Original Communication

EVALUATION OF THE ANTERIOR CRUCIATE LIGAMENT RELATED DISTAL FEMUR AND PROXIMAL TIBIA ANATOMICAL STRUCTURES ON DRY ADULT BONES

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ABSTRACT

Objectives: This study aims to determine the differences between genders by measuring the anterior cruciate ligament (ACL) related bony structures on the femur and tibia, which belong to the same individuals. Materials and Methods: The study included 219 bones [108 femurs (74 male/34 female) / 111 tibias (72 male/39 female)]. On the distal femur, bicondylar width (BCW) and intercondylar notch width (NW) were measured, and the intercondylar notch width index (NWI) was calculated as NW/BCW. On the proximal tibia, tibial width (TW) and tibial eminence width (EW) were measured, and the tibial eminence width index (EWI) was calculated as EW/TW. Results: In this study, the BCW, NW, and NWI parameters were determined to be 65.90±3.23, 20.91±2.39, 0.31±0.03 in females, and 75.08±3.96, 23.45±2.80, 0.30±0.03 mm in males, respectively. The TW, EW, and EWI parameters were determined to be 66.05±5.83, 8.89±1.48, 0.13±0.02 in females and 75.74±4.29, 11.02±1.96, 0.14±0.02 mm in males, respectively. Conclusions: This study showed morphological differences between genders, which is anatomically unavoidable. Also, the femur and tibia structures are statistically significantly correlated, and it would be more accurate to look for answers to ACL injuries by studying both bones together.

Keywords: *Anterior cruciate ligament; the distal end of the femur; intercondylar notch; tibial eminence width; proximal end of tibia.*

RESUMEN

Objetivos: Este estudio tiene como objetivo determinar las diferencias entre los géneros mediante la medición de las estructuras óseas relacionadas con el ligamento cruzado anterior (LCA) en el fémur y la tibia, que pertenecen a los mismos individuos. Materiales y Métodos: El estudio incluyó 219 huesos [108 fémures (74 hombres/34 mujeres) / 111 tibias (72 hombres/39 mujeres)]. En el fémur distal, se midieron el ancho bicondíleo (BCW) y el ancho de la muesca intercondílea (NW), y el índice de ancho de la muesca intercondílea (NWI) se calculó como NW/BCW. En la tibia proximal, se midieron el ancho tibial (TW) y el ancho de la eminencia tibial (EW), y el índice de ancho de la eminencia tibial (EWI) se calculó como EW/TW. Resultados: En este estudio, se determinó que los parámetros BCW, NW y NWI eran 65,90±3,23, 20,91±2,39, 0,31±0,03 en mujeres y 75,08±3,96, 23,45±2,80, 0,30±0,03 mm en varones, respectivamente. Se determinó que los parámetros TW, EW y EWI eran 66,05±5,83, 8,89±1,48, 0,13±0,02 en mujeres y 75,74±4,29, 11,02±1,96, 0,14±0,02 mm en varones, respectivamente. Conclusiones: Este estudio mostró diferencias morfológicas entre los géneros, lo cual es anatómicamente inevitable. Además, las estructuras del fémur y la tibia están significativamente correlacionadas desde el punto de vista estadístico, y sería más preciso buscar respuestas a las lesiones del LCA estudiando los dos huesos juntos.

Palabras clave: *Ligamento cruzado anterior; el extremo distal del fémur; muesca intercondílea; anchura de la eminencia tibial; extremo proximal de la tibia*

