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Differences in Knee Morphology According to Age and Gender: An Evaluation Based on MRI

Yaş ve Cinsiyete Göre Diz Morfolojisindeki Farklılıklar: MRG Üzerinden Yapılan Bir Değerlendirme

[1]Bedrettin ÇİNPOLAT, [2]Meltem AÇAR GÜDEK, [3]Şirin ASLAN BARAN

[1]Departman of Dental Services, Vocational Higher School of Health Services, Tokat Gaziosmanpaşa University, Tokat, Türkiye
[2]Departman of Anatomy, Faculty of Medicine, Samsun University, Samsun, Türkiye
[3]Departman of Physical Therapy and Rehabilitation, Faculty o f Medicine, Tokat Gaziosmanpaşa University, Tokat, Türkiye

Bedrettin Çinpolat: https://orcid.org/0000 0002 3325 1522
Meltem Açar Güdek: https://orcid.org/0000 0002 4517 5889
Şirin Aslan Baran: https://orcid.org/0000 0003 0153 973X

ABSTRACT

Objective: The knee joint is an articulation exposed to excessive load during daily activities at all ages. There are ongoing discussions about the suitability of the currently used standard implants for this joint in terms of age and gender. In our study, we aimed to determine the possible morphometric differences of the bone structures involved in this joint according to age groups and gender.
Materials and Methods: The magnetic resonance (MR) images of the knee joints of 212 individuals (106 males, 106 females) aged between 18 and 69 years were retrospectively analyzed, and morphometric data were obtained from these images. Patients were separated according to age groups and gender, and the obtained data were analyzed.
Results: In the study, the measurement values related to the morphology of the femur, tibia, patella, and patellar ligament were generally higher in males than in females ($p<0.05$). When evaluated separately by sex, statistically significant differences were observed in certain morphometric parameters among the age groups ($p<0.05$).
Conclusions: Our study has shown that human knee anatomy varies significantly according to age and gender. These differences should be considered in the design of individualized and gender-specific knee joint prostheses.
Keywords: Gender, knee, knee joint, morphometry, MRI

ÖZ

Amaç: Diz eklemi günlük aktiviteler sırasında her yaşta aşırı yüke maruz kalan bir eklemdir. Günümüzde bu ekleme uygulanan mevcut standart implantların yaşa ve cinsiyete uygunluğu ile ilgili tartışmalar devam etmektedir. Biz de çalışmamızda bu ekleme katılan kemik yapıların yaş gruplarına ve cinsiyete göre olası morfometrik farklılıklarının belirlenmesini amaçladık.
Materyal ve Metot: 18-69 yaş aralığındaki 212 kişiye (106 erkek, 106 kadın) ait diz manyetik rezonans (MR) görüntüleri retrospektif olarak incelenerek bu görüntüler üzerinden morfometrik veriler elde edildi. Hastalar yaş gruplarına ve cinsiyete göre ayrılarak elde edilen veriler analiz edildi.
Bulgular: Çalışmada, femur, tibia, patella ve patellar ligamentin morfolojisi ile ilgili ölçüm değerleri genel olarak erkeklerde kadınlardan daha yüksek bulundu ($p<0,05$). Cinsiyetler ayrı olarak değerlendirildiğinde, yaş grupları arasında bazı morfometrik parametrelerde istatistiksel olarak anlamlı farklılıklar tespit edildi ($p<0,05$).
Sonuç: Çalışmamızda insan diz anatomisinin yaşa ve cinsiyete göre önemli farklılıklar içerdiği gösterilmiştir. Bu farklılıklar bireysel ve cinsiyete özgü diz eklemi protezi tasarımı çalışmalarında dikkate alınmalıdır.
Anahtar Kelimeler: Cinsiyet, diz, diz eklemi, morfometri, MRG

Sorumlu Yazar / Corresponding Author:
Bedrettin Çinpolat
Address: Departman of Dental Services, Vocational Higher School of Health Services, Tokat Gaziosmanpaşa University, Tokat, Türkiye.
Tel.: +90 554 466 66 88
E-mail: bedrettin.cinpolat@gop.edu.tr

