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*Original Article*

# Morphometric Analysis of Tibial Plateau for Knee Arthroplasty and Prosthesis Design

*Diz Artroplastisi ve Protez Tasarımı için Tibial Platonun Morfometrik Analizi*

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## Abstract

**Background:** The knee is the largest joint in the human body and provides weight-bearing of the body besides locomotion. The knee joints can be deformed by fractures, osteoarthritis, or other sorts of traumas. One of the treatments is total or unicompartmental knee replacement. To have an accomplished outcome the prosthesis and the resected bone should match irreproachably. The aim of this study was to demonstrate the tibial plateau anatomy, the differences between medial and lateral condyles particularly, and provide that the Anatolian population has differences as other ethnicities have.

**Materials and Methods:** The current study was conducted on 159 tibia bones. The bones were stored at Anatomy Department in Bursa Uludag University. The tibial plateau bones were photographed in a standardized contrivance and transferred to a digital platform. 16 different parameters on the tibial plateau were measured. The measurements were obtained using Image J software and for the statistical analyses, SPSS (ver 20.0) software was performed.

**Results:** As the result of the statistical analyses between Byzantine and contemporary bones; statistical significance was revealed between the medial and lateral condyle. In a comparison of lateral and medial condyles area, breadth and length were greater in medial condyle in contemporary; when area, circumference, and length were greater in the medial condyle, breadth was greater in lateral condyle in Byzantine.

**Conclusions:** To accomplish designing the optimum knee prosthesis, the prosthesis should be designed by considering the basis of differences between not only medial and lateral condyles but also populations.

**Key Words:** Tibial plateau, Knee arthroplasty, Anatolian population, Morphometric analyses

## Öz

**Amaç:** Diz, insan vücudundaki en büyük eklemdir ve hareketin yanı sıra vücut ağırlığının taşınmasını sağlar. Diz eklemi kırıklar, osteoartrit veya diğer travmalar nedeniyle deforme olabilir. Tedavilerden biri total veya tek kompartmanlı diz protezidir. Başarılı bir sonuç elde etmek için protez ve rezeke edilen kemiğin kusursuz bir şekilde eşleşmesi gerekir. Bu çalışmanın amacı, tibial plato anatomisini, özellikle medial ve lateral kondiller arasındaki farklılıkları ortaya koymak ve diğer etnik gruplarda olduğu gibi Anadolu popülasyonunun da farklılıklara sahip olduğunu belirtmektir.

**Gereç ve Yöntem:** Mevcut çalışma 159 tibia kemiği üzerinde yapıldı. Kemikler Bursa Uludağ Üniversitesi Anatomi Anabilim Dalından temin edildi. Tibia plato standart bir düzenekte fotoğraflandı ve dijital platforma aktarıldı. Tibia platoda 16 farklı parametre ölçüldü. Ölçümler Image J yazılımı kullanılarak elde edildi ve istatistiksel analizler için SPSS (ver 20.0) yazılımı kullanıldı.

**Bulgular:** Bizans ve çağdaş kemikler arasında yapılan istatistiksel analizler sonucunda; medial ve lateral kondil arasında istatistiksel olarak anlamlılık ortaya çıktı. Lateral ve medial kondil alanı karşılaştırıldığında, çağdaşta medial kondilde genişlik ve uzunluk daha fazlaydı; Bizans'ta medial kondilde alan, çevre ve uzunluk daha fazla iken, lateral kondilde genişlik daha fazlaydı.

**Sonuç:** Optimum diz protezi tasarlamayı başarmak için protez, sadece medial ve lateral kondiller arasındaki farklılıklar değil, aynı zamanda popülasyonlar arasındaki farklılıklar da dikkate alınarak tasarlanmalıdır.