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INTRODUCTION

The femur is the longest and strongest bone in the human body. The distal end of the femur is widely expanded as a bearing surface to transfer weight to the tibia. The tibial surface of the femur is divided by the intercondylar fossa (intercondylar notch). The intercondylar fossa separates the two condyles distally and posteriorly. Furthermore, the proximal tibial surface has medial and lateral articular surfaces that articulate with the corresponding femoral condyles. The rough area between the articular surfaces of the condyles is narrowest in the middle, where there is an intercondylar eminence, the edges of which protrude as lateral and medial intercondylar tubercles. The anterior cruciate ligament (ACL) is attached to the anterior intercondylar region of the tibia (Standring et al., 2008). It ascends postero-laterally, twists around itself, and fans out to attach high on the posteromedial aspect of the lateral condyle (Girgis et al., 1975).
Several researchers have conducted studies on intercondylar notch width (NW) and intercondylar notch width index (NWI) to explain common ACL injuries in the clinic. Surgical (Shelbourne et al., 1998), cadaver (Good et al.,1991; Muneta et al., 1997), radiographic (Souryal and Freeman, 1993; Souryal et al., 1988; Anderson et al., 2007; Schickendantz and Weiker, 1993), computed tomography (CT) (Anderson et al., 1987), and magnetic resonance imaging (MRI) (Anderson et al., 2001; Herzog et al., 1994), methods determined the relationship between NW and ACL injuries. Some concluded that NW stenosis impacts ACL injuries in female athletes (Lund-Hanssen et al., 1994). However, some studies indicate no correlation between NW and ACL (Herzog et al., 1994; Lombardo et al., 2004). Various opinions have also been expressed about the reliability of the measurement results obtained on radiographs (Anderson et al., 2007; Schickendantz and Weiker, 1993; Herzog et al., 1994). Several researchers have also studied the effects of the eminence width (EW) and eminence width index (EWI) parameters on ACL injuries (Uhorchak et al., 2003; Xiao et al., 2016; Iriuchishima et al., 2020). The studies of the tibia were also performed on radiographs. It has even been hypothesized that the width of EW may prevent ACL injuries (Li et al., 2020).
The study aimed to determine the gender differences in the parameters bicondylar width (BCW), NW, NWI, tibia width (TW), EW, and EWI using dry bones from the same individuals. These parameters in clinical usage determine ACL injury susceptibility. To our knowledge, the bony structures related to the ACL of the femur and tibia have never been investigated combined with dry bones in the literature.

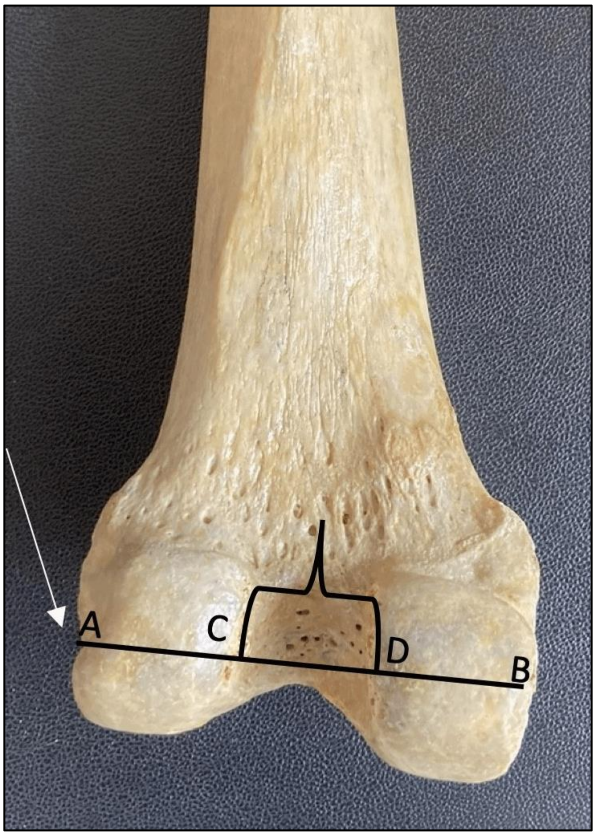

Figure 1- Shows the measurements of the bicondylar and intercondylar notch width from posterior view of the distal end of the femur. White arrow: Popliteal sulcus, A-B: Bicondylar width, C-D: Intercondylar notch width, C-D/A-B: Intercondylar notch width index.

MATERIALS AND METHODS

The study was designed in the order of morphometric anatomy and performed in the Anatomy Department. Dry bones in the study belong to the laboratory of the Department of Anatomy.
The study included bilateral femurs (48 right / 60 left) and tibias (54 right / 57 left) from 40 adult males and 20 adult females from the Turkish population. Bones with pathologies, impaired integrity, the distal end of the femur, and the proximal end of the tibia structures were excluded from the study.
The BCW is the bicondylar width of the femur, measured at the popliteal sulcus level. The NW is the width between the femur condyles and is

measured at the BCW line (Fig. 1). The NWI is calculated as NW/BCW.