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INTRODUCTION

The knee joint is a functional joint with a wide range of motion that supports body weight during various activities such as standing, walking, and running. Structurally, it consists of two joints: one between the tibia and femur within the synovial capsule and the other between the patella and the patellar surface of the femur. The joint between the femur and tibia supports body weight, while the joint between the patella and femur provides frictionless transfer of forces generated by the contraction of the quadriceps femoris muscle.[1]

During daily activities, the knee joint is exposed to excessive loads at all ages compared to other joints. In addition, sports activities that require running, jumping, balance, and physical contact make the joint more prone to injury. In addition to traumatic injuries, common problems of the knee joint include osteoarthritis, septic bursitis, tendonitis, and other conditions. Magnetic resonance imaging (MRI) is considered the most powerful radiological imaging technique for visualizing and diagnosing pathologies in the bones, ligaments, menisci, articular cartilage, tendons, synovium, and surrounding soft tissues of the knee joint.[1-4]

In our study, we aim to determine possible morphometric differences of the bone structures located in the knee joint according to age and gender, thus contributing to the increase of radiological knowledge about the region and providing insight to clinicians involved in regional rehabilitation.

MATERIALS AND METHODS

Ethical Approval: Our study was approved by the Tokat Gaziosmanpaşa University Clinical Research Ethics Committee (Date: 18.01.2024, decision no: 2024/01). The study was conducted following international declarations, guidelines, etc.

Patient Selection: The study included MRI records of 212 patients referred for knee imaging at Tokat Gaziosmanpaşa University Hospital between January 2017 and July 2024. Data were reviewed using Sectra Workstation IDS7 (v24.2.16.6066-2023) through the hospital's Picture Archiving and Communication System (PACS). The study included individuals aged 18–69 years with completed skeletal maturation and MRI scans of sufficient quality for radiological assessment. Exclusion criteria comprised congenital, traumatic, or inflammatory knee pathologies; fractures, dislocations, space-occupying lesions; radiological signs of osteoarthritis; prior knee surgeries; and artefacts or any factors that could impair measurement accuracy. Participants were stratified into three age groups: 18–34 years (Group 1), 35–49 years (Group 2), and 50–69 years (Group 3).[3] A total of 212 knees were evaluated, with an equal distribution of right and left knees (n=106 each) across both sexes. Demographic and imaging data (age, sex, laterality) were recorded using Microsoft Excel (Office 2013).

Measured Parameters: Information on the measured parameters of the femur, tibia, and patella is given below. Of these measured parameters, those expressing length were recorded in millimeters (mm), and those expressing angle were recorded in degrees (°).

The measured parameters of the femur bone are shown in Figure 1.

The measured parameters of the tibia bone are shown in Figure 2.

The measured parameters related to the patella and patellar ligament are shown in Figure 3.

MR Protocol: All images were obtained using a 1.5 Tesla MRI scanner (Signa EXCITE 14.0, GE Medical Systems, Waukesha, WI). Non-contrast sagittal, axial, and coronal MR images acquired in the extension position were evaluated in 212 patients. Measurements were performed on T1-weighted FSE sequences in the sagittal plane, PD-weighted FSE FS sequences in the axial plane, and PD-weighted FSE FS sequences in the coronal plane. The slice thickness was 4 mm for all images. All measurements were conducted by a single evaluator.

Statistical Analysis: Data analysis was performed using IBM SPSS Statistics version 22.0. Categorical variables were expressed as frequencies and percentages. The normality of continuous variables was assessed using visual methods and Kolmogorov-Smirnov/Shapiro-Wilk tests. For normally distributed variables, comparisons between independent groups were made using Student's t-test or One-Way ANOVA. Continuous variables were presented as mean ± standard deviation (SD). A p-value of <0.05 was considered statistically significant.

RESULTS

The 212 cases included in the study were evaluated in terms of gender, right and left knee separation, and age groups. Of the 212 cases, 106 (50%) were female and 106 (50%) were male. The age groups of the cases were divided into Group 1: 18-34 years, Group 2: 35-49 years, and Group 3: 50-69 years. The numbers of males and females and their distributions by age groups are presented in the tables (Tables 1 and 2).

