ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA
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Research Article

Distal femur morphology and the suitability of standard guides for knee arthroplasty in the Turkish population

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ARTICLE INFO

Article history:
Submitted February 09, 2021
Received in revised form
September 05, 2021
Last revision received form
October 26, 2023
Accepted November 23, 2023
Publication Date January 9, 2024

Keywords:
3°
Posterior condylar angle
Total knee arthroplasty
Rotation
Condylar twist angle

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ABSTRACT

Objective: The aim of this study was to evaluate the posterior condylar angle (PCA) and condylar twist angle (CTA) of the distal femur in the Turkish population and its concordance with the current standard prosthesis guides used in total knee arthroplasty (TKA).

Methods: Two hundred and forty knees of 120 Turkish subjects (60 male and 60 female) were included in this study. PCA, CTA, femoral mediolateral lengths (fML), medial femoral anteroposterior lengths (fMAP), lateral femoral anteroposterior lengths (fLAP), distances between the trochlear groove and fMAP (DBTG–fMAP), distances between the trochlear groove and fLAP (DBTG–fLAP), medial posterior condylar cartilage thickness (MPCCT) and lateral posterior condylar cartilage thicknesses (LPCCT) were measured on magnetic resonance imaging (MRI).

Results: The median CTA was 7° (range: 0°-13.0°) and the median PCA was 4° (range 0°-11.0°) ($P < .0001$). The median fML was 79.5 mm (range: 65.7-98.9). The median length of the fMAP was 58.2 mm (range: 46.8-69.0) and the median length of fLAP was 58.2 mm (range: 48.4-73.0). The DBTG–fMAP was 15.2 mm (range: 5.2-23.2), and DBTG–fLAP length was 21.9mm (range: 16.4-29.4). The median MPCCT and LPCCT were 2.4 mm (range: 1.6-3.6) and 2.3 mm (range: 1.2-2.8), respectively. The intraclass correlation coefficient for quantifying interobserver and intraobserver reliability showed excellent agreement regarding the PCA and CTA.

Conclusion: This study has shown us that PCA and CTA may be higher in the Turkish population. Although it is not known whether these results have any clinical utility, it may be useful for surgeons to keep this in mind to prevent femoral component malposition.

Level of Evidence: Level IV, Diagnostic Study.

Introduction

Femoral component rotation influences not only patellar tracking and stability but also tibiofemoral kinematics and knee stability.[1-7] The transepicondylar axis (TEA),[8] Whiteside´s anteroposterior trochlear line,[9] and posterior condylar axis (PCAx)[10] are bony landmarks used for correcting femoral rotation before making the distal femoral cut. Determining the amount of external rotation required to create a symmetrical flexion gap after ligament balancing is another option.[11,12] Theoretically, however, the surgical TEA seems ideal for patellar monitoring.[13-17]

Even after drawing axes using bony landmarks, it is sometimes difficult to place the femoral component perfectly parallel to the TEA.[18] Griffin et al reported a mean 3° internal rotation of the posterior condylar angle (PCA) relative to the surgical epicondylar axis.[19] Femoral cutting guides are usually set at an additional 3° external rotation. One of the issues associated with adjusting femoral rotation is that conventional methods ignore variants and recommend placing the cutting guide in 3° of external rotation in relation to the PCAx to achieve a rectangular flexion space. However, there are some important differences among populations, and existing standard prosthetic designs and surgical techniques may be less suitable for some populations.[21-24]

In Turkey, more than 100,000 total knee arthroplasties (TKAs) were performed in 2018. Most of the total knee designs and surgical techniques used in Turkey are based on Western populations; however, there may be some important differences between these populations, such as in distal femoral rotation, which can lead to complications, patient dissatisfaction, and revisions after TKA.[25] The condylar twist angle (CTA), posterior condylar angle (PCAn), and medial posterior condylar cartilage (MPCCT) and lateral posterior condylar cartilage (LPCCT) thicknesses may have an effect on distal femoral rotation. In 1987, Yoshioka et al were the first to describe the CTA in a cadaveric study, and the CTA was 5° and 6° in males and females, respectively.[26] Afterward, Yoshino et al in their CT-based study, stated that PCA can be calculated from the condylar twist angle by subtracting 3°.[27] In a study measuring femoral posterior condyle cartilage thickness in 111 individuals, the LPCCT was thicker than the MPCCT (2.15 vs. 1.95 mm).[28] However, these

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Cite this article as: *İncesoy MA, Güngören N, Aliyev O, Elmalı N, Tuncay İ, Yıldız F. Distal femur morphology and the suitability of standard guides for knee arthroplasty in the Turkish population. Acta Orthop Traumatol Turc., 2024;58(1):39-44.*

DOI: 10.5152/j.aott.2024.21066

morphological parameters were not stratified in terms of ethnicity. Therefore, we analyzed the distal femur in the Turkish population by measuring the condylar twist angle (CTA), posterior condylar angle (PCAn), and medial posterior condylar cartilage (MPCCT) and lateral posterior condylar cartilage (LPCCT) thicknesses bilaterally on magnetic resonance imaging (MRI). We hypothesized that the PCAn and CTA in the Turkish population differ from standard measures.

