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A Magnetic Resonance Imaging Study on Sex Based Difference in Morphometric Parameter of Knee Joint

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ABSTRACT
Total knee replacement (TKR) is a surgical procedure in which an artificial joint or prosthesis replaces a damaged knee joint. The aim of total knee replacement is pain relief and restoration of knee function and mobility. Morphometric evaluation based on MRI provides a more comprehensive evaluation of both osseous and soft tissue structures. Thus the aim of the study was to determine the morphometric measures of knee joint in Indian adults. This study was conducted among the healthy individuals of RMCH Bareilly. The knee joint data included 59 males and 59 females' knees. This study was conducted for approximately one year after the approval from Central Research Committee. A 1.5 TESLA MRI unit (Avanto Magnetomtim + dot system, Siemens, Erlangen, Germany) was utilized for imaging. The parameter of proximal tibia and distal femur were taken. There was a significant mean differences in all Morphometric parameters observed between males and females ($P<0.01$). Mean values were significantly less in females as compared to males. Mean TML in males was 7.56±0.37 and in females it was 6.49±0.28. Mean TMAP was in males was 4.84±0.33 while in females it was 4.13±0.31.

INTRODUCTION

Knee is an important hinge joint that is responsible for weight-bearing and movement. The femur (thigh bone), tibia (shin bone), and patella (kneecap) make up the bones of the knee joint. Knee osteoarthritis (OA), also known to be the most common degenerative joint disease around the world, and is typically the result of wear and tear and progressive loss of articular cartilage. The occurrence of OA varies from 3.8% - 70% around the world depending on the methodologies used for its diagnosis and the studied populations[1-3]. Knee joint instability is also one of the common sources of problem from which both athletes and non-athletes suffer which leads to osteoarthritis of the knee joint in long run. Many countries have health care systems focused on value-based care, which are systems focused on understanding the cost drivers, implementing high-value therapies, and improving methods and/or techniques to assess knee instability and rehabilitation therapies that could potentially reduce the health care costs associated with knee injury[4-8].

Total knee replacement (TKR) is a surgical procedure in which an artificial joint or prosthesis replaces a damaged knee joint. In recent years knee prosthesis has improved greatly and it has become one of the most reliable joint replacements. The aim of total knee replacement is pain relief and restoration of knee function and mobility. In fact, total knee replacement (TKR) is widely considered as an effective treatment for end-stage knee degenerative pathologies[9-11]. The analyses based on shape have identified sex differences in the femoral midshaft, distal femur, and patella. Using automated three-dimensional (3D) morphologic analysis, differences in knee morphology between the sexes has been identified. Reports of anthropometric studies have confirmed that there is a striking differences in knee morphology between males and females, where females having a smaller Mediolateral to Anteroposterior ratio and more narrow distal femurs[12-15]. Also research on implant mismatching carried out in various Asian countries have suggested that selection of TKA implants blindly is not rationalized since their designs are based on morphological data of a limited studied population of a certain region[16].

MRI technology employs a potent magnetic field and radiofrequency pulses to generate detailed imagery of knee joint structures, aiding in the diagnosis and assessment of joint conditions. It is a critical tool for evaluating pain, weakness, swelling, or internal derangement of the knee without the use of ionizing radiation, often informing the decision on whether surgery is necessary. While radiography is the initial standard in imaging for knee diagnosis, MRI provides a more comprehensive evaluation of both osseous and soft tissue structures. Despite its detailed imaging capabilities, conventional MRI is typically conducted with the knee at rest, which may not accurately represent the joint's physiological state during activity, potentially overlooking early signs of osteoarthritis (OA)[17,18].

Moreover, MRI studies have ventured into analysing knee joints under mechanical stress to detect disease-specific alterations. These investigations aim to elucidate the mechanical behaviour of musculoskeletal tissues under load, which can reveal malfunctions associated with early-stage OA[17-19]. Such studies underscore the need for MRI-compatible devices and techniques that accommodate the mechanical loading of joints during imaging, although they face challenges posed by the limitations of traditional MRI sequences. Thus the aim of the study was to determine the morphometric measures of knee joint in Indian adults.

