



Anthropometry of Nonarthritic Asian Knees: Is It Time for a Race-Specific Knee Implant?

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Background: This study was done to study the anthropometry of nonarthritic Asian knees; to determine the differences in morphology between knees of different ethnicities and to compare the knee anthropometry values with sizes of available knee implants.

Methods: Magnetic resonance imaging scans of 100 nonarthritic Indian knees were analyzed. Anteroposterior (AP) length, medio-lateral (ML) length, and aspect ratio of the distal femur and proximal tibia, patellar length, and patellar tendon length were measured. These values were compared with values of other ethnicities from literature. The values were also compared with sizes of available knee implants and evaluated for mismatch.

Results: All the parameters of female knees were significantly smaller than those of male knees ($p < 0.05$). The distal femur of Indian knees resembled that of Chinese knees with similar AP and ML lengths and aspect ratio. The distal femur of Indian knees had a significantly smaller AP, ML, and aspect ratio than those of Hispanic knees did. In comparison to Caucasian distal femur, Indian knees had smaller AP and ML lengths and larger aspect ratio. In terms of the proximal tibia, the Indian knees were smaller than Chinese (only ML), Caucasian (AP and ML) and Hispanic (AP and ML) knees. On comparison with implant sizes, there was a mismatch between the distal femur morphology and the dimensions of all implants. For a given AP length, the ML dimensions of all implants were smaller than the measured ML length of the knee. However, the tibial components of all the studied implants correlated well with the tibial morphology.

Conclusions: Distinct anthropometric differences exist between knees of different ethnicities. The knees of females were smaller than the knees of males. In Indian knees, the ML-AP aspect ratio of the distal femur was higher than that of the currently available femoral components. These results suggest the need for race-specific knee implants.

Keywords: *Knee joint, Arthroplasty, Knee implants*

The morphology of the knee joint has been proven to vary considerably amongst the various ethnic groups, genders, and morphotype of the patients. Having a normative data for a particular population subset is important as it helps

to design the knee joint prosthesis that will have the best fit and size for the knees.¹⁾ Suboptimal sizing and placement leads to various issues like patellar maltracking, persistent pain, early loosening, loss of bone stock, and increase in propensity of periprosthetic fractures.²⁾

Literature review revealed a striking paucity of information on anthropometric measurements of Asian knees. Most of the anthropometric data currently available for Indian knees are derived from measurements made on osteoarthritic knees.^{3,4)} Heidari⁵⁾ showed that the presence of osteophytes, subchondral sclerosis, bone attrition, and

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chondrocalcinosis in an arthritic knee alters the normal structural anatomy, resulting in altered anthropometric data. To the best of our knowledge, no study has been done to measure the anthropometry of Indian patients with healthy knees. Data obtained from magnetic resonance imaging (MRI) scans of healthy knees would give insights into the racial differences, if any, in knee anatomy, useful for consideration in total knee replacement (TKR). The Insall-Salvati ratio (ISR), bearing significance in the context of resurfacing during TKR, has not been substantially analyzed across ethnicities including the Indian population.

In this study, we aimed (1) to study the anthropometry of nonarthritic Indian knees and to determine any gender variations in the morphology, (2) to ascertain the differences that may exist between knees of different races, and (3) to study the match between the knee anthropometry values and available knee implants. The null hypothesis was that significant anatomical differences would exist between male and female knees and also between Indian and Western knees. Currently available implants designed based on Western data will not match the Indian knees.

METHODS

This is a single-center observational study. MRI that was done for suspected cases of ligament injuries of the knee was used in the study. Patients with MRI scans showing no evidence of bony injury and osteoarthritis were included. One knee per subject (left or right) was selected to be studied. The study population included 100 knees (38 women and 62 men). For measurement, 3.0-tesla, non-fat-suppressed, proton density, axial and sagittal MR images of 3-mm cut thickness were used. Measurements were made by using InstaRad Viewer software (Meddiff Technolo-

gies, Mumbai, India). Measurements were done by three observers (HM, PC and KT) and averages of both values were taken for the study.