Materials and methods

Study Overview

This retrospective study of previously acquired MRI images was approved by Bezmialem Vakıf University Institutional Review Board (Approval No: 45446446-010.99-3586). All procedures were conducted in accordance with the World Medical Association Declaration of Helsinki for human studies.[29]

Written informed consent was obtained from the patients who agreed to take part in the study.

We made measurements on previously acquired bilateral knee MRI images of 120 selected patients stored in the hospital database and picture archiving and communication system. We included images of non-arthritic knees of patients aged 18-70 years without intra- or extra-articular deformities on X-ray or MRI. We excluded patients with a history of extremity surgery, systemic disease, or a body mass index (BMI) ≥ 35 kg/m^2. We included 60 males and 60 females with a median age of 44.8 (range: 18-70) years.

Form, structure, and signal intensity changes in MRI were evaluated by an experienced musculoskeletal radiologist to classify the knees as native or to detect pathologies including cartilage softening or superficial scrapes.

All images were taken in the same radiology department using a MAGNETOM Avanto 1.5 Tesla MRI scanner (Siemens). During the scan, the subjects were supine with their knees extended. Radiological measurements were performed by 1 orthopaedic consultant and 1 senior orthopaedic resident, both of whom were blinded to the other's measurements.

The CTA was measured between the anatomical TEA, which runs from the medial epicondyle to the lateral epicondyle, and the PCAx (Figure 1). The PCAn was measured between the surgical TEA, lying from the medial epicondylar sulcus to the lateral epicondyle, and the PCAx (Figure 2).[30] We measured the widest mediolateral length of the distal femur (fML) in the axial plane (Figure 3), and the longest anteroposterior distances of the medial (fMAP) and lateral (fLAP) condyles over the cartilage tissue on axial images (Figure 3).[31] The distances

HIGHLIGHTS

- Most of the total knee prosthesis designs used in Turkey are based on Western populations; however, there may be anatomical differences which may result in inferior outcomes. This study aimed to evaluate the posterior condylar angle (PCA) and condylar twist angle (CTA) of the distal femur in the Turkish population and its concordance with the current standard prosthesis guides used in total knee arthroplasty (TKA).
- The median condylar twist angle was 7° (range: 0-13.0°) and the median posterior condylar angle was 4° (range: 0-11.0°).
- The posterior condylar angle and condylar twist angle may be higher in the Turkish population than in Caucasians. Rotation guides may be standardized to match the morphology of normal or osteoarthritic knees in the Turkish population.

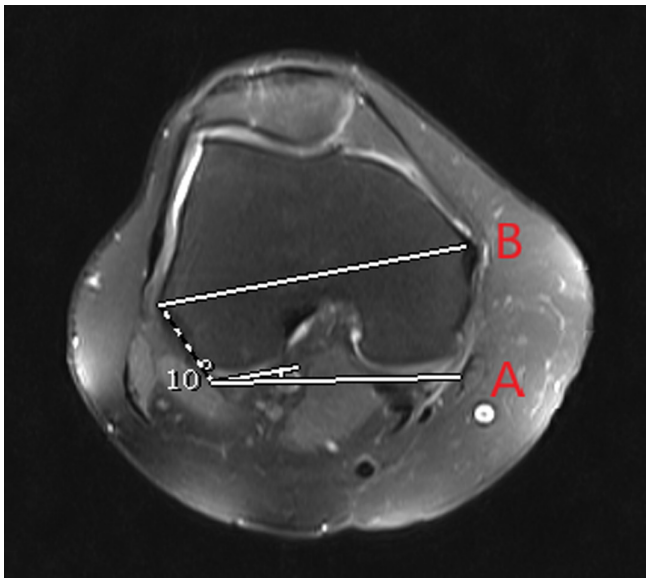

Figure 1. Condylar twist angle. A: Posterior condylar axis; B: Anatomical transepicondylar bxis.

between the trochlear groove and fMAP (DBTG–fMAP) and lateral fLAP (DBTG–fLAP) were also measured (Figure 4). Magnetic resonance images obtained 3 cm above the tibiofemoral joint were used to determine the deepest point of the trochlear groove. The distances from the trochlear groove to the fMAP and fLAP were measured. Medial posterior condylar cartilage and LPCCT were measured at the deepest point in the axial plane (Figure 5).

