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Original Article

Anatomy Section

Comparison of Morphometric Data of Upper End of the Tibia between North and East Indian Populations: A Cross-sectional Study

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ABSTRACT

Introduction: Knee joint problems, such as Osteoarthritis (OA), primarily affect the upper weight-bearing end of the tibia. Total and unicompartmental knee arthroplasty are commonly performed as treatment options. However, existing studies on morphometric assessment of the knee joint mainly focus on the Western population, with a lack of data among the Indian population. Obtaining such data is crucial for designing tibial components of knee prostheses tailored to the Indian population.

Aim: To compare the morphometric data of the upper end of the tibia between the North and East Indian populations.

Materials and Methods: A cross-sectional observational study was conducted in the Department of Anatomy at FMHS Medical College, SGT University, Gurugram, Haryana, North India, involving 41 dry tibias, and at Medical College and Hospital Kolkata in East India, involving 43 dry tibias. Measurements of the Anteroposterior (AP) and Transverse Diameters (TD) of the Medial Tibial Condyle (MTC), Lateral Tibial Condyle (LTC), and Total Tibial Condyles (TTC) were performed using digital Vernier callipers with a least count of 0.01 mm. The data was statistically analysed using Statistical Package for Social Sciences (SPSS) (version 21.0), and Student's t-test was applied, with $p<0.05$ considered significant.

Results: The mean TD and AP diameters of the tibial plateau were found to be greater in the East Indian population (TD: 65.47±5.46, AP: 44.29±4.36). In both samples, the AP diameter of MTC (North Indians: 38.30±3.54, East Indians: 40.63±3.46) was greater than that of LTC (North samples: 35.30±3.51, East samples: 35.70±3.96). When comparing parameters between the North and East samples using Student's t-test, significant differences were found on the right-side for the mean AP (p-value=0.0065) and TD (p-value=0.0213) of TTC, mean AP (p-value=0.0006) and TD (p-value=0.0219) of MTC, mean TD of LTC (p-value=0.0002), mean AP (p-value=0.0005) and TD ($p<0.0001$) of the Intercondylar area at anterior ends, and mean AP ($p<0.0001$) and TD (p-value=0.0017) of the Intercondylar area at posterior ends. On the left-side, significant differences between the North and East population were found for mean TD of LTC (p-value=0.0348), AP ($p<0.0001$) and TD (p-value=0.0207) of the Intercondylar area posterior end. When comparing the areas between the North and East populations, significant differences were found on the right-side only for the MTC (p-value=0.0013), LTC (p-value=0.0083), and TTC (p-value=0.0055).

Conclusion: There are significant regional variations in the anthropometric measurements of the North and East Indian populations, emphasising the need to develop population-specific tibial prostheses for improved surgical outcomes.

Keywords: Condyle, Osteoarthritis, Prosthesis, Surgical outcomes

INTRODUCTION

Cases of early-age OA of the knee are on the rise, and the condition worsens with old age. OA is a common indicator for Total Knee Arthroplasty (TKA) [1]. The World Health Organisation (WHO) studied the prevalence of OA from 1998 to 2015 and found that the number of OA cases is increasing by 10-15% every year. Along with it, the burden of musculoskeletal disability is also on the rise [2]. The knee joint is the largest synovial joint in the human body, consisting of two femorotibial articulations between the lateral and medial condyles of each bone, as well as one femoropatellar articulation.

The proximal end of the tibia bone widens to form medial and lateral condyles. The medial condyle is comparatively larger and ovoid, while the lateral condyle is smaller and circular [3]. The articular surfaces of the upper end are separated by an intercondylar eminence, which is surrounded by relatively rough anterior and posterior intercondylar areas. The tibial intercondylar tubercles and areas provide attachment for the menisci, which are the principal ligaments of the knee that hold the femur and tibia together [4]. The relatively incongruent nature of the joint space makes the knee joint inherently mobile. Proper interaction between the articular surfaces of the knee joint is necessary for movement and locomotion. Therefore, knowledge of the morphometry of the articular surfaces of both the upper and lower ends of the tibia is important [5].

Morphometric measurements of the tibia are very close to the living state, as it resists erosive forces and maintains its anatomical shape for a longer time [6]. Zalawadia AZ and Patel SM, mentioned that obesity is one of the important causes of the high incidence of OA [7]. Total knee replacement surgery can be beneficial for reducing pain and improving the lifestyle of patients with severe OA. However, a mismatch of the selected prosthesis may lead to severe complications such as cruciate ligament rupture, limited movement of the knee joint after surgery, and even loosening of the prosthesis. Therefore, knee prostheses made according to morphometric data of the femur and tibia will yield excellent results and fewer postoperative complications.

Total knee replacement surgery includes a resurfacing and realignment procedure to produce a pain-free and stable knee. In TKA, less than half an inch (9 mm) of the tibial and femoral articular surfaces are removed from the ends of the bones and replaced with metal and plastic caps [8]. The dimensions of each condyle are prerequisites for designing a prosthesis for TKA. Proper knowledge of the anatomy of the tibial condyles helps in designing an appropriate prosthesis to prevent loosening after surgery [9].