**Anahtar Kelimeler:** Tibia plato, Diz artroplastisi, Anadolu popülasyonu, Morfometrik analiz

## Introduction

The knee is the largest joint in the body, consisting of two joints: one between the femur and tibia, and the other between the femur and patella. The knee joint supports the majority of the body's weight, and as a consequence. The knee joint can often have affected by an acute injury or iterative micro-traumas, with the development of osteoarthritis in later life (1). The articular surfaces of the tibiofemoral joint in combination with the primary ligaments play an important role in controlling the biomechanical behavior of the joint (2). Osteoarthritic changes of the knee cause change to the structural geometry. Significant differences were found with regards to a few parameters between the person with arthritis and the non-arthritic knee (3).

The total knee arthroplasty is a precision surgery. It requires accurate bone cutting, adequate balancing of soft tissues and proper coverage of the resected bony surface by the components for achieving a successful outcome (4). Total knee arthroplasty is applied because of a variety of reasons, especially degenerative and inflammatory arthritis. The rise of the daily activities and lifetime, understanding of mechanics of total knee arthroplasty, development of surgical techniques and finding new solutions on emerging problems and having wide knowledge on this way has lead the total knee arthroplasty indications enlargement by covering young and wide range deformity group (5). Encouraging results have been published about unicompartmental knee arthroplasty, mostly in the medial compartment. Unicompartmental knee arthroplasty is a suitable procedure for elderly patients with unilateral knee osteoarthritis. However, indications are still not well designed, especially in the lateral compartment (6).

Ideally, Total knee arthroplasty should allow a reasonable range of motion should not change the joint kinematics and should provide anatomical integrity. Because of these reasons, the components of total knee arthroplasty should be designed according to the geometry and kinematics (7). Obtaining specific local anthropometric data for the development of implant for total knee replacement is crucial for positive long-term outcomes (8). Morphometric parameters of the upper end of the tibia can be used for used to guide treatment and monitor outcome of total knee replacement surgeries. An accurate and repeatable tibial measurement system aids in the definition of tibial deformity and improvement of tibial prosthesis design (9). Recent anthropometric studies have suggested that current designs of unicompartmental knee arthroplasty do not address the racial anthropometric differences. This leads to the problem of an implant size or shapes mismatch with the resected bony surface in different populations (10).

The purpose of this study was to draw attention to anatomical differences between medial condyle and lateral condyle, and morphometric differences between ethnicity by the measurements of tibia plateau and comparing between sides and races for the process of designing total knee prosthesis and unicompartmental knee prosthesis in order to have an accomplished outcome after total or unicompartmental knee arthroplasty.

## Materials and Methods

This study was based on 159 human tibia bones of 129 from Byzantine, 30 from contemporary. The bones were stored in Bursa Uludag University, Department of Anatomy. The human tibia bones of Byzantine belong to adult males who were burned in the Roman outdoor theatre in the 13th century and excavated in Nicea/Bursa by Ozbek et al. in 1980-83 (11). The tibia bones had deformity or fracture on the plateau were excluded from the study. The plateau of tibia bones was photographed in a standardized contrivance using five mp and 2592x1944 maximum photo resolution pixels Apple camera. All the measurements of the parameters (Figure1, Table 1) were recorded using Image J software.

The data obtained was performed using SPSS (ver.20.0) software and expressed as means ± standard deviation (SD) followed by application of Student's t-test on both right and left-sided bones of Byzantine and contemporary and p-value $< 0.05$, 0.01 and 0.001 were considered significant for analysis. All of the statistical tests were scrutinized and were discussed by comparing some other literature.

**Table 1. The parameters measured on tibial plateau**

| | |
|---|---|
| **ALC** | Area of the lateral condyle |
| **CLC** | Circumference of the lateral condyle |
| **BLC** | Breadth of the lateral condyle |
| **LLC** | Length of the lateral condyle |
| **AMC** | Area of the medial condyle |
| **CMC** | Circumference of the medial condyle |
| **BMC** | Breadth of the medial condyle |
| **LMC** | Length of the medial condyle |
| **ALEI** | Anteroposterior length of the eminentia intercondylaris |
| **LAIA** | Length of the area intercondylaris anterior |
| **LAIP** | Length of the area intercondylaris posterior |
| **MLEI** | Mediolateral length of the eminentia intercondylaris |
| **WAIA** | Width of the area intercondylaris anterior |
| **WAIP** | Width of the area intercondylaris posterior |
| **DAFN** | Distance of anterior foramen nutricium |
| **DPFN** | Distance of posterior foramen nutricium |