MATERIALS AND METHODS

Study Design: Descriptive cross-sectional study

Study Setting: Department of Anatomy, Rohillkhand Medical College, Bareilly after approval from the College research committee and Institutional ethical committee (IECno.BIU/REG/PhD/551)

This study was conducted among the healthy individuals of RMCH Bareilly. The knee joint data included 59 males and 59 females' knees. This study was conducted for approximately one year after the approval from Central Research Committee.

Inclusion criteria:

- Age group of 22 to 60 years of age[20]
- Healthy knee joints
- Only complete and fully ossified bones was included

The study received ethical approval from the Institutional Review Board.

Exclusion criteria[21]: Patients with previous knee joint surgeries or had a knee trauma, fracture, dislocation, or a ruptured or torn anterior cruciate ligament (ACL) of any sprained ligament (sprain II and above) was not include in the study.

Magnetic Resonance Imaging Technique: A 1.5 TESLA MRI unit (Avanto Magnetomtim + dot system, Siemens, Erlangen, Germany) was utilized for imaging. Images were obtained at a thickness of 3 mm with a 0.3 mm interval. Subjects were positioned supine with their knee joints at a 0° angle, and patellas facing forward to capture axial images parallel to the knee joints. The

NUMARIS/4 syngo MR D13 system was employed to measure morphometric parameters in the axial images of the proximal tibia and distal femur.

In this study, about 13 morphological features will be measured.

The parameters of proximal Tibia[21]:

- **Tibia Anterioposterior width (tAP):** Distance between two tangents parallel to Trans Epicondylar Axis and passing through anterior and posterior extremities.
- **TEA:** Distance between the lateral and medial epicondyles.
- **Tibia Medial Condyle Anterioposterior Length (tMAP):** The tibial medial anteroposterior length (tMAP) is the length from the anterior medial tibia plateau to the posterior plateau. The tibial lateral anteroposterior length (tLAP) : the length from the anterior lateral tibia plateau to the posterior plateau.
- **Tibia Medial-Lateral width (tML):** Distance between medial and lateral extremities in the resected plane measured parallel to the mediolateral axis was defined as tibial mediolateral width (tML)

The Parameters of Distal Femur[21]:

- **The Femur Epicondylar Width (fEW):** "It is defined as the transverse distance across the femur at the level of the epicondyles, which are the rounded bony prominences at the distal end of the femur where ligaments and tendons attach. This measurement is taken as the straight line distance between the most lateral point of the lateral epicondyle and the most medial point of the medial epicondyle."
- **Femur Medial Condyle Anterioposterior length (fMAP):** Defined as the distance from the most anterior point on the femur medial condyle to the posterior condylar line.
- **Femur Lateral Condyle Anterioposterior length (fLAP):** Distance from the most anterior point on the femur lateral condyle.
- **Femur Medial-Lateral length (fML):**Referenced by the femoral epicondyle axis, defined as the most salient point between the medial and lateral attachment on the femoral condyle.
- **Femur Medial Condyle Width (fMW):** The transverse distance across the medial condyle of the femur, which is the innermost of the two rounded prominences at the end of the thigh bone, where it meets the knee.
- **Femur Lateral Condyle Width (fLW):** The measurement of the transverse distance across the lateral condyle of the femur, the outermost of the two prominences.
- **Intercondylar Fossa Width (ICW):** The measurement of the distance across the intercondylar fossa, the groove between the medial and lateral femoral condyles.
- **Intercondylar Fossa Height (ICH):** Vertical measurement from the deepest part of the intercondylar fossa to the top of the fossa's ridge.
- And Femoral Aspect Ratio (Ration of femoral ML/AP). The data extraction was done along the three different view- planes such as transverse plane, sagittal plane and coronal plane of the scan.

Statistical Analysis: Data was entered in excel and analyzed using SPSS (V-20). Matirx data was expressed in mean ± standard deviation and categorical data was expressed in frequencies/percentages. Morphometric measures between the gender was compared using independent sample t-test. P-value <0.05 was set statistically significant.

RESULTS AND DISCUSSIONS

There were 59 male and 59 female participants with a total of 118 included in the study.

