

Is there any relation between distal parameters of the femur and its height and width?

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Abstract The purpose of this study was to reveal the association whether the distal morphometry of femur had a relation with femur height or width. Sixty-six adult (35 right and 31 left) dry femurs from Caucasians were used in this study. Computed tomography (CT) imaging was applied to obtain measurement values of the femur. Femur height (413.29 ± 28.40 mm) and width (29.86 ± 2.72 mm) were all checked one by one to determine the correlation with the parameters obtained. Both values exposed high rates of correlation with height (26 ± 2.34 mm) and width (20.85 ± 2.76 mm) of femur notch; also, measures of epicondylar, bicondylar and condylar diameters of femur were obtained. Measures were checked if there was a correlation with femur height and width. Differences displayed in distal morphometry of femur according to race and sex are due to other morphometric measures of femur rather than race and sex. We believe that displaying the high rates of correlation of distal morphometry of femur with femur height and width will be the factor which determines the selection and production of prosthesis among the long or short individuals of folks.

Keywords Femur · Morphometry · Knee dimensions · Replacement surgery · Epicondyles

Introduction

Bones vary not only in their primary shape but also in lesser surface details. Depressions (fossae) and elevations vary in size and shape and interrupt otherwise featureless osseous surfaces [29]. Measurements of the distal femur are important anatomic landmarks for total knee arthroplasty [3, 4, 15]. Nevertheless, anatomic descriptions of the distal femoral epicondyles are vague and scarce [29, 37]. It is important to obtain the anthropometric data to achieve the best stability and longevity for implant [14, 36]. A lot of studies have determined that the same kind of prostheses is not suitable for different population [12, 18]. We thought that, the difference appears possibly owing to the relation of distal morphometry of femur with femur height and width. For this reason we aimed to study morphometry of the distal femur and its relation with the height and width and its importance to obtain prostheses data. We believe that, simply knowing the measures of femur height and width in the event of performing total knee prosthesis will be the main factor in determining selection of the material and selection and production of prosthesis in the folks having different populations.

Materials and methods

Sixty-six adult (35 right and 31 left) dry femurs from Caucasian were used in this study. The study was carried out on the bones used for the educational purpose in department of anatomy. Therefore, institutional review

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board approval was not essential for this study. All femurs were totally complete and there were no defects. We ignored the gender because, many authors implied that there was no certain difference in femoral condyles' geometry between male and female [9, 10, 26, 38]. We used computer tomography (CT) imaging to obtain measurement values of the femur, because, the consensus regarding CT is more sensitive and reliable device for sizing the bony structures [5, 7, 20, 34]. All of the femurs were scanned by a 16-detector CT scanner (Philips Medical Systems MX 8000 IDT Multislice CT System-V 2.5). Scan parameters were 120 kV, 200 mAs, 750 ms rotation time with a slice width of 2 mm and increments of 1 mm, using a detector collimation of 16×1.5 mm (pitch 0.6). All measurements of the femur were evaluated on post-processed images (Fig. 1) obtained from multi-planar reformation (MPR), maximum intensity projection (MIP) and volume rendering (VR) techniques based on the axial scan. All measurements, performed by two radiologists, were used to calculate the average values for analysis. The CT imaging analysis of the femur included measurements on a workstation of measurement points and their localizations as mentioned in Table 1. Upper, intermediate and lower medial–lateral intercondylar distances have been measured from sections crossing middle portion of anteroposterior intercondylar distance on coronal MPR images. Lower intercondyler distance extends between end points of articular surface intersecting intercondyler notch at most distal part, as upper intercondyler distance extends between points of notch walls where wall begins to curve. Middle intercondyler distance was accepted as transverse extends between mid points of upper and lower intercondyler distance (Fig. 1h). Measurement of three values has been averaged to obtain only the single measurement value.

Statistical analysis was performed by SPSS for Windows V.15.0. The data were summarized as the mean and standard deviation. Distributions were evaluated by using one sample Kolmogorov–Smirnov test. The data analysis was performed by using the *t* test, Pearson's correlation coefficient. Values for $p < 0.05$ were regarded as statistically significant. A *p* value of less than 0.05 was considered to be statistically significant.