Study Parameters

Femoral morphology

The femoral mediolateral (fML) and anteroposterior (fAP) dimensions of the distal femur were measured by using a viewing plane that was placed perpendicular to the mechanical axis of the femur (6° greater than the anatomical axis). The measurements were taken in the cuts that were 9–10 mm from the articular surface of the medial femoral condyle. These cuts were chosen, as the normal distal femoral cut taken in TKR is 9 mm. The fML was defined as the maximum length measured on the cut surface (viewing plane) along the femoral transepicondylar axis (Fig. 1A). The fAP dimension was measured as the average of the distances between the most posterior point of the posterior condyle and the most anterior point of the corresponding anterior condyle, both for the medial and lateral condyles (Fig. 1A). Subsequently, the femoral aspect ratio (fAR = fML/fAP) was calculated.

Tibial morphology

With the viewing plane set perpendicular to the tibial anatomical axis, the cut just proximal to the tip of the fibular head was used for measuring the tibial ML (tML) and tibial AP (tAP) dimensions of the tibial plateau. The maximum distance between medial and lateral extremities on the tibial plateau (viewing plane) parallel to the posterior condylar line corresponded to the tML (Fig. 1B). The AP dimensions were measured for both the medial (tMAP) and lateral (tLAP) plateau and averaged to give the tAP dimension (Fig. 1B). Finally, the tibial aspect ratio (tAR = tML/tAP) was calculated.

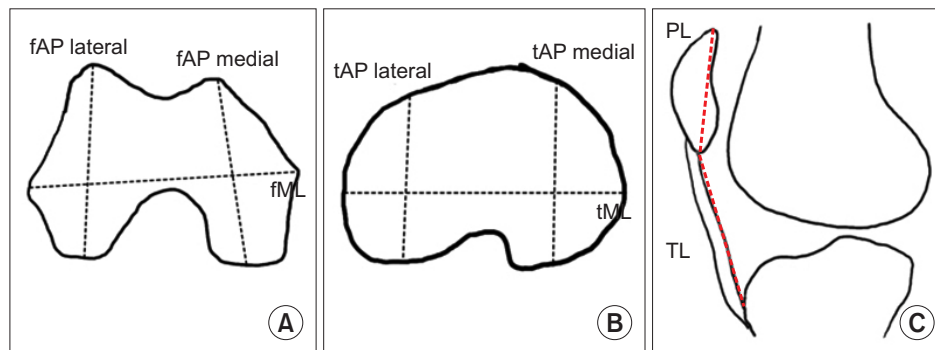


Fig. 1. Illustration of parameter measurement on axial and sagittal magnetic resonance imaging. (A) Distal femoral cut with measured parameters. (B) Proximal tibial cut with measured parameters. (C) Sagittal section of the knee for measurement of the patellar length and patellar tendon length. fAP: femoral anteroposterior, tAP: tibial anteroposterior, fML: femoral mediolateral, tML: tibial mediolateral, PL: patellar length, TL: tendon length.

Patellar morphology

The patellar tendon length (TL) and patellar length (PL) were measured on the sagittal MRI scans, where TL was defined as the length of the posterior surface of the patellar tendon from its insertion on the tibia to the lower pole of the patella, while PL was defined as the maximum pole-to-pole distance on the patella (Fig. 1C). In those cases where the patellar tendon was not straight, the contour was ignored and the length was measured as the distance from the lower pole of the patella and the patellar tendon insertion. Subsequently, the ISR (TL/PL) was calculated.

Comparison by Ethnicity

To establish the racial difference in knee anthropometry, we compared the results of our study with those of similar studies done on healthy knees in different populations. We used the data from studies by Li et al.⁶⁾ for Caucasian and Chinese populations and data from Mcnamara et al.⁷⁾ for the Hispanic population.

