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Distal femur morphometry: a gender and bilateral comparative study using magnetic resonance imaging

Received: 26 August 2003 / Accepted: 21 June 2004 / Published online: 2 December 2004
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Abstract Among the anthropometric factors to be considered, anatomic differences in the distal femur and intercondylar notch have been implicated as a cause of the different rates of anterior cruciate ligament (ACL) rupture between men and women; therefore, in this study our aim was to evaluate a number of morphometric measurements in the distal part of the femur. Two hundred knee MRI examinations were analyzed: 56 male right, 44 male left, 42 female right and 58 female left. Measurements of the intercondylar height (ICH), intercondylar width (ICW), medial condylar width (MCW), lateral condylar width (LCW) and epicondylar width (EW) were obtained. The notch shape index (NSI) was also calculated. Statistical analysis for comparisons was done by Student's *t*-test. Correlations between the parameters studied were calculated by Pearson correlation coefficients. Significant bilateral differences were not found ($p > 0.05$). In all measurements, males showed significantly greater values than females ($p < 0.001$). No difference was seen in the NSI between males and females ($p > 0.05$). Conversely a significant association was obtained between age and all parameters. We conclude that the results of this study may be useful for anatomic evaluation of the distal femur region prior to orthopaedic operations.

Keywords Distal femur · Intercondylar notch · Measurements · Anatomy

Introduction

The dimensions of the intercondylar notch of the knee have importance in assessing the risk of the anterior cruciate ligament (ACL) rupture, prediction of the outcome of ACL reconstruction, and interpretation of degenerative changes or the appearance of “notch stenosis” on radiographs. An understanding of the anatomic relationships of the intercondylar notch of the knee throughout its course, therefore, has direct clinical value [22]. The geometry of the intercondylar notch is one of the factors suspected to predispose individuals to ACL injury and may differ between males and females [38].

Anthropologists have established that men and women are morphologically different, but little is known about anthropometric differences regarding the intercondylar notch [30]. LaPrade and Burnett and Teitz et al. [22, 33] reported that no difference exists between males and females, while Shelbourne et al. [30] found that regarding height and weight as covariants, women had significantly narrower notches than men. Giorgi [11] reported congenital variability of the notch, and Feagin et al. [9] stated that narrowing of the notch could be, among other factors, congenital. The relationship between rupture of the ACL and the width of the intercondylar notch of the knee was noted by several authors [20, 22, 25, 32]. Houseworth et al. [17] reported that a narrowed posterior arch of the intercondylar notch is a predisposing factor to ACL tearing.

It has also been reported that the intercondylar notch becomes increasingly narrow after rupture of the ACL [9, 29]. Koukoubis et al. [21] noted that osteoarthritis leads to narrowing of the intercondylar notch. Two postulates prevail concerning intercondylar notch stenosis [27]. The first states that a narrow notch will have a correspondingly smaller ACL. A smaller ACL would be less strong and more likely to rupture. The second postulate states that a narrow notch surrounding a normal-sized ACL would provide insufficient space for

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the ligament to work normally. The reduced space could pinch the ACL resulting in damage to the ligament.

Another potentially critical aspect of the intercondylar notch is the shape of the notch itself [34]. Hutchinson and Ireland [18] suggested that the intercondylar notch shapes may be classified as inverted U- or A-shaped, and Anderson et al. [2] 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 [34].

Given the discrepancy in the reported observations about the variability of the size of the intercondylar notch and its relationship to gender effects, this study was undertaken to examine and compare the dimensions of the distal femur, including NSI, in samples of male and female MRI examinations.

Materials and methods

Two hundred knee axial MRI examinations were analyzed in the Radiology Department of Meram Faculty of Medicine, Selçuk University. The analyzed images concerned 56 male right, 44 male left, 42 female right and 58 female left knees with an age range between 18 and 78 years. The subjects had been referred to the Orthopaedic Outpatient Clinic for knee pain treatment but had no morphologic knee abnormalities and were selected by radiologists as normal cases. The axial MRI scans had been performed on a 1.5 T superconducting unit (Picker International, Highlands, Ohio) using spin-echo sequences. The images were T1-weighted axial images (TR: 674, TE: 20). Slice thickness was 3.5 mm, gap 0.5 mm, field of view 20 cm and display matrix 160×256.