Results

Mean, minimum, maximum and standard deviation values for all femur measurements are shown in Table 2. On account of these measurements, we ignored the sides. Mean femur height was 413.29 ± 28.40 mm and mean width of the three different points of the femur was 29.86 ± 2.72 mm. Correlation of these two values was significant ($r = 0.721$; $p < 0.01$). Moreover, the

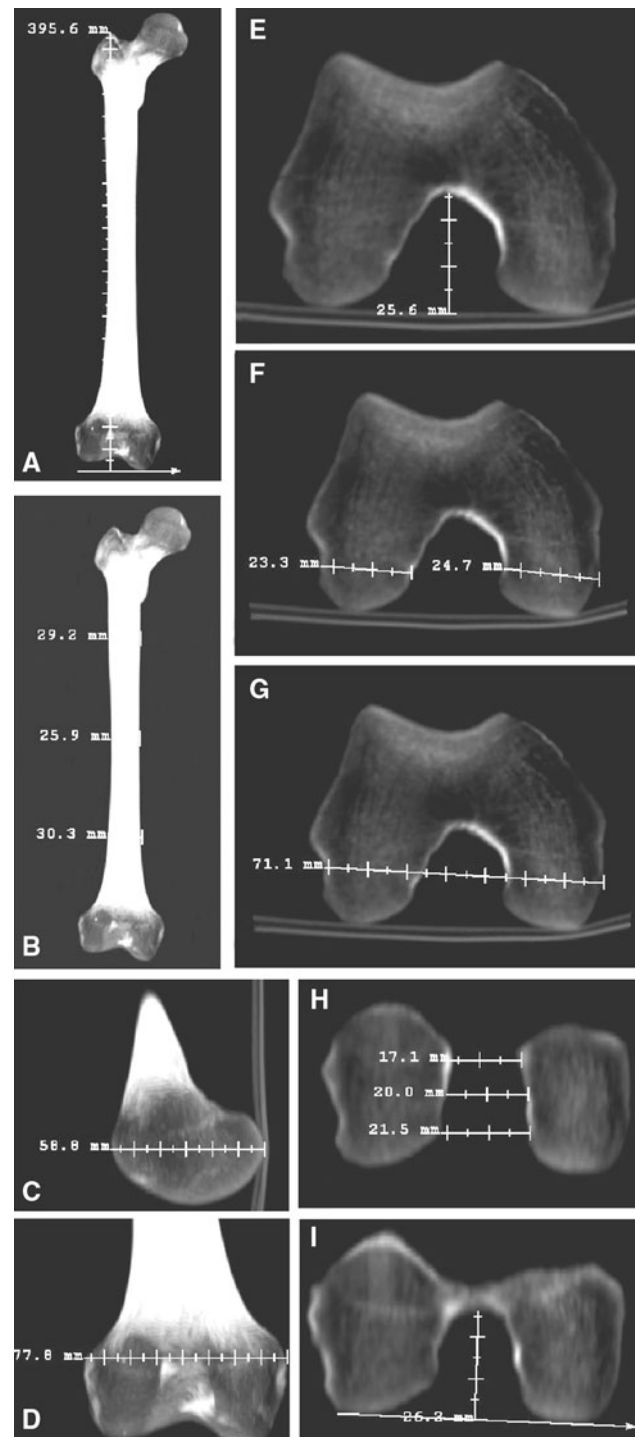


Fig. 1 The points have been measured on the CT images of femur dry bone. Explanations on each square and measurement areas have been given in Table 1

correlations between the femur height and width, and all measured parameters have been inspected individually. The parameters exhibiting powerful correlation with these values have been showed in Figs. 2 and 3.