The Mean age of all participants was 22.20±5.03. Mean height and Weight were 164±8.46 (cms) and 61.53±11.28 (Kgs) respectively.

The mean values (TIBIA) of TML, TAP, TMAP and TLAP respectively were 7.02±0.63, 4.39±0.42, 4.49±0.48 and 4.22±0.46. The mean values (FEMUR) of FML, FMAP, FLAP, FEW, FMW, FLW, ICW, ICL and FAR respectively were 7.50±0.68, 5.67±0.51, 6.00±0.51, 7.58±0.86, 2.43±0.28, 2.31±0.26, 2.39±0.29, 2.36±0.35 and 0.92±0.10.

It was observed that there was significant mean differences in age, height and weight between males and females (P<0.01).

There was a significant mean differences in all Morphometric parameters observed between males and females (P<0.01). Mean values were significantly less in females as compared to males. Mean TML in males was 7.56±0.37 and in females it was 6.49±0.28. Mean TMAP was in males was 4.84±0.33 while in females it was 4.13±0.31.

Mean FML, FEW and FLW in males was 8.04±0.50, 8.24±0.63 and 2.49±0.16 respectively while in females it was 6.97±0.33, 6.92±0.46 and 2.13±0.19 Table 5.

A comparative analysis of femoral measurements reveals a discernible trend of larger dimensions in male subjects compared to female counterparts. This pattern is consistently observed across a spectrum of femoral metrics, including the Femur Lateral Condyle Width (fEW), the Femur Medial Condyle

Table 1: Sex distribution of study participants

Sex	Frequency	Percent
Male	59	50.0
Female	59	50.0
Total	118	100.0

Table 2: Age and Anthropometric measures of all participants

Variables	Mean	Std. Deviation	Minimum	Maximum
AGE	22.20	5.03	18.00	44.00
HEIGHT (cm)	164.66	8.46	144.00	186.00
WEIGHT (Kg)	61.53	11.28	38.00	90.00

Table 3: Morphometric measures of knee joint

Variables	Mean	Std. Deviation	Minimum	Maximum
TIBIA				
TML	7.02	0.63	5.87	8.45
TAP	4.39	0.42	3.47	5.70
TMAP	4.49	0.48	3.32	5.81
TLAP	4.22	0.46	3.38	5.32
FEMUR				
FML	7.50	0.68	5.98	9.16
FMAP	5.67	0.51	4.14	7.34
FLAP	6.00	0.51	4.90	7.29
FEW	7.58	0.86	5.98	9.32
FMW	2.43	0.28	2.06	3.06
FLW	2.31	0.26	1.85	2.90
ICW	2.39	0.29	1.73	2.90
ICL	2.36	0.35	1.73	3.08
FAR	0.92	0.10	0.67	1.24

Table 4: Comparison of Anthropometric measures between gender

Sex	Male	Female	t-value	P-value*
AGE	23.51±5.82	20.90±3.71	2.905	0.004
HEIGHT (cm)	170.66±6.21	158.66±5.72	10.925	<0.001
WEIGHT (Kg)	66.14±10.22	56.92±10.43	4.850	<0.001

**Based on Independent sample t-test*

Table 5: Comparison of Morphometric measures between gender

Sex	Male	Female	t-value	P-value*
TIBIA				
TML	7.56±0.37	6.49±0.28	17.865	<0.001
TAP	4.64±0.41	4.13±0.25	8.096	<0.001
TMAP	4.84±0.33	4.13±0.31	12.060	<0.001
TLAP	4.56±0.34	3.88±0.27	12.008	<0.001
FEMUR				
FML	8.04±0.50	6.97±0.33	13.810	<0.001
FMAP	5.98±0.46	5.36±0.35	8.074	<0.001
FLAP	6.34±0.40	5.66±0.34	9.933	<0.001
FEW	8.24±0.63	6.92±0.46	13.041	<0.001
FMW	2.61±0.19	2.25±0.24	9.227	<0.001
FLW	2.49±0.16	2.13±0.19	11.205	<0.001
ICW	2.52±0.15	2.25±0.32	5.919	<0.001
ICL	2.57±0.21	2.15±0.33	8.190	<0.001
FAR	0.97±0.10	0.88±0.09	5.220	<0.001

