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SYSTEMATIC REVIEW

What Differences in Morphologic Features of the Knee Exist Among Patients of Various Races? A Systematic Review

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Abstract

Background Most TKA prostheses are designed based on the anatomy of white patients. Individual studies have identified key anthropometric differences between the knees of the white population and other major ethnic groups, yet there is limited understanding of what these findings may indicate if analyzed collectively.

Question/purpose What are the differences in morphologic features of the distal femur and proximal tibia among and within various ethnicities?

Methods A systematic review of the PubMed database and a hand-search of article bibliographies identified 235 potentially eligible English-language studies. Studies were excluded if they did not include morphology results or had insufficient data for analysis, were unrelated to the distal femur or proximal tibia, were conducted in pediatric patients or those undergoing unicondylar knee arthroplasty, or bone surface measurements were obtained for trauma products. This left 30 eligible studies (9050 knees). Study quality was assessed and reported as good, fair, or poor according to the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies. Morphometric data for the distal femur and proximal tibia were available for four ethnic groups: East Asian (23 studies; 5543 knees), white (11 studies; 3111 knees), Indian (three studies; 283 knees), and black (three studies; 113 knees). Although relatively underrepresented, the knees from the Indian and black studies were maintained for hypothesis-generating purposes and to highlight crucial gaps in the data. The two key dimensions for selecting a suitable implant based on a patient's unique anatomy—AP length and mediolateral (ML) width—were assessed for the femur and

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tibia, in addition to aspect ratio, calculated by dividing the ML width by the AP length. Study measurement techniques were compared visually when possible to ensure that each pooled study conducted a similar measurement process. Any significant measurement outliers were reviewed for eligibility to determine if the measurement techniques and landmarks used were comparable to the other studies included.

Results White patients had larger femoral AP measurements than East Asians (62 mm, [95% CI, 57–66 mm] vs 59 mm, [95% CI, 54–63 mm]; mean difference, 3 mm; $p < 0.001$), a smaller femoral aspect ratio than East Asians (1.20, [95% CI, 1.11–1.29] vs 1.25, [95% CI, 1.16–1.34]; mean difference, 0.05; $p = 0.001$), and a larger tibial aspect ratio than black patients (1.55, [95% CI, 1.40–1.71] vs 1.49, [95% CI, 1.33–1.64]; mean difference, 0.06; $p = 0.005$).

Conclusions This analysis uncovered differences of size (AP height and ML width of the femur and tibia) and shape (tibial and femoral aspect ratios) among knees from white, East Asian, and black populations. Future research is needed to understand the clinical implications of these discrepancies and to provide additional data with underrepresented groups.

Introduction

Globally, a surge is expected in the number of TKAs performed in the coming years owing to increased life expectancies and an increased burden of osteoarthritis [17]. Although TKA is considered a highly successful procedure, with the ability to relieve pain, enhance quality of life, and improve function in patients with knee arthritis [11], nearly all TKA prostheses were designed based on the anthropomorphic features of male [49], Western, and primarily white patients [6, 21].

To date, the topic of anatomic differences according to ethnicity has not garnered as much attention as that of the role of gender, which has been the subject of numerous studies [7, 10, 15, 16, 19, 48]. These analyses were key for identifying now well-established anatomic differences in knees of males and females, with the latter having been shown to have narrower mediolateral (ML) to AP aspect ratios [2, 5], less pronounced anterior condyles [7, 12], and greater quadriceps angle [22, 48].

Studies that have detailed anthropometric differences according to ethnicity primarily have done so in white and East Asian populations [18, 20, 40]. They found that, compared with the white population, Chinese females and males have a substantially more-valgus anatomic axis, females have more-valgus condylar angles (angle between the mechanical or anatomic axis line of the femur and a line tangent to the femoral condyles), and males have more-valgus condylar-plateau angles (angle between the condylar angle and tibial plateau angle) [18]. They also found that female patients have substantially more varus alignment of the lower extremity [40], and that AP length of the lateral condyle and total width of the distal condyle also differed in a group of patients who was mostly (81%) female [20]. Femurs in the Chinese population also are substantially more externally rotated than the traditionally accepted 3° in Western patients [55].

Although such studies indicate potentially relevant differences exist among ethnic groups, to our knowledge there has not been an analysis to pool various morphologic results in the largest dataset possible to clarify what the extent of those differences might be. Such an analysis is important for identifying areas where possible mismatches between average morphologic features of particular ethnicities and the size options of existing devices for TKA might occur. In turn, this may identify populations for further study to determine the clinical implications of such mismatches.

The current systematic analysis was done to identify anthropometric characteristics of the bony structures of the knee (distal femur and proximal tibia) among various ethnicities. Therefore, we asked: What are the differences in morphologic features of the distal femur and proximal tibia among and within various ethnicities?