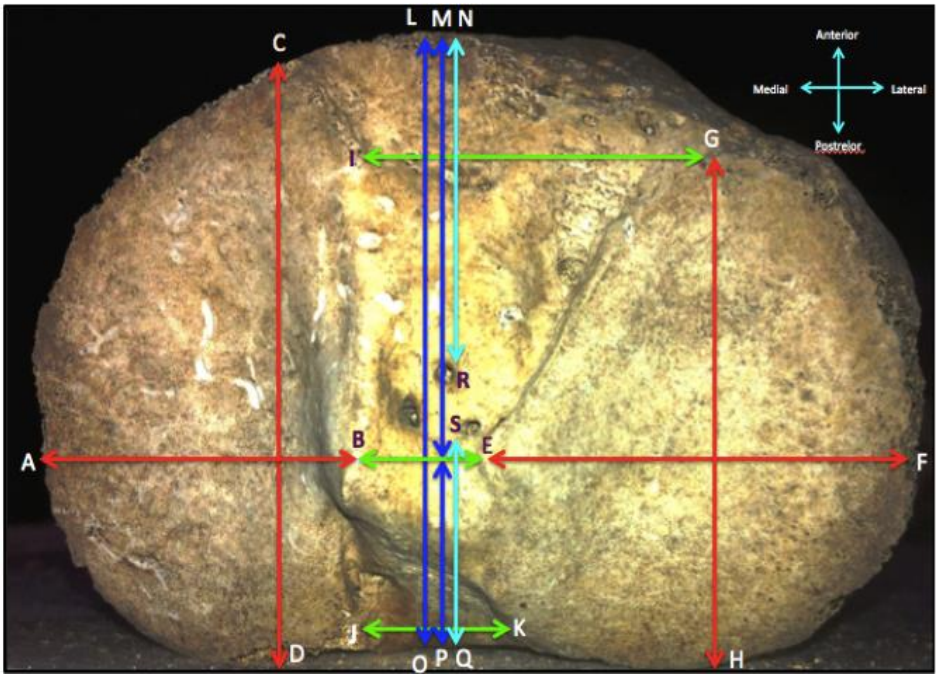


**Figure 1.** Parameters measured on tibial plateau
***AB-*** *Maximum transverse distance of medial condyle,* ***CD-*** *Maximum anteroposterior distance of medial condyle,* ***EF-*** *Maximum transverse distance of lateral condyle,* ***GH-*** *Maximum anteroposterior distance of lateral condyle,* ***LQ-*** *Maximum anteroposterior distance of tibial plateau,* ***MS-*** *Maximum anteroposterior distance of area intercondylaris anterior,* ***SP-*** *Maximum anteroposterior distance of area intercondylaris posterior,* ***BE-*** *Maximum transverse distance of intercondylar eminence,* ***GI-*** *Maximum transverse distance of area intercondylaris anterior,* ***JK-*** *Maximum transverse distance of area intercondylaris posterior,* ***NR-*** *Maximum anteroposterior distance between anterior foramen nutricum and anterior border of tibia plateau,* ***SQ-*** *Maximum anteroposterior distance between posterior foramen nutricum and posterior border of tibia plateau*

## Results

Morphometric study of 16 parameters conducted on the tibial plateau of Anatolian population revealed the under-mentioned essential observations. Abbreviations related to parameters were given in Table 1.
The descriptive statistical analysis of measurements of the study was given in Table 2. and Table 3. When we compared the results of measurements of tibia plateau belong to Byzantine and contemporary; the differences between area of lateral condyle, length of lateral condyle, length of medial condyle, length of area intercondylaris posterior, mediolateral length of intercondylar eminence and distance of posterior foramen nutricum were statically significant (p-value <0.001); the difference between circumference of the lateral condyle was statistically significant (p-value <0.01) and the difference between anteroposterior length of intercondylar eminence was statistically significant (p-value < 0.05). At the same time, measurements of ALC, LLC, LMC, LAIP, DPFN, CLC and ALEI were greater on tibial plateau of Byzantine but measurement of MLEI was greater in tibial plateau of contemporary.