**Based on Independent sample t-test*

Anteroposterior length (fMAP), the Femur Lateral Condyle Anteroposterior length (fLAP), the Femur Medial Condyle Mediolateral length (fML), the Femur Medial Condyle Width (fMW), the Intercondylar Fossa Width (ICW), the Intercondylar Fossa Length (ICL), the Femoral Mediolateral Length (FML), and the femoral aspect ratio (ML/AP). These findings underscore the importance of considering gender-specific anatomical differences in femoral dimensions for clinical and surgical applications.

Distribution of Study Population According to Anthropometric Measures: Table 2, 3 and 4 presents the age and anthropometric measures of all participants. The mean age of the study participants was 22.20±5.03 years. It's worth noting that age-related variations in knee joint morphometry have been explored in various studies. For instance, Choi *et al*. (2021) analyzed age and gender variations of the patellofemoral joint using MRI, highlighting the relevance of age in knee joint studies[22,23].

Additionally, the mean height was 164 cm ±8.46 cm, while the mean weight was 61.53 ±11.28 Kg. These measures provide a comprehensive overview of the participants demographic characteristics and physical attributes, which were crucial for understanding how these factors related to the morphometric measures of the knee joint.

A study by Mortensen *et al*.[20] evaluated articular cartilage height in patients using extremity-MRI and specialized radiography, highlighting the importance of precise measurements in the context of knee joint health. Another study by Sieron *et al*.[25] observed associations between knee surface area and dimensions, although the association was reported as weak. This suggests that while surface area and dimensions can provide insights into joint morphology, they may not always be strongly correlated.

Comparison of Anthropometric Measures Between Gender: A comparison of anthropometric measures between males and females, along with statistical analysis using an independent sample t-test. The data included three key parameters: age, height (in centimetres), and weight (in kilograms) for both genders.

In terms of age, males had a higher mean age of 23.51 years (±5.82), while females had a slightly lower mean age of 20.90 years (±3.71). The statistical analysis showed a significant difference with a t-value of 2.905 and a p-value of 0. 004.Secondly, in terms of height, males had a notably higher mean height of 170.66 cm (±6.21) compared to females, who had a mean height of 158.66 cm (±5.72). When it comes to weight, males exhibited a higher mean weight of 66.14 kg (±10.22) compared to females with a mean weight of 56.92 kg (±10.43). The t-value and a p-value revealed a statistically significant difference in height and weight between males and females.

Comparison of Morphometric Measures of Tibia Between Gender: A detailed comparison of morphometric measures between genders, specifically focusing on male and female subjects. These measures encompass various aspects of bone dimensions, particularly the tibia and femur, and the statistical analysis was based on the independent sample t-test. Males had a significantly longer average tibia length (7.56 cm ± 0.37) compared to females (6.49 cm ± 0.28).Once again, males exhibited a significantly greater anteroposterior measurement (4.64 cm ± 0.41) compared to females (4.13 cm ± 0.25). Tibia

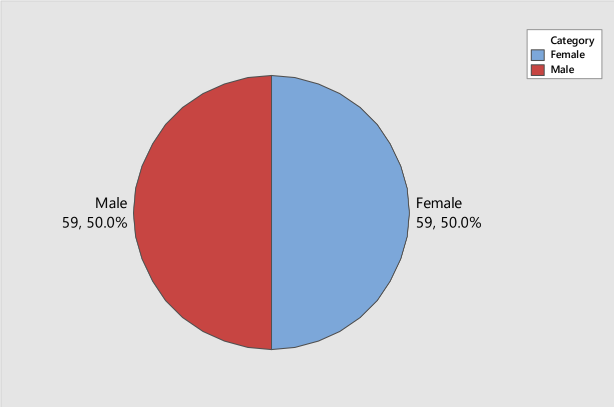

Fig. 1: Sex distribution of study participants

Mediolateral Anteroposterior (TMAP) and Tibia Lateromedial Anteroposterior (TLAP) also showed significant differences, with males having larger values.