Statistical analysis

Kolmogorov–Smirnov and Shapiro–Wilk tests showed that the data were not normally distributed ($P < .001$). Continuous variables were tested using the Mann–Whitney *U*-test. A single measure (2-way mixed) intraclass correlation coefficient was used for quantifying interobserver and intraobserver reliability of the PCAn and CTA (values of >0.75 indicate satisfactory reliability). Intraobserver

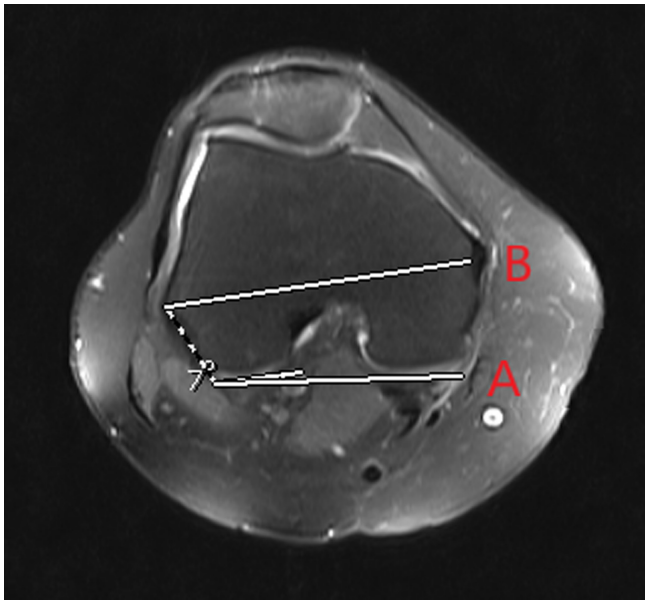

Figure 2. Posterior condylar angle. A: Posterior condylar axis; B: Surgical transepicondylar axis.

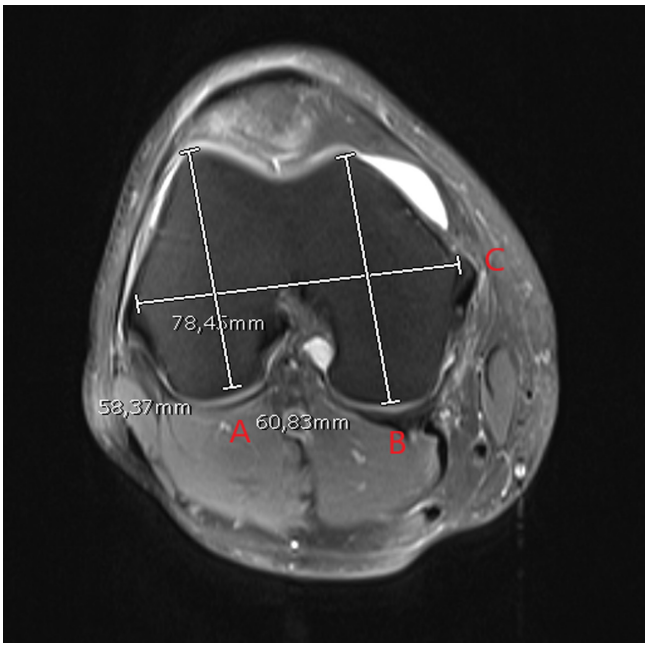

Figure 3. A: fMAP (medial anteroposterior lenght); B: fLAP (lateral anteroposterior lenght); C: fML (mediolateral lenght).

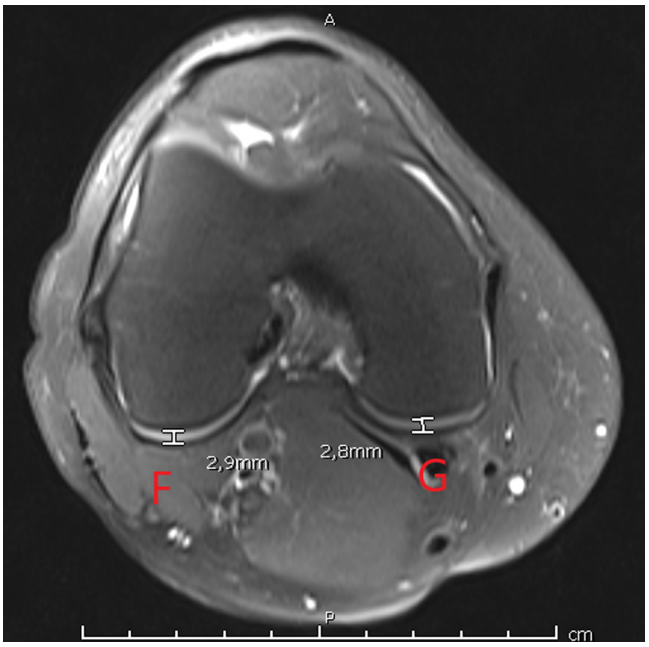

Figure 5. MPCCT (medial posterior condylar cartilage thicknesses) and G: LPCCT (lateral posterior condylar cartilage thicknesses).

reliability was checked by having observers repeat all the measurements 1 week after the first one. The data were statistically analyzed using Statistical Package for the Social Sciences Statistics software for Windows, version 22.0 (IBM SPSS Corp.; Armonk, NY, USA). Significance was set at $\alpha < 0.05$.

