International Journal of Orthopaedics Sciences

ISSN: 2395-1958
IJOS 2017; 3(4): 242-249
© 2017 IJOS
www.orthopaper.com
Received: 11-08-2017
Accepted: 13-09-2017

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Computer tomography 3D reconstruction based study of knee anthropometry of Indian population: Comparison with other ethnic groups and current TKA implants

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DOI: <https://doi.org/10.22271/ortho.2017.v3.i4d.34>

Abstract

Introduction: Most of the implants used for total knee arthroplasty in Asian patients have been produced based on anthropometry of Western people. Anthropometric studies have shown that there are significant variations in knee morphology between the Asian and Western population. Data of Indian knee morphometry of healthy and non osteoarthritic knee was lacking. Objective of this study was to study the knee anthropometry of Indian population and its comparison with other ethnic groups and current TKA Implants.

Materials and Methods: 60 patients, 29 female and 31 male with peri-articular knee injuries from the period of June 2016 to November 2016 were studied. 3D reconstruction of normal knee of the patients undergoing CT scan for injured knee was done. Measurement of the mediolateral width, anteroposterior width and aspect ratio of distal femur and proximal tibia was done. Data was compared with other ethnic groups and currently available and commonly used knee systems.

Results: Indian females were found to have significantly ($p > 0.01$) smaller dimensions of femur and tibia than Indian males and both had smaller aspect ratios than the Western population. Also study suggests that there is a morphological mismatch between commonly used implants and Indian knees.

Conclusion: Our study suggests that why Western implant mismatches when implanted in Indian patients. Also this study provides definite rationale for designing total knee prosthesis, especially a gender-specific design suitable for the Indian population.

Keywords: Total knee arthroplasty, TKA, anthropometry, knee morphology, aspect ratio

1. Introduction

Most of the implants used for total knee arthroplasty (TKA) in Asian patients have been produced based on anthropometry of western people. Since anatomic features and life styles are different between western and eastern people, there would be ethnic differences in terms of conformity of implants to the patient's anatomy and clinical results after TKA ^[1]. Being shortage of data on the morphometry of distal femur and proximal tibia in the Indian population, implants designed for knees of the western population are being used without modifications for the ethnic group ^[2]. Anthropometric studies have shown that there are striking variations in knee morphology between the Asian and western population ^[3].

In TKA, maximal implant coverage on the bone surface minimizes the stress applied to the bone-implant interface ^[4, 5]. A good shape of the knee prosthesis which matches the resected surface of knee has been reported as a factor for long-term survivorship in TKA ^[6].

Research on implant mismatching carried out in various Asian countries has led to the conclusion that the Asian-Pacific population should have special designs of TKA implants ^[7, 8, 9]. Data of Indian knee morphometry of healthy and non-osteoarthritic knee was lacking ^[10]. Objective of this study was to study the knee anthropometry of Indian population and its comparison with other ethnic groups and current TKA Implants. This study representative of the Indian population can be used to manufacture prosthetic inventories suitable for most of the Asian-Pacific population having smaller knee anthropometry.

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2. Materials and Methods

2.1 Subjects

We studied 60 patients, 29 female and 31 male who came to the hospital with peri-articular knee injuries from the period of June 2016 to November 2016. 3D reconstruction of normal knee of the patients undergoing CT scan for injured knee was done. Patients with bilateral knee injuries and knee with osteoarthritis or inflammatory arthritis were excluded from the study.

Fig 1: 3D reconstructed image of proximal tibia and distal femur

2.2 CT scan technique

All CT scans of knee were performed on 64 sliced helical CT scan system (Seimans Healthineers). During the scan, the subject was lying supine with his or her knee in a relaxed and extended position. The scanning procedure was performed to acquire 0.625 mm CT slices (resolution, 512 × 512 pixels) with a field of view of 360 × 360 mm around knee joint. The raw data obtained from the scans was first copied in DICOM file format. 3D reconstruction of raw data of the normal side was done.

2.3 Femoral Morphology

The medio-lateral (fML) and antero-posterior (fAP) size of the femur was measured using a viewing plane set perpendicular to the femoral long axis. The femur was rotated about its long axis so as to make the posterior condylar tangent line horizontal. The fML and fAP dimensions of the femur were then measured. In addition, the femoral aspect ratio (fML/fAP) was also calculated [11].