Comparison with Available Implants

The femoral and tibial AP and ML values obtained from each patient were compared with the sizes of available knee implants. The femur sizes were compared with PFC Sigma (Depuy, Warsaw, IN, USA), Attune (Depuy), Triathlon (Stryker, Kalamazoo, IN, USA), Nexgen (Zimmer, Warsaw, IN, USA), and Vanguard (Biomet, Warsaw, IN, USA). The tibial sizes were compared with PFC Sigma (Depuy), Attune (Depuy), Nexgen (Zimmer), and Vanguard (Biomet). Scatter graphs were plotted with the patient size and the best possible implant size for all the implants.

Statistical Analysis

The values obtained were expressed as means and standard deviations. Student *t*-test and Mann-Whitney *U*-test were used for comparison of parametric and nonparametric data, respectively. With 95% confidence interval adopted, a *p*-value <0.05 was considered statistically significant.

RESULTS

The mean age of our study population was 44 ± 14 years. Men were younger than women with a mean age of 42 ± 15 years and 47 ± 12 years, respectively. The knees of men were significantly larger than the female knees. All the femoral parameters including AP and ML lengths and aspect ratio were significantly higher in men than in women. In the case of tibia, the AP and ML lengths were significantly smaller in women, while no difference was

seen in terms of tibial aspect ratio. The average values of all parameters along with gender differences are shown in Table 1. The average ISR for the entire study group was 1.14 ± 0.17 . There was no significant difference in the ISR between male and female knees ($p = 0.545$).

Comparison of Distal Femur in Different Races

There was a significant difference in measured anthropometric parameters between different races. The Indian distal femur had a significantly smaller AP length than the Caucasian knees ($p < 0.001$). Though the ML length of Indian knees were smaller than Caucasian knees, the difference was not statistically significant ($p = 0.2$). Indian knees had a significantly higher aspect ratio than Caucasians ($p < 0.01$). The Indian knees resembled Chinese knees with similar AP and ML lengths and aspect ratio ($p > 0.05$). Indian knees were significantly smaller than Hispanic knees with smaller AL and ML lengths and a smaller aspect ratio (Table 2, Fig. 2).

Comparison of Proximal Tibia in Different Races

The proximal tibia of Indian knees had a significantly smaller ML length than Caucasian knees ($p < 0.001$). The AP length was significantly smaller only in women. Though the Chinese proximal tibia had a larger ML length than Indian knees ($p = 0.01$), their AP lengths were similar. The Indian proximal tibia was smaller than Hispanic knees in terms of both AP and ML lengths ($p < 0.001$) (Table 3, Fig. 2).

Table 1. Anthropometric Data of Male and Female Nonarthritic Indian Knees

Variable	Total	Male	Female	<i>p</i> -value
No. of knees	100	62	38	
Femur				
Mediolateral	70.32 ± 5.8	73.74 ± 4.07	64.75 ± 3.37	<0.001
Anteroposterior	55.73 ± 3.87	57.52 ± 3.12	52.8 ± 3.13	<0.001
Aspect ratio	1.26 ± 0.08	1.28 ± 0.07	1.23 ± 0.07	<0.001
Tibia				
Mediolateral	71.8 ± 6.3	75.66 ± 4.29	65.52 ± 3.21	<0.001
Anteroposterior	46.9 ± 4.47	49.12 ± 3.85	43.29 ± 2.7	0.001
Aspect ratio	1.53 ± 0.09	1.55 ± 0.1	1.52 ± 0.07	0.103
Patella				
Insall-Salvati ratio	1.14 ± 0.17	1.13 ± 0.19	1.16 ± 0.15	0.545

Values are presented as mean \pm standard deviation in millimeters.