A post hoc power analysis was performed for the difference in terms of component alignment degrees. Based on the results of previous studies, we found Cohen's d (0.66).[32,33] With an alpha value of 0.05 and a power of 0.9, the calculated sample size was 82 knees (G*Power v3.1.9.7; Heinrich Heine University of Düsseldorf, Düsseldorf, Germany). The present study, with 240 knees, was adequately powered to be able to detect a 1° difference in alignment (alpha = 0.05, 2-way) with 90% power assuming a standard deviation of 3°.

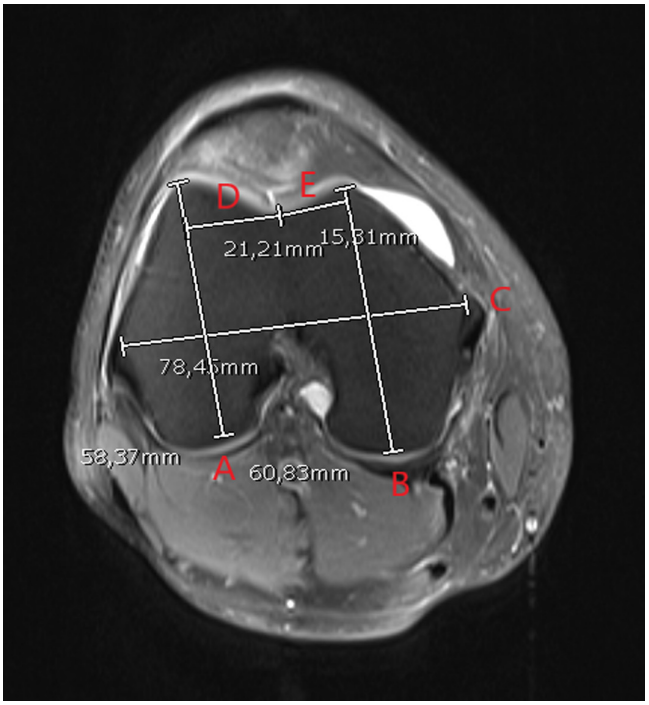

Figure 4. D: DBTG–fMAP (distance between trochlear groove and medial anteroposterior lenght); E: DBTG–fLAP (distance between trochlear groove and lateral anteroposterior lenght).

Results

Both observers detected the medial sulcus in knee MRI images of all patients. The median CTA was 7° (range: 0-13.0°) and the median PCAn was 4° (range: 0-11.0°) ($P < .0001$). The median fML, fMAP, and fLAP were 79.5 (range: 65.7-98.9 mm), 58.2 (range: 46.8-69.0 mm), and 58.2 (range: 48.4-73.0 mm), respectively. The median DBTG–fMAP and DBTG–fLAP were 15.2 (range: 5.2-23.2 mm) and 21.9 (range: 16.4-29.4 mm), respectively. The median MPCCT and LPCCT were 2.4 (range: 1.6-3.6 mm) and 2.3 (range: 1.2-2.8 mm), respectively.

We did not find any significant differences between the left and right knees (Table 1). There were gender differences in the PCAn ($P = .01$),

Table 1. The median value of all parameters for both sides

	Right knee (n = 120)		Left knee (n = 120)		
Parameters	Median	Minimum–Maximum	Median	Minimum–Maximum	*P*
CTA	7.0°	(1°-13°)	7.0°	0°-13°	.70
PCAn	4.0°	0°-11°	4.0°	0°-10°	.60
fML	79.7	67.1-98.1	79.1	65.7-98.9	.93
fMAP	58.2	47.3-69.0	58.4	46.8-68.9	.76
fLAP	58.4	48.4-73.0	58.1	48.8-71.6	.80
DBTG–fMAP	15.2	8.1-21.6	15.28	5.2-23.2	.75
DBTG–fLAP	22.1	16.6-29.3	21.6	16.4-29.2	.10
MPCCT	2.4	1.7-3.6	2.5	1.7-3.3	.55
LPCCT	2.3	1.4-3.1	2.3	1.2-3.2	.16

CTA, condylar twist angle; DBGT–fLAP, distance between trochlear groove and lateral anteroposterior length; DBTG–fLAP, distance between trochlear groove and lateral anteroposterior length; fLAP, lateral anteroposterior length; fMAP, medial anteroposterior length; fML, mediolateral length; LPCCT, lateral posterior condylar cartilage thicknesses; MPCCT, medial posterior condylar cartilage thicknesses; PCAn, posterior condylar angle.