Search Strategy and Criteria

A systematic review was conducted and finalized on April 19, 2015 using the PubMed database. Studies were eligible for inclusion if they featured morphologic measures of the distal femur and/or proximal tibia in the following populations: white, black, Asian, Middle Eastern, or African. Conversely, studies were excluded if they were conducted with unicompartmental knee arthroplasty or trauma products, exclusively measured the patella, were conducted in pediatric or nonhuman subjects, featured data unrelated to the distal femur or proximal tibia, or data that were considered insufficient for analysis. The search was limited to English-language studies with the following terms appearing in their abstract or title: (Knee* AND (morphometr* OR (morphology OR morphological) OR (anthropometric OR anthropometry)) AND (ethnic* OR ethnicity); (race* OR racial*); (Asia* OR Asian*); (Caucasian* OR White* OR America*); (Western* OR Eastern*); (Asian-Pacific*); (African* OR Africa* OR Black*); (Middle East* OR Middle Eastern*); (China OR Chinese); (India* OR Indian*); (Korea* OR Korean*);

(Indonesia* OR Indonesian*); (Japan* OR Japanese*); (Philippines* OR Filipino*); (Vietnam* OR Vietnamese*); (Thailand* OR Thai*); (Hong Kong*); (Pakistan* OR Pakistani*); (Bangladesh* OR Bangladeshi*); (Egypt* OR Egyptian*); (Iran* OR Iranian*); (Turkey* OR Turkish*); (Iraq* OR Iraqi*); (Saudi Arabia* OR Saudi Arabian*); (Nigeria* OR Nigerian*); (Ethiopia* OR Ethiopian*); (Congo* OR Congolese*).

The search identified 235 potentially eligible published studies. After review of the title, abstract, and full text by one of the authors (MP), 206 of these studies were excluded and 29 were deemed eligible (Fig. 1). Review of the reference lists of the 29 studies revealed an additional eligible study, giving us 30 studies [1, 2, 4, 6, 8, 13, 14, 23, 24, 26, 27, 29–32, 34, 36, 39, 41–43, 45–47, 50–54, 56] for inclusion (Fig. 1). All included studies were considered cross-sectional observational studies. Individual arms of higher-quality evidence were treated as cross-sectional observational studies. Study quality was assessed and reported as good, fair, or poor, by using the National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies [35].

Collectively, the 30 studies included data on 9050 knees (mean sample size, 302 knees; Table 1) from patients with a mean age of 63 years, and 37% of whom were male. From these studies, data were obtained from four ethnic groups. There were 23 studies (5543 knees; mean sample size, 241 knees) of East Asian patients (mean age, 63 years; 27% male), 11 studies (3111 knees; mean sample size, 283 knees) of white patients (mean age, 61 years; 52% male), three studies (283 knees; mean sample size, 94 knees) of Indian patients (mean age, 56 years; 49% male), and three studies (113 knees; mean sample size, 38 knees) of black patients (mean age, 51 years; 38% male). The category of East Asian patients comprised those from Chinese, Japanese, Korean, Malaysian, and Thai nationalities. There were no available studies with Middle Eastern or African patients.

Fig. 1 The flowchart shows the results of our literature search and the articles identified at each stage, with the reasons for exclusion. UKA = unicompartmental knee arthroplasty.

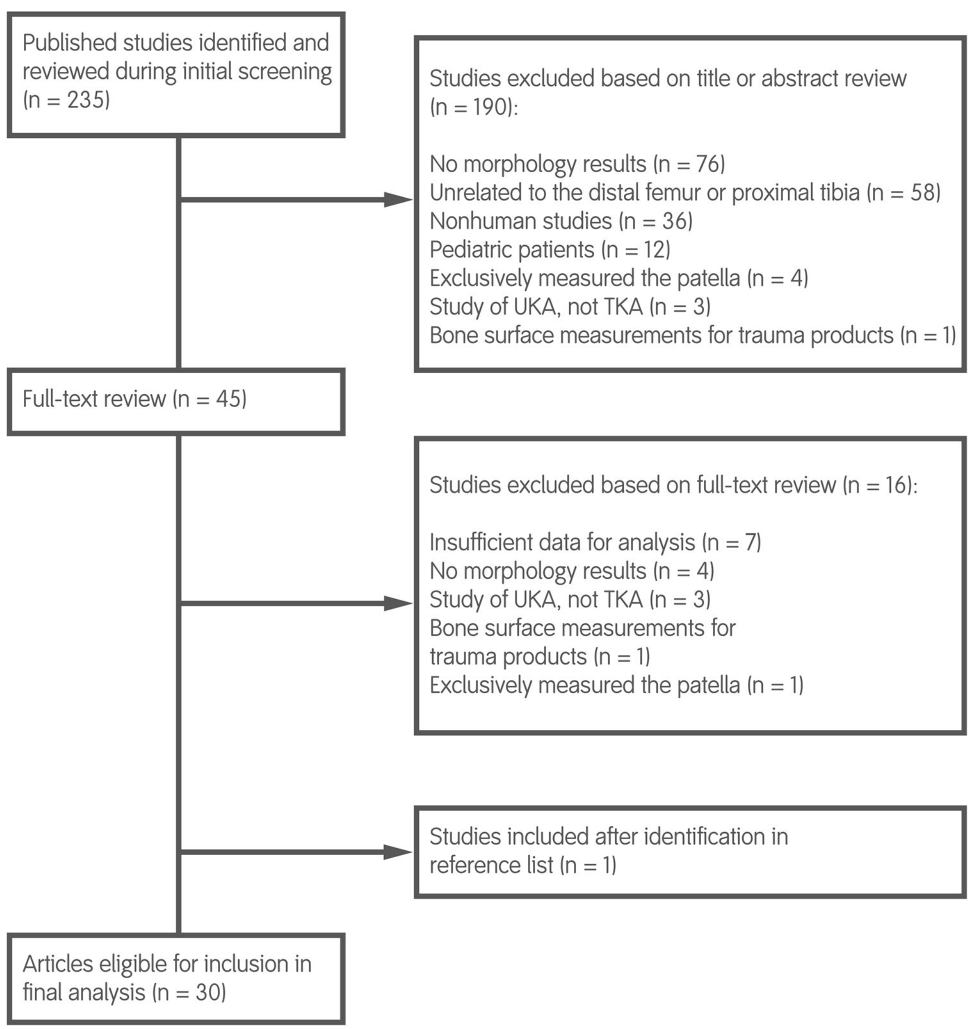

Table 1. Summary of included studies of morphologic features of the knee (n = 30)