A successful outcome in TKA depends on precise bone cutting, appropriate soft tissue balancing, and maximum tibial bone coverage with a suitable implant size [10]. Proper prosthesis design also corrects varus and valgus deformities of the knee [11]. Recent

studies show that revision surgery is often required after TKA to correct aseptic loosening of the implant. Implant stability can be influenced by various factors, one of which is the characteristics of the prosthesis design [12]. Orthopaedicians avoid using implants with incomplete coverage of the tibia during surgery as this may cause the implant to collapse [13].

The morphology of the tibial component of the prosthesis should match the resected surface in order to restore stability and ensure proper load transmission after knee replacement surgery [14]. Earlier, various studies were conducted on the measurement of different parameters of the tibial plateau [15-20], but none focused on subpopulation variations. Anthropometry varies widely among different populations around the world. Indians and Chinese generally have a smaller build and stature compared to Western populations. It is likely that Indians may be at risk of component oversizing in TKA with most commercially available prosthesis [21]. To ensure better compatibility, population-specific appropriate sizing is required.

Very few studies have been conducted on the anthropometry of the proximal tibia in the Indian population [1,9,22]. The present study was conducted separately in Gurugram and West Bengal, as differences in stature are often observed among people originating from these two places. For the present study, cadaveric tibia bones from the North and East Indian populations were considered due to the availability of both. The aim of the present study was to investigate any regional variations in the tibial plateau among these two population samples and to apply the collected data in designing a suitable tibial component for knee prostheses for the Indian population, focusing on these two subpopulations.

MATERIALS AND METHODS

A cross-sectional observational study was conducted in the Department of Anatomy at FMHS, SGT University in Gurugram and Medical College and Hospital in Kolkata, West Bengal, India from May 2021 to June 2022. The study focused on dry cadaveric tibia bones, with no involvement of patients or animals.

Inclusion and Exclusion criteria: Only fully ossified, processed, grossly normal, and completely dry tibias were considered for the study. Tibia bones that were damaged, broken, improperly processed, or showing gross malformations were excluded.

Sample size calculation: The sample size was calculated using the formula [23]:

$$n=Z^2\times P(1-P)/d^2$$

Here, 'n' is the sample size, Z is the statistic corresponding to the level of confidence (95% confidence level corresponds to Z=1.96), 'P' is the expected prevalence (50%), and 'd' is the desired precision (11%). The estimated sample size calculated using these values was 80.

Study Procedure

A total of 84 dry adult cadaveric tibias (42 right and 42 left) were studied, regardless of sex. Among these, 43 tibias (22 right and 21 left) from the East Indian population were studied at Medical College and Hospital in Kolkata, while 41 tibias (20 right and 21 left) from the North Indian population were studied at FMHS, SGT University in Gurugram.

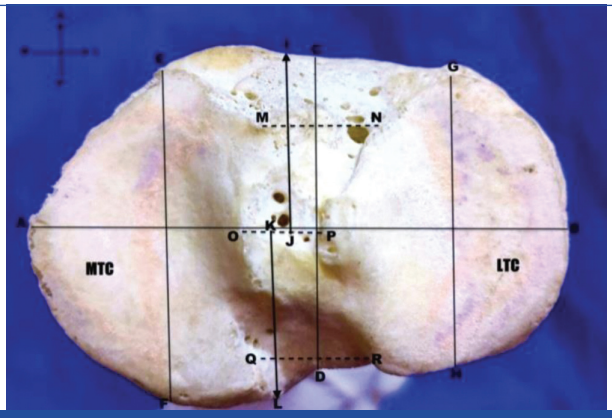
Each tibia was assigned a serial number. Measurements were taken by using digital Vernier callipers (CT-ZT-VERNIER by zhart) as shown in [Table/Fig-1] with a least count of 0.01 mm. Three readings were taken for each sample. All the measurements taken are shown in [Table/Fig-2] which includes total AP diameter, total (TD) of TTC, AP and TD of MTC, LTC and Intercondylar area.

The area of the TTC was measured using the formula:

Area of condyle=AP×TD of condyle [9].

The areas of the MTC and LTCs were measured separately and statistically analysed.

[Table/Fig-1]: Total Transverse Diameter (TD) of tibial plateau measurement using Vernier callipers.



[Table/Fig-2]: Showing the various parameters of upper end of right tibial plateau measured.
AB: Total transverse diameter, CD: Total anteroposterior diameter, EF: Anteroposterior diameter of MTC, GH: Anteroposterior diameter of LTC, IJ; Anteroposterior diameter of anterior intercondylar area, KL: Anteroposterior diameter of posterior intercondylar area, Transverse diameters of Intercondylar area are marked as MN: Anterior, OP: Middle, QR: Posterior

The aspect ratio was calculated using the formula:

Aspect ratio=TD/AP×100 [22].

STATISTICAL ANALYSIS

The data was statistically analysed using SPSS (version 21.0) software. Measured variables were presented as mean, range and Standard Deviation (SD). The data was tabulated, and in order to compare the two populations, a Student's t-test was applied, with a p-value of <0.05 considered statistically significant.