Table 1 The CT imaging analysis of the femur including measurements on a workstation of measurement points and their localizations

Measurement points	Explanation
Height of the femur	In coronal MIP image, the distance between uppermost point of trochanter major and lowermost point of medial condyle (Fig. 1a)
Width of the femur	It was performed in three different locations of femur. One of these is mid point of the femur height; the other is mid point of proximal and distal half of the femur (Fig. 1b)
The mean value of the intercondylar notch width	Measurements of medial–lateral intercondylar distance were obtained in three different point as upper, median and lower on the coronal MPR images (Fig. 1h)
Anterior–posterior measurement of the intercondylar notch	Was obtained from the axial section in which localization displayed the longest distance measurement (Fig. 1e)
Upper–lower measurement of the intercondylar notch	Was obtained from the axial section in which localization displayed the longest distance measurement (Fig. 1i)
Medial–lateral condyles	Measurements of medial and lateral diameters of both condyles were obtained from axial section (Fig. 1f) Measurements of anterior–posterior diameters were obtained from the widest points on sagittal MIP image (Fig. 1c)
Epicondylar distance	It was measured as distance between the most medial and lateral prominences of epicondyles (coronal MIP) (Fig. 1d)
Bicondylar distance	It was measured as the width in the resected surface of the femur in the medial–lateral axis (axial view) (Fig. 1g)

Table 2 Average values of the femur morphology measurement (mm)

Measured points	Mean + SD (mm)	Min–Max (mm)
Femur		
Height	413.29 ± 28.40	348–489
Width	29.86 ± 2.72	23.43–34.93
Intercondylar diameters		
Medial–lateral (mean width)	20.85 ± 2.76	14–26.63
Anterior–posterior (height)	26 ± 2.34	20.30–31.70
Upper–lower (depth)	27 ± 2.9	21.5–35.20
Medial femoral condyle		
Anterior–posterior	57 ± 4.71	43–66
Upper–lower	33.68 ± 2.81	26.60–41.40
Medial–lateral	24.61 ± 2.58	18.10–30.50
Lateral femoral condyle		
Anterior–posterior	60.94 ± 4.5	47.60–69.30
Upper–lower	29.26 ± 3.56	23.10–37.70
Medial–lateral	23.61 ± 2.18	16.20–29.10
Epicondylar distance		
Medial–lateral	78.43 ± 5.76	64.50–89.70
Bicondylar distance		
Medial–lateral	71.13 ± 5.24	57.50–81.70

SD standard deviation

Average value of bicondylar distance was closely similar to submit of the intercondylar, medial and lateral femoral condyle diameters (Table 2). Intercondylar medial–lateral dimensions were different in each point (upper, middle and lower). Values of these points were 19.50 ± 3.06 mm for upper portion, 21.90 ± 2.75 mm for

middle portion and 21.15 ± 3.24 mm for lower portion. There is a significant correlation between for these three points ($p < 0.01$). Width of the femur was measured in three different points and the values of these measurements were 29.90 ± 2.93 , 28.03 ± 2.58 and 31.66 ± 3.31 mm for upper, middle and lower points, respectively. There is also a significant correlation among these three points ($p < 0.01$). Most of the femur distal parameters were significantly correlated (Table 3; Figs. 2, 3) but interestingly, we could not see any correlation of the intercondylar depth (27 ± 2.9 mm) with femur height ($r = -0.033$; $p = 0.793$) and width ($r = 0.015$; $p = 0.902$).

Discussion

Preoperatively understanding the morphology of the distal femoral condyle is important [22]. Orthopedic surgeons obtain conventional radiographs of standing knees or legs before total knee arthroplasty for preoperative planning. But in some cases there are limitations in the correct sizing of the femoral component and selecting the proper implants using only anteroposterior and lateral conventional radiographs [16]. If sizing of the femoral component on imaging is nearly consistent with real femoral sizing before total knee arthroplasty, general preoperative planning would be possible, and these results could allow the surgeon to determine the properly sized prosthesis and the prosthesis manufacturers to provide appropriately sized implants preoperatively [22].