Figure 2- Shows the measurement of the tibia and tibial eminence width from anterior view of the proximal end of the tibia. A-B: Tibia width, C-D: Tibial eminence width, C-D/A-B: Tibial eminence width index

The TW measured the most mediolateral width of the proximal end of the tibia. The EW was measured between the bases of the intercondylar tubercles of the tibia at the same level as the TW (Fig. 2). The EWI was calculated as EW/TW.
Measurements were made using a manual sliding caliper with an error of ±0.01 mm and were taken twice at different times by a single observer, with mean values taken and noted.
Data were analyzed using the IBM SPSS Statistics for Macintosh (v 26.0. Armonk, NY: IBM Corp) package software program. The student's t-test was used to determine the difference between the two independent groups. Correlations were evaluated as none (0.0-0.09), poor (0.10 - 0.29), fair (0.30 - 0.59), moderate (0.60 - 0.79), very strong (0.80 - 0.99), perfect (1). Pearson's correlation was used to determine the correlations between variables, and data obtained by counting was analyzed with the Chi-Squared test. The level of error was 0.05.

RESULTS

A total of 21 bones were excluded from the study, and 219 were included. The bones are classified as femur, tibia, female, and male. Table 1 shows the distribution of bone numbers by gender and side because of grouping.

Bone	***Femur***				***Tibia***			
Gender	Male		Female		Male		Female	
Side	Right	Left	Right	Left	Right	Left	Right	Left
	31	43	17	17	33	39	21	18
n (%)	74 (68.5%)		34 (31.5%)		72 (64.9%)		39 (35.1%)	
N	108				111			
	219							

Table 1- Distributions of the bones in terms of gender and side

Table 2 displays the results of the measurements and statistical analyses.
It was found that BCW (p=0.001), NW (p=0.001), TW (p=0.001), EW (p=0.001), and EWI (p=0.008) parameters had higher mean values in males than females and the difference between them was statistically significant. The only parameter with no statistically significant difference between gender mean scores was NWI (p=0.434) (Table 2).
The following correlations were discovered in males based on Pearson correlation analysis: between BCW and NW (r=0.206, p=0.013), between BCW and NWI (r=-0.288, p=0.000) and between BCW and TW (r=0.370. p=0.000); between NW and BCW and NWI (r=0.874,

p=0.000); between NWI and BCW and NW, and between TW and BCW, EW (r=-0.167, p= 0.044), between TW and EWI (r=0-.262, p=0.001); between EW and TW and EWI (r=0.690, p=0.000) (Table 3).

	Parameter	Total Mean±sd	Gender	n	Mean±Sd	Result
Femur n=108	BCW	72.19±5.68	M	74	75.08±3.96	t= 11.81
			F	34	65.90±3.23	**p=0.001***
	NW	22.65±2.92	M	74	23.45±2.80	t=4.57
			F	34	20.91±2.39	**p=0.001***
	NWI	0.30±0.03	M	74	0.30±0.03	t=0.78
			F	34	0.31±0.03	p=0.434
Tibia n=111	TW	72.34±7.73	M	72	75.74±4.29	t=9.97
			F	39	66.05±5.83	**p=0.001***
	EW	10.27±2.07	M	72	11.02±1.96	t=5.89
			F	39	8.89±1.48	**p=0.001***
	EWI	0.13±0.02	M	72	0.14±0.02	t=2.71
			F	39	0.13±0.02	**p=0.008***

Table 2- The total mean of parameters and comparisons between genders. BCW bicondylar width, NW intercondylar notch width, NWI intercondylar notch width index, TW tibia width, EW eminence width, EWI eminence width index, M Male, F Female- n Number of bones, Sd Standard deviation * p<0.05

