Morphometric analysis of distal femur through MRI in Turkish population and review of the literature

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SUMMARY

Measurements of the distal femur are highly variable among different subjects. To obtain the best stability and longevity of the knee implants, anthropometric data of the distal femur is required. The aim of this study was to investigate the anatomical structure of the distal femur according to age and gender and to determine the changes in the groups, of the patients with meniscopathy and controls. A total of 488 patients were included in the study according to age groups (0-15, 16-30, 31-45, 46-60, 61 and above). Intercondylar width, intercondylar anteroposterior distance, medial condylar width, lateral condylar width, bicondylar width, medial condyle anteroposterior distance, and lateral condyle anteroposterior distance were measured on axial Magnetic Resonance Imaging (MRI).

Intercondylar width, medial condylar width, lateral condylar width and bicondylar width were significantly higher in men in all age groups compared to women ($p < 0.05$). Intercondylar anteroposterior distance, medial condyle anteroposterior distance and lateral condyle anteroposterior distance were statistically significantly higher in males than in females except 0-15 age group ($p < 0.05$). There was no significant difference in medial and lateral anteroposterior distance values in men ($p > 0.05$), and found to be statistically significant ($p < 0.05$) on the right and left side in women. Although personalized implant production is expensive compared to today's conditions, we think that age and gender changes should be considered in the selection of prosthesis, since the dimensions of the distal femur will affect the stability and duration of use of knee implants.

Key words: Anatomy – Femur – Magnetic resonance imaging – Morphometry – Total knee arthroplasty

INTRODUCTION

Total knee arthroplasty is an effective surgical intervention that can relieve the pain of patients who suffered from end-stage arthritis and restore their joint functions (Singh and Sloan, 2008; Dusad et al., 2015). The distal part of the femur has two condyles, lateral and medial, separated by an

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intercondylar notch (Adhikari et al., 2017; Eboh and Igbinedion, 2020). Measurements of the distal part of the femur are very valuable for total knee arthroplasty (Berger et al., 1993; Arima et al., 1995). Anthropometric data must be accurate and reliable to obtain the best stability and longevity for the implant (Westrich et al., 1995).

Menisci are fibrocartilaginous discs located between the femur and the medial and lateral articular surfaces of the tibia in the knee. The most important tasks of these are weight transfer, dynamic shock absorption during movement, and protection of joint cartilage (Walker and Erkman, 1975). Meniscal injuries occur as a result of rotation of the tibia on the os femoris or the rotation of the os femoris on the tibia, especially when the knee joint is partially flexed, while the knee joint carries body weight (Hai-Nan et al., 2014). Meniscal tears have been classified because the location, size, and type of meniscopathy are very important in terms of treatment planning (Jee et al., 2003).

In this study, it was aimed to examine the morphometric and morphological structure of the anatomical formations of the distal femur according to age and gender in individuals with meniscopathy and in the control group, and to determine the changes in the groups. This study also aimed to determine a guideline for the femoral component of total knee prostheses for theTurkish population.

MATERIALS AND METHODS

What have been studied are 488 knee Magnetic Resonance Imaging (MRI) belonging to 488 patients. In the Picture Archiving and Communication Systems (PACS) archive of the Selcuk University Faculty of Medicine Radiology Department were included in the study. The data of the cases were obtained by retrospectively scanning the (MR) images between January 15, 2013, and January 15, 2018.

The study was carried out on a 1.5 T Toshiba brand device serving in the Department of Radiology. Measurements were made on the axial images of the fat-suppressed proton density sequence. Imaging parameters TR: 2125, TE: 45. Section thickness was 3.7 mm, the gap was 0.4-1 mm, the field of view was 14-18 cm, and the display matrix was 640 x 640.

The cases diagnosed with meniscopathy by the radiologists in the Radiology Department and the cases without any pathological findings (such as meniscopathy, chondromalacia, trauma, or tumor) in knee MRIs were evaluated as healthy and included in the study. There were 244 females (117 right knee, 127 left knee) and 244 males (119 right knee, 125 left knee) in our study. They were grouped according to 5 different age ranges (0-15, 16-30, 31-45, 46-60, 61 and over), between 7-92 years of age (Table 1). The grades of meniscopathy were determined by a radiologist with 15 years of experience according to MR images of these cases.

Table 1. Distribution of cases according to age groups and gender.

