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Morphometric measurements of knee joints using magnetic resonance imaging (MRI) scans

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Abstract

Introduction: Most commercially available total knee arthroplasty implants are designed for western populations, which typically have larger build and stature compared to their Asian counterparts often resulting in mismatch between resected bony surfaces and implant components. There is paucity of morphometric data of distal femur and proximal tibia in a Nepalese population, hence this study was conducted.

Method: A prospective, cross sectional study was performed in knee MRI of patients attending Patan Academy of Health Sciences, Lalitpur, Nepal. One hundred and seventy digital knee MRI of patients fulfilling inclusion criteria were included in study. Different parameters were measured from distal femur and proximal tibia using RadiAnt DICOM viewer software. Student's t-test was applied to assess whether there were significant gender differences in measured femoral and tibial parameters.

Result: The mean mediolateral and anteroposterior dimensions of distal femur were 7.39±0.71 cm and 4.94±0.48 cm respectively, whereas for proximal tibia, 6.94±0.64 cm and 4.56±0.48 cm respectively. The mean aspect ratio for femur was 1.50±0.11 and for tibia was 1.52±0.094. All measured morphometric parameters in distal femur and proximal tibia were found to be statistically significantly higher in males compared to females ($p<0.001$). However, there was no significant gender difference in tibial aspect ratio ($p>0.05$).

Conclusion: This study provides knee joint morphometric data to help orthopaedic surgeon in selecting appropriately sized prostheses for total knee arthroplasty. The findings also highlight significance of considering gender based anatomical variations during prosthesis design and selection.

Keywords: Distal femur; Gender difference; Knee morphometry; Proximal tibia; Total knee arthroplasty

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Introduction

Total knee arthroplasty (TKA) is an effective surgical procedure done to relieve pain, improve quality of life, and restore joint function in patients with end stage knee osteoarthritis.[1] Upto 25% of post TKA patients remain dissatisfied with surgically restored knee which could be attributed to prosthesis factors.[2] Mismatch in size of prosthesis used may lead to loosening of implant or impingement of surrounding soft tissue.[3]

Understanding knee joint anthropometry is essential for improving implant design, as prostheses are designed to mimic natural articulation. MRI based morphometric measurement have been shown to correspond well with intraoperative measurements.[4] Most implants are designed for knee anatomy of Western population, leading to geometric mismatch with smaller build of the Asian population.[5] In Nepal, few studies were conducted on morphometry of distal femur or proximal tibia only.[6] But studies assessing knee joint morphometry along with gender-wise comparisons are scarce. Hence, this study aims to measure morphometric parameters of distal femur and proximal tibia using magnetic resonance imaging (MRI) scans and to assess whether there is any gender wise variation in these measured parameters. This study provides data on the average dimensions of the distal femur and proximal tibia. These findings may help the orthopaedic surgeons in selecting the appropriate size of the prosthesis in knee surgery. Furthermore, the morphometric data may be useful to forensic experts for anthropometric and identification purposes.

Method

A cross sectional study was conducted in Patan Academy of Health Sciences, Lalitpur, Nepal from January to December 2024. Digital Knee MRI of those patients aged 18 years and above of both sexes was included whereas knee MRI of those patients exhibiting artifacts, fractures or gross bony defects involving the knee were excluded.

In knee MRI, morphometric parameters of the distal femur and proximal tibia were measured. All these knee MRI were performed in the Philips Ingenia MRI system with field strength of 1.5 Tesla. For distal femur, measurements were performed in the axial section images at level of the epicondyles. Similarly, proximal tibial measurements were performed from axial section image approximately 6-8mm below lateral tibial plateau. The various measurements performed from distal femur and proximal tibia is shown in figure 1. Consent was taken from research participant before knee MRI was performed. Ethical approval was obtained from Institutional Review