Table 1 compares the measurement values of the anatomical structures related to the knee joint between males and females. In the male group, MCW, LCW, BW, MCH, LCH, ICW, ICD, TSD, TSW, MFW, LFW, TPW, IEW, MTPD, MTPL, LTPL, PL, PW, PTL values were found to be statistically significantly higher than in the female group

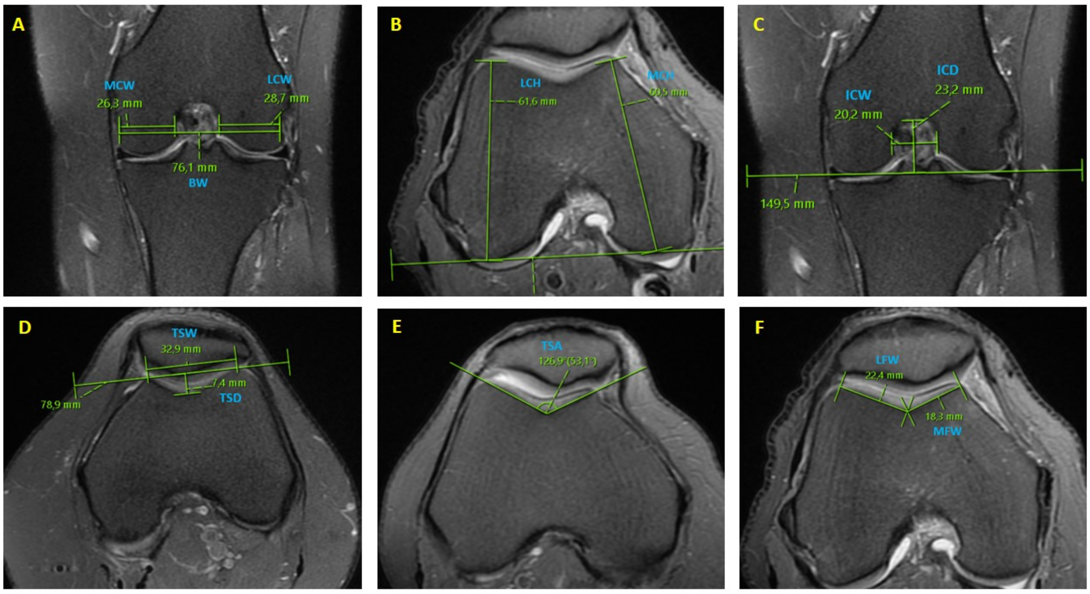

Figure 1. Parameters measured on the femur. A: In the coronal section of the left knee; The distance between the medial and lateral borders of the medial femoral condyle (MCW), and the distance between the medial and lateral borders of the lateral femoral condyle (LCW), and the distance between the medial border of the medial femoral condyle and the lateral border of the lateral femoral condyle (BW). B: In the axial section of the right knee; The greatest anteroposterior length of the lateral femoral condyle (LCH), and the greatest anteroposterior length of the medial femoral condyle (MCH). C: In the coronal section of the left knee; The distance between the medial border of the lateral femoral condyle and the lateral border of the medial femoral condyle (ICW), and the perpendicular distance from the apex of the intercondylar fossa to the line tangent to the lowest points of the femoral condyles (ICD). D: In the axial section of the left knee; the distance between the lateral and medial peaks of the patellar surface (TSW), and the length of the perpendicular dropped from the line passing through the lateral and medial summit points of the facies patellaris to the deepest point of the trochlear sulcus (TSD). E: In axial section of the right knee; The angle formed by the two lines connecting the deepest point of the trochlear sulcus to the highest points of the medial and lateral condyles (TSA). F: In the axial section of the right knee; Length of the lateral facet of the patellar surface of the femur (LFW), and Length of the medial facet of the patellar surface of the femur (MFW).