Age groups	Genders		Total
	Female	Male	
0-15	48	48	96
16-30	49	49	98
31-45	48	51	99
46-60	52	48	100
61+	47	48	95
Total	**244**	**244**	**488**

Measurements

In the study, distal femur parameters; intercondylar width (ICW), intercondylar anteroposterior distance (ICD), medial condylar width (MCW), lateral condylar width (LCW), bicondylar width (BW), medial condyle anteroposterior distance (MAP), and lateral condyle anteroposterior distance (LAP) were measured on axial MRI. In all cases, measurements were made on axial plane MRI images passing through both epicondyles in the axial plane.

ICW: longest transverse width of the intercondylar notch; it is the length between the medial point of the lateral condyle and the medial point of the medial condyle. ICD: vertical line drawn from the upper part of the intercondylar notch to the lowest level of the imaged condyles (Murshed et al., 2005; Terzidis et al., 2012; Yazar et al., 2012) (Fig. 1). MCW: the shortest mediolateral width of the medial condyle. LCW: the shortest mediolateral

Fig. 1.- Measured parameters. **A:** The intercondylar notch width of the femur (ICW). **B:** The intercondylar notch anteroposterior distance of the femur (ICD). **C:** The medial condylar width of the femur (MCW). **D:** The lateral condylar width of the femur (LCW). **E:** Medial condyle anteroposterior distance of the femur (MAP). **F:** Lateral condyle anteroposterior distance of the femur (LAP). **G:** The bicondylar width of the femur (BW) (M: Medial L: Lateral).

width of the lateral condyle (Murshed et al., 2005; Yazar et al., 2012; Kim et al., 2013; Pinskerova et al., 2014) (Fig. 1). BW: longest mediolateral dimension. The longest horizontal line connecting the lateral and medial condyles (Murshed et al., 2005; Terzidis et al., 2012; Pinskerova et al., 2014) (Fig. 1). MAP: the longest distance between the anterior and posterior point of the medial condyle. LAP: the longest distance between the anterior and posterior point of the lateral condyle (Mensch and Amstutz, 1975; Terzidis et al., 2012; Kim et al., 2013; Fan et al., 2017) (Fig. 1).

In the evaluation of the degree of meniscopathy, Kaya (2008) reported the classification based on MRI as follows. Grade 0: Homogeneous intensity. Grade 1: Point-like intensity. Grade 2: Internal intensity that does not extend to the surface. Grade 3: Intrameniscal intensity extending to the joint surface (Fig. 2).

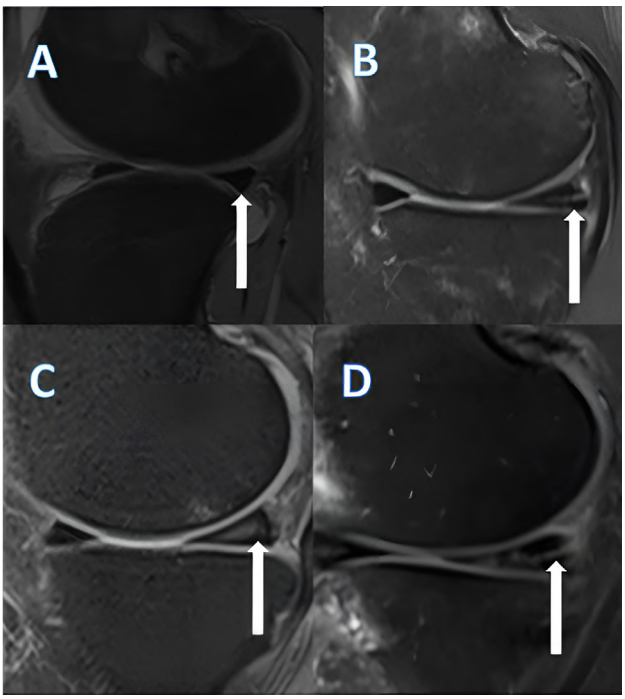

Fig. 2.- Evaluation of the degree of meniscopathy. **A:** Homogeneous intensity grade 0 (normal meniscus) in the posterior horn of the lateral meniscus on MRI of the left knee. **B:** Grade 1 degeneration of the medial meniscus posterior horn on MRI of the right knee. **C:** Grade 2 degeneration of medial meniscus and lateralis on MRI of the left knee. **D:** Grade 3 horizontal tear of posterior horn of a degenerated lateral meniscus on MRI of the right knee.

Statistical analysis

All measurements were evaluated according to age groups, gender, right-left knee difference, and degree of meniscopathy.