RESULTS

In the present study, various parameters of the tibial plateau, such as the AP and TD of the TTC, MTC, LTC, and the Intercondylar Area (ICA) (anterior end, middle, and posterior end), were observed and compared between the North and East Indian populations.

The North Indian samples [Table/Fig-3] showed that the mean AP diameter of the MTC (38.30±3.54 mm) was slightly greater than that of the LTC (35.30±3.51 mm), but the mean TD was almost similar in both condyles. Both the TD (21.78±2.82 mm) and AP (26.04±2.21 mm) of the anterior intercondylar area were found to be greater than those of the posterior intercondylar area. The area of the TTC was slightly larger on the left-side (2722 mm^2) than on the right-side (2669 mm^2).

In the East Indian samples [Table/Fig-3], the mean AP diameter of the MTC (40.63±3.46) was significantly higher than that of the LTC (35.70±3.96), but the mean TD was almost similar in both condyles. The mean AP diameter of the anterior intercondylar area (28.31±2.86) was greater than that of the posterior intercondylar area (22.11±3.24). The TD of the anterior and posterior intercondylar areas was almost similar. The area of the TTC was significantly larger on the right-side (3025 mm^2) compared to the left-side (2805 mm^2). The area of each condyle was calculated by multiplying

Parameters	North Indian population				East Indian population			
	Mean±SD			p-value	Mean±SD			p-value
	Right (n=20)	Left (n=21)	Total		Right (n=22)	Left (n=21)	Total	
TD of TTC	63.14±3.47	63.51±5.45	63.33±4.54	0.79	66.31±4.90	64.59±5.99	65.47±5.46	0.30
AP diameter of TTC	42.19±2.73	42.68±2.98	42.44±2.83	0.58	45.36±4.19	43.17±4.35	44.29±4.36	0.10
AP diameter of MTC	37.31±3.40	39.24±3.50	38.30±3.54	0.08	41.05±3.10	40.18±3.82	40.63±3.46	0.41
TD of MTC	25.81±3.54	26.42±3.17	26.12±3.33	0.56	28.21±2.98	28.33±3.35	28.27±3.13	0.90
AP diameter of LTC	34.79±4.02	35.77±2.97	35.30±3.51	0.37	35.89±3.85	35.51±4.16	35.70±3.96	0.75
TD of LTC	25.72±2.03	26.94±2.62	26.34±2.41	0.10	28.88±2.92	28.7±2.60	28.79±2.73	0.83
AP diameter of anterior ICA	25.72±2.59	26.36±1.78	26.04±2.21	0.36	28.85±2.72	27.73±2.96	28.31±2.86	0.20
TD of anterior ICA	21.49±2.71	22.06±2.96	21.78±2.82	0.52	17.56±2.78	16.80±1.92	17.19±2.40	0.30
AP diameter of posterior ICA	17.78±1.55	18.27±1.57	18.03±1.56	0.32	22.27±3.31	21.93±3.23	22.11±3.24	0.73
TD of posterior IC	15.24±2.32	15.30±2.09	15.27±2.18	0.93	17.50±2.02	17.07±2.64	17.29±2.33	0.55
TD of middle ICA	10.00±1.58	10.17±0.95	10.08±1.30	0.34	9.71±1.68	8.95±2.00	9.34±1.89	0.09
Total area	2669.6±276.5	2722.2±387.38	2696±338.89	0.30	3025.68±473.24	2805.6±484.26	2918.23±491.13	0.07
Aspect ratio	1.49±0.08	1.48±0.08	1.49±0.08	0.69	1.46±0.09	1.50±0.09	1.48±0.09	0.15

[Table/Fig-3]: Showing mean morphometric measurements of the right and left tibia bones of North and East Indian populations and a comparison of the right and left-side in each population group using Student's t-test.

the AP diameter and TD (AP×TD) of each condyle [Table/Fig-3]. The total area summation of the North Indian samples (41 samples) was 110559.87 mm^2. The mean area of the North Indian samples was 2696±338.89. The total area summation of the East Indian samples (43 samples) was 125483.92 mm^2. The mean area of the East Indian samples was 2918±491.13.

The aspect ratio (TD/AP×100), which defines the relationship between the TD and AP diameter, was calculated as it helps anticipate the shape of the tibial component of the prosthesis. The aspect ratio [Table/Fig-3] for the North Indian population was 1.49±0.08, while for the East Indian population, it was 1.48±0.09. A comparison of the parameters of the North and East Indian population samples is given in [Table/Fig-4-6]. From [Table/Fig-4], it can be seen that the mean AP (p-value=0.0065) and TD (p-value=0.0213) of the TTC were found to be significant when comparing between the North and East populations on the right-side. In the case of the medial condyle, only on the right-side, the mean AP (p-value=0.0006) and TD (p-value=0.0219) of the North and East samples were found to be significant in comparison. For the lateral condyle, the mean TD of the North and East samples was found to be significant on both sides (right-side p-value=0.0002 and left-side p-value=0.0348).