Study	Population	Female/male	Knees	Measurement method	Endpoints included	NIH Quality of Evidence
Barnes et al. [1]	Black	12/3	15	Virtual (CT)	FAP, FML	Fair
Chaichankul et al. [2]	East Asian	119/81	200	Virtual (MRI)	FAP, FML, femoral aspect ratio, TAP, TML	Fair
Cheng et al. [3]	East Asian	78/94	172	Virtual (CT)	FAP, FML, FLAP, FMAP, femoral aspect ratio, TAP, TML, TLAP, TMAP, tibial aspect ratio	Good
Chung et al. [6]	East Asian	975/50	1025	Physical (intraoperative)	FAP, femoral aspect ratio	Good
Dai & Bischoff [8]	Indian	47/50	97	Virtual (CT)	TML, TLAP, TMAP	Good
Gandhi et al. [13]	Indian	50/50	100	Physical (intraoperative)	TAP, TLAP, TMAP	Poor
Gillespie et al. [14]	White	660/547	1207	Physical (cadaver)	Femoral aspect ratio	Fair
Hussain et al. [23]	East Asian	50/50	100	Virtual (CT)	FAP, FML, femoral aspect ratio	Fair
Ishimaru et al. [24]	East Asian	40/40	80	Virtual (CT)	FML, FLAP, FMAP, femoral aspect ratio,	Fair
Kwak et al. [26]	East Asian	100/100	200	Virtual (CT)	FAP, FLAP, femoral aspect ratio	Good
Kwak et al. [27]	East Asian	100/100	200	Virtual (CT)	TAP, TML, TLAP, TMAP	Good
Li et al. [29]	White	48/79	275	Virtual (MRI for white, CT for East Asian)	FAP, FLAP, femoral aspect ratio, TAP, TML, tibial aspect ratio	Fair
	East Asian	87/61				
Lim et al. [30]	East Asian	59/56	115	Virtual (MRI)	FML, FLAP, FMAP, TML, TLAP, TMAP	Good
Liu et al. [31]	East Asian	195/129	324	Virtual (CT)	TAP, TML, TLAP, TMAP	Poor
Mahfouz et al. [32]	Black	40/40	80	Physical & virtual (cadaver and CT)	FAP, FLAP, FMAP, femoral aspect ratio, TAP, TML, tibial aspect ratio	Good
	White	340/500	840			
	East Asian	40/40	80			
Mensch & Amstutz [34]	White	39/44	83	Physical (cadaver 36.1%) & (radiographs 63.9%)	FML, FLAP, TML, TLAP, TMAP	Poor
Nishikawa et al. [36]	East Asian	154/25	179	Virtual (CT)	FAP, FML	Good
Rooney et al. [39]	White	68/128	196	Physical (intraoperative)	FML, FLAP, FMAP, TML, TLAP, TMAP	Fair
Terzidis et al. [41]	White	168/192	360	Physical (cadaver)	FLAP, FMAP	Poor
Uehara et al. [42]	East Asian	77/23	100	Physical (intraoperative)	TAP, TML	Poor
Urabe et al. [43]	White	30/0	100	Physical (radiographs)	FLAP	Fair
	East Asian	70/0				
Vaidya et al. [45]	Indian	48/38	86	Physical & virtual (cadaver & CT)	FAP, FML	Fair
van den Heever et al. [46]	Black	0/18	60	Virtual (MRI)	FML, FLAP, FMAP, femoral aspect ratio	Fair
	White	22/20				
Wanitcharo-enporn et al. [47]	East Asian	170/30	200	Physical (intraoperative)	FML, FLAP, FMAP, femoral aspect ratio	Poor
Yan et al. [50]	East Asian	50/50	100	Virtual (CT)	FAP, FML, femoral aspect ratio	Fair
Yang et al. [51]	East Asian	799/177	976	Physical (intraoperative)	TAP, TML, TLAP, TMAP	Good
Yang et al. [52]	East Asian	658/164	822	Physical (intraoperative)	TLAP, TMAP	Fair
Yang et al. [53]	East Asian	65/65	130	Virtual (CT)	FAP, FML, femoral aspect ratio	Fair

Table 1. continued

Study	Population	Female/male	Knees	Measurement method	Endpoints included	NIH Quality of Evidence
Yang et al. [54]	East Asian	65/65	130	Virtual (CT)	TAP, TML, TLAP, TMAP, tibial aspect ratio	Fair
Yue et al. [56]	White	20/20	40	Virtual (CT)	FAP, FML, femoral aspect ratio, TAP, TML, TLAP, TMAP, tibial aspect ratio	Poor
	East Asian	16/20	36			

FAP = femoral AP; FLAP = femoral lateral AP; FML = femoral mediolateral; FMAP = femoral medial AP; TAP = tibial AP; TML = tibial mediolateral; TLAP = tibial lateral AP; TMAP = tibial medial AP.