Shapiro Wilks Test was used to test the conformity of the distribution of the data of all variables related to the normality assumption, one of the parametric test assumptions, to the normal distribution. T-test for independent samples (Independent Samples T-Test) from parametric tests to test whether the variables that fit the normal distribution differ according to the groups in the comparisons of two groups, and the Mann-Whitney U test to test whether the variables that do not fit the normal distribution differ according to the groups used. In more than two group comparisons ANOVA, one of the parametric tests, was used to test whether it was different according to the groups, and the Kruskal-Wallis test, one of the non-parametric tests, was used to test whether the variables not suitable for normal distribution were different according to the groups. Chi-square test

Table 2. Differences (mean±standard deviation) (mm) values of the parameters in each age group as per gender.

Age		ICW		ICD		MCW		LCW		BW		MAP		LAP	
		mean+SD	p	mean+SD	p	mean+SD	p	mean+SD	p	mean+SD	p	mean+SD	p	mean+SD	p
0-15	Female (48)	18.35±2.25	0.002*	26.66±5.04	0.487*	21.53±3.28	0.001*	46.57±8.16	0.000*	62.34±8.28	0.000*	22.99±3.50	0.281	46.68±8.35	0.07
	Male (48)	20.05±2.87		27.38±5.04		23.97±3.53		48.98±8.22		69.38±8.75		25.79±3.89		50.17±8.09	
16-30	Female (49)	0.02±2.50	0.000*	28.47±3.15	0.000*	23.33±2.14	0.000*	53.48±3.41	0.000*	67.86±4.14	0.000*	24.40±2.19	0.000*	54.48±4.04	0.000*
	Male (49)	22.28±2.35		32.52±3.57		27.26±2.12		60.76±4.37		78.70±4.29		28.68±2.78		61.83±4.30	
31-45	Female (48)	20.54±2.33	0.000*	28.50±3.20	0.000*	24.82±2.45	0.000*	55.25±3.85	0.000*	70.44±4.44	0.000*	25.52±2.53	0.000*	55.99±4.05	0.000*
	Male (51)	22.35±2.61		30.97±3.14		27.32±2.66		59.92±4.83		77.05±5.37		28.14±3.15		59.88±5.08	
46-60	Female (52)	19.86±2.38	0.000*	28.30±2.52	0.000*	24.90±1.87	0.000*	55.34±3.47	0.000*	69.17±3.63	0.000*	25.11±2.30	0.000*	55.58±4.37	0.000*
	Male (48)	22.55±2.58		31.58±3.65		27.53±1.94		59.97±4.85		77.40±4.17		28.12±2.73		59.82±5.36	
61+	Female (47)	20.26±2.16	0.000*	27.88±2.43	0.000*	24.63±1.36	0.000*	54.38±3.99	0.000*	68.72±3.68	0.000*	25.27±1.67	0.000*	55.18±3.73	0.000*
	Male (48)	22.57±2.77		30.89±3.27		26.91±2.28		59.06±4.21		75.94±5.04		27.61±2.99		59.23±4.51	

*p<0.05 (ICW; intercondylar width. ICD; intercondylar anteroposterior distance. MCW; medial condylar width. LCW; lateral condylar width. BW; bicondylar width. MAP; medial condyle anteroposterior distance. LAP; lateral condyle anteroposterior distance)

Table 3. The relationship of the parameters (mean±standart deviation) (mm) values in male and female. according to the right and left side.

Parameter	Female		Male		p	
	Right (117)	Left (127)	Right (119)	Left (125)	Female	Male
ICW	20.01±2.43	19.62±2.43	22.11±2.95	21.82±2.63	0.168	0.345
ICD	28.02±3.54	27.93±3.34	30.26±4.31	31.08±3.95	0.535	0.077
MCW	23.85±2.92	23.86±2.34	26.76±2.87	26.47±2.87	0.945	0.325
LCW	24.44±2.57	24.87±2.71	28.00±3.02	27.37±3.46	0.254	0.129
BW	67.33±6.36	68.09±5.22	76.59±6.42	74.90±6.66	0.375	0.065
MAP	53.73±6.20	52.41±5.48	58.32±7.01	57.26±6.97	0.002	0.202
LAP	54.21±6.56	53.06±5.85	58.56±6.60	57.90±7.21	0.014	0.599

*$p < 0.05$ (ICW; intercondylar width. ICD; intercondylar anteroposterior distance. MCW; medial condylar width. LCW; lateral condylar width. BW; bicondylar width. MAP; medial condyle anteroposterior distance. LAP; lateral condyle anteroposterior distance).

was used in the analysis of categorical data. All analyses were evaluated at the 5% significance level (95% confidence level).