From [Table/Fig-5], it can be observed that the mean AP diameter of the intercondylar area at the anterior end was significantly different between the North and East samples on the right-side (p-value=0.0005). The mean AP diameter of the intercondylar area at the posterior end showed high significance (p-value <0.0001)

Condyles	Diameter	Side	Population (n)	Mean±SD	p-value
Lateral	Anteroposterior	Right	North (20)	34.79±4.02	0.3706
			East (22)	35.89±3.85	
		Left	North (21)	35.77±2.97	0.8169
			East (21)	35.51±4.16	
	Transverse	Right	North (20)	25.72±2.03	0.0002
			East (22)	28.88±2.92	
		Left	North (21)	26.94±2.62	0.0348
			East (21)	28.70±2.60	
Medial	Anteroposterior	Right	North (20)	37.31±3.40	0.0006
			East (22)	41.05±3.10	
		Left	North (21)	39.24±3.50	0.4107
			East (21)	40.18±3.82	
	Transverse	Right	North (20)	25.81±3.54	0.0219
			East (22)	28.21±2.98	
		Left	North (21)	26.42±3.17	0.0691
			East (21)	28.30±3.35	
Total tibial	Anteroposterior	Right	North (20)	42.19±2.73	0.0065
			East (22)	45.36±4.19	
		Left	North (21)	42.68±2.98	0.6725
			East (21)	43.17±4.35	
	Transverse	Right	North (20)	63.14±3.47	0.0213
			East (22)	66.31±4.90	
		Left	North (21)	63.51±5.45	0.5446
			East (21)	64.59±5.99	

[Table/Fig-4]: Mean condylar diameters of the upper ends of tibias in the North and East Indian populations on the right and left-sides were measured, and a comparison was made between the two population samples on each side using a Student's t-test.

Intercondylar area	Diameter	Side	Population (n)	Mean±SD	p-value
Anteroposterior	Anterior end	Right	North (20)	25.72±2.59	0.0005
			East (22)	28.85±2.72	
		Left	North (21)	26.36±1.78	0.0766
			East (21)	27.73±2.96	
	Posterior end	Right	North (20)	17.78±1.55	p<0.0001
			East (22)	22.27±3.31	
		Left	North (21)	18.27±1.57	p<0.0001
			East (21)	21.93±3.23	
Transverse	Anterior end	Right	North (20)	21.49±2.71	p<0.0001
			East (22)	17.56±2.78	
		Left	North (21)	22.06±2.96	p<0.0001
			East (21)	16.80±1.92	
	Middle	Right	North (20)	10.00±1.58	0.5687
			East (22)	9.71±1.68	
		Left	North (20)	10.17±0.95	0.0173
			East (22)	8.95±2.00	
	Posterior end	Right	North (20)	15.24±2.32	0.0017
			East (22)	17.50±2.02	
		Left	North (21)	15.30±2.09	0.0207
			East (21)	17.07±2.64	

[Table/Fig-5]: Comparison of the mean measurements of the Anteroposterior (AP) and Transverse Diameters (TD) of the intercondylar area on the right and left-sides in North and East Indian populations, using Student's t-test.

on both sides when comparing both samples. The mean TD of the intercondylar area at the anterior end was highly significant when comparing between the North and East samples on both sides (p-value <0.0001). Similarly, the TD of the intercondylar area at the posterior end was found to be significant on both sides (right p-value=0.0017, left p-value=0.0207) when comparing between the North and East samples. The mean TD of the middle intercondylar area was found to be significant only on the left-side (p-value=0.0173).

In [Table/Fig-6], the areas of tibial condyles were compared between the North and East samples. The results were found to be significant only on the right-side for the medial condyle (p-value=0.0013), lateral condyle (p-value=0.0083), and TTC (p-value=0.0055).

Area of condyles	Side	Population (n)	Mean±SD	Area %	p-value
Lateral	Right	North (20)	897.73±135.01	39.22%	0.0083
		East (22)	1045.02±199.07	55.83%	
	Left	North (21)	968.12±151.93	35.56%	0.2828
		East (21)	1025.45±187.47	58.81%	
Medial	Right	North (20)	959.65±128.94	41.92%	0.0013
		East (22)	1164.37±234.2	62.20%	
	Left	North (21)	1042.56±191.09	38.29%	0.8801
		East (21)	1051.96±209.84	60.33%	
Total tibial	Right	North (20)	2669.6±276.5		0.0055
		East (22)	3025.68±473.24		
	Left	North (21)	2722.2±387.38		0.5412
		East (21)	2805.6±484.26		

[Table/Fig-6]: Mean area of the medial, lateral, and TTCs in the North and East Indian populations on the right and left-sides, and their comparison using a Student's t-test.

DISCUSSION

With the increase in sedentary lifestyles and lack of exercise, knee joint diseases, especially OA, have become very common worldwide. As a result, the demand for knee joint replacement surgeries like uni-compartmental and TKA is also rising. However, the prostheses types currently available in the market are best suited for the Western and Caucasian population, whereas Asians, including Indians, generally have a smaller stature compared to tall and robust Caucasians.