Table 2. The median value of the all parameters for both gender

	Males (n = 60)		Females (n = 60)		
Parameters	Median	Minimum–Maximum	Median	Minimum–Maximum	*P*
CTA	7.0°	2°-12°	7.0°	0°-13°	0.93
PCAn	3.0°	0°-8°	4.0°	0°-11°	0.01
fML	84.8	75.7-98.9	75.2	65.7-83.7	0.00
fMAP	61.1	54.9-69.0	55.3	46.8-55.4	0.00
fLAP	61.0	52.7-73.0	54.9	48.4-62.2	0.00
DBTG–fMAP	16.1	9.4-21.8	14.0	5.2-23.2	0.00
DBTG–fLAP	23.3	16.7-29.7	20.8	16.4-27.8	0.00
MPCCT	2.4	1.73.6	2.6	1.6-3.2	0.01
LPCCT	2.3	1.4-3.1	2.3	1.2-3.2	0.10

CTA, condylar twist angle; DBGT–fMAP, distance between trochlear groove and medial anteroposterior length; DBTG–fLAP, distance between trochlear groove and lateral anteroposterior length; fLAP, lateral anteroposterior length; fMAP, medial anteroposterior length; fML, mediolateral length; LPCCT, lateral posterior condylar cartilage thickness; MPCCT, medial posterior condylar cartilage thickness; PCAn, posterior condylar angle.

Table 3. The intraclass correlation coefficient for quantifying inter- and intraobserver reliability

		95% Confidence Interval		
Variables	Intraclass Correlation Coefficient	Lower Bound	Upper Bound	*P*
Intraobserver reliability				
PCAn	0.99	0.99	0.99	0.00
CTA	0.96	0.94	0.97	0.00
Interobserver reliability				
PCAn	0.93	0.91	0.94	0.00
CTA	0.93	0.91	0.94	0.00

CTA, condylar twist angle; PCAn, posterior condylar angle.

fML (P = .00), fMAP (P = .00), fLAP (P = .00), DBTG–fMAP (P = .00), and DBTG–fLAP (P = .00) (Table 2). There were no correlations between PCA and MPCCT (P = .82), PCAn and LPCCT (P = .9), CTA and MPCCT (P = .13), or CTA and LPCCT (P = .65) (Table 2).

The intraclass correlation coefficient for quantifying interobserver and intraobserver reliability is shown in Table 3. The intraclass correlation coefficient for quantifying reliability showed excellent agreement regarding the PCAn and CTA.

Discussion

Femoral component rotation affects patellar tracking and stability, as well as tibiofemoral kinematics and knee stability. Therefore, optimal rotational alignment of the femoral component is important to reduce mechanical problems after TKA.[1-7,34,35] Internal rotation of the femoral component causes patellofemoral maltracking and disruption of the knee rotation center. Excessive external rotation causes mid-flexion instability because of increased resection of the posteromedial condyle and an asymmetrical flexion gap.[36-38] Bellemans et al[39] found that a reduction of the posterior condylar offset by 1 mm after TKA decreased knee flexion by 6.1°. Although it is important that the femoral component be placed parallel to the TEA, the components can still be placed in internal rotation despite the recommendations of modern guidelines.[38]

Some studies have reported differences in knee anthropometric measurements among different populations.[21-23,40] The Turkish population may differ from Western ones, which seems to be supported by our measurements of the former population. We measured the PCAn with reference to the surgical TEA, and found that the PCAn is more likely to be in internal rotation than in other populations. Therefore, the femoral component can inadvertently be placed in internal rotation with standard 3° guides. The mediolateral and anteroposterior measurements were similar to those of the Caucasian population. We made MRI measurements because the guides are based on cartilage tissue during total knee arthroplasty. We believed that an MRI-based study would be preferable, as the angles can vary depending on cartilage thickness.[13,41] Asano et al[13] demonstrated that the functional flexion–extension axis accorded well with the surgical TEA and that knee flexion and extension can be described in terms of rotation around this fixed axis. Berger et al. showed that the PCAn, referenced from the surgical TEA, can be used to visually check rotational alignment during primary arthroplasty and may improve alignment of the femoral component during revision.[6] However, it can be difficult to identify the medial epicondylar sulcus from CT and MRI images and during surgery.[27,42] Therefore, we measured the CTA according to the anatomical TEA.

Yoshioka et al[26] were the first to describe the CTA in a cadaveric study (5° in males and 6° in females). We found an increased CTA and PCAn compared to other populations.

Previous studies found no significant difference in CTA between normal and arthritic knees.[43-45] Therefore, measurements considering cartilage thickness seem more appropriate. Asada et al[46] measured the PCAn with and without cartilage remnants by CT arthrography in 31 patients and found a significant difference. Similarly, we found a significant ($P < .0001$) difference in the medial and lateral posterior condyle cartilage thicknesses.[46] Therefore, it was important that our measurements considered cartilage tissue, just like during surgery.

The measured resection technique is popular in Turkey and typically uses guides with 3° of external rotation. Therefore, it makes sense to use adjustable guides. The surgical TEA represents the true rotational axis, so it is ideal to determine rotation using this axis. However, locating the medial condylar sulcus in the arthritic knee may require advanced soft tissue dissection and can be associated with intraoperative errors. However, the CTA can be easily determined in cases where the surgical TEA cannot be confirmed.