2.4 Tibial Morphology

The tibial long axis was passing through the middle of the tibial spines and oriented parallel to the posterior wall of the

tibial shaft in the sagittal plane. In the coronal plane, it was angled equally with respect to the medial and lateral edges of the tibial shaft [11].

The tibia was rotated about its long axis. The tML dimension was taken as the longest medio-lateral length of the proximal tibial surface. The tAP dimension was taken as perpendicular to tML and passing through the midpoint of the tibial intercondylar eminence [7, 12]. Subsequently, the tibial aspect ratio (tML/tAP) was calculated.

2.5 Comparison with different ethnic groups and knee systems

Data obtained from this study was compared to available data of Americans, Chinese, Japanese and Korean knees. Also comparison of data with five commonly used knee systems at our center which included PFC Sigma Knee System (DePuy), NexGen LPS Flex Mobile Knee System (Zimmer) and Scorpio NRG Knee System (Stryker), Freedom (MAXX) and Buechal Pappas, was done.

2.6 Statistical Analysis

Comparative statistical analyses between genders were made using the paired t-test for parametric continuous data. Linear regression analysis was performed to determine correlations of simulated bones and size-matched components among 5 total knee prosthetic systems. A p value of <0.05 was considered as statistically significant. All analysis was performed using SPSS 20.0 software.

3. Results

60 knees were included in the study, in which 29 were female and 31 were male. Mean age of male patients was 39±10.5 yrs and of female patients was 38±9.9 yrs (Table 1).

Table 1: Subject Demographics

	Total	Female	Male
Number	60	29	31
Age: mean±SD (Range)	38±9.9 (20-54)	37±9.1 (20-52)	39±10.5 (22-54)

3.1 Morphology of Indian Knee

Mean fML was found to be 72.0±5.7 mm in whole population under study while mean fAP was 61.1±4.0 mm. Average femoral aspect ratio was 1.18±0.6. Males had larger values of fML and fAP as compared to females (p < 0.001). A positive correlation was observed between fAP and fML for both males and females. In case of the femoral aspect ratio, statistically significant difference was found between males and females (p < 0.001). Femoral measurements for the study population have been compared across genders in Table 2.

The average tML length was 70.4±5.8 mm and average tAP length was 46.1±4.0 mm. The average tibial aspect ratio was 1.52±0.08. Males had larger values of tML and tAP as compared to females (p < 0.001). A positive correlation was observed between tAP and tML for both the genders. In case of the tibial aspect ratio, no statistically significant difference was found between males and females (p = 0.78). Tibial measurements for the study population have been compared across genders in Table 2.

3.2 Comparison across other ethnicities

To compare the Indian knees morphologically with other ethnic groups, the anthropometric measurements of knees of various ethnicities were retrieved from literature. The data of the distal femur of study population was compared with that

of American, Chinese, Japanese and Korean population (Table 3). Also the data of the proximal tibia of the study

population was compared to that of American, Chinese, Japanese and Korean population as shown (Table 4).

Table 2: Distal femoral and proximal tibial morphology.

	Total Mean±SD (Range)	Female Mean±SD (Range)	Male Mean±SD (Range)	P value
fML	72.0±5.7 (60.1-81.3)	67.4±3.7 (60.1-74.2)	76.4±3.2 (69.9-81.3)	<0.001
fAP	61.1±4.0 (51.9-68.5)	59.4±4.1 (51.9-68.5)	62.7±3.2 (56.8-68.3)	<0.001
fML/fAP	1.18±0.6 (1.03-1.29)	1.13±0.5 (1.03-1.28)	1.21±0.4 (1.14-1.29)	<0.001
tML	70.4±5.8 (60.7-84.2)	65.8±3.9 (60.7-74.3)	74.7±3.6 (69.9-84.2)	<0.001
tAP	46.1±4.0 (38.5-53.1)	43.1±3.0 (38.5-50.4)	48.9±2.6 (42.0-53.1)	<0.001
tML/tAP	1.52±0.08 (1.40-1.79)	1.52±0.08 (1.42-1.79)	1.52±0.08 (1.40-1.78)	0.78

Table 3: Distal femoral morphology of various ethnic groups.