Morphologic Endpoints

Two dimensions, AP and ML width, were assessed for the femur (Fig. 2) and tibia (Fig. 3). These dimensions are used to define size, and included the following measures: femoral AP, femoral mediolateral, femoral lateral AP, femoral medial AP, tibial AP, tibial mediolateral, tibial lateral AP and tibial medial AP.

These endpoints were supplemented by an analysis of aspect ratio. Femoral aspect ratio (Fig. 2) and tibial aspect ratio (Fig. 3) are calculated by dividing ML width by lateral AP. Aspect ratio allows for the prediction of prosthesis shape [27].

To be included, endpoints were required to be reported in five or more studies. As femoral AP and femoral lateral AP were considered to essentially repeat the same measurement, it was decided to remove the latter measurement from the analysis. Thus, there were nine endpoints total for analysis; four with the femur and five with the tibia. Mean measurements for available ethnicities were reported for three morphologic features with the femur (Fig. 4) and four with the tibia (Fig. 5).

Many studies provided visual descriptions of how measures were conducted. These were assessed to ensure the studies conducted measurements similarly. Any significant measurement outliers were reviewed by one author (MP) for eligibility to determine if the measurement techniques and landmarks used were comparable to those in other included studies.

Statistical Analysis

A two-way random effects ANOVA with main effects of ethnicity was performed using SAS® 9.2 software (SAS®, Cary, NC, USA). Reported values were weighted by the inverse of the variance. A Tukey-Kramer multiple comparisons post hoc test was done to examine the specific effects of ethnicity and ethnicity by sex. Means and 95% CIs were provided, along with mean differences and p values. Significance was determined as a probability less than 0.01 owing to the large number of comparisons completed. A more conservative significance value attempts to control for type 1 error in the model with multiple comparisons.

Sex was incorporated by being included as a main effect, which also accounts for differences in ethnicity across sex, and examining interaction effects between ethnicity and sex.

Results

For the femur, white patients had larger femoral AP measurements than East Asian (62 mm [95% CI, 57–66 mm]

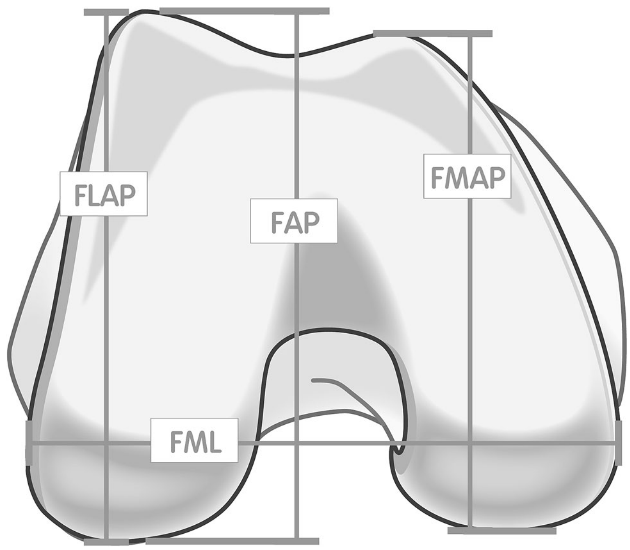

Fig. 2 The four femoral morphologic endpoints measured are shown. FAP = femoral AP (AP dimension of the lateral femoral condyle [identical with FLAP]); FML = femoral mediolateral (mediolateral width at the condyle); FLAP = femoral lateral AP (longest dimension of the lateral condyles in the AP axis); FMAP = femoral medial AP (longest dimension of the medial condyles in the AP axis). In addition, the femoral aspect ratio was calculated by dividing femoral mediolateral by femoral AP.

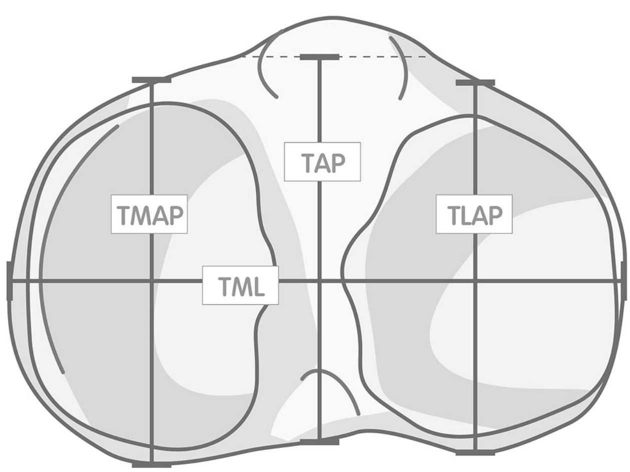

Fig. 3 The four tibial morphologic endpoints measured are shown (tibia measured postresection). TAP = tibial AP (line perpendicular to and passing through the midpoint of the tibial mediolateral line); TML = tibial mediolateral (the longest mediolateral length of the proximal tibial cut surface); TLAP = tibial lateral AP (a line drawn parallel to the tibial AP and passing through the posterior-most points of the laterial tibial condyles); TMAP = tibial medial AP line (a line drawn parallel to tibial AP line and passing through the posterior-most points of the medial tibial condyles). In addition, the tibial aspect ratio was calculated by dividing the tibial mediolateral by tibial AP.