Although in TKA there are several alignment and resection methods, to our knowledge most surgeons prefer the measured resection technique for the neutral mechanical alignment method, in which posterior condylar resection is aimed to be parallel to TEA. To achieve this, it was cut in 3° of external rotation through the cutting guides of the implant systems or the surgeon draw TEA or Whiteside's line for the orientation. On the other hand, this technique is not relevant for the ligament balancing technique and functional or kinematic alignment methods in which posterior condylar resection is made parallel to PCA. The results of this study are important for understanding variability in distal femoral geometry and for measuring resection techniques in TKA.

East Asian patients exhibited smaller anteroposterior (AP) dimensions than Caucasian patients, according to a comprehensive study by Kim et al.[47] This led to a higher mediolateral (ML)/AP femoral surface ratio in East Asian patients. Therefore, it would be necessary to use TKA components with comparatively smaller AP and broader ML dimensions. A gender-specific femoral component design is required, according to Koh YG et al's[48] research, which found that AP was much higher in male patients than in female ones. To the best of our knowledge, no prior evaluations of the DBTG–fMAP and DBTG–fLAP among different ethnic groups have been conducted. Understanding the design of the femoral component as well as preoperative planning

Table 4. Anatomical variations of the knee in different ethnic groups

	Parameter	Ethnicity	Female Mean	Male Mean	Total Mean
Kim et al[47]	fML	White	69	79	74
	fMAP		59	65	62
	fML	Black	67	71	69
	fMAP		63	63	64
	fML	East Asian	67	76	71
	fMAP		60	56	58
	fML	Indian	61	70	65
	fMAP		–	–	–
McNamara et al[49]	fML	Hispanic	66.3	77.2	71.7
Han et al[50]	fML	Korean	73.9	83.2	78.6
Koh YG et al[48]	fMAP	Korean	55.3	60.8	56.1
	fLAP		53.4	58.7	54.2

fML, mediolateral length; fMAP, medial anteroposterior length; fLAP, lateral anteroposterior length.

may be aided by knowledge of these parameters in healthy populations. In our investigation, it was revealed that Turkish participants had higher fML levels than East Asian, Caucasian, Korean, and African individuals (Table 4). Turkish people's fMAP is smaller than that of East Asian, Caucasian, and African patients, but it is similar to that of Korean subjects (Table 4). Regarding the fML, fMAP, fLAP, DBTG–fMAP, DBTG–fLAP, and MPCCT, there were considerable differences between male and female respondents. These findings demonstrate that for both male and female Turkish populations, a gender-specific femoral component design may be required.

Although this was the first study of its kind to include a Turkish population, it had some limitations. First, we did not measure the mechanical axis of the lower extremity. Secondly, measurements were made only in healthy Turkish individuals; osteoarthritic knees may give different results. Thirdly, whether rotation guides should be standardized to match the morphology of normal or osteoarthritic knees in the Turkish population needs further study. It is also not known whether these results have any clinical utility.

In the Turkish population, the PCAn and CTA may be higher, and it may be useful for surgeons to keep this in mind to prevent femoral component malposition and to make better templating for TKA. In addition, the results of this study may help in developing total knee implants that are nation-specific or appropriate to the patient's needs. Understanding the morphological data of the distal femur may be aided by the present study.

Ethics Committee Approval: This study was approved by Ethics Committee of Bezmialem Vakif University (Approval No: 45446446-010.99-3586, Date: March 3,2020).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – F.Y., O.A.; Design – F.Y., O.A.; Supervision – F.Y., I.T., N.E.; Resources – I.T.; Materials – N.E., I.T.; Data Collection and/or Processing – O.A., N.G.; Analysis and/or Interpretation – M.A.I., F.Y.; Literature Search – M.A.I., O.A.; Writing – M.A.I., F.Y.; Critical Review – M.A.I., F.Y.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