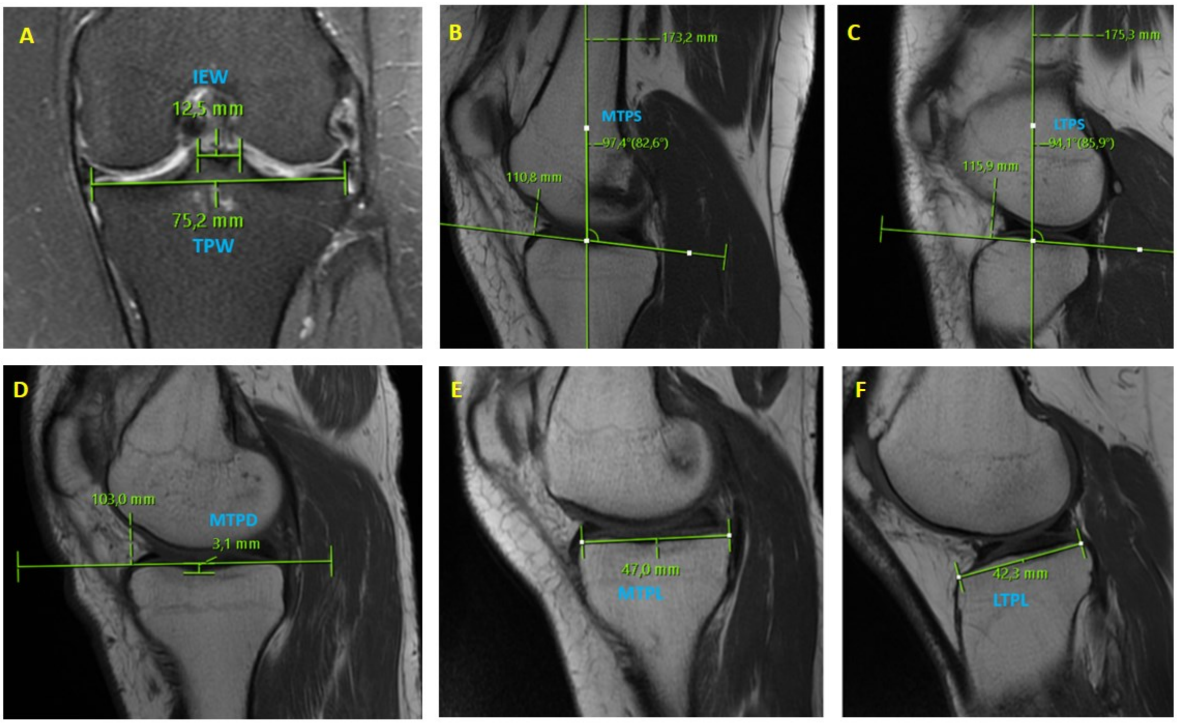

Figure 2. Measured parameters of the tibia. A: In the coronal section of the left knee; The length of the line drawn between the lateral and medial borders of the tibia, parallel to the superior surface of the tibial plateau (TPW), and the length between the highest points of the lateral intercondylar tubercle and the medial intercondylar tubercle (IEW). B: In the sagittal section of the left knee; The angle between the longitudinal line drawn equidistant from both cortices at the midline of the tibial shaft and the line connecting the anterior and posterior summit points of the medial tibial plateau (MTPS). C: In the sagittal section of the left knee; The angle between the longitudinal line drawn equidistant from both cortices at the midline of the tibial shaft and the line connecting the anterior and posterior points of the lateral tibial plateau (LTPS). D: In the sagittal section of the left knee; The length of the perpendicular dropped from the line connecting the anterior and posterior summit points of the medial tibial condyle to the deepest point of the medial condyle (MTPD). E: In the sagittal section of the right knee; The length of the line connecting the anterior and posterior summit points of the medial tibial condyle (MTPL). F: In the sagittal section of the right knee; The length of the line connecting the anterior and posterior summit points of the lateral tibial condyle (LTPL).