The following parameters were measured on the axial images: The maximal height of the intercondylar notch (supero-inferior dimension) (ICH) was measured by drawing a vertical line from the top of the notch to the most inferior level of the condyles as displayed in Fig. 1; the maximal transverse width of the intercondylar notch (ICW) was measured by drawing horizontal line at the widest portion of the notch where the cruciate ligaments would pass through as displayed in Fig. 1; the epicondylar width (the greatest mediolateral dimension) (EW) was measured by drawing horizontal lines connecting the two epicondyles as displayed in Fig. 2; the lateral condylar width (LCW) and the medial condylar width (MCW) were measured at the level of the narrowest width of the intercondylar notch as displayed in Fig. 3. The NSI was also calculated, by dividing the width of the intercondylar notch by its height.

Data were summarized as means \pm standard deviations. The SPSS for Windows 10.0 program was used for statistical analysis. Student's *t*-test was applied to compare male-female and right-left measurements. To

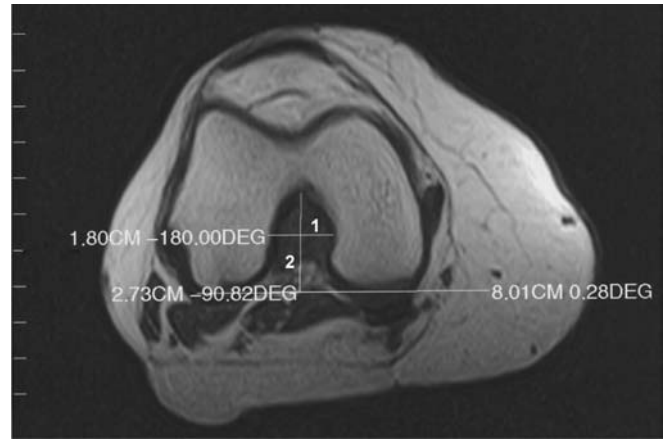


Fig. 1 The maximal transverse width of the intercondylar notch (ICW, line 1) and the maximal height of the intercondylar notch (ICH, line 2)

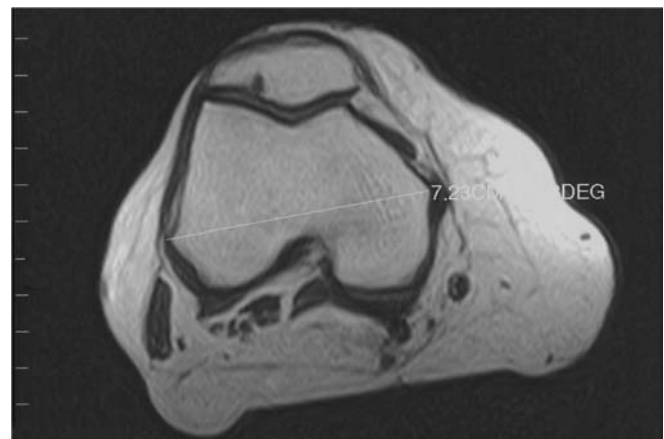


Fig. 2 The epicondylar width of the femur (EW)

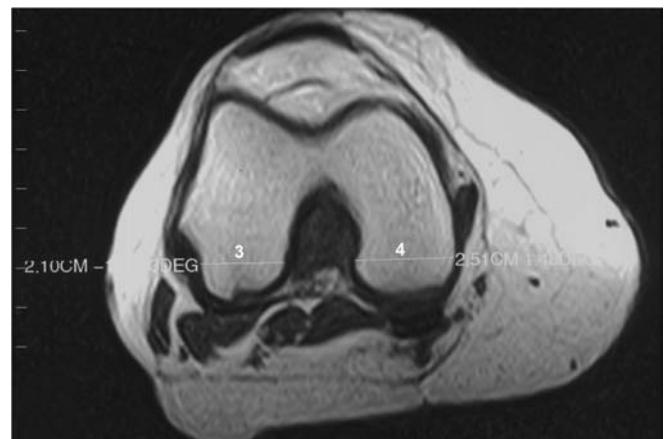


Fig. 3 The lateral condylar width of the femur (LCW, line 3) and the medial condylar width of the femur (MCW, line 4)

determine the relationships between age and the studied measurements, Pearson correlation coefficients were calculated and analyzed.