Pandit R and Sharma N, and Nayak G et al., found significant results for the AP diameter of the lateral condyle in right and left comparisons [24,25]. However, in the present study, right and left-side comparisons did not show significant results when compared for each population. When the right and left-side comparison was performed between the North and East populations using a student's t-test, it was found to be significant for the medial condyle, both AP diameter (0.0006) and TD (0.0219) on the right-side, Lateral condyle TD (0.0002) on the right-side, and TTC, both AP (0.0065) and TD (0.0213) on the right-side [Table/Fig-4].

A comparison of the size of Indian knees (North and East Indian population) with other studies was conducted internationally [Table/Fig-7] [15-20,26,27]; and nationally [Table/Fig-8] to determine the exact size of knee implants that will fit Indians better [1,9,22,25,28-31].

Upon comparing the present study findings with those of other nationalities [Table/Fig-7], authors observed that all the morphometric measurements of the proximal tibia in the present study population were smaller than those reported in other studies, except for the study conducted by Yue B et al., [26]. This suggests that Indian knees are generally smaller than knees from other populations worldwide. A consistent finding across all studies was that the total TD was higher than the total AP diameter of the upper end of the tibia.

Authors with study population	Total Transverse Diameter (TD) (mm)	Total AP diameter (mm)	Medial condyle AP diameter (mm)	Lateral condyle AP diameter (mm)	Aspect ratio
Present study North Indian population	63.33±4.54	42.44±2.83	38.30±3.54	35.30±3.51	1.49±0.08
East Indian population	65.47±5.46	44.29±4.36	40.63±3.46	35.70±3.96	1.48±0.09
Yue B et al., [26] Chinese	75.20±3.60 (M)	41.50±2.10 (M)	46.10±2.10 (M)	36.80±2.10 (M)	1.82±0.07 (M)
	66.20±2.10 (F)	37.30±2.80 (F)	41.50±3.00 (F)	33.20±3.20 (F)	1.78±0.10 (F)
Kwak DS et al., [27] Koreans	76.10±4.00 (M)	48.20±3.30 (M)	48.50±3.70 (M)	44.60±3.20 (M)	1.58 (M)1.56 (F)
	67.64±3.12 (F)	43.20±2.30 (F)	43.50±2.90 (F)	39.80±2.50 (F)	
Cheng FB et al., [15] Chinese	76.40±2.80 (M)	51.30±2.00 (M)	53.30±2.50 (M)	47.70±2.70 (M)	1.49±5.70 (M)
	68.80±4.60 (F)	45.70±1.90 (F)	47.50±2.40 (F)	42.40±2.30 (F)	1.51±6.10 (F)
Erkocak OF et al., [16] Turkish	77.10±5.10 (M)	47.60±3.80 (M)	53.90±4.20 (M)	45.90±3.70 (M)	1.62 (M) 1.68 (F)
	68.70±3.60 (F)	40.90±3.10 (F)	47.50±3.90 (F)	39.90±3.30 (F)	
Phombut C et al., [17] Thai population	77.52±3.22 (M)	49.26±2.49 (M)	51.79±2.64 (M)	46.73±2.73 (M)	1.57±0.07 (M)
	67.51±3.17 (F)	43.45±2.53 (F)	46.65±2.44 (F)	40.45±2.37 (F)	1.55±0.09 (F)
Dai Y and Bischoff JE [18] Caucasians	78.13±3.91 (M)		54.35±2.99 (M)	48.62±2.95 (M)	1.12±0.05 (M)
	69.11±2.82 (F)		47.95±2.36 (F)	42.63±2.31 (F)	1.13±0.05 (F)
Karimi E et al., [19] Iranians	77.80±3.78 (M)	48.79±3.08 (M)	53.14±3.21 (M)	51.94±3.57 (M)	1.60±0.10 (M)
	66.52±4.48 (F)	43.07±2.68 (F)	45.48±2.98 (F)	43.71±3.46 (F)	1.55±0.11 (F)
Eboh DEO [20] Nigerians	70.37±7.49	45.82±5.69	44.36± 4.96	39.44± 4.87	

[Table/Fig-7]: This study finding compared with findings of other international authors [15-20,26,27].

	Medial condyle				Lateral condyle			
	Total AP (mm)		Total TD (mm)		Total AP (mm)		Total TD (mm)	
Studies in different parts of India	Right	Left	Right	Left	Right	Left	Right	Left
Present study North Indian population	37.31±3.40	39.24±3.50	25.81±3.54	25.81±3.54	34.79±4.02	35.77±2.97	25.72±2.03	26.94±2.62
East Indian population	41.05±3.10	40.18±3.82	28.21±2.98	28.33±3.35	35.89±3.85	35.51±4.16	28.88±2.92	28.7±2.60
Pooja B et al., [1] North Indian population	45.36±3.18	44.18±4.25	29.86±2.05	28.24±2.89	38.85±2.75	39.26±3.56	27.43±2.08	28.08±2.19
Srivastava A et al., [9] North Indian population	38.63	39.94	29.73	27.5	36.47	36.94	29.21	29.77
Ahmad N et al., [22] North Indian population	40.18±4.75	40.21±5.64	28.46±3.63	28.27±2.95	35.94±4.59	37.02±3.87	27.89±4.26	27.92±3.06
Reeti R et al., [28] East Indian population	47.90±0.63	46.94±0.46	30.08±0.38	29.16±0.43	40.62±0.40	40.33±0.17	28.54±0.10	28.89±0.05