1. Insall JN, Kelly M. The total condylar prosthesis. *Clin Orthop Relat Res*. 1986;205:43-48. [CrossRef]
2. Merkow RL, Soudry M, Insall JN. Patellar dislocation following total knee replacement. *J Bone Joint Surg Am*. 1985;67(9):1321-1327. [CrossRef]
3. Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM. Insall Award paper. Why are total knee arthroplasties failing today? *Clin Orthop Relat Res*. 2002;404(404):7-13. [CrossRef]
4. Barrack RL, Schrader T, Bertot AJ, Wolfe MW, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. *Clin Orthop Relat Res*. 2001;392(392):46-55. [CrossRef]
5. Bell SW, Young P, Drury C, et al. Component rotational alignment in unexplained painful primary total knee arthroplasty. *Knee*. 2014;21(1):272-277. [CrossRef]
6. Berger RA, Crossett LS, Jacobs JJ, Rubash HE. Malrotation causing patellofemoral complications after total knee arthroplasty. *Clin Orthop Relat Res*. 1998;356(356):144-153. [CrossRef]
7. Laskin RS. Flexion space configuration in total knee arthroplasty. *J Arthroplasty*. 1995;10(5):657-660. [CrossRef]
8. Luring C, Perlick L, Bäthis H, Tingart M, Grifka J. The effect of femoral component rotation on patellar tracking in total knee arthroplasty. *Orthopedics*. 2007;30(11):965-967. [CrossRef]
9. Arima J, Whiteside LA, McCarthy DS, White SE. Femoral rotational alignment, based on the anteroposterior axis, in total knee arthroplasty in a valgus knee. A technical note. *J Bone Joint Surg Am*. 1995;77(9):1331-1334. [CrossRef]
10. Hungerford DS, Kenna RV. Preliminary experience with a total knee prosthesis with porous coating used without cement. *Clin Orthop Relat Res*. 1983;176(176):95-107. [CrossRef]
11. Stiehl JB, Abbott BD. Morphology of the transepicondylar axis and its application in primary and revision total knee arthroplasty. *J Arthroplasty*. 1995;10(6):785-789. [CrossRef]
12. Stiehl JB, Cherveny PM. Femoral rotational alignment using the tibial shaft axis in total knee arthroplasty. *Clin Orthop Relat Res*. 1996;331(331):47-55. [CrossRef]
13. Asano T, Akagi M, Nakamura T. The functional flexion-extension axis of the knee corresponds to the surgical epicondylar axis: in vivo analysis using a biplanar image-matching technique. *J Arthroplasty*. 2005;20(8):1060-1067. [CrossRef]
14. Berger RA, Rubash HE, Seel MJ, Thompson WH, Crossett LS. Determining the rotational alignment of the femoral component in total knee arthroplasty using the epicondylar axis. *Clin Orthop Relat Res*. 1993;286(286):40-47. [CrossRef]
15. Churchill DL, Incavo SJ, Johnson CC, Beynnon BD. The transepicondylar axis approximates the optimal flexion axis of the knee. *Clin Orthop Relat Res*. 1998;356(356):111-118. [CrossRef]
16. Frankel VH, Burstein AH, Brooks DB. Biomechanics of internal derangement of the knee. Pathomechanics as determined by analysis of the instant centers of motion. *J Bone Joint Surg Am*. 1971;53(5):945-962. [CrossRef]
17. Walker PS, Shoji H, Erkman MJ. The rotational axis of the knee and its significance to prosthesis design. *Clin Orthop Relat Res*. 1972;89:160-170. [CrossRef]
18. Castelli CC, Falvo DA, Iapicca ML, Gotti V. Rotational alignment of the femoral component in total knee arthroplasty. *Ann Transl Med*. 2016;4(1):4. [CrossRef]
19. Griffin FM, Insall JN, Scuderi GR. The posterior condylar angle in osteoarthritic knees. *J Arthroplasty*. 1998;13(7):812-815. [CrossRef]
20. Fan L, Xu T, Li X, Zan P, Li G. Morphologic features of the distal femur and tibia plateau in Southeastern Chinese population: A cross-sectional study. *Med*. 2017;96(46):e8524. [CrossRef]
21. Ho WP, Cheng CK, Liau JJ. Morphometrical measurements of resected surface of femurs in Chinese knees: correlation to the sizing of current femoral implants. *Knee*. 2006;13(1):12-14. [CrossRef]
22. Kwak DS, Surendran S, Pengatteeri YH, et al. Morphometry of the proximal tibia to design the tibial component of total knee arthroplasty for the Korean population. *Knee*. 2007;14(4):295-300. [CrossRef]
23. Vaidya SV, Ranawat CS, Aroojis A, Laud NS. Anthropometric measurements to design total knee prostheses for the Indian population. *J Arthroplasty*. 2000;15(1):79-85. [CrossRef]
24. Yue B, Varadarajan KM, Ai S, Tang T, Rubash HE, Li G. Differences of knee anthropometry between Chinese and white men and women. *J Arthroplasty*. 2011;26(1):124-130. [CrossRef]
25. Misir A, Yildiz KI, Kizkapan TB. Wider femoral and mediolaterally narrower tibial components are required for total knee arthroplasty in Turkish patients. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(7):2155-2166. [CrossRef]
26. Yoshioka Y, Siu D, Cooke TD. The anatomy and functional axes of the femur. *J Bone Joint Surg Am*. 1987;69(6):873-880. [CrossRef]
27. Yoshino N, Takai S, Ohtsuki Y, Hirasawa Y. Computed tomography measurement of the surgical and clinical transepicondylar axis of the distal femur in osteoarthritic knees. *J Arthroplasty*. 2001;16(4):493-497. [CrossRef]
28. Schub DL, Frisch NC, Bachmann KR, Winalski C, Saluan PM. Mapping of cartilage depth in the knee and elbow for use in osteochondral autograft procedures. *Am J Sports Med*. 2013;41(4):903-907. [CrossRef]
29. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310(20):2191-2194. [CrossRef]
30. Loures FB, Furtado Neto S, Pinto L, et al. Rotational assessment of distal femur and its relevance in total knee arthroplasty: analysis by magnetic resonance imaging. *Radiol Bras*. 2015;48(5):282-286. [CrossRef]
31. Kim TK, Phillips M, Bhandari M, Watson J, Malhotra R. Erratum to: what differences in morphologic features of the knee exist among patients of various races? A systematic review. *Clin Orthop Relat Res*. 2017;475(5):1507. [CrossRef]