vs 59 mm, [95% CI, 54–63 mm]; mean difference, 3 mm; p < 0.001) (Table 2). There were no differences in the measurements of femoral ML (Table 3) or femoral medial

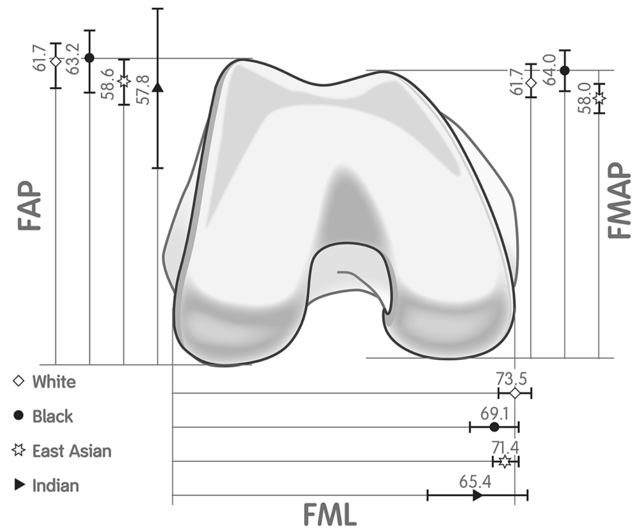

Fig. 4 The average values for the three femoral morphologic endpoints measured are shown. FAP = femoral AP; FML = femoral mediolateral (mediolateral width at condyle); FMAP = femoral medial AP.

AP (Table 4). White patients had smaller femoral aspect ratios (Fig. 6) than East Asians (1.20, [95% CI, 1.11–1.29] vs 1.25, [95% CI, 1.16–1.34]; mean difference, 0.05; p = 0.001) (Table 5).

For the tibia, there were no observable differences in tibial AP (Table 6), tibial ML (Table 7), tibial lateral AP (Table 8), or tibial medial AP measurements (Table 9). However, white patients had larger tibial aspect ratios (Fig. 7) than black patients (1.55, [95% CI, 1.40–1.71] vs 1.49, [95% CI, 1.33–1.64]; mean difference, 0.06; p = 0.005 (Table 10).

Discussion

As TKA is increasingly performed around the globe, and patterns of immigration continue to change the demography of Western nations, it is necessary to obtain a better understanding of the size and shape of knees among patients of different ethnicities. Although individual studies have been conducted measuring relevant morphologic endpoints among various distinct populations [1, 2, 4, 6, 8, 13, 14, 23, 24, 26, 27, 29–32, 34, 36, 39, 41–43, 45–47, 50–54, 56], to our knowledge to date there has not been a systematic analysis of their findings to clarify what specific differences exist among ethnicities. We hoped that performing this analysis would facilitate research in the clinical implications of these anatomic differences and determine whether design initiatives would be merited to address the potential for compromised implant fit.

There are several key limitations to this analysis that must be considered when interpreting these results. First,

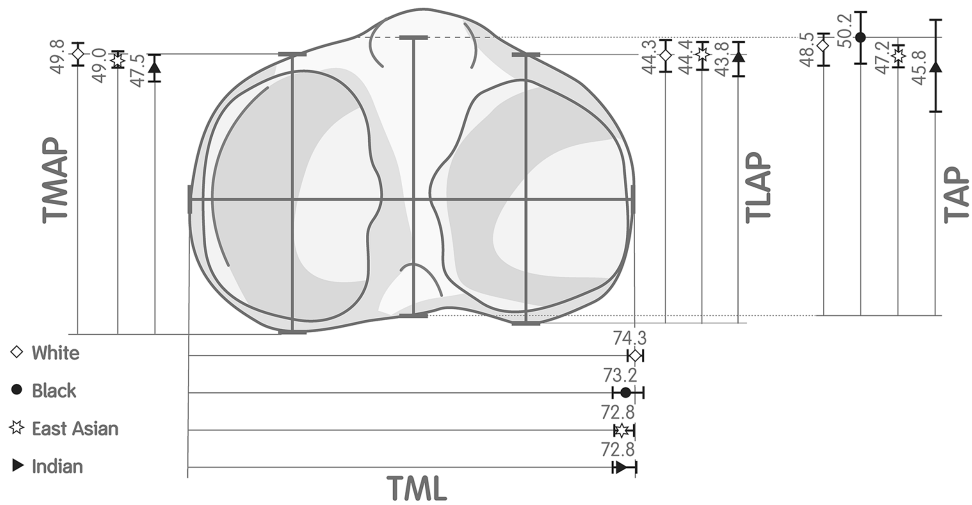

Fig. 5 The average values for the four tibial morphologic endpoints measured are shown. TAP = tibial AP; TML = tibial mediolateral; TLAP = tibial lateral AP; TMAP = tibial medial AP.

Table 2. Femoral AP measurements† (3650 knees; 13 studies)

Ethnicity	Males		Females		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	64	60–69	59	54–64	62	57–66
Black	66	61–70	61	55–67	63	58–68
East Asian	61	57–66	56	52–60	59	54–63
Indian	61	45–77	55	39–70	59	42–73

† Measurements in mm; p values of main effects: ethnicity (< 0.001); sex (< 0.001); interaction (0.954); white versus black (0.639), East Asian (< 0.001), Indian (0.957); black versus white (0.639), East Asian (0.012), Indian (0.900); East Asian versus black (0.012), white (< 0.001), Indian (0.999); Indian versus black (0.900), white (0.957), East Asian (0.999).