RESULTS

In our study on axial MRI; the mean values of ICW, BW, MCW, and LCW were statistically significantly higher in males than females in each age group ($p < 0.05$). Mean values of ICD, MAP, and LAP were statistically significantly higher in males than females in all age groups except the 0-15 age group ($p < 0.05$) (Table 2).

Considering the mean values of ICW, ICD, MCW, LCW, and BW in our study, it was not found statistically significant between the right and left knees in men and women. However, while there was no significant difference between the right and left in the mean values of MAP and LAP in men ($p > 0.05$), it was found that it was statistically significantly higher ($p < 0.05$) on the right than on the left in women (Table 3).

DISCUSSION

Most anatomical morphometric studies have been performed with different methods such as radiography, computed tomography, magnetic resonance imaging, cadavers, and 3D modeling (Mensch and Amstutz, 1975; Murshed et al., 2005; Cheng et al., 2009; Yue et al., 2011; Yazar et al., 2012; Terzidis et al., 2012). In the literature, there are significant differences between bone parameters with different radiological measurements (Herzog et al., 1994; Uslu et al., 2005). Herzog et al., (1994) compared direct cadaveric intercondylar notch measurements with radiographic and MRI measurements, and found no difference in caliper measurement of cadaver bones (20.3 mm) and MRI (20.8 mm) measurements, but with caliper measurement of cadaver bones and radiographic measurements. 22 mm were found to be significant differences. With this study, Herzog et al. (1994) confirmed the accuracy of magnetic resonance measurements and their superiority over flat film measurements.

Many studies emphasize the differences between genders and ethnic groups (Urabe et al., 2008; Cheng et al., 2009; Chin et al., 2011; Yue et al., 2011; Yazar et al., 2012). The distal part of the femur, especially the two condyles, is morphologically different in males from females (Murshed et al., 2005; Guy et al., 2012; Terzidis et al., 2012; Kim et al., 2013; Fan et al., 2017). However, some studies have shown that there is no significant difference in the morphology of the distal femoral condyle between men and women (Poilvache et al., 1996; Griffin et al., 2000). Many studies have found that the same type of prosthesis is not suitable for different populations (Ho et al., 2006; Kwak et al., 2007). While studies are reporting that the knee morphometry of Asian people is smaller than that of Western people (Kwak et al., 2007), there are also researchers reporting that they could not find any difference between European and Afri-

Table 4. Comparison of parameters (mean±standard deviation) (mm) values.

Researchers	Research plane	Method	Group	ICW		ICD		MCW		LCW	
				Female	Male	Female	Male	Female	Male	Female	Male
Mensch and Amstutz (1975)	North America	X-Ray	Male (44) Female (39)	18.9±1.5	22.6±6.0			24.5±1.2	29.9±2.2	26.5±1.8	31.4±2.3
Mensch and Amstutz (1975)	North America	Dry bone	Male (44) Female (39)	18.7±2.5	20.8±3.6			24.5±1.5	29.9±2.6	26.6±1.5	31.4±2.6
Charlton et al.. (2002)	Pennsylvania	MRI	Male (28) Female (20)	17.4	17.7						
Murshed et al.. (2005)	Turkey	MRI	Male (100) Female (100)	19.1±2.0	21.3±2.4	29.0±2.6	33.2±2.8	23.7±2.2	27.0±2.1	23.2±2.3	26.6±2.8
Yue et al.. (2011)	China	CT	Male (20) Female (20)	18.6±1.4	21.8±0.8			22.0±1.3	24.9±1.4	24.2±1.7	27.5±2.5
Terzidis et al.. (2012)	Caucasia	Dry bone	Male (192) Female (168)	18.7±0.1	22.0±0.18	23.07±0.12	27.8±0.16				
Yazar et al.. (2012)	Turkey	CT	66	20.85±2.76		27±2.9		24.61±2.58		23.61±2.18	
Kim et al.. (2013)	Korea	CT	Male (88) Female (114)	18.97±2.75	21.66±2.66	27.16±1.85		23.46±2.39	25.78±1.85	24.05±2.00	27.96±1.91
Pinskerova et al.. (2014)	Czech Republic	MRI	Male (100) Female (100)					26.95±3.37	23.28±1.75	26.8±3.26	23.78±1.60
Our study (2018)	Konya	MRI	Male (196) Female (196)	20.16±2.35	22.43±2.56	28.29±2.83		24.42±2.08	27.26±2.26	25.07±2.22	28.14±2.92

