft Tissue Insertions on the Tibial Plateau: Data Acquisition and Statistical Shape Analysis. PLoS ONE. 2014;9(5):e96515. doi:10.1371/journal.pone.0096515
17. Dai Y, Bischoff JE. Comprehensive assessment of tibial plateau morphology in total knee arthroplasty: Influence of shape and size on anthropometric variability. J Orthop Res Off Publ Orthop Res Soc. 2013;31(10):1643-1652. doi:10.1002/jor.22410
18. Moghtadaei M, Moghimi J, Farahini H, Jahansouz A. Morphology of proximal tibia in Iranian population and its correlation with available prostheses. Med J Islam Repub Iran. 2015;29:225.
19. Karimi E, Zandi R, Norouzian M, Birjandinejad A. Correlation of Anthropometric Measurements of Proximal Tibia in Iranian Knees with Size of Current Tibial Implants. Arch Bone Jt Surg. 2019;7(4):339-345.
20. Miyatake N, Sugita T, Aizawa T, et al. Comparison of intraoperative anthropometric measurements of the proximal tibia and tibial component in total knee arthroplasty. J Orthop Sci. 2016;21(5):635-639. doi:10.1016/j.jos.2016.06.003
21. Hafez MA, Sheikhedrees SM, Saweeres ESB. Anthropometry of Arabian Arthritic Knees: Comparison to Other Ethnic Groups and Implant Dimensions. J Arthroplasty. 2016;31(5):1109-1116. doi:10.1016/j.arth.2015.11.017
22. Shah S, Agarwal N, Jain A, Srivastav S, Thomas S, Agarwal S. MRI Based Comparison of Tibial Bone Coverage by Five Knee Prosthesis: Anthropometric Study in Indians. J Arthroplasty. 2015;30(9):1643-1646. doi:10.1016/j.arth.2015.03.041.