Table 3. Femoral mediolateral measurements† (1884 knees; 15 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	79	75–83	69	65–72	74	70–77
Black	71	65–77	67	60–75	69	64–74
East Asian	76	73–79	67	64–70	71	69–74
Indian	70	59–80	61	49–73	65	55–76

† Measurements in mm; p values of main effects: ethnicity (0.167); sex (< 0.001); interaction (0.564); black versus white (0.254), East Asian (0.560), Indian (0.458); black versus white (0.254), East Asian (0.738), Indian (0.911); East Asian versus black (0.738), white (0.560), Indian (0.670); Indian versus black (0.911), white (0.458), East Asian (0.670).

Table 4. Femoral medial AP measurements† (2183 knees; eight studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	65	61–68	59	55–62	62	58–65
Black	65	61–70	63	56–70	64	59–69
East Asian	60	57–64	56	52–59	58	54–62

† Measurements in mm; p values of main effects: ethnicity (0.009); sex (0.004); interaction (0.156); white versus black (0.338), East Asian (0.012); black versus white (0.338), East Asian (0.022); East Asian versus black (0.022), white (0.012)

knees from black and Indian populations were underrepresented in comparison to the numbers from East Asian and white populations (representing 1.2% and 3.1% of total knees, respectively, versus 61.2% and 34.4%, respectively), potentially underpowering comparisons and accounting for large variations in confidence intervals with these groups. Endpoints such as femoral medial AP, where knees from black populations showed a trend toward larger measurements than knees from East Asian populations, may or may not have shown established differences with greater patient numbers. Although such questions inevitably remain, we considered it important to extend the analysis to all available ethnicities to highlight current gaps and identify potential trends that could form the basis of future investigations. Because we were unable to identify any studies with our chosen endpoints in Middle-Eastern or African patients, it was especially troubling. As TKA is increasingly performed across the world, it will be important to draw greater numbers of these populations in clinical studies to determine if relevant morphologic differences exist, as observed in our analysis.

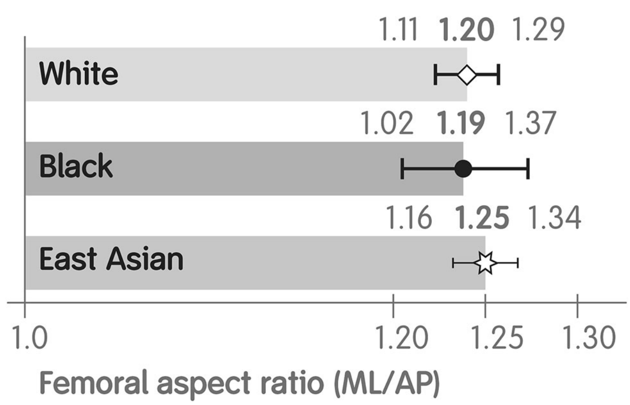

Fig. 6 The mean femoral aspect ratio and 95% CIs are shown for the available ethnicities (white, black, and East Asian).

Second, broad categorizations of ethnicity, such as those we used, inevitably overlook anatomic heterogeneity in such groups (for example, notable discrepancies in rheumatoid arthritis susceptibility between northern and southern Chinese members of the same Han ethnic group [28, 57]). Individual studies are susceptible to obvious enrollment or economic limitations, and cannot be expected to include sufficiently representative numbers from all subgroups in an ethnicity. Therefore, one must rely on the same broad categorizations that the studies use.

Third, although we tried to ensure that all studies used consistent measurement strategies for the chosen outcomes, it is possible that there are differences in the methods they used. As previously noted, efforts were taken to ensure that studies conducted measurements in a similar fashion, despite inherent variability in their reporting. Any significant measurement outliers were reviewed for eligibility to determine if the measurement techniques and landmarks used were comparable to those used in the other included studies. This occurred only with two studies excluded (Fig. 1) owing to measurements used for trauma devices, in which the values were inconsistent with those in similar analyses. We also chose to pool the measurements which appeared most commonly in published analyses. Future studies are

Table 5. Femoral aspect ratio (4825 knees; 14 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	1.22	(1.13–1.31)	1.17	(1.08–1.26)	1.20	(1.11–1.29)
Black	1.19	(1.09–1.29)	1.19	(1.08–1.26)	1.19	(1.02–1.37)
East Asian	1.27	(1.18–1.35)	1.23	(1.15–1.32)	1.25	(1.16–1.34)

P values of main effects: ethnicity (0.002); sex (0.558); interaction (0.195); white versus black (0.996), East Asian (0.001); black versus white (0.996), East Asian (0.694); East Asian versus black (0.694), white (0.001).

Table 6. Tibial AP measurements† (3553 knees; 11 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	52	49–54	45	43–48	48	46–51
Black	53	48–58	48	43–53	50	46–54
East Asian	50	48–53	45	43–47	48	45–49
Indian	48	40–56	44	36–52	46	38–54

† Measurements in mm; p values of main effects: ethnicity (0.401); sex (< 0.001); interaction (0.662); white versus black (0.664), East Asian (0.646), Indian (0.904); black versus white (0.664), East Asian (0.409), Indian (0.722); East Asian versus black (0.409), white (0.646), Indian (0.969); Indian versus black (0.722), white (0.904), East Asian (0.969).