(CT: Computerized Tomography. MRI: Magnetic Resonances Imaging.) (ICW; intercondylar width. ICD: intercondylar anteroposterior distance. MCW; medial condylar width. LCW; lateral condylar width)

can population parameters (Tillman et al., 2002). Artificial knee joint prosthesis systems, which are widely used in China, are designed according to the anatomical characteristics of European and American populations. When these joint replacement systems designed for Western patients are used in Asian patients, prosthesis mismatch often occurs due to ethnic differences (Yip et al., 2004; Cheng et al., 2009). In some studies, the Chinese population has been found to have lower and flatter anterior condyles and wider posterior condyles than westerners (Yip et al., 2004; Sun et al., 2007). In a study comparing the morphology of the distal femur between Caucasian and Japanese women, morphological measurements of the distal femur reported that Caucasian women had significantly longer anteroposterior width of the condyles (Urabe et al., 2008). In a study investigating the anthropometric differences between Koreans and Westerners, it was reported that Koreans were shorter, less overweight, had a smaller skeletal structure, and had a higher incidence of constitutional varus alignment of the lower extremity. This study also reported that Koreans have lifestyles that require high flexion positions of the knee such as squatting, kneeling and sitting cross-legged, and that the incidence of postoperative deep vein thrombosis and pulmonary thromboembolism is lower in Koreans than in Westerners (Kim et al., 2015). In a study investigating the causes of failure after total knee arthroplasty in Korea in the last 5 years, it was reported that the most common cumulative cause was infection, followed by loosening, wear, instability and stiffness (Koh et al., 2014). Considering the anatomical differences between races in the development of implants to be used in the Turkish population, we think that the data of our study, in which we examined the distal femur measurements in 488 cases in different age groups, should be made according to each race.

In the existing literature, studies examining intercondylar notch dimensions (ICW, ICD), condyle widths (MCW, LCW), condyle anteroposterior distance (MAP, LAP) and bicondylar width measurements were conducted in different races, in men and women, and only in adults, and differences according to age groups were not evaluated. In our study, the statistically significant differences we obtained in 5 different age groups determined that the measurements showed serious differences between different age groups in men and in women.

Studies examining the dimensions of the intercondylar notch (ICW and ICD) in different races and with different methods are available in the literature (Table 4). The differences between the dimensions of the intercondylar notch in these studies may be related to the method used, the number of samples and racial differences. In the studies of Murshed et al. (2005), Kim et al. (2013), Terzidis et al. (2012) and Yue et al. (2011) in the ICW, there was a significant difference in males (over 16 years) compared to females, in line with our data on the adult group (over 16 years of age) was found to be statistically larger ($p < 0.05$). In the ICH, Murshed et al. (2005), Kim et al. (2013), and Terzidis et al. (2012) were found to be statistically significant in males compared to females, consistent with our data on the adult group (over 16 years of age) was found to be larger ($p < 0.05$). Kim et al. (2013), in their study on Koreans, stated that they aimed to develop a Korean-specific equation with intercondylar notch dimensions and to show the usefulness of the equations for specific population groups.

The studies of Murshed et al. (2005), Kim et al. (2013), Yue et al. (2011) and Pinskerova et al. (2014) in MCW and LCW were consistent with the data of our adult group (over 16 years old) in our study. It was found to be larger in men than in women ($p < 0.05$), and the difference was statistically significant.

BW is the most frequently measured anatomical parameter of the distal femur. In the literature, there is great variability in the definition of measurement points of bicondylar width, measurement techniques, and races. In BW, the studies of Murshed et al. (2005), Cheng et al. (2009), Terzidis et al. (2012) and Pinskerova et al. (2014) showed statistically significant differences in males compared to females, in line with our data on the adult group (over 16 years of age). It was found to be significantly larger ($p < 0.05$) (Table 5).

In the literature, MAP and LAP has been defined as the maximum anteroposterior diameter of

Table 5. Comparison of parameters (mean±standard deviation) (mm) values.