Chaitra D et al., [29] South Indian population	39.51±3.24	38.95±4.56	26.36±2.81	27.25±2.76	33.57±3.06	32.87±3.00	24.71±2.49	25.39±3.26
Bamne A and Gayathri UP, [30] Central Indian population	39.38±4.08	40.08±3.44	27.64±2.64	29.11±3.14	34.81±3.76	35.41±3.33	28.52±3.28	29.54±3.06
Nayak G etal., [25] East Indian population	41.7±0.50	41.2±0.42	27.8±0.34	28.1±0.59	36.6±0.31	39.2±0.30	28.7±0.55	31.2±0.68
Thakur A et al., [31] West Indian population	41.71±4.37	42.24±4.05	29.28±2.87	29.69±2.95	37.6±3.35	36.93±3.44	29.69±3.10	30.16±2.94

[Table/Fig-8]: This study finding compared with other Indian author studies [1,9,22,25,28-31].

Yue B et al., discovered in their study that Chinese knees are smaller than White knees [26]. When comparing their study to the present, authors found that the total TD was higher, but the total AP diameter was smaller in the study conducted by Yue B et al., [26]. Mohan H et al., conducted a study on 100 non arthritic Indian knees using Magnetic Resonance Imaging (MRI) and found that Indian knees were smaller than Chinese knees (only in terms of TD) as well as Caucasian and Hispanic knees (both in terms of AP and TD) [32]. This finding aligns with the study conducted by Mohan H et al., albeit using dry cadaveric tibias [32].

Multiple authors have reported that Asian knees, including Indian knees, are generally smaller than Caucasian knees [15,27]. Consequently, Asians with their smaller skeletal profile would require smaller-sized knee prostheses. According to the study by Mahoney OM and Kinsey T a mismatch in the size of the resected bony surface and the prosthesis can lead to overhanging or undercoverage of the implant, resulting in poor surgical outcomes [33]. The optimal solution to this problem is to design TKA implants that cater to different populations. Such customised implants would provide better anatomical conformity, improved fitting and coverage, enhanced gait patterns, favourable long-term outcomes, and restoration of normal knee biomechanics.

In TKA, the tibial component is more susceptible to complications than the femoral component [34]. Overhanging of the tibial component can cause instability, soft tissue irritation, and knee pain, particularly on the medial side [33]. Similarly, underhanging of the tibial component can lead to aseptic loosening due to increased tibial bone resorption [35].

Most of the total knee prostheses currently available have been developed based on measurements from Caucasians. However, Caucasian knees are generally larger than Asian knees [36].

Therefore, for Indians, authors need population-specific knee implants that will provide a better quality of life after knee surgery.

In the present study, the aspect ratio was calculated to anticipate the shape of the tibial component of the prosthesis. It was found that the aspect ratio in Indians is higher than that of Caucasians but lower than that of the Chinese, Thai population, Iranians, and Koreans [15,17-19,27].

When the aspect ratio is 100%, it indicates that the total TD equals the AP diameter, and the symmetric tibial component is circular in shape. However, when the aspect ratio is above 100%, it indicates a transversely oval tibial component [22]. In the present study, the aspect ratio for the North samples was 1.49±0.08, and for the East samples, it was 1.48±0.09 [Table/Fig-3]. The study also found a higher aspect ratio for smaller AP diameter and a lower aspect ratio for larger AP diameter. Therefore, the tibial component becomes more oval with a decrease in AP diameter and vice versa.

These findings on aspect ratio are similar to the studies conducted by Cheng FB et al., Ahmad N et al., and Kwak DS et al., [15,22,27]. Hence, the available tibial prostheses in the market will not suit Asians, including Indians. This is because the implants have a constant condylar aspect ratio or show an increase in aspect ratio with increased AP diameter [37]. Therefore, Indians require a tibial prosthesis that ensures good tibial implant coverage and shows a decrease in tibial aspect ratio with an increase in AP diameter.

[Table/Fig-8], the present study's findings are compared with those of other Indian authors to determine whether a similar prosthesis size is required for all Indian populations or if it will vary regionally. In the present study, the AP diameter and TD of the medial condyle were greater on the right-side compared to the lateral condyle. However, on the left-side, the total TD of the lateral condyle was higher than that of the medial condyle. This finding does not align with many other Indian studies that report greater anthropometric measurements of both AP and TD for the medial condyle than the lateral condyle [22,28,29].

Prostheses specific to the Indian population are required, taking into account regional variations. The present study reveals that the East Indian population has higher measurements compared to the North Indian population, indicating the need for smaller prostheses for North Indians.

In general, the total TD and AP diameter are used to select the implant size and determine the ideal tibial component required. Pooja B et al., conducted a study on the proximal end of the tibial condyle in the North Indian population [1]. They found that the total TD on the right-side was 63.38±4.23 mm and on the left-side was 63.88±5.32 mm. The total AP diameter on the right-side was 40.96±4.24 mm, and on the left-side was 42.88±4.38 mm. These findings align closely with the study conducted by Pooja B et al., [1].