**Table 2. Descriptive statistics of contemporary**

| Parameters (mm) | Range | Minimum | Maximum | Mean ± SD |
|---|---|---|---|---|
| Maximum anteroposterior distance of tibial plateau | 16.44 | 20.04 | 36.48 | 45.98 ± 5.61 |
| Area of the lateral condyle *** | 682.67 | 620.46 | 1303.13 | 944.07 ± 166.54 |
| Circumference of the lateral condyle ** | 35.79 | 101.89 | 137.68 | 119.48 ± 9.35 |
| Breadth of the lateral condyle | 20.26 | 22.50 | 42.76 | 31.69 ± 4.77 |
| Length of the lateral condyle **** | 17.28 | 29.00 | 46.28 | 37.14 ± 4.46 |
| Area of the medial condyle | 760.32 | 807.00 | 1567.32 | 1099.97 ±211.13 |
| Circumference of the medial condyle | 43.85 | 110.22 | 154.08 | 131.93 ± 12.29 |
| Breadth of the medial condyle | 24.29 | 22.83 | 47.12 | 32.07 ± 5.45 |

| | | | | |
|---|---|---|---|---|
| Length of the medial condyle** | 24.60 | 30.78 | 55.38 | 42.61 ± 6.65 |
| Anteroposterior length of the eminentia intercondylaris* | 16.32 | 38.28 | 54.59 | 46.18 ± 4.22 |
| Length of the area intercondylaris anterior | 12.04 | 24.01 | 36.05 | 29.53 ± 3.15 |
| Length of the area intercondylaris posterior*** | 8.12 | 12.47 | 20.60 | 16.45 ± 2.49 |
| Mediolateral length of the eminentia intercondylaris*** | 13.49 | 5.22 | 18.71 | 9.96 ± 3.10 |
| Width of the area intercondylaris anterior | 20.63 | 11.28 | 31.90 | 24.37 ± 4.46 |
| Width of the area intercondylaris posterior | 6.00 | 11.41 | 17.41 | 14.06 ± 2.03 |
| Distance of anterior foramen nutricium | 11.06 | 18.86 | 29.92 | 23.93 ± 3.08 |
| Distance of posterior foramen nutricium *** | 12.00 | 11.30 | 23.30 | 17.40 ± 3.18 |

*** *p-value < 0.001 between contemporary and Byzantine*
** *p-value < 0.01 between contemporary and Byzantine*
* *p-value < 0.05 between contemporary and Byzantine*

The comparison right and left tibia were given in Table 4. On comparing right and left; the difference between the area of the medial condyle is significant statistically (p-value < 0.05) and the AMC on the left tibial plateau was greater. On the other hand: the parameters between area of the lateral condyle, breath of the lateral condyle, area of the medial condyle and breath of the medial condyle were statistically significant (p-value < 0.001), the parameters between circumference of the lateral condyle and circumference of the medial condyle were statistically significant (p-value 0.01), and the parameters between anteroposterior length of intercondylar eminence was statistically significant (p-value < 0.05). In addition, when the measurements of ALC, CLC, BLC, and MLEI were higher on the right tibial plateau of Byzantine, the sizes of AMC, CMC and BMC were higher on the left.