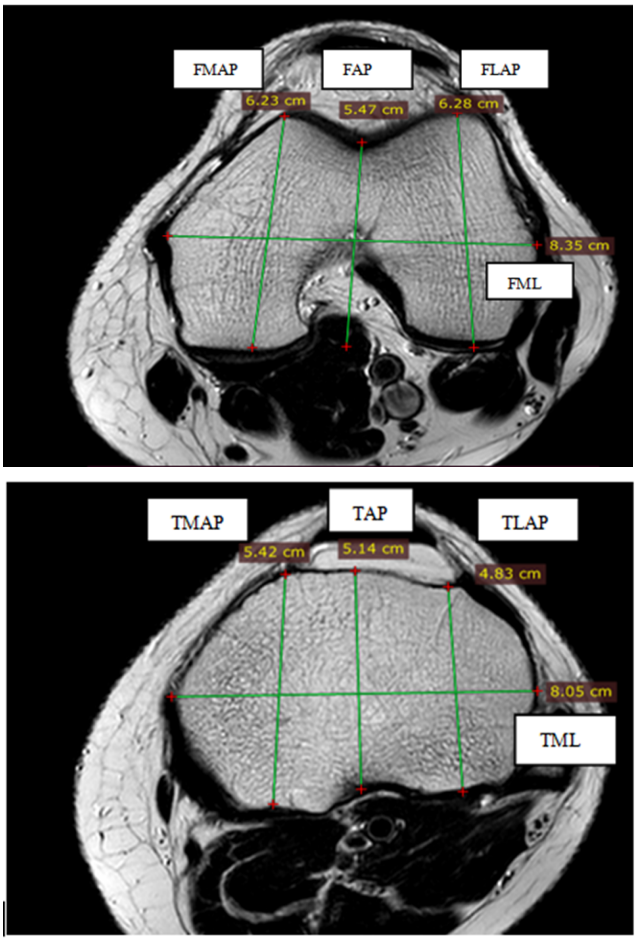

Figure 1. Morphometric measurements of distal femur and proximal tibia in axial MRI sections

Committee (IRC) of PAHS (Ref no: drs2403221844) before conducting this study.

In present study, sample size was calculated based on the sample size formula for mean estimation:

Sample size:

Calculated using formula: $n = \frac{Z^2 * \sigma^2}{e^2}$

Where,
n=required sample size
Z_α = 1.96 for the 95% confidence interval, σ=estimated standard deviation, e = precision
Standard deviation of measured mediolateral distance = 4.6 (Cheng et al.)[7]
Mean value=73.0,
Relative precision = 1% of mean
=0.01x73
=0.73
$n= (1.96)^2x(4.6)^2/(0.73)^2$
$=3.84x21.16/0.5329$
=152.4
=153
After amplification of sample size by 10% for measurement errors: 10x153/100=15.3=16
Total sample size required =153+16
=169
In this study we have included 170 samples.

For morphometric analysis of knee joint different parameters was measured from distal femur and proximal tibia as described in previous study.[8,9]

Distal femur measurements included:

1. Femoral mediolateral width (FML): Measured as widest distance between medial and lateral femoral epicondyle.
2. Femoral medial anteroposterior distance (FMAP): Measured as the widest distance between the anterior and posterior edge of medial femoral condyle.
3. Femoral lateral anteroposterior distance (FLAP): Measured as the widest distance between the anterior and posterior edge of lateral femoral condyle.
4. Femoral anteroposterior distance (FAP): Measured as the length of the line drawn through the midpoint of FML.
5. Femoral aspect ratio (FAR): The aspect ratio of distal femur is the ratio between FML and FAP given by formula FAR= FML/FAP.

Proximal tibia measurements included:

1. Tibial mediolateral length (TML): The widest horizontal distance between medial and lateral margins of the tibial surface.
2. Tibial medial anteroposterior distance (TMAP): Measured as the widest distance between the anterior and posterior margin of medial tibial condyle.
3. Tibial lateral anteroposterior distance (TLAP): Measured as the widest distance between the anterior and posterior margin of lateral tibial condyle.
4. Tibial anteroposterior distance (TAP): Measured as the length of the line drawn through the midpoint of TML.
5. The tibial aspect ratio (TAR): Is defined as the ratio of TML to the TAP, given by the formula TAR= TML/TAP.

All anthropometric measurements of knee were performed by same investigator to prevent inter observer bias. The measurements were performed by using software RadiAnt DICOM Viewer.

Statistical analysis

Collected data were entered into Microsoft Excel sheet and analyzed using Statistical Package for the Social Science (SPSS v-16). Measured parameters were presented as Mean ±SD. Student's t-test was applied to assess gender differences in measured femoral and tibial dimensions. P-value <0.05 was considered statistically significant.