		BCW	NW	NWI	TW	EW	EWI
BCW	Pearson	1	**.206***	**-.288****	**.370****	-.120	-.061
	Sig. (2-tailed)		**.013**	**.000**	**.000**	.148	.463
	N	146	146	146	146	146	146
NW	Pearson	**.206***	1	**.874****	.160	-.052	-.026
	Sig. (2-tailed)	**.013**		**.000**	.054	.534	.751
	N	146	146	146	146	146	146
NWI	Pearson	**-.288****	**.874****	1	-.029	.009	.005
	Sig. (2-tailed)	**.000**	**.000**		.727	.910	.954
	N	146	146	146	146	146	146
TW	Pearson	**.370****	.160	-.029	1	**-.167***	**-.262****
	Sig. (2-tailed)	**.000**	.054	.727		**.044**	**.001**
	N	146	146	146	146	146	146
EW	Pearson	-.120	-.052	.009	**-.167***	1	**.690****
	Sig. (2-tailed)	.148	.534	.910	**.044**		**.000**
	N	146	146	146	146	146	146
EWI	Pearson	-.061	-.026	.005	**-.262****	**.690****	1
	Sig. (2-tailed)	.463	.751	.954	**.001**	**.000**	
	N	146	146	146	146	146	146

Table 3- Pearson's correlation of the parameters in males. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

Females showed the following correlations: between BCW and NW (r=0.491, p=0.000); between BCW and TW (r=-0.734, p=0.000); between BCW and EW (r=-0.444, p=0.000); between NW and BCW, NWI (r=0.753, p=0.000), between NW and TW (r=-0.429, p=0.000), between NW and EW (r=-0.256, p=0.029); between NWI and NW and between TW and BCW, NW, EW (r=0.621, p= 0.000); between EW and BCW, NW, TW and EWI (r=0.872, p=0.000) (Table 4).

		BCW	NW	NWI	TW	EW	EWI
BCW	Pearson	1	**.491****	-.198	**-.743****	**-.444****	-.196
	Sig. (2-tailed)		**.000**	.093	**.000**	**.000**	.096
	N	73	73	73	73	73	73
NW	Pearson	**.491****	1	**.753****	**-.429****	**-.256***	-.113
	Sig. (2-tailed)	**.000**		**.000**	**.000**	**.029**	.340
	N	73	73	73	73	73	73
NWI	Pearson	-.198	**.753****	1	.075	.045	.020
	Sig. (2-tailed)	.093	**.000**		.526	.705	.867
	N	73	73	73	73	73	73
TW	Pearson	**-.743****	**-.429****	.075	1	**.621****	.220
	Sig. (2-tailed)	**.000**	**.000**	.526		**.000**	.061
	N	73	73	73	73	73	73
EW	Pearson	**-.444****	**-.256***	.045	**.621****	1	**.872****
	Sig. (2-tailed)	**.000**	**.029**	.705	**.000**		**.000**
	N	73	73	73	73	73	73
EWI	Pearson	-.196	-.113	.020	.220	**.872****	1
	Sig. (2-tailed)	.096	.340	.867	.061	**.000**	
	N	73	73	73	73	73	73

Table 4- Pearson's correlation of the parameters in females. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

DISCUSSION

The normal range should be known as the "narrowness" or "width" of an anatomical structure. "Narrowness" or "width" can be determined by direct measurements, especially when bony structures are involved.

In this study, all measured parameters differ between gender groups except the NWI. According to the results of the bones in our study, and considering the differences in anatomical structures between males and females, it is interpreted as an expected result that males have a more comprehensive BCW range than females. Similarly, the correlation study has shown that the NW parameter will increase the BCW in both female and male bones. When NWI values are compared, there is no difference between genders. However, it has been demonstrated in the correlation study that it might change concerning NW in both female and male bones.

It determined that the EWI parameter is smaller in females, which is different from the NWI parameter. TW and EW parameters were found to correlate with BCW in females. Statistically significant correlations between BCW and NW, and TW parameters in both genders are interpreted as data indicating that femoral and tibial arrangements influence each other.