Results

The results of the statistical comparisons between the measurements made on the left and right knees are shown in Table 1. No statistically significant differences were seen between these measurements ($p > 0.05$) (Table 1). Gender comparative statistics with the means and standard deviations are shown in Table 2. Significant differences were found between male and female measurements, the values being greater in males ($p < 0.01$) (Table 2). The statistical correlations between the studied parameters are given in Table 3. Parameters were found to be significantly associated with each other ($p < 0.01$) (Table 3), except for LCW and ICW ($p > 0.05$). Furthermore, an inversely significant correlation was found between the age of the studied samples and all the measurements ($p < 0.01$) (Table 3). As regards the NSI,

Table 1 Bilateral comparative results of the parameters studied (mean \pm SD, t and p values) (*ICH*, intercondylar height; *ICW*, intercondylar width; *MCW*, medial condylar width; *LCW*, lateral condylar width; *EW*, epicondylar width)

Parameters	Left Mean \pm SD (mm)	Right Mean \pm SD (mm)	t	p
ICH	30.8 \pm 3.4	31.4 \pm 3.4	0.757	0.451
ICW	19.9 \pm 2.3	20.4 \pm 2.7	0.924	0.358
MCW	24.9 \pm 2.9	25.8 \pm 2.4	1.721	0.088
LCW	24.9 \pm 3.3	24.9 \pm 2.8	0.088	0.930
EW	78.2 \pm 6.4	79.2 \pm 8.7	0.676	0.501

Table 2 Gender comparative results of the parameters studied (mean \pm SD, t and p values) (*ICH*, intercondylar height; *ICW*, intercondylar width; *MCW*, medial condylar width; *LCW*, lateral condylar width; *EW*, epicondylar width; *NSI*, notch shape index)

Parameters	Male Mean \pm SD (mm)	Female Mean \pm SD (mm)	t	p
ICH	33.2 \pm 2.8	29.0 \pm 2.6	7.782	0.000*
ICW	21.3 \pm 2.4	19.1 \pm 2.0	4.967	0.000*
MCW	27.0 \pm 2.1	23.7 \pm 2.2	7.500	0.000*
LCW	26.6 \pm 2.8	23.2 \pm 2.3	6.668	0.000*
EW	83.1 \pm 7.7	74.4 \pm 4.3	7.013	0.000*
NSI	0.643 \pm 0.007	0.660 \pm 0.007	1.197	0.234

* $p < 0.001$

Table 3 Correlation coefficients (r) among the measurements studied, including correlations with age (*ICH*, intercondylar height; *ICW*, intercondylar width; *MCW*, medial condylar width; *LCW*, lateral condylar width; *EW*, epicondylar width)

	Age	EW	LCW	MCW	ICW
ICH	-0.346**	0.685**	0.541**	0.625**	0.528**
ICW	-0.272**	0.410**	0.229*	0.304**	
MCW	-0.278**	0.519**	0.605**		
LCW	-0.288**	0.484**			
EW	-0.336**				

* $p < 0.05$

** $p < 0.01$

an insignificant difference between males and females was found ($p > 0.05$) (Table 2).

Discussion

Among the anthropometric factors to be considered, anatomic differences in the distal femur and intercondylar notch have been implicated as a cause for the difference in ACL injury rates between men and women [12, 17, 25]. Numerous investigators have evaluated dimensions of the distal femur and the intercondylar notch with roentgenograms [4, 16, 17, 22, 25, 31, 32]. They demonstrated significant differences between control and ACL-deficient knees in various measurements, including the posterior notch outlet, the anterior outlet, and the notch width index. Anderson et al. [1] reported that the intercondylar notch dimensions were smaller in women, but no sex difference in the shape of the notch was found. Furthermore, they stated that anatomic differences in morphologic intercondylar notch characteristics between men and women have not been proven to be the cause for sex differences in ACL injury rates. Herzog et al. [16] compared direct cadaveric notch measurements with radiographic and MRI measurements. They found no difference in direct and MRI measurements but did find significant differences between direct and radiographic measurements.