Researchers	Research plane	Method	Group	BW		MAP		LAP	
				Female	Male	Female	Male	Female	Male
Mensch and Amstutz (1975)	North America	X-Ray	Male (44) Female (39)			61.1±2.2	68.2±4.1	62.6±2.3	70.3±4.3
Mensch and Amstutz (1975)	North America	Dry bone	Male (44) Female (39)			61.1±2.7	68.1±3.6	67.9±3.3	69.9±2.6
Murshed et al.. (2005)	Turkey	MRI	Male (100) Female (100)	74.4±4.3	83.1±7.7				
Kim et al.. (2013)	Korea	CT	Male (88) female (114)			55.25±3.02	61.22±3.06	58.39±2.76	64.63±3.65
Yue et al.. (2011)	China	CT	Male (20) Female (20)			55.3±2.7	62.2±3.9	58.8±2.5	65.0±2.8
Cheng et al.. (2009)	China	CT	Male (94) Female (78)	66.8±3.1	74.4±2.9	49.8±3.2	52.6±2.4	49.3±4.1	51.8±3.7
Terzidis et al.. (2012)	Caucasia	Dry bone	Male (192) Female (168)	78.5±0.3	88.6±0.42	55.9±0.29	61.1±0.34	55.4±0.21	61.1±0.33
Yazar et al.. (2012)	Turkey	CT	66	78.43±5.76		57±4.71		60.94±4.5	
Pinskerova et al.. (2014)	Czech Republic	MRI	Male (100) Female (100)	78.19±3.54	88.81±3.33	63.43±2.15	69.84±3.29	65.64±3.42	71.79±3.12
Fan et al.. (2017)	Southeast china	MRI	Male (114) Female (130)			59.6±3.6	64.9±3.5	58.3±3.9	64.0±3.8
Our study (2018)	Konya	MRI	Male (196) Female (196)	69.05±4.06	77.27±4.82	54.62±3.73	59.93±4.58	55.31±4.07	60.19±4.89

(CT: Computerized Tomography. MRI: Magnetic Resonances Imaging.). (BW; bicondylar width. MAP; medial condyle anteroposterior distance. LAP; lateral condyle anteroposterior distance)

each femoral condyle (Cheng et al., 2009, Yue et al., 2011; Terzidis et al., 2012, Yazar et al., 2012, Kim et al., 2013, Pinskerova et al., 2014, Fan et al., 2017). But there are serious differences between measurement techniques and methods in studies. In our study, as in other studies, the adult group (over 16 years of age) was found to be statistically larger in males than females ($p < 0.05$), which is consistent with our data.

Distal femur measurements were made in adults in all studies in the literature. For this reason, we could not find the opportunity to evaluate our data on the 0-15 age group in our study.

In studies on distal femur measurements in the literature, the differences between the left and right sides in women and men were examined, and it was found that there were no statistically significant differences between the right and left in these studies, consistent with our study (Souryal and Freeman, 1993; Anderson et al., 2001; Charlton et al., 2002; Murshed et al., 2005; Cheng et al., 2009; Terzidis et al., 2012; Yazar et al., 2012; Kim et al., 2013). However, in our study, distal femur measurements (MAP of on the right side (53.73±6.20 mm) in women on the left (52.41±5.48 mm) and LAP of on the right side in women (54, 21±6.56) were found to be statistically significantly ($p < 0.05$) higher than the left (53.06±5.85).

The most important limitation of our study is the inability to examine the height and weight, living conditions, occupation, and sports habits of the subjects, since it is a retrospective study. These criteria are very important criteria affecting the distal femur, and there is a need for prospective studies in which these criteria can be taken into account.

CONCLUSION

By this article, ICW, MCW, LCW and BW were statistically significantly greater in men than in women in all age groups ($p < 0.05$). ICD, MAP and LAP were statistically significantly greater in males than females in all age groups except the 0-15 age group ($p < 0.05$).

Our study will support other literature studies in terms of providing the morphological definition of the distal femur and contributing to the anatomical evaluation of the distal femur region before orthopedic operations such as knee implants. Although personalized implant production is expensive compared to today's conditions, we think that age and gender changes should be considered in the selection of prosthesis, since the dimensions of the distal femur will affect the stability and duration of use of knee implants.

Additionally, the data obtained from this study can be used as a guideline in designing femoral component of the total knee prosthesis in Turkish population.

ETHICS STATEMENT

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval (approval number 2018/347) was given by the Local Ethics Committee of the Medical Faculty. This single-center retrospective study was approved by the local institutional review board with a waiver of the requirement for written, informed consent. This study was conducted at Selcuk University Faculty of Medicine.

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