However, these study findings are smaller than those reported by Ahmad N et al., who also measured the tibial plateau of North Indians [22]. Ahmad N et al., found that the total TD on the right-side was 66.03±6.60 mm and on the left-side was 66.72±5.13 mm. The total AP diameter on the right-side was 42.24±5.12 mm, and on the left-side was 42.89±4.38 mm.

Bamne A and Gayathri UP conducted a study on the Central Indian population and reported a total TD on the right-side of 63.89±7.29 mm and on the left-side of 66.22±4.38 mm [30]. The total AP diameter on the right-side was 43.58±3.89 mm, and on the left-side was 45.12±3.66 mm. These findings were generally lower than those of Bamne A and Gayathri UP except for the total AP diameter on the right-side [30].

Anthropometric measurements of the intercondylar area were studied and compared with the findings of other authors in [Table/Fig-9,10] [1,8,22,25,28,29]. When compared with other Indian studies [Table/Fig-9], the present study found that the AP diameter of the intercondylar area in the East Indian samples was higher than that of the South and North Indian populations. The AP measurement of the intercondylar area in the North Indian samples of the present study was smaller than the findings of other studies conducted on the same population.

Studies	AP diameter of intercondylar area (mm) Mean±SD			
	Anterior end		Posterior end	
Present study	Right	Left	Right	Left
North Indian population	25.72±2.59	26.36±1.78	17.78±1.55	18.27±1.57
East Indian population	28.85±2.72	27.73±2.96	22.27±3.31	21.93± 3.23
Pooja B et al., [1] (North Indians)				
Male	22.18±1.85	20.25±5.14	16.23±2.06	21.18±2.49
Female	24.06±2.18	23.75±4.16	18.87±2.82	20.48±2.74
Ahmad N et al., [22] (North Indians)	26.09±3.55	27.29±3.40	20.83±2.88	20.73±2.64
Chaitra D et al., [29] (South Indians)	27.33±3.04	27.50±2.96	19.41±1.93	19.88±2.15
Gandhi S et al., [8] (North Indians)				
Male	23.84±2.90	21.96±6.76	17.86±2.98	23.22±2.55
Female	25.48±2.38	25.04±3.48	21.84±2.64	22.38±2.84

[Table/Fig-9]: Measurements of intercondylar area AP diameter of this study compared with other Indian authors [1,8,22,29].

Studies	Transverse Diameter (TD) of intercondylar area (mm) Mean±SD					
	Anterior end		Posterior end		Middle part	
Present study	Right	Left	Right	Left	Right	Left
North Indian population	21.49±2.71	22.06±2.96	15.24±2.32	15.30±2.09	10.00±1.58	10.17±0.95
East Indian population	17.56±2.78	16.80±1.92	17.50±2.02	17.07±2.64	9.71±1.68	8.95±2.00
Pooja B et al., [1]						
Male	26.76±3.18	27.45±4.18	11.24±1.16	10.25±1.22	9.25±2.08	9.26±1.05
Female	24.18±2.19	24.61±2.86	9.74±1.24	9.19±1.02	8.21±1.06	8.14±1.06
Ahmad N et al., [22]	23.50±4.67	23.23±6.13	16.87±3.22	17.5±3.86		
Reeti R et al., [28]	24.71±0.55	26.13±0.35	14.14±0.44	13.24±0.51		
Chaitra D et al.,[29]	20.42±3.62	20.78±3.70	15.48±2.81	14.52±2.18	9.54±1.84	9.92±1.69
Nayak G et al., [25]	28.7±0.55	31.2±0.68	18.5±0.42	12.8±0.39	13.1±0.20	12.5±0.23
Gandhi S et al., [8]						
Male	24.82±3.22	25.40±4.20	7.18±1.14	7.41±0.95	7.18±1.14	7.41±0.95
Female	22.33±3.48	22.61±2.41	6.72±1.06	6.38±0.79	6.72± 1.06	6.38±0.79

[Table/Fig-10]: Measurements of Transverse Diameter (TD) of intercondylar area of this study compared with findings of other authors [1,8,22,25,28,29].

In the measurement of the tibial plateau, the TD of the intercondylar area was found to be largest in the anterior end, followed by the posterior end, and the middle part had the smallest measurement in both populations under study. The TD of the intercondylar area on both sides was found to be smaller in the East Indian samples. Therefore, among all the measurements of the tibial plateau, only the TD of the intercondylar area was found to be smaller in the East Indian population.

When comparing these study findings on the TD of the intercondylar area with other Indian authors [Table/Fig-10], the measurements of the East Indian samples were found to be the smallest among all. The measurement of the TD of the intercondylar area among the North Indian samples was found to be greater than the study conducted by Chaitra D et al., on the South Indian population but smaller than the findings of other authors [29]. According to Bellemans J et al., the morphology of the knee joint has been proven to vary considerably among various ethnic groups, genders, and morphotypes of patients [36]. Having normative data for a specific population subset is important as it helps design knee joint prostheses that provide the best fit and size for the knees.