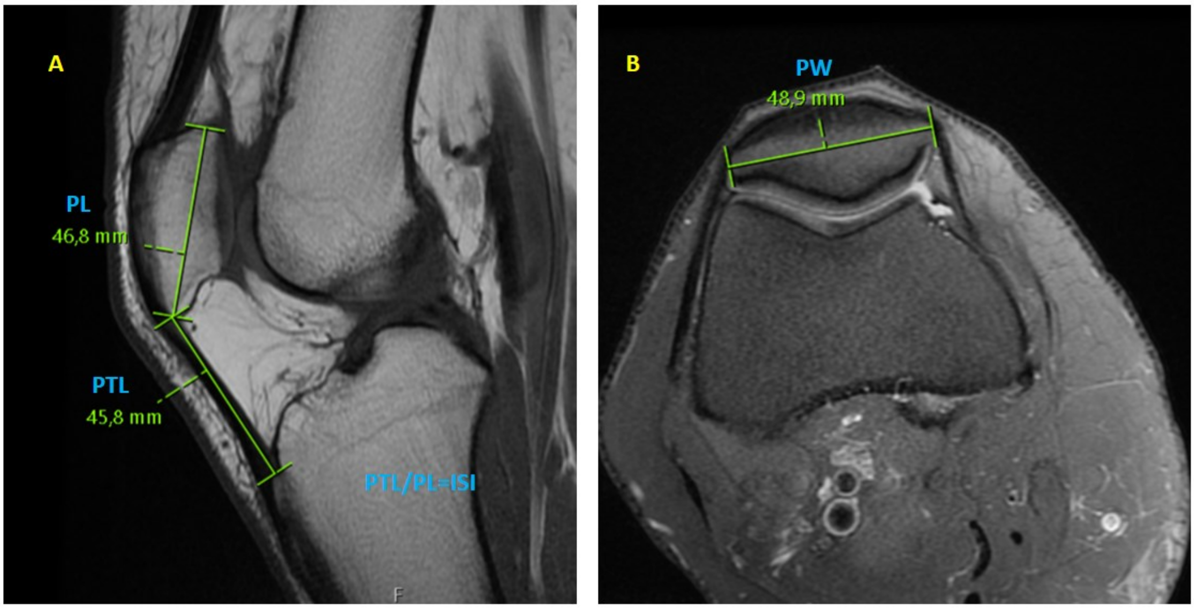

Figure 3. Measured parameters of the patella. A: In the sagittal section of the right knee; The maximum longitudinal length of the patella (PL), and the length of the patellar ligament (PTL), and the patellar ligament to patellar length ratio (ISI). B: In the axial section of the right knee; The maximum transverse width of the patella (PW).

Table 1 Comparison of morphological measurements between genders.

Parameters	Male (n=106) (Mean ± SD)	Female (n=106) (Mean ± SD)	p-value
MCW	26.61 ± 1.98	23.17 ± 1.82	**0.000**
LCW	28.92 ± 2.25	25.01 ± 2.17	**0.000**
BW	76.45 ± 4.02	66.56 ± 3.71	**0.000**
MCH	61.00 ± 4.27	54.25 ± 3.26	**0.000**
LCH	61.66 ± 4.14	55.14 ± 3.45	**0.000**
ICW	20.72 ± 2.14	18.16 ± 2.47	**0.000**
ICD	24.58 ± 2.60	21.85 ± 2.09	**0.000**
TSD	7.79 ± 1.31	6.81 ± 1.19	**0.000**
TSW	37.97 ± 2.70	33.57 ± 2.40	**0.000**
TSA(°)	128.28 ± 5.84	129.54 ± 7.02	0.155
LFW	23.33 ± 2.07	20.43 ± 1.80	**0.000**
MFW	17.07 ± 2.18	14.56 ± 1.57	**0.000**
TPW	77.51 ± 4.27	68.19 ± 3.40	**0.000**
IEW	13.11 ± 1.80	12.10 ± 1.74	**0.000**
MTPS (°)	4.82 ± 1.68	5.71 ± 2.17	**0.001**
LTPS (°)	3.60 ± 1.97	3.79 ± 2.26	0.510
MTPD	3.11 ± 0.81	2.56 ± 0.62	**0.000**
MTPL	48.80 ± 3.65	42.47 ± 2.72	**0.000**
LTPL	39.22 ± 3.84	34.21 ± 3.01	**0.000**
PL	44.02 ± 3.17	38.11 ± 2.69	**0.000**
PW	45.64 ± 3.59	39.21 ± 2.64	**0.000**
PTL	46.36 ± 5.42	42.96 ± 4.74	**0.000**
ISI	1.05 ± 0.14	1.13 ± 0.14	**0.000**

n: sample size; SD: Standard deviation; P-values ($p<0.05$) are highlighted in bold; MCW: Medial condylar width; LCW: Lateral condylar width; BW: Bicondylar width; MCH: Medial condyle height; LCH: Lateral condyle height; ICW: Intercondylar width; ICD: Intercondylar depth; TSD: Trochlear sulcus depth; TSW: Trochlear sulcus width; TSA: Trochlear sulcus angle; LFW: Lateral facet width; MFW: Medial facet width; TPW: Tibial plateau width; IEW: Intercondylar eminence width; MTPS: Medial tibial plateau slope; LTPS: Lateral tibial plateau slope; MTPD: Medial tibial plateau depth; MTPL: Medial tibial plateau length; LTPL: Lateral tibial plateau length; PL: Patellar length; PW: Patellar width; PTL: Patellar tendon length; ISI: Install Salvati Indeks.