In this study: the BCW parameter was determined to be 65.90±3.23 mm in females, 75.08±3.96 mm in males, and 72.19±5.68 mm overall. In the literature, mean BCW values of 73.79 mm in the Indian population (Attada, 2018), 73.4 mm in the Nigerian population (Eboh and Igbinedion, 2020), 78.5 mm in females, 88.6 mm in males, and 83.9 mm overall in the Greek population (Terzidis et al., 2012), have been reported using dry bone measurements. Our findings show minor differences between the Indian and Nigerian populations and the overall mean values. It has been discovered that the Greek population's averages for both males and females are significantly below this. This difference could be because Terzidis et al. (2012) measured the most expansive region of the femoral condyles as the BCW measurement method, whereas we used the popliteal sulcus. Relatively, different results may have occurred because the broadest areas of bone may vary. However, looking at it geographically, one might expect similar results for the Greek population and differences for the Indian and Nigerian populations. However, if we compare the results of this study with those of other studies, we find that the results obtained by the same method are close. The NW parameter was detected to be 20.91±2.39 in females, 23.45±2.80 in males, and 22.65±2.92 overall. Average values in the Indian population were 22.4 mm (Didia et al., 2002), 18.49 mm (Attada, 2018), 23.9 mm in the Nigerian population (Eboh and Igbinedion, 2020), 18.7 mm in females, 22.0 mm in males, and 20.5 mm overall in the Greek population (Terzidis et al., 2012). From the study results, the total mean values are higher than the other studies except in the Nigerian population.

Furthermore, males' and females' mean values were higher than those of the Greek population. Interestingly, BCW values in the Greek population were higher, whereas the NW parameter was higher in our measurements. The reason is that we also performed the NW parameter on the line passing through the popliteal sulcus, and there may be differences between the method of Terzidis et al. (2012). The NWI parameter was determined as 0.31±0.03 in females, 0.30±0.03 in males, and 0.30±0.03 mm in total. Atta (2018), who determined the index value from dry bone measurements, reported the NWI parameter to be 0.25 mm on average in the Indian population. When the mean values are compared, the index values are higher than those of the Indian population. Although there is no significant difference in the BCW measurements, it appears that the NW averages form this result.

In this study: the TW parameter was found to be 66.05±5.83 in females, 75.74±4.29 in males, and 72.34±7.73 overall. The parameter EW was determined to be 8.89±1.48 mm in females, 11.02±1.96 mm in males, and 10.27±2.07 mm overall. The EWI parameter was detected to be 0.13±0.02 in females, 0.14±0.02 in males, and 0.13±0.02 mm overall. Among the radiographic studies of the tibia in the literature, Xiao et al. (2016) reported the TW parameter as 81.5 mm in the ACL-ruptured group, 80.5 mm in the control group, the EW parameter as 11.3 mm in the ACL-ruptured group, 13.0 mm in the control group, the EWI parameter as 0.14 mm in the ACL-ruptured group and 0.16 mm in the control group in the Chinese population. In the Japanese population, Iriuchishima et al. (2020) found the EW parameter to be 12.5 mm in the ACL-ruptured group and 13.9 mm in the control group. When the population means were compared, it was found that the TW parameter was higher than the mean of both the ACL-ruptured and control groups from the Chinese population. On the other hand, the parameter EW has similar values to the ACL-ruptured group of the Chinese population and the male bone measurements, while it has a lower mean value in both female and male bones than in the control group. The EWI parameter was similar to the ACL-ruptured group, although lower than the Chinese population control group. The mean values in the ACL-ruptured and control groups appear similar to the Japanese population. The use of radiography in the study by Xiao et al. (2016) and Iriuchishima et al. (2020) could explain the difference between the Chinese and Japanese populations, particularly for the parameters TW and EW. The lack of significant differences in index values may indicate mean similarities, and the index value may be misleading in determining EW narrowness.

In conclusion, females with narrower NWs than males may be anatomically unavoidable and do not support the hypothesis that this factor influences ACL injuries. We believe assessments of the femur or tibia alone may not be sufficient for ACL injuries. The integrity evaluation of the bones in the lower extremity alignment may be more effective in responding to ACL injury susceptibility.

Conflict of Interests

The author declares that they have no conflict of interest.

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None

Ethical Approval

Ethical approval is not necessary for this type of study. The 1964 Helsinki declaration and its later amendments or comparable ethical standards carried out the research.

Informed consent
Not applicable

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