Result

Among 170 participants, 78(45.90%) were male and 92(54.10%) were female. The age of the patient ranged from 18-70 years. The mean age of the participants is 38.99±12.92 years. Among 170 knee MRI, 88(51.8%) were of right side and 82(48.2%) were of left side.

We found that all measured distal femoral parameters showed significant gender difference, with males exhibiting higher values compared to females (p<0.001). The femoral aspect ratio also revealed a statistically significant difference (p<0.05), Table 1. We also found that morphometric parameters of proximal tibia showed significant gender difference, with males exhibiting higher morphometric values compared to females (p<0.001), except for TAR, where no significant difference was observed (p>0.05), Table 2.

Table 1. Morphometric measurement of distal femur and gender wise comparison of these measured parameters

Measurements	Value in centimeters (mean±SD)			P value (t-test)
	Combined (n=170)	Male (n=78)	Female (n=92)	
Femoral mediolateral (FML)	7.39±0.71	8.00±0.48	6.87±0.38	<.001
Femoral anteroposterior (FAP)	4.94±0.48	5.28±0.40	4.65±0.33	<.001
Femoral medial anteroposterior (FMAP)	5.46±0.52	5.85±0.43	5.13±0.33	<.001
Femoral lateral anteroposterior (FLAP)	5.63±0.50	5.98±0.43	5.33±0.33	<.001
Femoral aspect ratio (FAR)	1.50±0.11	1.51±0.10	1.48±0.10	<.05(.033)

Table 2. Morphometric measurement of proximal tibial and gender wise comparison of these measured parameters.

Measurements	Value in centimeters (mean±SD)			P value (t-test)
	Combined (n = 170)	Male (n = 78)	Female (n = 92)	
Tibial mediolateral (TML)	6.94±0.64	7.48±0.43	6.47±0.38	<.001
Tibial anteroposterior (TAP)	4.56±0.48	4.94±0.37	4.23±0.28	<.001
Tibial medial anteroposteior (TMAP)	4.67±0.47	5.06±0.35	4.35±0.27	<.001
Tibial lateral anteroposterior (TLAP)	4.22±0.47	4.61±0.34	3.90±0.27	<.001
Tibial aspect ratio (TAR)	1.52±0.94	1.52±0.94	1.53±0.94	>0.05(.36)

Discussion

A well matched prosthesis to the resected surface of knee is essential for the long-term success of total knee arthroplasty with minimal complications.[10] The success of the arthroplasty relies on a thorough understanding of the knee's morphometry and the selection of a geometrically compatible prosthesis.[9] Therefore, understanding of knee anthropometry is essential for designing and selecting prosthesis that closely replicate the native anatomy and function of the knee joint.[4] This study aimed to measure the morphometric parameters of distal femur and proximal tibia using magnetic resonance imaging (MRI) and to assess genderwise variations in these measured parameters.

Morphometry of distal femur: In this study, average femoral anteroposterior distance (FAP) was 4.94±0.48 with values of 5.28±0.40 cm in males and 4.65±0.33 cm in females. These results are consistent with findings reported from Philippines.[9] However, smaller values than ours was reported by Mensch et al.[12] While, larger values has been observed in Chinese, Emirati, Indian, and Caucasian populations.[7,8,13,14] The mean femoral mediolateral distance was 8.0±0.48 cm for male and 6.87±0.38 cm for females. These measurements are comparable to studies from America, India and Southern china.[12-14] However, they are lower than findings reported in Caucasian, Korean and in other Asian population.[15-17] But higher values observed in studies from UAE and the Philippines.[8,9] Overall, all femoral parameters in our study were lower compared to those in Caucasian populations.[15] These differences in measured value between present study and previous studies may be attributed to differences in body height, build and genetic predisposition between the races.[18]

In present study, the mean values of all measured femoral parameters were found to be statistically significantly higher in males than in females ($p<0.001$). The findings of our study align with previous research conducted in UAE, Philippines, India, China, Korea and Thailand.[8,9,13,14,16,19] Gender differences in femoral measurements might be due to genetic, hormonal, environmental, and lifestyle factors.

Femoral surface aspect ratio (FAR) provides a general estimate of the distal femur's shape and is a key factor in assessing the suitability of prosthesis with the native knee. The average FAR in present study is 1.50±0.11 which is higher than reported from Emirati Population, Philippines, India and China [8,9,13,14] and is lower than the value reported by Mahfouz et al. in Asian population.[17] The study by Mahfouz et al included data from different Asian ethnic group such as Chinese, Korean, and Japanese populations. There the inclusion of multiple ethnic groups within pooled Asian population may have influenced the overall mean femoral aspect ratio, making it different from the values reported in individual country studies.