($p < 0.05$). MTPS and ISI values were found to be statistically significantly lower in males than in females ($p < 0.05$).

Table 2 compares the measurement values of anatomical structures related to the knee joint in males and females of different age groups. The ICD value in Group 1 was significantly higher than in the other two groups. In males, the MFW value was found to be significantly lower in Group 1 compared to the other groups. TPW value was significantly higher in Group 3 than in Groups 1 and 2. In addition, the PTL and ISI values in Group 1 were found to be significantly higher than the other two groups ($p<0.05$). In females, the ICD value, PTL value and ISI value in Group 3 were found to be significantly lower than the other two groups, while the TPW value was found to be significantly higher than Groups 1 and 2 ($p <0.05$) (Table 2).

Table 2. Comparison of morphological measurements of male and female ındividuals according to age groups.

Parameters	Male (Mean ± SD)				Female (Mean ± SD)			
	Group 1 (Age: 18-34) (n=35)	**Group 2 (Age: 35-49) (n=39)**	**Group 3 (Age: 50-69) (n=32)**	**p-value**	**Group 1 (Age: 18-34) (n=16)**	**Group 2 (Age: 35-49) (n=35)**	**Group 3 (Age: 50-69) (n=55)**	**p-value**
MCW	26.5 ± 2.18	26.43 ± 2.02	27.11 ± 1.65	0.225	22.86 ± 1.45	22.76 ± 1.69	23.52 ± 1.94	0.115
LCW	28.52 ± 2.67	29.01 ± 2.02	29.26 ± 2.01	0.394	24.66 ± 1.99	25.21 ± 2.61	24.98 ± 1.93	0.703
BW	75.97 ± 4.17	76.14 ± 4.20	77.35 ± 3.57	0.316	66.59 ± 3.09	66.04 ± 3.49	66.88 ± 4.02	0.583
MCH	60.72 ± 4.69	60.40 ± 4.26	62.04 ± 3.73	0.249	54.75 ± 2.93	54.15 ± 3.31	54.18 ± 3.37	0.810
LCH	61.50 ± 4.99	61.36 ± 3.78	62.22 ± 3.59	0.663	55.28 ± 3.45	55.20 ± 3.21	55.05 ± 3.65	0.963
ICW	20.86 ± 1.85	20.61 ± 2.44	20.69 ± 2.09	0.874	18.87± 2.51	17.84 ± 2.42	18.15 ± 2.49	0.392
ICD	25.58 ± 2.72	24.21 ± 2.46	23.94 ± 2.38	**0.018**	22.95 ± 2.25	22.03 ± 2.10	21.42 ± 1.94	**0.029**
TSD	7.50 ± 1.14	7.92 ± 1.43	7.95 ± 1.30	0.273	7.01 ± 1.41	6.55 ± 1.31	6.93 ± 1.03	0.275
TSW	37.18 ± 2.51	38.06 ± 2.93	38.73 ± 2.44	0.061	32.02 ± 1.90	33.61 ± 1.71	33.99 ± 2.73	**0.014**
TSA (°)	129.2 ± 5.17	127.5 ± 6.42	128.0 ± 8.81	0.441	126.6 ± 6.69	131.3 ± 7.60	129.2 ± 6.50	0.075
LFW	23.06 ± 2.02	23.31 ± 2.24	23.65 ± 1.94	0.520	20.21 ± 1.76	20.21 ± 1.60	20.64 ± 1.94	0.487
MFW	16.20 ± 2.25	17.37 ± 1.87	17.65 ± 2.23	**0.012**	13.99 ± 1.37	14.36 ± 1.52	14.86 ± 1.61	0.099
TPW	76.56 ± 3.84	76.96 ± 4.38	79.23 ± 4.19	**0.021**	66.77 ± 2.48	67.70 ± 3.14	68.91 ± 3.65	**0.049**
IEW	12.98 ± 1.87	13.18 ± 1.91	13.16 ± 1.63	0.876	11.93 ± 1.67	12.16 ± 1.63	12.11 ± 1.86	0.907
MTPS (°)	5.09 ± 1.65	4.57 ± 1.74	4.84 ± 1.66	0.432	5.14 ± 2.04	5.73 ± 2.58	5.88 ± 1.92	0.493
LTPS (°)	4.17 ± 1.84	3.41 ± 2.05	3.21 ± 1.90	0.101	3.60 ± 1.69	4.26 ± 2.93	3.55 ± 1.88	0.331
MTPD	3.02 ± 0.67	3.22 ± 0.95	3.09 ± 0.78	0.571	2.71 ± 0.74	2.64 ± 0.59	2.46 ± 0.59	0.248
MTPL	48.32 ± 3.62	48.51 ± 4.01	49.70 ± 3.16	0.250	41.96 ± 3.39	42.29 ± 2.41	42.73 ± 2.71	0.548
LTPL	39.16 ± 3.90	38.39 ± 3.49	40.30 ± 4.03	0.113	34.18 ± 2.70	34.32 ± 2.55	34.14 ± 3.37	0.961
PL	43.53 ± 3.34	44.05 ± 2.77	44.53 ± 3.45	0.442	37.87 ± 2.58	37.97 ± 1.99	38.27 ± 3.10	0.813
PW	45.61 ± 3.29	45.37 ± 4.29	45.99 ± 2.99	0.774	38.88 ± 2.07	39.27 ± 2.32	39.26 ± 2.99	0.866
PTL	48.11 ± 3.93	45.30 ± 5.87	45.73 ± 5.91	**0.040**	45.12 ± 5.70	43.76 ± 3.95	41.83 ± 4.66	**0.023**
ISI	1.11 ± 0.12	1.03 ± 0.13	1.03 ± 0.17	**0.030**	1.19 ± 0.19	1.15 ± 0.12	1.09 ± 0.13	**0.029**