Significant differences with different radiologic measurement between bone parameters were found in the

Table 3 Correlation analysis between several measurements points of the distal femur morphometry

Parameters	Intercondylar diameters		Medial femoral condyle			Lateral femoral condyle			Epicondylar distance Medial–lateral
	Anterior–posterior	Upper–lower	Anterior–posterior	Upper–lower	Medial–lateral	Anterior–posterior	Upper–lower	Medial–lateral	
Intercondylar diameters									
Upper–lower									
<i>r</i>	–0.01								
<i>p</i>	0.907								
Medial femoral condyle									
Anterior–posterior									
<i>r</i>	0.69	–0.11							
<i>p</i>	0.000	0.375							
Upper–lower									
<i>r</i>	0.39	–0.13	0.54						
<i>p</i>	0.001	0.282	0.000						
Medial–lateral									
<i>r</i>	0.53	0.05	0.63	0.44					
<i>p</i>	0.000	0.685	0.000	0.000					
Lateral femoral condyle									
Anterior–posterior									
<i>r</i>	0.75	–0.07	0.89	0.53	0.66				
<i>p</i>	0.000	0.588	0.000	0.000	0.000				
Upper–lower									
<i>r</i>	0.13	–0.14	0.35	0.81	0.30	0.31			
<i>p</i>	0.297	0.268	0.004	0.000	0.014	0.011			
Medial–lateral									
<i>r</i>	0.55	0.11	0.54	0.54	0.76	0.57	0.39		
<i>p</i>	0.000	0.373	0.000	0.000	0.000	0.000	0.001		
Epicondylar distance									
Medial–lateral									
<i>r</i>	0.72	0.00	0.83	0.48	0.66	0.83	0.23	0.63	
<i>p</i>	0.000	0.975	0.000	0.000	0.000	0.000	0.064	0.000	
Bicondylar distance									
Medial–lateral									
<i>r</i>	0.64	0.04	0.73	0.52	0.73	0.75	0.28	0.74	0.93
<i>p</i>	0.000	0.756	0.000	0.000	0.000	0.000	0.024	0.000	0.000

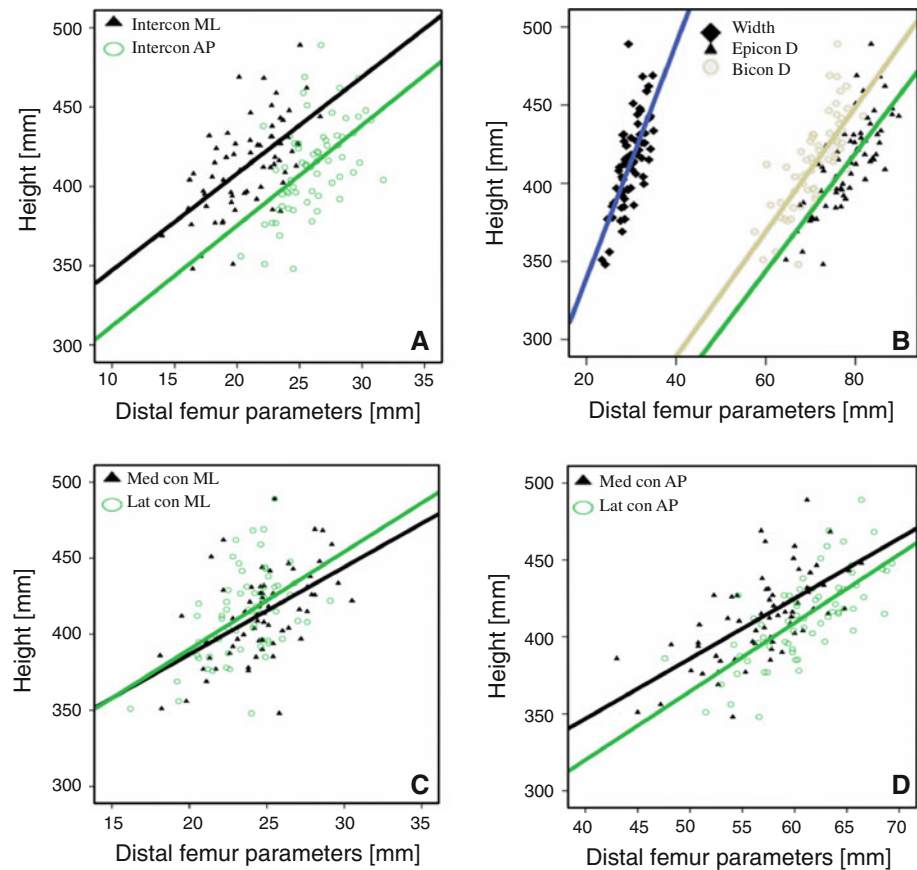
literature [11, 34]. Herzog et al. [11] compared direct cadaveric femur notch measurements with radiographic and MRI measurements. They found significant differences between direct and radiographic measurements. Preoperative analysis of CT scans and anticipating the ideal femoral component size more precisely may help to solve the problems inherent in patients that require in-between sized implants [34]. We think that since CT was chosen for the measurements in this study, our results and their estimated correlations are reliable.