Table 2. Comparison of Distal Femoral Morphology of Different Ethnicities

Femur	Indian	Caucasian		Chinese		Hispanic	
	Mean ± SD	Mean ± SD	p-value	Mean ± SD	p-value	Mean ± SD	p-value
Mediolateral							
Male	73.74 ± 4.07	74.6 ± 3.9	0.204	72.7 ± 3.8	0.146	77.2 ± 4.1	<0.001
Female	64.75 ± 3.37	65.4 ± 1.4	0.129	64.4 ± 2.6	0.588	66.3 ± 3.0	0.004
Anteroposterior							
Male	57.52 ± 3.12	59.6 ± 3.2	<0.001	56.5 ± 2.5	0.048	49.9 ± 3.8	<0.001
Female	52.8 ± 3.13	55.4 ± 2.8	<0.001	52.8 ± 2.6	1.00	45.6 ± 3.2	<0.001
Aspect ratio							
Male	1.28 ± 0.07	1.25 ± 0.05	0.004	1.29 ± 0.04	0.334	1.55 ± 0.11	<0.001
Female	1.23 ± 0.07	1.18 ± 0.05	<0.001	1.22 ± 0.05	0.442	1.46 ± 0.09	<0.001

Values are presented as mean ± standard deviation in millimeters.
SD: standard deviation.

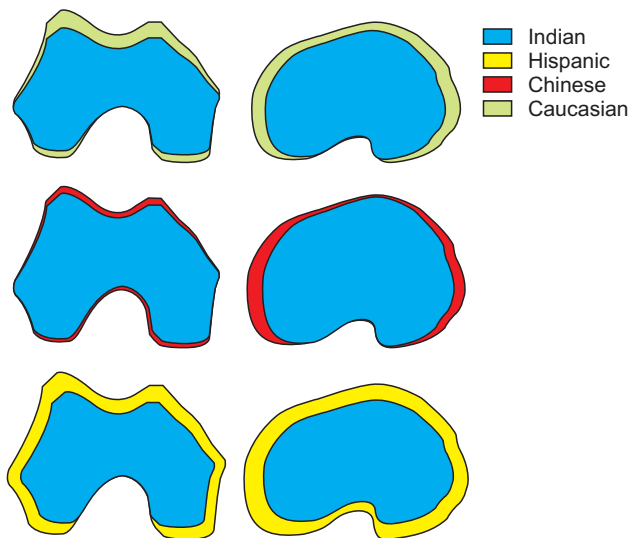


Fig. 2. Representative images of morphology of average Indian knees in relation to average knees of other ethnicities.

Comparison of Knee Measurements with Implant Sizes

There was a mismatch between the distal femur morphology and the dimensions of all five implants. For a given AP length, the ML dimensions of all implants were smaller than the measured ML length of the knee. Choosing an implant size to match the AP length resulted in undercoverage in ML dimension. Similarly, matching of ML lengths resulted in overhang of the implant (Fig. 3). The tibial components of all the studied implants (Attune, PFC Sigma, Vanguard and Nexgen) correlated well with the tibial morphology (Fig. 4).

DISCUSSION

Our study is one of the first studies that have obtained data from Indian patients with healthy, nonarthritic knees. Anthropometric data should be taken from normal knees as the osteoarthritic knees are usually deformed and alters the anatomic dimensions.⁵⁾ While knee replacement is done for arthritic knees, our study has been done in nonarthritic knees with a rationale that the aim of TKR is restoration of biomechanics and anatomy of the native knee. While the presence of osteophytes may seem to visibly alter the AP and lateral dimensions of the bone, the native bone on which the implant needs to be placed remains unaltered and forms the basis of sizing. In fact, most releases would require removal of these osteophytes to achieve a perfect balance.

MRI scans were used for the measurements. MRI better displays the cartilage contour, which corresponds to most sizing techniques during TKR. Loures et al.⁸⁾ in 2017 showed that MRI is a reliable tool for measurement of knee anthropometry and the values were similar to those obtained intraoperatively by direct measurement.