**Table 3. Descriptive statistics of Byzantine**

| Parameters (mm) | Range | Minimum | Maximum | Mean ± SD |
|---|---|---|---|---|
| Maximum anteroposterior distance of tibial plateau | 33.29 | 32.12 | 65.41 | 47.46 ± 6.29 |
| Area of the lateral condyle*** | 844.44 | 591.64 | 1436.08 | 1069.69 ± 148.72 |
| Circumference of the lateral condyle ** | 57.69 | 96.93 | 154.62 | 125.51 ± 8.94 |
| Breadth of the lateral condyle | 18.70 | 21.19 | 39.88 | 32.69 ± 3.66 |
| Length of the lateral condyle **** | 23.01 | 30.96 | 53.98 | 41.12 ± 3.89 |
| Area of the medial condyle | 909.07 | 762.89 | 1671.97 | 1175.74 ± 178.04 |
| Circumference of the medial condyle | 59.10 | 108.20 | 167.30 | 136.65 ± 11.55 |
| Breadth of the medial condyle | 18.22 | 21.66 | 39.87 | 31.05 ± 3.81 |
| Length of the medial condyle ** | 18.92 | 36.73 | 55.66 | 46.55 ± 3.88 |
| Anteroposterior length of the eminentia intercondylaris* | 25.31 | 30.71 | 56.02 | 47.76 ± 3.44 |
| Length of the area intercondylaris anterior | 16.71 | 20.82 | 37.53 | 29.06 ± 3.07 |
| Length of the area intercondylaris posterior*** | 16.58 | 11.30 | 27.88 | 18.80 ± 3.22 |
| Mediolateral length of the eminentia intercondylaris*** | 9.77 | 3.88 | 13.66 | 8.32 ± 1.91 |
| Width of the area intercondylaris anterior | 21.76 | 11.65 | 33.41 | 24.41 ± 4.43 |
| Width of the area intercondylaris posterior | 11.77 | 9.29 | 21.06 | 14.15 ± 2.06 |
| Distance of anterior foramen nutricium | 15.41 | 14.84 | 30.25 | 25.00 ± 2.62 |
| Distance of posterior foramen nutricium *** | 12.23 | 13.66 | 25.88 | 19.28 ± 2.47 |

*** *p-value < 0.001 between contemporary and Byzantine* ** *p-value < 0.01 between contemporary and Byzantine*
* *p-value < 0.05 between contemporary and Byzantine*

The comparison of the lateral and medial condyles was stated in Table 5. When it was compared; the parameters between the breath of lateral and medial condyles were statistically significant (p-value < 0.001), the parameters between the area of the medial and lateral condyles and length of lateral and medial condyles were statistically significant (p-value < 0.01). Furthermore, AMC, BMC, and LMC of the contemporary tibial plateau were greater. The parameters between area, circumference, breadth, and length of the medial and lateral condyles were statistically significant (p-value < 0.001). However, AMC, CMC, and LMC were greater, BLC was higher on the tibial plateau of the Byzantine.