Some authors reported Asian people's knee morphometry is smaller than western society knee morphometry in size [12, 18]. However, Tillman et al. [32] did not find

differences between European and African society parameters. Similar studies compared races and gender. Also many studies have shown that there is no certain difference in femoral condyle geometry between male and female [9, 10, 26, 38]. In addition to this, there are studies about femur height and weight with distal femur morphometry that show no difference between males and females [19, 31]. Contrarily to these studies Ziylan and Murshid [39] stated that the geometry of the intercondylar notch may differ between males and females.

Femur height is stated as one-fourth of the body height [8]. Therefore, measurements based on femur height or individual's height are supposed to be similar. Femur

Fig. 2 Correlation between femur height and distal parameters is given.
a Correlation curve between femur height to distance of medial–lateral (Intercon ML) and antero-posterior (Intercon AP) of intercondylar notch;
b correlation curve between femur height and femur width to epicondylar (Epicon D) and bicondylar (Bicon D) diameters.;
c correlation curve between femur height to medial (Med con ML)–lateral (Med con ML) distances of both condyles;
d correlation curve between femur height to antero (Med con AP)- posterior (Lat con AP) distances of both condyles



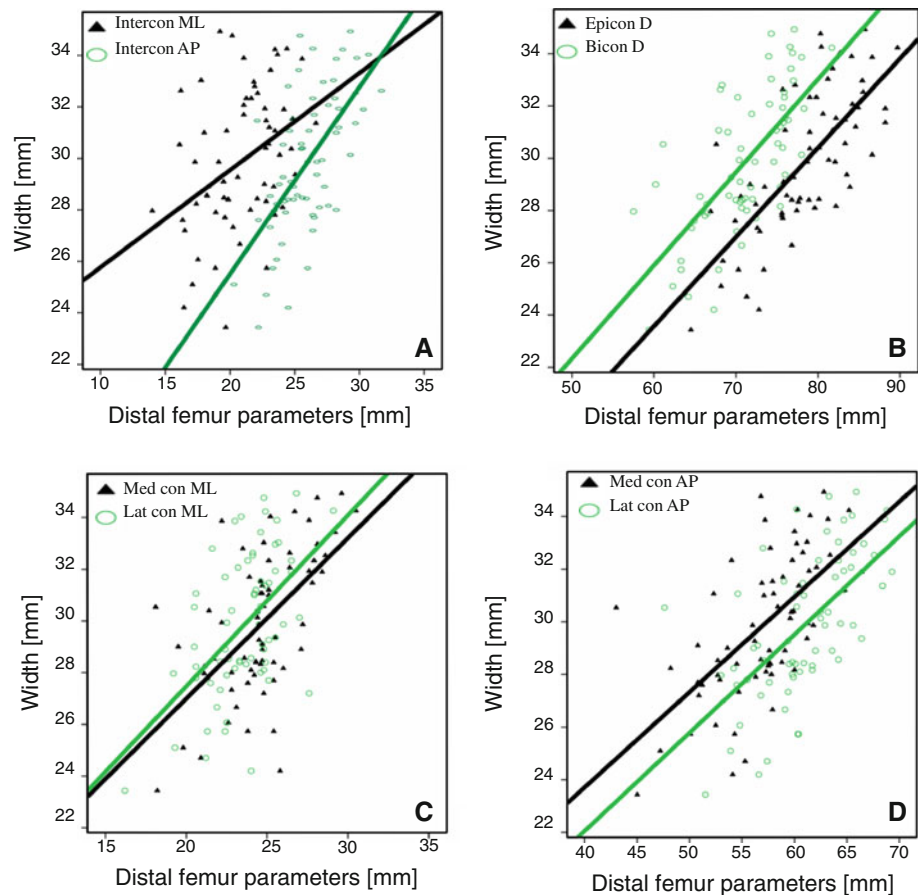
height or individual's height correlation with bony parameters is shown by several studies [5, 30]. Cheng et al. [5] reported femur distal morphometry of different populations on a table. In addition to these studies we present separately the correlation both between femur height and distal femur morphometry, and femur width and distal femur morphometry. Besides, we found the remarkably good correlation between these two parameters ($r = 0.721$; $p < 0.01$). (Fig. 2b). Consequently, every value correlates with the femur height and width (Figs. 2, 3).