Our anthropometry values differed from the previous study on Indian knees by Shah et al.³⁾ who studied three-dimensional computed tomographic models of 50 arthritic Indian knees. All the parameters were smaller for both men and women except for the femoral and tibial aspect ratio, which was higher in our study. The difference in values can be attributed to the fact that the previous study was done in arthritic knees and our study was based on healthy knees. The presence of osteophytes and chon-

Table 3. Comparison of Proximal Tibial Morphology of Different Ethnicities

Tibia	Indian	Caucasian		Chinese		Hispanic	
	Mean ± SD	Mean ± SD	p-value	Mean ± SD	p-value	Mean ± SD	p-value
Mediolateral							
Male	75.66 ± 4.29	79.4 ± 4.3	<0.001	77.4 ± 3.3	0.013	80.3 ± 4.0	<0.001
Female	65.52 ± 3.21	70.2 ± 2.7	<0.001	69.1 ± 2.8	<0.001	69.8 ± 3.1	<0.001
Anteroposterior							
Male	49.12 ± 3.85	49.5 ± 2.9	0.505	49.6 ± 2.4	0.409	54.7 ± 3.3	<0.001
Female	43.29 ± 2.7	45.2 ± 2.3	<0.001	44.2 ± 2.3	0.095	47.1 ± 2.6	<0.001

Values are presented as mean ± standard deviation in millimeters.
 SD: standard deviation.

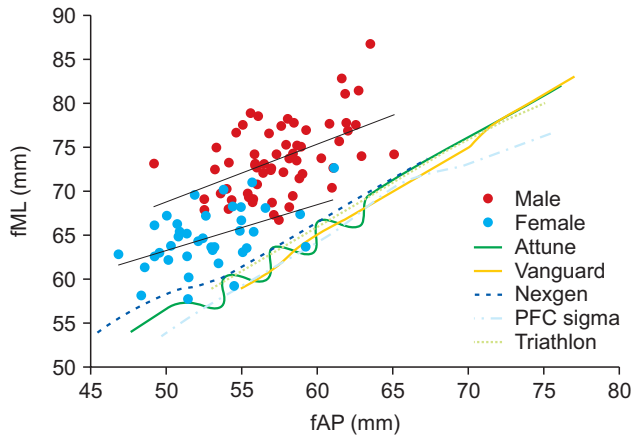


Fig. 3. Graph showing correlations between the femur size and implants. fML: femoral mediolateral, fAP: femoral anteroposterior.

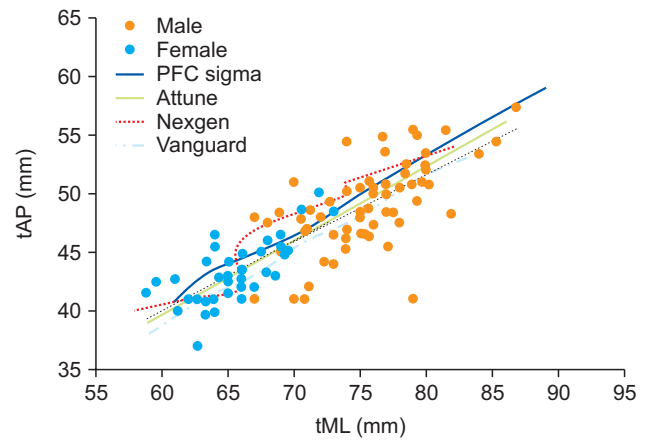


Fig. 4. Graph showing correlations between the tibia size and implants. tAP: tibial anteroposterior, tML: tibial mediolateral.

drocalcinosi in arthritic knees leads to false higher values during measurements.⁵⁾

The ISR obtained in our study was 1.14 ± 0.17 , with no significant difference between men and women. Our results were similar to those of previous studies done on Asian knees. Upadhyay et al.⁹⁾ reported a mean ISR of 1.14 ± 0.18 for Indian knees with higher values in women than men. They proposed that the normal range of ISR for Indians varied from 0.7 to 1.5. Leung et al.¹⁰⁾ obtained similar results in Chinese knees. All these values were higher than the ISR of American and European knees reported by Insall et al.¹¹⁾ and Norman et al.¹²⁾ (Table 4). The higher ISR was attributed to longer length of the patellar tendon in Asian population where sitting-down and squatting are routine activities.⁹⁾ The lengthening of tendon could be due to migration of its insertion, which is under constant traction due to activities. Experimental studies have shown that insertion of ligaments and tendons can migrate along