Notch width is most often reported as the notch width index (NWI) [34]. The NWI is calculated as the ratio of intercondylar notch width to the width of the femoral condyles [13, 22, 27]. Anderson et al. [2] detected significant differences between NWI in ACL-injured individuals and normal individuals. Souryal and Freeman [31] deduced that athletes with stenotic intercondylar notches were more likely to suffer ACL injuries; furthermore, La Parde and Burnett [22] studied 213 collegiate athletes and concluded that intercondylar notch stenosis was associated with ACL injury, but no NWI differences were detected when compared by gender. Teitz et al. [33] compared data from individuals who had suffered non-contact ACL injuries with normal individuals and detected no differences in NWI for males and females or between normal healthy individuals and injured individuals. Muneta et al. [27] created molds of the ACL from 16 cadaver knees to investigate the relationship between ligament size and notch size. They concluded that the width of the intercondylar notch is not related to the size of the ACL. Odensten and Gillquist [29] reported a notch width of 21 mm and Koukoubis et al. [21] reported it as 19.2 mm. Herzog et al. [16], in their comparative study, found that the notch width in the direct cadaveric measurements was 20.3 mm, on plain film was 22 mm and on MRI was 20.8 mm. These observations compare favorably with our mean width of 20.2 mm. Anderson et al. [1], in their MRI measurements, observed that the notch width of male basketball players was significantly greater than in female players (23.7 mm and 20.5 mm respectively). In

the present study, male subjects were also found to have larger notch widths than female subjects (21.3 mm and 19.1 mm respectively). These results were in accordance with those obtained by Anderson et al. [1] and Shelbourne et al. [30]. Souryal and Freeman [31], in a study of 902 high school athletes, found that the notch width index was less for adolescent girls than for boys. Anderson et al. [1] also reported that the notch width increases as height increases for male subjects, but not for female subjects.

The anatomic relationships between the dimensions of the intercondylar notch of the knee and the direct clinical value of the risk of ACL injuries have been studied by several investigators who have proven conclusively that female athletes have a disproportionately high number of ACL injuries when compared with their male counterparts [3, 7, 8, 10, 14, 15, 19, 23, 26, 36, 37]. Neither Shelbourne et al. [30] nor Gwinn et al. [15] found extrinsic differences that make women more likely to sustain ACL tears. Subsequently, a variety of intrinsic factors have been implicated, including ligamentous laxity [5, 28], the hormonal effects of estrogen [24, 35], and anthropometric differences in men and women [3]. Wojtys et al. [35] demonstrated a statistically significant association between the stage of the menstrual cycle and the likelihood of ACL injury, the incidence of ACL injury being greater during the ovulatory phase of the menstrual cycle when a surge of estrogen production occurs. Tillman et al. [34] 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 between races. These findings indicate that people of European descent could be more predisposed to ACL injury than those of African descent because less room is available in the intercondylar notch for normal movement of the ACL [34].

In this study, a significant gender difference in NSI was not found. This is in agreement with the finding of Tillman et al. [34], who were not able to find significant differences in NSI between European and African males and females. Anderson et al. [1] have also reported no sex difference in the shape of the notch. There was a discrepancy in the maximal heights of the intercondylar notch obtained by us and those obtained by Koukoubis et al. [21] and Herzog et al. [16]. One of the expected factors in this discrepancy was the difference in the levels at which the measurements were performed. In this study, the mean values of the notch height were 33.2 ± 2.8 mm and 29.0 ± 2.6 mm in males and females, respectively. Koukoubis et al. [21] reported 24 mm, but this distance was measured from the bottom of the posterior condyle to the top of the notch. Herzog et al. [16], 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, respectively, in males and females control subjects.

In the literature, the bicondylar and epicondylar widths were not statistically analyzed as independent

variables and were considered factors for calculating the notch width index (NWI) [34] or the ratio of epicondylar width/notch width [21]. Charlton et al. [6] found that the bicondylar width in males was significantly greater (71.6 mm) than in females (67.2 mm). These significant differences between males and females were in agreement with our findings regarding the epicondylar width. Furthermore, results of the present study showed that males have significantly greater MCW and LCW than females. Ziyilan and Murshed [38] reported that the epicondylar widths were 77.3 and 76.8 mm in the left and right femora, respectively. Charlton et al. [6] also reported a significant difference in the femoral bicondylar width between short and tall subjects, with the taller subjects having larger values. Furthermore, they stated that no significant difference in femoral bicondylar width with respect to weight and age was found. In our study, inversely significant associations were found between age and all parameters. This indicated that increasing age is accompanied by a reduction in the dimensions of the parameters studied that could be considered a symptom of calcium metabolic disturbances, calcium deficiency and osteoporotic causes in older subjects.

The discrepancy in notch measurements reported in the literature may be explained by several factors, including analysis of different populations. Differences in measurement techniques may be another confounding variable. Points of measurement on the distal femur were not uniform, which makes comparison of the results difficult.

We conclude that the results of this study may be useful for MRI anatomic evaluation of the distal femur region for diagnosis and/or treatment, especially orthopaedic operations.

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