Seedhom et al. [27], in a radiographic cadaveric study that evaluated sizing for knee prostheses, supported the idea that the required femoral component size should be based on the mediolateral dimension of the femoral condyle. Proper measurement of the transepicondylar distance and determination of the transepicondylar axis would be fundamental in total knee arthroplasty [20]. Cheng et al. [5] found correlation of tibia mediolateral distance and femur lateral condyle anteroposterior, mediolateral distance; Kwak et al. [18] found the correlation of tibial condyle mediolateral distance with individual's height. In our study, the related femur height and both distances of mediolateral femur, bicondylar, epicondylar and each distance of mediolateral condyle were measured separately. Bicondylar distance was calculated as 71.13 ± 5.24 mm. These measurements were in the interval

that Cheng et al. [5] emphasized during femur distal, medial and lateral measurements in different populations (66.8 ± 3.1 – 85.6 ± 5.1 mm). Gender differences were considered to be originated from the average height differences among genders [5]. Zylan and Murshed [39] noticed epicondylar distance of left and right to be 77.3 and 76.8 mm, respectively. In our study there is no significant difference between the left and right epicondylar distances and it was calculated as 78.43 ± 5.76 mm. In Tillman et al. [32], the bicondylar and epicondylar widths were not statistically analyzed as independent variables and were considered to be the factors for calculating the notch width index (NWI). Contrary to this opinion, in our study there was a significant correlation between the bicondylar and epicondylar widths ($r = 0.928$; $p < 0.01$). At the same time, these two values strongly correlate with femur height and width (Figs. 2b, 3b).

In normal knees, full flexion is accompanied by impingement between the posterior femur and the posterior horn of the medial meniscus [25]. Increased flexion in the knee joint may require a longer posterior condyle to avoid impingement of the tibia on the posterior femur [33]. Uslu et al. [34] measured femoral condyle anteroposterior diameter, using dry bone, with plain roentgenogram and CT. Different authors have investigated the anteroposterior

Fig. 3 Correlation between femur width to distal parameters has been given. **a** Correlation curve between femur width to medial–lateral (Intercon ML) and antero–posterior (Intercon AP) distances of intercondylar notch; **b** correlation curve between femur width to epicondylar (Epicon D) and bicondylar (Bicon D) diameters.; **c** correlation curve between femur width to medial (Med con ML)–lateral (Lat con ML) distances of both condyles; **d** correlation curve between femur width to antero (Med con AP)–posterior (Lat con AP) distances of both condyles



diameter of femoral condyle [20, 33, 34]. In our study, in addition to the measurement of both the anteroposterior diameter of femur condyle, femur height and width also, the correlations between these values were investigated. (Figs. 2d, 3d). Uslu et al. [34] measured the femur anteroposterior diameter of medial or lateral condyles as 55.10 mm on real bone, 51.98 mm on direct roentgenography and 55.73 mm on CT. Cheng et al. [5] measured the anterior–posterior distances of the medial and lateral condyles as average 51.3 ± 3.3 and 50.7 ± 4.0 mm in males and females, respectively. And Chow [6] measured the anteroposterior distance of the lateral condyle as 64.2 ± 3.4 mm. These studies indicate that the anteroposterior distance of femur condyle is between 51.3 ± 3.3 and 64.2 ± 3.4 mm. In our study, we came up with the similar results (Table 2). We thought that the differences are due to the differences in the femur height. As a result, the femur height or person's height must be stated with these measurements.