Table 4. Insall-Salvati Ratio Obtained in Previous Studies

Study (investigation used for measurement)	No. of knees	Insall-Salvati ratio
This study (MRI)	100	1.14 ± 0.17
Upadhyay et al. ⁹⁾ (X-ray)	800	1.14 ± 0.18
Leung YF et al. ¹⁰⁾ (X-ray)	173	1.17 ± 0.18
Norman et al. ¹²⁾ (X-ray)	91	Female, 1.08; male, 0.98
Insall et al. ¹¹⁾ (X-ray)	114	1.02 ± 0.13
Miller et al. ¹³⁾ (X-ray)	44	1.0 ± 0.2

Values are presented as mean ± standard deviation.

with the growth of the underlying periosteum.¹⁴⁾

Our study shows that the female knees are significantly smaller than the male knees. All parameters except

the tibial aspect ratio was significantly lower in women. Nieves et al.¹⁵⁾ showed that men have larger skeletal size and bone mass than women, despite comparable body size. Similar results were seen in previous studies done in Asian and Western knees. Shah et al.³⁾ found the dimensions of Indian female knees to be significantly smaller than male knees and suggested a need for gender-matched implants. Li et al.⁶⁾ and Yue et al.¹⁶⁾ showed that female knees were significantly smaller than male knees in both Chinese and Caucasian population. This gender disparity explains the observation that women tend to have more ML overhang than men while using the older TKR components.¹⁷⁾ Downsizing the implant can prevent this overhang. But

this will also alter the AP coverage and may result in defective soft-tissue balancing and implant positioning. The solution for this would be the use of gender-matched implants. These gender variations in knee anthropometry were taken into account while designing new femoral and tibial implants by certain implant manufacturers.

Our study shows that significant differences exist between the knees of different races (Tables 5 and 6).^{3,6,7,16,18)} The Indian knees resembled the Chinese knees, but were smaller than the Caucasian and Hispanic knees. This racial difference explains the implant size mismatch seen in our study. Most of the commercially available implants were designed based on the anthropometric data of western

Table 5. Knee Anthropometry of Nonarthritic Male Knees of Different Races Available in Literature

Study	Study group	Nature of knee	Method of study	fML	fAP	fAR	tML	tAP	tAR
This study	Indian	Healthy	MRI	73.74 ± 4.07	57.52 ± 3.12	1.28 ± 0.07	75.66 ± 4.29	49.12 ± 3.85	1.55 ± 0.1
Li et al. ⁶⁾	Caucasian	Healthy	MRI	74.6 ± 3.9	59.6 ± 3.2	1.25 ± 0.05	79.4 ± 4.3	49.5 ± 2.9	1.61 ± 0.08
Li et al. ⁶⁾	Chinese	Healthy	CT	72.7 ± 3.8	56.5 ± 2.5	1.29 ± 0.04	77.4 ± 3.3	49.6 ± 2.4	1.56 ± 0.07
Mcnamara et al. ⁷⁾	Hispanic	Healthy	MRI	77.2 ± 4.1	49.9 ± 3.8	1.55 ± 0.11	80.3 ± 4.0	54.7 ± 3.3	
Yue et al. ¹⁶⁾	Caucasian	Healthy	MRI	86.0 ± 5.6	67.5 ± 3.6	1.28 ± 0.07	78.7 ± 5.4	45.0 ± 2.8	1.75 ± 0.11
Yue et al. ¹⁶⁾	Chinese	Healthy	CT	82.6 ± 3.6	65.0 ± 2.8	1.27 ± 0.03	75.2 ± 3.6	41.5 ± 2.1	1.82 ± 0.07
Chaichankul et al. ¹⁸⁾	Thai	Healthy	MRI	70.15 ± 3.87	48.55 ± 3.73	1.45 ± 0.11	74.44 ± 3.44	50.15 ± 3.09	-
Shah et al. ³⁾	Indian	Arthritic	CT	83.6 ± 2.6	67.2 ± 2.9	1.25 ± 0.05	80.9 ± 2.6	58.5 ± 2.5	1.51 ± 0.05

Values are presented as mean ± standard deviation.

fML: femoral mediolateral, fAP: femoral anteroposterior, fAR: femoral aspect ratio, tML: tibial mediolateral, tAP: tibial anteroposterior, tAR: tibial aspect ratio, MRI: magnetic resonance imaging, CT: computed tomography.