**Table 4. Comparison of right and left tibia**

| Parameters (mm) | Right | Left | | Right | Left | |
|---|---|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | P | Mean ± SD | Mean ± SD | P |
| ALC | 992.013 ± 172.02 | 892.71±149.60 | | 1132.31±130.74 | 1004.76± 138.95 | p<0.001 |
| CLC | 122.07 ± 9.73 | 116.70 ±8.39 | | 127.83±7.64 | 123.10± 9.60 | p<0.01 |
| BLC | 33.24 ± 4.14 | 30.04 ±4.98 | | 34.68±2.94 | 30.64± 3.18 | p<0.001 |
| LCL | 37.85 ± 4.76 | 36.38 ±4.16 | | 41.75 ±3.25 | 40.47± 4.39 | |
| AMC | 1022.71 ± 211.01 | 1182.75 ±183.83 | p<0.05 | 1095.18±143.76 | 1259.27±172.57 | p<0.001 |
| CMC | 128.41± 11.97 | 135.70 ±11.88 | | 133.71 ±11.95 | 139.70± 10.37 | p<0.01 |
| BMC | 30.36 ± 6.24 | 33.90 ±3.88 | | 28.70 ±3.10 | 33.48± 2.83 | p<0.001 |
| LMC | 41.07 ± 6.53 | 44.26 ±6.62 | | 46.02±3.60 | 47.10± 4.10 | |
| ALEI | 45.78 ± 4.20 | 46.61 ±4.36 | | 47.85 ±3.82 | 47.67± 3.04 | |
| LAIA | 28.96 ± 2.76 | 30.14 ±3.52 | | 29.32 ±3.03 | 28.80± 3.11 | |
| LAIP | 16.75 ± 2.29 | 16.13 ±2.74 | | 18.48 ±2.87 | 19.12± 3.55 | |
| MLEI | 9.66 ± 2.76 | 10.27 ±3.51 | | 8.72 ±1.78 | 7.91± 1.97 | p<0.05 |
| WAIA | 24.52 ± 5.20 | 24.21 ±3.70 | | 25.06 ±4.10 | 23.73± 4.69 | |
| WAIP | 13.63 ± 1.89 | 14.53 ±2.14 | | 13.97±2.05 | 14.34± 2.08 | |
| DAFN | 23.50 ± 2.94 | 24.40±3.26 | | 25.12±2.48 | 24.87± 2.78 | |
| DPFN | 16.92 ± 3.38 | 17.91 ±2.99 | | 19.44±2.32 | 19.11± 2.62 | |

**Table 5. Comparison of the right and left condyles**

| Parameters (mm) | Contemporary | | | Byzantine | | |
|---|---|---|---|---|---|---|
| | Lateral | Medial | | Lateral | Medial | |
| | Mean ± SD | Mean ± SD | P | Mean ± SD | Mean ± SD | P |
| Area of the condyles | 944.07 ± 166.54 | 1099.97±211.13 | p<0.01 | 1069.69±148.72 | 1175.74±148.72 | p<0.001 |
| Circumference of the condyles | 119.48 ±9.35 | 131.93±12.29 | | 125.51±8.94 | 136.65±11.55 | p<0.001 |
| Breadth of condyles | 31.69 ± 4.77 | 32.07±5.45 | p<0.001 | 32.69±3.66 | 31.05±3.81 | p<0.001 |
| Length of the condyles | 37.14 ± 4.46 | 42.61±6.65 | p<0.01 | 41.12±3.89 | 46.55±3.88 | p<0.001 |

## Discussion

The anatomy of the knee, the largest joint in the body, is very complicated. Its role as one of the main weight-bearing joints exposes it to the risk of injury and osteoarthritic degeneration (1). One of the processes used by orthopedists is total knee arthroplasty or unicompartmental knee arthroplasty. To be successful on knee arthroplasty prosthesis must match the resected surface of tibia plateau; otherwise, it may cause problems. Because of this reason, to improve a design for prosthesis, the shape of the knee was studied widely (9,12,13).

In some other populations, one of the reasons of mismatching between the prosthesis and resected tibial plateau is the anthropometric differences between people. Because currently the prostheses that can be found in the markets are produced according to the anatomical features of European and North American populations (10). Hence, the rate of surgical treatment for osteoarthritis of the knee varies dramatically according to sex, race or ethnic group, and region (14). It must be taken into account that the Turkish population also have different anthropometric differences with respect to Asian, European, and North American populations, as demonstrated in anthropometric studies (15).

Sun et al. (2014) measured the anteroposterior diameter of the medial plateau and anteroposterior diameter of the lateral plateau for the Chinese population (51.04±4.21, 44.46±3.30 respectively) (16). They found that the anteroposterior diameter of the medial plateau was greater than the lateral plateau. Kwak et al. (2007) measured the medial anteroposterior, and lateral anteroposterior length for Korean population (48.05±4.2, 42.02±3.7 respectively). As a result, they also found that measurement of medial anteroposterior was greater than lateral (4). Servien et al., (2008) measured anteroposterior measurements of medial and lateral condyles in the French population and they found that the medial condyle was greater than lateral (50.08±3.3; 47.2±3.3 respectively) (6). In current study we found the length of the medial condyle as 42.61 ± 6,65 mm in contemporary times and 46.455±3.88 mm in the Byzantine period. We found the length of the lateral condyle as 37.14±4.46 mm in contemporary times and 41.12±3.89 mm in the Byzantine period.