The geometry of the intercondylar notch is one of the factors suspected to predispose individuals to ACL injury [39]. An understanding of the anatomic relationships of the intercondylar notch of the knee throughout its course, therefore, has direct clinical value [19]. Notch width is the most often reported as the NWI [32]. The NWI is

calculated as the ratio of intercondylar notch width to the width of the femoral condyles [19, 23]. Hutchinson and Ireland [13] suggested that the intercondylar notch shapes might be classified as inverted U- or A-shaped, and Anderson et al. [1] also observed that notches of normal width are generally inverted U-shaped and narrow notches tend to be more wave- or A-shaped. The intercondylar notch shape index (NSI) was determined by dividing the width of the intercondylar notch by the height of the notch [32]. Tillman et al. [32] and Murshed et al. [24] stated that there were no significant gender differences in NSI of femur. Also Anderson et al. [2] have also reported that there was no sex difference in the shape of the notch. Additionally, Tillman et al. [32] found that the notch width and area indices for individuals of African descent were greater than the same indices in individuals of European descent, while NSI did not vary among races. These studies have indicated that there are no gender differences about notch shape and geometry. Herzog et al. [11], who took the measurement from the level of the popliteal recess to the anterior outlet of the notch, found notch heights of 22.8 and 20.5 mm, in males and females subjects, respectively. Koukoubis et al. [17] reported 24 mm, but this distance was measured from the bottom of the posterior condyle to the top of the notch. We measured notch height from axial

section as did by Koukoubis et al. [17] and it was found to be 26 ± 2.34 mm.

In measurements with normal cadavers, the total width of the femur is the distance between the most lateral and medial points of the respective condyles [21, 35, 38]. This is not suitable for femoral implant design because this width is different compared to the total width after cutting the distal femur [12]. Murshed et al. [24] measured width of the intercondylar notch from the maximal transverse distance and it was found as 21.3 ± 2.4 mm for men and 19.1 ± 2.0 mm for women. Ho et al. [12] measured the total width of the femur notch after completing to cut the distal femur. On the other hand, we think that one measured point could not give correct dimension of the femur notch. Owing to this reason, we measured three different points of the femur notch and got mean value of these three points. These three points from the top of the condyles, center of the notch height and the bottom of the notch, and values of these three points of the femur notch width were 21.15 ± 3.2 , 21.9 ± 2.7 and 19.5 ± 3 mm, respectively, and mean value of the notch was 20.85 ± 2.7 mm. These findings are similar to the studies performed by Murshed et al. [24]. The discrepancy in notch measurements reported in the literature may be explained by several factors, including the analysis of different populations. Differences in measurement techniques may be another confounding variable. Points of measurement on the distal femur were not uniform, which made the comparison of the results difficult [24].

The implant component should be designed with several medial–lateral widths (as measured our study) for one anterior–posterior height to obtain a better anatomical fit. Yet, most implant systems provide only one medial–lateral width for one anterior–posterior height of the femur notch [12].

Conclusion

A surgeon can develop an opinion about distal femur which has importance in knee arthroplasty by looking radiologically femur height and width. In this study the high correlation between distal femur morphometry and femur height and width is presented. There are some literatures supporting the difference between intercondylar areas of men and women [28] and some do not support [19, 31]. The difference of distal femur morphometry according to race and sex depends on the other morphometric measurements of femur. As a result, the femur height should be the basic parameter instead of sex or race distinction. Distal femur morphometric measurements presented in this study and the relation between height and width showed that the general average height of the society should be considered while manufacturing and choosing prosthesis.

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Conflict of interest The authors declare that they have no conflict of interest.

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