Table 6. Knee Anthropometry of Nonarthritic Female Knees of Different Races Available in Literature

Study	Study group	Nature of knee	Method of study	fML	fAP	fAR	tML	tAP	tAR
This study	Indian	Healthy	MRI	64.75 ± 3.37	52.8 ± 3.13	1.23 ± 0.07	65.52 ± 3.21	43.29 ± 2.7	1.52 ± 0.07
Li et al. ⁶⁾	Caucasian	Healthy	MRI	65.4 ± 1.4	55.4 ± 2.8	1.18 ± 0.05	70.2 ± 2.7	45.2 ± 2.3	1.54 ± 0.07
Li et al. ⁶⁾	Chinese	Healthy	CT	64.4 ± 2.6	52.8 ± 2.6	1.22 ± 0.05	69.1 ± 2.8	44.2 ± 2.3	1.56 ± 0.07
Mcnamara et al. ⁷⁾	Hispanic	Healthy	MRI	66.3 ± 3.0	45.6 ± 3.2	1.46 ± 0.09	69.8 ± 3.1	47.1 ± 2.6	
Yue et al. ¹⁶⁾	Caucasian	Healthy	MRI	76.4 ± 4.0	59.7 ± 2.6	1.28 ± 0.06	69.0 ± 4.2	39.3 ± 2.6	1.76 ± 0.08
Yue et al. ¹⁶⁾	Chinese	Healthy	CT	72.8 ± 2.6	58.8 ± 2.5	1.24 ± 0.04	66.2 ± 2.1	37.3 ± 2.8	1.78 ± 0.10
Chaichankul et al. ¹⁸⁾	Thai	Healthy	MRI	59.91 ± 3.75	43.32 ± 3.69	1.39 ± 0.12	64.95 ± 3.45	43.23 ± 2.57	-
Shah et al. ³⁾	Indian	Arthritic	CT	76.3 ± 3.8	62.1 ± 4.9	1.23 ± 0.06	72.2 ± 3.6	52.2 ± 4.2	1.51 ± 0.08

Values are presented as mean ± standard deviation.

fML: femoral mediolateral, fAP: femoral anteroposterior, fAR: femoral aspect ratio, tML: tibial mediolateral, tAP: tibial anteroposterior, tAR: tibial aspect ratio, MRI: magnetic resonance imaging, CT: computed tomography.

population. The mismatch in size leads to overhang of the implant or undercoverage, both of which are associated with poor outcome.¹⁹⁾ The solution to this is to have TKA implants designed to suit the different populations. Such implants will have better anatomical conformity, leading to better fit and coverage. This can restore the normal biomechanics of knee, leading to better gait patterns and favorable long-term outcomes.

Our study has limitations. Firstly, the sample size was 100 knees. More subjects would have increased the power of the study. However, our study is still significant as all the previous Indian studies on knee anthropometry were based on even smaller study groups and our study is the first study done on healthy knees. The mismatch between knee morphology and implant size was assessed based on the scatter graph. The best way to compare the implants with the knee size is intraoperative comparison

with trial implants, which was not done in our study. However, our study is still significant, as previous studies have shown that MRI-based measurements of the knee are similar to direct intraoperative measurements.⁸⁾

We conclude that distinct anthropometric differences exist between the knees of different ethnicities. The knees of women are smaller than the knees of men. In Indian knees, the ML-AP aspect ratio of the distal femur was higher than the ratios of the currently available femoral components. These results suggest the need for race-specific knee implants.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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