	fML	fAP	fML/fAP
Indians (Our Study)	72.0±5.7 (C) 67.4±3.7 (F) 76.4±3.2 (M)	61.1±4.0 (C) 59.4±4.1 (F) 62.7±3.2 (M)	1.18±0.6 (C) 1.13±0.5 (F) 1.21±0.4 (M)
Americans Berger <i>et al.</i> ^[13] Griffin <i>et al.</i> ^[14]	75.4 ± 2.3(F) 85.6 ± 5.1(M) 78.0 ± 6.7(C) 74.1 ± 4.6(F) 84.1 ± 4.4(M)	60.2 ± 2.0(F) 68.1 ± 4.6(M)	
Chinese Cheng <i>et al.</i> ^[6]	71.0 ± 3.0(C) 66.8 ± 3.1(F) 74.4 ± 2.9(M)	64.1 ± 2.7(C) 61.0 ± 2.7(F) 66.6 ± 2.4(M)	1.11 ± 0.03(C) 1.09 ± 0.04(F) 1.12 ± 0.03(M)
Japanese Urabe <i>et al.</i> ^[8]	70.6 ± 4.5(C)		
Koreans Lee <i>et al.</i> ^[17]	75(C)		

(C- Combined males & females, F- female, M- male)

Table 4: Proximal tibial morphology of various ethnic groups.

	tML	tAP	tML/tAP
Indians (Our Study)	70.4±5.8 (C) 65.8±3.9 (F) 74.7±3.6 (M)	46.1±4.0 (C) 43.1±3.0 (F) 48.9±2.6 (M)	1.52±0.08 (C) 1.52±0.08 (F) 1.52±0.08 (M)
Americans Mensch <i>et al.</i> ^[15]	70.1 ± 2.8 (F) 80.3 ± 3.7 (M)	42.1 ± 1.7 (F) 48.9 ± 2.3 (M)	
Chinese Cheng <i>et al.</i> ^[6]	73.0 ± 4.6 (C) 68.8 ± 4.6 (F) 76.4 ± 2.8 (M)	48.8 ± 3.4 (C) 45.7 ± 1.9 (F) 51.3 ± 2.0 (M)	1.49 ± 0.05 (C) 1.51 ± 0.06 (F) 1.49 ± 0.06 (M)
Japanese Uehara <i>et al.</i> ^[2]	74.3 ± 6.6 (C) 71.7 ± 4.0 (F) 83.0 ± 6.2 (M)	48.3 ± 5.4 (C) 46.6 ± 3.6 (F) 53.8 ± 6.6 (M)	
Koreans Kwak <i>et al.</i> ^[16]	71.9 ± 5.6 (C) 67.6 ± 3.1 (F) 76.1 ± 4.0 (M)	45.7 ± 3.8 (C) 43.2 ± 2.3 (F) 48.2 ± 3.3 (M)	1.57 (C) 1.56 (F) 1.58 (M)

(C- Combined males & females, F- female, M- male)

3.3 Comparison with conventional implants

The Indian knees were compared to the following commercially available conventional implants – PFC Sigma Knee System (DePuy, USA), Freedom Knee System (MAXX, USA), NexGen LPS Flex Mobile Knee System (Zimmer Holdings, USA), Scorpio NRG Knee System (Stryker Corp., USA) and Buechel Pappas highflex mobile bearing knee system (TTK healthcare Ltd., USA).

3.1.1 Femoral Components

In case of the femoral components, NexGen LPS and Scorpio NRG implants sizes had shown some correlation with the

Indian population (Figure 2). However, in other three systems implants with smaller fAP were undersized in fML and those with larger fAP showed overhang in fML i.e. the slope of the implant sizes and Indian population was different. This was clearly seen in the graph of femoral aspect ratio (fML/fAP) vs. fAP. The femoral aspect ratio of the Indian population showed a decreasing trend with increase in fAP; however, implants had an almost constant femoral aspect ratio (Figure 5).

For female population, the femoral components tended to be too large for a given AP measurement, with the most overhangs in the larger sizes (Figure 3).

Fig 2: Comparison of fAP vs fML between study population and different knee systems.

Fig 3: Comparison of fAP vs fML between female in study population and different knee systems.

Fig 4: Comparison of fAP vs fML between male in study population and different knee systems.

Fig 5: Comparison of fAP vs fML/fAP between study population and different knee systems.

Fig 6: Comparison of fAP vs fML/fAP between female in study population and different knee systems.