32. McEwen PJ, Dlaska CE, Jovanovic IA, Doma K, Brandon BJ. Computer-assisted kinematic and mechanical axis total knee arthroplasty: A prospective randomized controlled trial of bilateral simultaneous surgery. *J Arthroplasty*. 2020;35(2):443-450. [CrossRef]
33. Dossett HG, Swartz GJ, Estrada NA, LeFevre GW, Kwasman BG. Kinematically versus mechanically aligned total knee arthroplasty. *Orthopedics*. 2012;35(2):e160-e169. [CrossRef]
34. Akagi M, Matsusue Y, Mata T, et al. Effect of rotational alignment on patellar tracking in total knee arthroplasty. *Clin Orthop Relat Res*. 1999;366(366):155-163. [CrossRef]
35. Briard JL, Hungerford DS. Patellofemoral instability in total knee arthroplasty. *J Arthroplasty*. 1989;4(suppl):S87-S97. [CrossRef]
36. Matziolis G, Brodt S, Windisch C, Roehner E. Changes of posterior condylar offset results in midflexion instability in single-radius total knee arthroplasty. *Arch Orthop Trauma Surg*. 2017;137(5):713-717. [CrossRef]
37. Minoda Y, Mizokawa S, Ohta Y, et al. Posterior reference guides do not always maintain the size of posterior femoral condyles in TKA. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(8):2489-2495. [CrossRef]
38. Wuertele N, Beckmann J, Meier M, Huth J, Fitz W. Posterior condylar resections in total knee arthroplasty: current standard instruments do not restore femoral condylar anatomy. *Arch Orthop Trauma Surg*. 2019;139(8):1141-1147. [CrossRef]
39. Bellemans J, Banks S, Victor J, Vandenneucker H, Moemans A. Fluoroscopic analysis of the kinematics of deep flexion in total knee arthroplasty. Influence of posterior condylar offset. *J Bone Joint Surg Br*. 2002;84(1):50-53. [CrossRef]
40. Cheng FB, Ji XF, Lai Y, et al. Three dimensional morphometry of the knee to design the total knee arthroplasty for Chinese population. *Knee*. 2009;16(5):341-347. [CrossRef]
41. Silva A, Pinto E, Sampaio R. Rotational alignment in patient-specific instrumentation in TKA: MRI or CT? *Knee Surg Sports Traumatol Arthrosc*. 2016;24(11):3648-3652. [CrossRef]
42. Akagi M, Yamashita E, Nakagawa T, Asano T, Nakamura T. Relationship between frontal knee alignment and reference axes in the distal femur. *Clin Orthop Relat Res*. 2001;388(388):147-156. [CrossRef]
43. Matsuda S, Matsuda H, Miyagi T, Sasaki K, Iwamoto Y, Miura H. Femoral condyle geometry in the normal and varus knee. *Clin Orthop Relat Res*. 1998;349(349):183-188. [CrossRef]
44. Nagamine R, Miura H, Inoue Y, et al. Reliability of the anteroposterior axis and the posterior condylar axis for determining rotational alignment of the femoral component in total knee arthroplasty. *J Orthop Sci*. 1998;3(4):194-198. [CrossRef]
45. Takai S, Yoshino N, Isshiki T, Hirasawa Y. Kneeling view: a new roentgenographic technique to assess rotational deformity and alignment of the distal femur. *J Arthroplasty*. 2003;18(4):478-483. [CrossRef]
46. Asada S, Akagi M, Matsushita T, Hashimoto K, Mori S, Hamanishi C. Effects of cartilage remnants of the posterior femoral condyles on femoral component rotation in varus knee osteoarthritis. *Knee*. 2012;19(3):185-189. [CrossRef]
47. Kim TK, Phillips M, Bhandari M, Watson J, Malhotra R. What differences in morphologic features of the knee exist among patients of various races? A systematic review. *Clin Orthop Relat Res*. 2017;475(1):170-182. [CrossRef]
48. Koh YG, Nam JH, Chung HS, Kim HJ, Chun HJ, Kang KT. Gender differences in morphology exist in posterior condylar offsets of the knee in Korean population. *Knee Surg Sports Traumatol Arthrosc*. 2019;27(5):1628-1634. [CrossRef]
49. McNamara CA, Hanano AA, Villa JM, Huaman GM, Patel PD, Suarez JC. Anthropometric measurements of knee joints in the Hispanic population. *J Arthroplasty*. 2018;33(8):2640-2646. [CrossRef]
50. Han H, Oh S, Chang CB, Kang SB. Anthropometric difference of the knee on MRI according to gender and age groups. *Surg Radiol Anat*. 2016;38(2):203-211. [CrossRef]