Hussain and Abdulkadir (2010) measured the tibial mediolateral length and anteroposterior tibial length for Malay populations (72.06±6.8, 48.1±4.7 respectively) (8). We found the maximum anteroposterior distance of tibial plateau for contemporary times as 45.98±5.61 mm and 47.46±6.29 mm for the Byzantine period.

Yue et al. (2011) compared differences of knee anthropometry between Chinese and White men & women based on not only tibia but also femur and as a result they found that the dimensions of Chinese knees were generally smaller than white knees (17). Gandhi et al. (2014) also measured tibial plateau respectively sex and side for North Indian population and the results were BLC ( 28.62±3.1 mm in male's right and 28.32±3.12 mm in male's left; 26.14±.5 mm in female's right and 26.00±3.06 mm in female's left) , LLC (40.86±3.79 mm in male's right and 40.69±4.13 mm in male's left; 36.78±3.03 mm in female's right and 37.30±3.81 mm in female's left); BMC (30.18±2.83 mm in males right and 29.38±3.14 mm in male's left; 27.25±3.05 mm in female's right and 26.96±2.18 mm in female's left) , LMC (48.45±4.14 mm in male's right and 47.73±4.37 mm in male's left; 42.39±4.19 mm in female's right and 42.36±4.65 mm in female's left) , ALEI (47.19±2.93 mm in male's right and 49.11±3.97 mm in male's left; 43.09±3.62 mm in female's right and 44.64 mm in female's left) , LAIA (23.84±2.90 mm in male's right and 21.96±6.76 mm in male's left; 25.48±2.38 mm in female's right and 25.04±3.48 mm in female's left), LAIP (17.86±2.98 mm in male's right and 23.22±1.55 mm in male's left; 21.84±2.64 mm in female's right and 22.38±2.84 mm in female's left), MLEI (7.18±1.4 mm in male's right and 7.41±0.95 mm in male's left; 6.72±1.006 mm in female's right and 6.38 0.79 mm in females left) , WAIA (24.82± .22 mm in male's right and 25.40±4.20 mm in male's left; 22.33±3.48 mm in female's right and 22.61±2.41 mm in female's left) and WAIP (7.18±1.14 mm in male's right and 7.41±0.95 mm in male's left; 6.72±1.06 mm in female's right and 6.38±0.79 mm in female's left). Gandhi et al. (2014) also compared the results with Danish, French, and Korean population (9).

Eboh (2022) studied on 133 dry tibias belonging to the Nigerian population. He found the anteroposterior length of medial tibia plateau 44.36 (4.96) mm, the anteroposterior length of medial tibia plateau 30.93 (3.40) mm, the anteroposterior length of medial tibia plateau 39.45 (4.87) mm, the anteroposterior length of medial tibia plateau 3.36 (3.89) mm (18).

The anthropometric studies in literature demonstrate that not only medial and lateral condyles but also populations have varieties. To have an accomplished total or unicompartmental knee replacement outcome, the surgeons should pay attention the matching of the prosthesis and resected tibia, and in addition, the manufacturers should consider the differences between medial and lateral condyles and also the differences (9,10,12,13).

## Conclusion

Our study provides anthropometric data for the tibial plateau of Anatolian populations and demonstrates that as other communities have differences, Anatolian society also has variations on the tibial plateau. We have the prospect that our study will give a lead for designing prosthesis considering not only the differences between condyles but also populations.

***Ethical Approval: None***
***Author Contributions:*** *Concept: SB, IMK; Literature Review: SB; Design: SB, İMK; Data acquisition: SB; Analysis and interpretation: SB, İMK; Writing manuscript: SB; Critical revision of manuscript: SB, İMK.*
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