Fig 7: Comparison of fAP vs fML/fAP between male study population and different knee systems.

3.1.2 Tibial Components

In case of the tibial components, the various implant sizes covered the entire range of the Indian population (Figure 8). However, as observed for femoral components, the slope of the implant sizes and Indian population was different—implants with smaller tAP were undersized in tML and those with larger tAP showed overhang in tML (Figure 8). The graph of tibial aspect ratio (tML/tAP) vs. tAP clearly

displayed the above result. Although the tibial aspect ratio of the Indian population had a decreasing trend with increasing tAP, implants had an almost constant tibial aspect ratio (Figure 11).

Like as the femoral components, for females tAP tended to be too large for a given tML measurement, with overhang in the larger sizes mainly in PFC DEPUY, Freedom MAXX and Scorpio NRG Stryker (Figure 9).

Fig 8: Comparison of tML vs tAP between study population and various knee systems.

Fig 9: Comparison of tML vs tAP between female in study population and various knee systems.

Fig 10: Comparison of tML vs tAP between male in study population and various knee systems.

Fig 11: Comparison of tAP vs tML/tAP between study population and various knee systems

Fig 12: Comparison of tAP vs tML/tAP between female in study population and various knee systems

Fig 13: Comparison of tAP vs tML/tAP between male in study population and various knee systems

4. Discussion

For long term survival of total knee arthroplasty, replaced prosthesis should match the knee size of the patient [6]. Maximal implant coverage on the bone surface minimizes the stress applied to the bone-implant interface [4, 5]. Most TKA prosthesis designs are based on the anthropometry of western population, which differs from Asian knee morphometry [3].

Data of Indian knee morphometry of healthy and non osteoarthritic knee was lacking [10].

We studied the knee morphometry of Indian healthy and non osteoarthritic knee. We found significant difference ($p < 0.001$) in the measurement of fAP, fML, tAP, tML and femoral aspect ratio among males and females of study population (Table 2).

We compared our data of Indian anthropometry with the data available in literature of other ethnic groups (Table 3). Indian fML was found to be smaller than that of Americans fML but larger than other ethnic group in study, while fAP of Indians was smallest (Table 3). tML and tAP of Indian knee was found to be least (Table 4).

This study used a 3D CT image technique for morphological measurements of the tibia and femur in an Indian population. The measurements from the CT images strongly correlate to intra-operative measurements since the 3D CT image of the knee can undergo unconstrained rotation and the correct three dimensional axis can be determined and maintained [17].

The Indian knees were compared to Western implants which were commonly available in the Indian market and used by surgeons for TKA of Indian patients. In case of the femoral components, NexGen LPS and Scorpio NRG implants sizes had shown some correlation with the Indian population. However, in other three systems implants with smaller fAP were undersized in fML and those with larger fAP showed overhang in fML i.e. the slope of the implant sizes and Indian population was different (Figure 2). The femoral data of the Indian population showed a decreasing aspect ratio (fML/fAP) as the fAP dimension increased (Figure 5).

In case of the Indian tibia, the various implant sizes covered the entire range of the Indian population (Figure 8). However, as observed for femoral components, the slope of the implant sizes and Indian population was different, implants with smaller tAP were undersized in tML and those with larger tAP showed overhang in tML. The tibial aspect ratio (tML/tAP) of the Indian population decreased as the tAP increased (Figure 11).

In contrast to these observations in the aspect ratios of Indian patients, variations in aspect ratios of most implants were insignificant. For both the femur and tibia, it was found that the ML dimension was undersized with smaller AP and overhang was observed for larger AP dimensions. Thus our results suggest that Western implants may not be suitable for Indian patients.

The limitation of this study was that we measured the unresected sizes of 3D reconstructed knee, but our results were similar to other Indian study [10]. Also it was short term single institutional study, with smaller sample size.

5. Conclusion

Our study suggests that why Western implant mismatches when implanted in Indian patients. Also, this study provides definite rationale for designing total knee prosthesis, especially a gender-specific design suitable for the Indian population. This study clearly shows that while designing the prostheses, the relationship between aspect ratio and antero-posterior dimension of the tibia and femur should also be taken into account apart from the relationships between medio-lateral and antero-posterior dimensions.

6. Acknowledgement

No benefits or funds were received in support of this study. All authors report no conflict of interest.

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