n: sample size; SD: Standard deviation; P-values ($p<0.05$) are highlighted in bold; MCW: Medial condylar width; LCW: Lateral condylar width; BW: Bicondylar width; MCH: Medial condyle height; LCH: Lateral condyle height; ICW: Intercondylar width; ICD: Intercondylar depth; TSD: Trochlear sulcus depth; TSW: Trochlear sulcus width; TSA: Trochlear sulcus angle; LFW: Lateral facet width; MFW: Medial facet width; TPW: Tibial plateau width; IEW: Intercondylar eminence width; MTPS: Medial tibial plateau slope; LTPS: Lateral tibial plateau slope; MTPD: Medial tibial plateau depth; MTPL: Medial tibial plateau length; LTPL: Lateral tibial plateau length; PL: Patellar length; PW: Patellar width; PTL: Patellar tendon length; ISI: Install Salvati Indeks.

DISCUSSION AND CONCLUSION

Numerous studies have investigated the complex morphology of the knee joint using various imaging modalities.[4-6] However, due to the clinical importance of this region, the continuous evolution of surgical techniques, and ongoing debates regarding the appropriateness of standard implants across different age and gender groups, this study aimed to examine knee joint morphology in relation to age and gender.

This study is notable for its sample size and methodological comprehensiveness. A total of 212 cases (106 males, 106 females) aged between 18 and 69 years were divided into three age groups, and 23 morphometric parameters of the distal femur, proximal tibia, and patella were assessed.

Regarding distal femur morphology, values such as MCW, LCW, BW, MCH, and LCH were significantly greater in males ($p<0.05$), consistent with findings by Sharma et al.,[4] who also reported larger femoral condyles in males based on MRI data. Similar outcomes were reported in studies using CT, X-ray, and dry bone analysis, highlighting consistent sex-based anatomical differences.[5,6]

Measurement techniques and reference points vary across morphometric studies, which are often based on dry bones, radiographs, CT, MRI, cadaveric studies, or 3D modelling.[7] Ethnic variation is also a prominent factor. For instance, Prithishkumar et al.[8] found that knee dimensions differ significantly across ethnic groups, and Kwak et al.[9] reported larger measurements in Western populations compared to Asians. These findings support the notion that ethnic differences influence knee anatomy, which should be considered in prosthesis design.