Hitt et al. reported that femoral aspect ratio represents the proportional relationship between mediolateral and anteroposterior dimensions of the distal femur. In their study population an inverse relationship between knee size and aspect ratio was observed, where larger knees demonstrated lower aspect ratio.[21] However, in our study, FAR values were found to be statistically significantly higher in males compared to females ($p<0.05$). These findings are consistent with earlier studies.[8,9,13] Collectively, these studies indicate that males tend to have higher FAR values than females, suggesting relatively greater femoral mediolateral dimensions in relation to anteroposterior dimensions. Morphometry of proximal tibia: In present study, average tibial anteroposterior (TAP) distance was 4.56±0.48 cm which is consistent to the findings reported in studies from Philippines, India, Thailand and Korea.[9,22-24] The mean tibial mediolateral (TML) distance was 7.48±0.43 cm for male and 6.47±0.38 cm for females. These values are similar to those reported in studies from Philippines and India.[9,13] But, are smaller compared to those observed in Americans, Chinese and Caucasian populations.[12,14,25] When comparing our study findings with Caucasian populations, all measured tibial parameters were found to be higher in Caucasians.[25] Likewise, compared to Americans, the measured value of TAP and TMAP was higher than in our study, whereas TLAP values were quite similar.[12] These ethnic differences in tibial morphology highlight a potential issue of implant size mismatch when using existing knee prostheses, which are designed based on western population. Such implants may not be appropriate for the Asian population, who generally has a smaller skeletal build, underlining the need for region specific implants.[4] In the present study, the mean values of all measured proximal tibial dimensions- TAP, TML, TMAP, TLAP were significantly higher in males compared to females ($p<0.001$). Similar significant gender differences have also been reported in previous studies.[7-9,13,14,23,24] These findings emphasize the importance of considering gender-specific differences in proximal tibial dimensions when designing and selecting knee prostheses.

Similar to FAR, the tibial aspect ratio (TAR) reflects the shape of proximal tibia. A higher tibial aspect ratio indicates a relatively greater mediolateral width compared anteroposterior length. Hitt et al. Reported an inverse relationship between knee size and TAR In their study population with smaller knees exhibiting higher TAR values and larger knees demonstrating lower TAR values. [21] In present study, the average TAR was 1.52. Higher ratios than those observed in

our study have been reported in previous studies from Philippines, India, Thailand and Korea.[9,13,24,25] In contrast, lower ratios have been observed in Chinese and caucasians.[7,14,25] These variations in aspect ratio of different populations may be influenced by factors such as ethnic and genetic differences. In the present study, there was no statistically significant difference in measured TAR between male and female (p>0.05). These findings are consistent with those reported in previous studies.[10,11,14,15] The lack of a significant difference may be attributed to the proportional growth of tibial dimensions in both sexes.

Limitation of study: As this study was conducted atPatan Hospital, a tertiary care centre patients from all over country visit this hospital for treatment. Therefore, the findings may to some extent reflect morphometric characteristics of Nepalese population. However, complete generalizability remain limited. In addition, Intraobserver reliability of the morphometric measurements was not assessed which could have influenced the reproducibility of measurements. In this study anthropometric parameters such as height, weight and body mass index were not correlated with the morphometric measurements of knee joints. Such correlations could provide additional information into anatomical variations among individuals.

Conclusion

The present study provides MRI based morphometric data of the distal femur and proximal tibia that helps orthopaedic surgeons in selecting appropriately sized prostheses for total knee arthroplasty. The findings also highlight significance of considering gender based anatomical variations during prosthesis design and selection.

Conflict of Interest

None

Funding

None

Author Contribution

Concept, design, planning: TS, NTS, TRB; Literature review: TS, TRB, NTS, PP, DSM; Data collection: TS, NTS; Data analysis: TS; Draft manuscript: TS NTS, TRB, PP, DSM; Revision of draft: TS, NTS, TRB, PP, DSM; Final manuscript: TS, NTS, TRB, PP, DSM; Accountability of the work: TS, NTS, TRB, PP, DSM; Guarantor: TS.

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