Table 7. Tibial mediolateral measurements† (4194 knees; 14 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	79	78–81	69	68–71	74	73–76
Black	80	76–83	67	63–70	73	71–76
East Asian	77	76–78	69	68–70	73	72–74
Indian	77	74–79	69	66–71	73	71–75

† Measurements in mm; p values of main effects: ethnicity (0.039); sex (< 0.001); interaction (0.013); white versus black (0.771), East Asian (0.036), Indian (0.361); black versus white (0.771), East Asian (0.984), Indian (0.990); East Asian versus black (0.984), white (0.036), Indian (1.000); Indian versus black (0.990), white (0.361), East Asian (1.000).

Table 8. Tibial lateral AP measurements† (3488 knees; 12 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	47	44–50	42	39–45	44	42–47
Indian	46	43–49	42	38–45	44	41–47
East Asian	47	45–49	42	40–44	44	42–47

† Measurements in mm; p values of main effects: ethnicity (0.859); sex (< 0.001); interaction (0.829); white versus East Asian (0.994), Indian (0.906); East Asian versus white (0.994), Indian (0.858); Indian versus white (0.906), East Asian (0.858).

Table 9. Tibial medial AP measurements† (3541 knees; 12 studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	53	51–55	47	45–49	50	48–52
Indian	51	48–53	45	42–53	48	45–50
East Asian	52	50–53	46	45–48	49	48–51

† Measurements in mm; p values of main effects: ethnicity (0.096); sex (< 0.001); interaction (0.466); white versus East Asian (0.598), Indian (0.079); East Asian versus white (0.598), Indian (0.287); Indian versus white (0.079), East Asian (0.287).

warranted to gauge the effect of additional factors such as differences in valgus and varus angle and axial rotation.

Fourth, we relied only on the PubMed database for uncovering studies. It is possible that the addition of a second search engine (eg, Embase®) might have identified other studies. However, our thorough hand search of related articles and reference lists of previously published articles found in PubMed was exhaustive, and we believe it has uncovered if not all, then nearly all relevant publications on this topic.

Two of the three differences we noted in our analysis were with aspect ratio, which is defined as the ML width divided by the AP height of the femur or tibia. A larger aspect ratio corresponds to a larger ML dimension for a given AP size, whereas a smaller aspect ratio corresponds to a smaller ML dimension for a given AP size (Fig. 8). The benefits of understanding aspect ratio are that femoral shape can be predicted and it can act as a guide to femoral component size. In addition, the aspect ratio provides a measure of the relative dimension of the knee between patients. In terms of the femoral aspect ratio in our analysis, knees from East Asian patients appear shorter in the AP dimension compared with knees from white patients. This would result in a relatively larger ML/AP aspect ratio. As such, proper fit for East Asian patients may call for a TKA device that is relatively smaller in AP direction and wider in ML dimension; however, future studies will need to evaluate whether such differences will make a clinically important difference on the results of TKA.

Mismatches in terms of femoral aspect ratio have been noted between available TKA prostheses and the resected femurs of Chinese patients [20]. Failure to correlate the femoral aspect ratio with a properly sized prosthesis carries a resulting risk of ML overhang and impingement of the intraarticular soft tissues [9, 20]. The actual clinical effect of such mismatches is unclear. Overhang has been associated with approximately one-quarter of the cases of clinically relevant knee pain after TKA [33]. However, gender-specific components that have been designed to reduce the rate of overhang and have succeeded in doing so, generally have failed to improve functional outcomes, decrease rates of pain, or lessen the risk of revision [49]. Downsizing of the femoral component to circumvent the risk of overhang can result in an undersized AP dimension, risking instability in flexion and perhaps causing the surgeon to compensate by overresecting the distal femur to raise the joint line [9]. As many East Asian patients present with large flexion contractures but with preserved maximum flexion, it is a frequent clinical scenario for surgeons to address a larger flexion gap with an upsized femur [25]. If ML overhang originating from a narrow distal femur does not allow surgeons to upsize the femur, they must elect to resect additional distal femur or to accept flexion instability, both of which can cause problems.

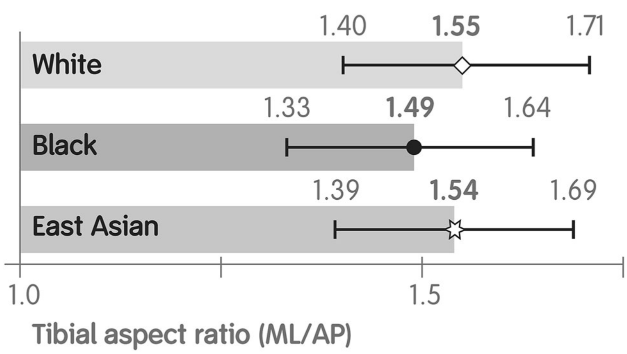

Fig. 7 The mean tibial aspect ratio and 95% CIs are shown for the available ethnicities (white, black, and East Asian).

Our analysis of tibial endpoints revealed that knees from black patients had larger AP dimensions than did knees from white patients, which results in a smaller tibial aspect ratio. In a reverse of the effect in femurs from East Asian patients, this could result in possible mismatches in which a tibial component that fits white patients potentially would be relatively small in the AP dimension for black patients. A correlating increase in AP dimension with a decrease in aspect ratio also has been observed by others [2, 3, 51]. Most available designs use constant or increased aspect ratio with an increasing AP dimension, potentially leading to issues of underhang or overhang in certain patients [51]. A suitable fit is necessary to achieve coverage of the resected tibial surface. It is common practice not to accept overhang owing to concerns regarding pain or limitations to ROM, and instead to select smaller components. However, such decisions may necessitate the loss of a substantial portion of the tibia bone surface necessary for durable implant fixation. Furthermore, even when the tibia is downsized, it is common to observe AP overhang in the lateral tibia plateau, which can impinge against the popliteus tendon posteriorly and the iliotibial band anteriorly.