The intercondylar fossa, a region closely associated with anterior cruciate ligament injuries, was evaluated in our study via ICW and ICD measurements. Both values were significantly higher in males ($p<0.05$), corroborating findings from similar studies.[6,10]

The trochlear sulcus plays a key role in patellofemoral stability. In our study, TSD, TSW, LFW, and MFW were significantly higher in males, whereas TSA showed no significant gender difference despite being higher in females. These findings are consistent with those of Günaydın and Duran,[11] Hsu et al.,[12] and Hasler et al.,[13] who also reported sex-based differences in trochlear morphology.

Morphometric parameters of the proximal tibia, such as TPW, IEW, MTPD, MTPL, and LTPL, were significantly greater in males ($p<0.05$), while MTPS was higher in females. These findings align with studies by Sharma et al.,[4] Yue et al.,[6] and Yanagisawa et al.,[14] all of whom observed larger tibial measurements in males. Research also links increased tibial slope with ACL injuries. Kodama et al.[15] demonstrated that higher MTPS values correlate with increased rates of ACL degeneration and medial meniscus root tears. Weinberg et al.[16] found that MTPS exceeds LTPS, and both values are generally greater in females, which was partially supported by our findings.

Patellar and patellar ligament morphometry (PL, PW, PTL, and ISI) revealed that PL, PW, and PTL were significantly greater in males, while ISI was higher in females ($p<0.05$). These results are supported by multiple studies, including those by Nguyen et al.,[17] Meier et al.,[18] Le Hoang et al.,[19] and Hong et al.,[20] which showed similar gender-based patterns in patellar measurements and ISI values.

Our study is limited by its focus on a single ethnic group (Turkish individuals), which may restrict generalizability. Ethnic differences in patellar dimensions have been demonstrated by Pontoh et al.[21] and Jain et al.,[22] who reported smaller patellae in Asian populations compared to Western populations.

In terms of age, ICD, ISI, and PTL values were significantly higher in younger adults in both sexes, while TPW was significantly greater in older adults ($p<0.05$). Other parameters showed no significant age-related variation. While previous studies have explored these measurements by gender and ethnicity, age-related differences remain less frequently addressed, making this aspect of our study a noteworthy contribution.

In conclusion, along with those of comparable studies, indicate that knee joint anatomy varies significantly with ethnicity, age, and gender. Understanding the morphometric characteristics of knee bone structures is crucial for prosthesis design, especially given that total knee arthroplasty is performed across all age groups for various indications. It has been reported that most commercially available prostheses are based on Western anatomical data and may not be suitable for many Asian populations. In the current era of personalized arthroplasty, the appropriateness of standard implant designs in relation to age and gender remains a subject of ongoing debate. In this context, we believe that knee prosthesis design should take into account gender, age, and ethnic anatomical differences. This study has certain limitations. First, the data were derived solely from individuals of Turkish ethnicity, limiting generalizability. Second, all measurements were based on MRI, as CT images were not available for most patients. While MRI offers high-resolution soft tissue imaging, CT is generally preferred for detailed bone structure evaluation. A comparative analysis using both modalities on the same joints would provide more comprehensive insights. Lastly, due to the retrospective nature of the study, patient-specific data such as dominant side, height, and weight could not be collected. The potential influence of these variables, particularly the height and weight of the morphometric parameters, should be explored in future research.

Ethics Committee Approval: Our study was approved by Tokat Gaziosmanpaşa University Clinical Research Ethics Committee (Date: 18.01.2024, decision no: 2024/01). The study was conducted following international declarations, guidelines, etc.
Conflict of Interest: No conflict of interest was declared by the authors.
Author Contributions: Concept – BÇ, MAG; Supervision – BÇ, MAG, ŞAB; Materials – MAG, ŞAB; Data Collection and/or Processing – BÇ; Analysis and/or Interpretation – BÇ, MAG, ŞAB; Writing – BÇ, MAG.
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