Hence, the mean values of all the measurements of the tibial plateau in the present study would be helpful in manufacturing the tibial component of a knee prosthesis for the Indian population while accounting for regional variations.

When calculating the area (in mm^2) of the TTC (AP×TD), the North samples showed 2669.6+276.5 on the right-side and 2722.2+387.38 on the left-side. Much higher values were found in the East samples, with 3025.68+473.24 on the right-side and 2805.6+484.26 on the left-side [Table/Fig-6].

Pooja B et al., conducted a study on the North Indian population and found the total area (in mm^2) on the right-side of male tibias to be 2559.12+301.6 and on the left-side 2675.39+353.8 [1]. The total tibial area (in mm^2) on the right-side of female tibias was 2599.34+332.7 and on the left-side was 2664.63+377.9. The findings of the present study in the North Indian population are higher than those of Pooja B et al., [1].

In the present study [Table/Fig-6], the area covered by the medial condyle on the right-side was found to be 41.92% in North Indian samples and 62.20% in East Indian samples. On the left-side, it was 38.29% in North Indian samples and 60.33% in East Indian samples. The area covered by the Lateral Condyle in this study was found to be 39.22% in North samples and 55.83% in East samples on the right-side. On the left-side, the area covered by the Lateral Condyle was found to be 35.56% and 58.81% in North and East samples, respectively.

Malegaonkar SS et al., conducted a study on 60 dry tibias (32 Right and 28 Left) in South India and found that the area covered by the MTC on the right-side was 41.57% and on the left-side was 40.76% [39]. The area covered by the LTC on the right-side was 36.84% and on the left-side was 35.38% of the total condylar area. On comparison, it is seen that the findings in the East samples in this study are much higher, while the North sample findings are quite similar to the study of Malegaonkar SS et al., [38].

A recent study by Agichani SR et al., on 80 dry tibias in central India showed that the mean AP diameter of the medial condyle was 39.25±3.92 mm, and for the lateral condyle, it was 35.43±2.70 mm [39]. The mean TD of the medial condyle was 27.99±3.27 mm, and for the lateral condyle, it was 27.00±2.09 mm. A comparison of the AP diameter of the medial condyle revealed that the Eastern samples in this study had much higher values, while the Northern samples showed much lower values than the findings of Agichani SR et al., [39].

Thakur A et al., conducted a study on 500 dry tibia bones (250 right, 250 left) collected from the population of Rajasthan, India [31]. They compared their study findings with Western studies and found striking variations in knee morphology between the Asian and Western populations. In their study, the results showed that the mean AP diameter of the medial condyle on the right-side was 41.71±4.37 mm and on the left-side was 42.24±4.05 mm. The TD on the right-side was 29.28±2.87 mm, and on the left-side, it was 29.69±2.95 mm. For the lateral condyle, the mean AP diameter on the right-side was 37.6±3.35 mm and on the left-side was 36.93±3.44 mm. The TD on the right-side was 29.69±3.10 mm, and on the left-side, it was 30.16±2.94 mm. They also calculated the area (mm^2) and found that the area of the medial condyle on the right-side was 1229.75±225.01 mm^2 and on the left-side was 1261.59±218.73 mm^2. For the lateral condyle, the area on the right-side was 1123.91±199.79 mm^2, and on the left-side, it was 1119.43±184.88 mm^2. The lateral condyle dimensions in the study of Thakur A et al., were found to be much higher than the findings of the previous study [31,39]. Similarly, when comparing the medial condyle, it was found that the parameters of the Northern samples in the present study were lower, while the dimensions of the Eastern samples were closer to the results of the study by Thakur A et al., [31]. When comparing the areas, all parameters were higher in the study by Thakur A et al., [31].

Therefore, the implant sizes designed for the Western population will not be suitable for Asians, and there are also regional variations among Indians. This study by Rodriguez-Merchan EC highlights the importance of information on the morphometry of the proximal articular surface of the tibia for orthopaedic surgeons [40]. Current challenges in knee prosthetic design revolve around attempting to produce normal kinematics, decrease wear and tear, and achieve greater longevity.

Limitation(s)

Only right and left-side comparisons were possible, and sex differentiation has not been considered. Although the cadaveric bones used in the present study belonged to the respective regions, the chances of the bones belonging to a migratory class of people can't be ruled out, although the possibility of this is slim. The present study was performed on dry bones, which may have undergone shrinkage in their morphology compared to live specimens. Tibial diameters beyond the various parameters taken in the present study need further investigation in this area.

CONCLUSION(S)

The morphometric data in the present study reveal ethnic variations. Available tibial implants are designed based on dimensions of Western populations and may lead to a size mismatch when used for the Indian population. The data obtained from the present study will help in designing appropriately size-matched unicompartmental and total knee prostheses for Indians, with a focus on the North and East populations. This detailed study on measurements of the tibial plateau is not only helpful for orthopaedic surgeons but also beneficial to physical anthropologists, forensic experts, clinical anatomists, and medical students.

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