Table 10. Tibial aspect ratio measurements (1653 knees; five studies)

Ethnicity	Male		Female		Both sexes	
	Mean	95% CI	Mean	95% CI	Mean	95% CI
White	1.57	1.42–1.73	1.54	1.38–1.69	1.55	1.40–1.71
Black	1.54	1.38–1.70	1.43	1.27–1.59	1.49	1.33–1.64
East Asian	1.53	1.38–1.69	1.54	0.39–1.70	1.54	1.39–1.69

P values of main effects: ethnicity (0.006); sex (0.003); interaction (0.005); white versus black (0.005), East Asian (0.382); black versus white (0.005), East Asian (0.057); East Asian versus black (0.057), white (0.382).

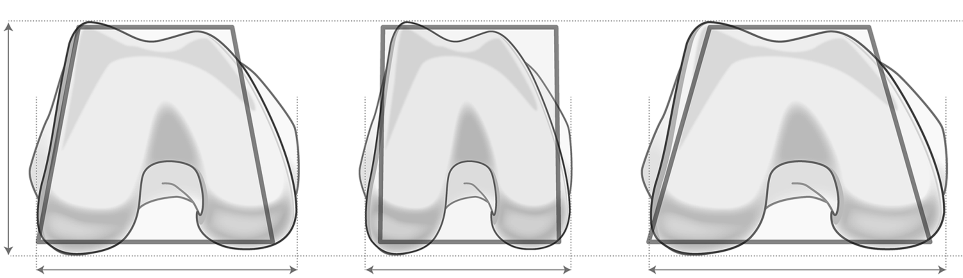

Fig. 8A–C The (**A**) reference femoral aspect ratio, compared with a (**B**) smaller aspect ratio with a smaller ML for a constant AP and a (**C**) larger aspect ratio with a wider ML for a constant AP are shown.

However, there are many patients with such overhang who experience no symptoms, therefore, at this time we do not know how often such overhang causes clinically important symptoms. Future studies should analyze whether an asymmetric tibial component may be of use in these patients to ensure optimal size and rotation.

There is some indication from studies using 3-dimensional CT that the morphologic measurements among various ethnicities may not fully match with available prostheses for TKA. Urabe et al. [44] obtained the femoral dimensions of 44 Japanese patients and observed a tendency for the widths of the medial condyles and the lengths of the lateral posterior condyles to be larger and shorter, respectively, than those of available prostheses, leading them to determine that improved anatomic fit could be obtained with components designed to meet this wider distribution of sizes. Similarly, Kwak et al. [27] used CT for 200 cadaveric knees from Korean patients and observed, in many cases, these patients had a proximal tibial cut surface smaller than commercially available implants, with a resulting risk for undersizing for smaller devices and overhang for larger devices. Another CT analysis observed that although a majority of Indian men (86.8%) were satisfactorily addressed by existing designs, this was true of fewer of their female counterparts (60.4%; $p < 0.001$), who had femoral AP diameters smaller than the smallest available femoral component [45].

When considering the development of novel prosthesis designs to accommodate differing morphologic features, it is important to note the example of gender-specific TKA, perhaps the most-prominent recent example of such an effort. In an attempt to better match the anatomic considerations of women, who undergo TKA at a higher rate than men [38], gender-specific prostheses were introduced in the mid-2000s. The majority of clinical studies conducted to date have not uncovered relevant clinical advantages for these prostheses over unisex models, despite accomplishing one of their intended goals in reducing overhang of the femoral component [4, 49]. This serves as a cautionary example that not all changes to implants driven by morphologic findings result in discernible improvements. We note, though, that the ML width of the distal femur is associated primarily with femur length, not gender [37], which could play a role in the inability of gender-specific implants to confer a clinical benefit [4]. The differences in aspect ratio and femoral shape identified between ethnicities in our analysis may prove to be a more relevant factor in the long-term success of TKA, and is worthy of additional analysis.

In the current review, we uncovered three key morphologic differences in the distal femur and proximal tibia among and within various ethnicities. For the femur, white patients had larger femoral AP measurements and smaller aspect ratios than East Asian patients. For the tibia, white patients had larger aspect ratios than black patients. Matching the size of TKA components to the size of the resected bony surfaces may help to minimize complications and prolong survival. If important differences in size or shape of the distal femur or proximal tibia exist among separate patient populations, thereby theoretically leading to poor size matching with existing knee prostheses, it is conceivable that this could result in persistent pain, surgical complications, or premature revision surgery. Although the development of patient-specific devices modeled on unique anatomic considerations may supersede general design efforts according to ethnicity, such technology is still in its early stages, and it is likely that economic and technologic restrictions will prevent their wide adaptation across all regions of the globe where TKAs will be performed. Therefore, the differences and variations noted among and within each ethnicity in our analysis provide important data from which to design future research elucidating the effect on clinical outcomes these might have on separate populations. Additional studies also are needed to expand our knowledge of anatomic measurements in underrepresented populations, such as Middle-Eastern and African patients.

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