The findings of this research are in concordance with similar studies focusing on the morphometrics of knee joints. Research by Tummala *et al*. has highlighted differences in knee joint structures such as condylar alignment (CA) and congruity index (CI) between genders, particularly within medial tibiofemoral (MTF) joints. Their research suggests that female knees often have a higher CA and a lower CI, which could reflect the gender-specific variations in tibial dimensions that our study also identifies[25,26]. Similarly, Park *et al*. have reported significant differences in knee dimensions between genders, specifically in measurements like notch width (NW), bicondylar width (BCW), and medial condylar width (MCW). Such findings give additional support to the gender-related differences noted in the present study[27].

Moreover, Terzidis *et al*. found greater bicondylar width in men compared to women, aligning with the pattern of larger tibial dimensions in males observed in this study[28]. These studies collectively reinforce the importance of considering gender differences in knee joint morphometrics, particularly when designing knee-related medical interventions or comparing anatomical variations across different populations.

Comparison of Morphometric Measures of Femur Between Genders: In the comparison of morphometric parameters of knee joints related to femur, males have substantially longer femurs, with an average of 8.04 cm (±0.50) compared to females with 6.97 cm (±0.33). Femur Mediolateral Anteroposterior (FMAP) and Femur Lateromedial Anteroposterior (FLAP): both measurements indicate that males have larger dimensions compared to females. Males have a wider femur endocortical width (8.24 cm ± 0.63) compared to females (6.92 cm ± 0.46). Femur Midshaft Width (FMW) and Femur Lateromedial Width (FLW): Once again, males exhibit greater values in both measurements.

The comparison of anthropometric measures between genders in the context of knee joint morphometrics is a critical area of study, especially considering the objectives of understanding the variations in the Indian population and comparing them with global data. Merchant *et al*. found that women had comparable or even better outcomes after total knee arthroplasty (TKA) compared to men, and they observed that clinical results did not correlate with sex-based morphological differences[28]. In contrast, Cheng *et al*. proposed that morphological data could be valuable for prosthesis design, emphasizing the suitability of sex-specific designs[29,30]. Guy *et al*. discovered significant disparities in the distal femoral morphology between men and women, particularly noting that many female cases exhibited femoral component overhang in standard prostheses[31]. To assess the clinical impact, they recommended long-term studies and suggested that sex-specific implants might mitigate potential medial-lateral overhang. Furthermore, anthropometric measurements indicated that women had smaller distal femoral dimensions compared to men.

Loures' study, which examines the correlation between knee anthropometrics and prosthetic implant sizing, also confirms the presence of gender-specific variations in the dimensions of the distal femur[32]. These studies collectively highlight the importance of recognizing and understanding the differences in knee joint morphology along gender lines, particularly within the Indian demographic. Such insights are crucial for orthopedic surgical planning and provide a useful point of reference for global comparative studies.

In the morphometric analysis conducted by Lim *et al*., which utilized MRI for precision, the medial-lateral (ML) width for the studied cohort averaged at 81.5 mm in males and 76.7 mm in females. The study further revealed that the anteroposterior (AP) width of the medial compartment measured 62.7 mm in males and 56.8 mm in females, and for the lateral compartment, the dimensions were 59.0 mm in males compared to 58.4 mm in females[12]. Other parameters, including the intercondylar width (ICW), intercondylar length (ICL), and femoral aspect ratio (FAR), also presented significant variations between the sexes. Statistical analysis indicated a highly significant difference in these morphometric parameters between male and female subjects ($p<0.001$).

CONCLUSION

The study outcomes emphasized noticeable gender-related distinctions in critical tibia and femur parameters, consistently revealing larger dimensions in males. These findings hold relevance for knee health, orthopedic evaluations, and prosthetic design considerations. The inclusion of anthropometric variables like age, height, and weight underscored their significance in comprehending knee joint morphometry. Moreover, the research employed Receiver Operating Characteristic (ROC) analysis to demonstrate the discriminatory power of various anatomical parameters linked to bone dimensions. These analytical approaches served as indispensable tools for both clinicians and researchers, aiding in establishing cutoff values for specific morphometric measurements.

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