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Assessment of femoral notch morphology in male patients with anterior cruciate ligament injury: an MRI study

Ön Çapraz Bağ Yaralanmalı Erkek Hastalarda Femoral Çentik Morfolojisinin Değerlendirilmesi: MRI Çalışması

Ayşe Serap Akgün[1], Aybars Tekcan[2*]

1.İstanbul Medipol University, Medicine Faculty, Department of Radiology, Istanbul, Turkey
2.İstanbul Medipol University, Medicine Faculty, Department of Orthopedic and Traumatology, Istanbul, Turkey

ABSTRACT

Aim: The objective of the present study was to evaluate the femoral notch type, notch width index (NWI), notch angle (NA) and α angle in patients with ACL injury and compare with nonathletic male population, using magnetic resonance imaging (MRI).
Methods: 79 patients with complete ACL tear and 80 patients as control group (aged 19-43 years) who had knee MRI were evaluated. NWI, NA measurements and notch shape were evaluated on axial fat-saturated proton-weighted sequences. Femoral notch shape was classified as A, U and W types.
Results: A statistically significant association was found between notch type, NWI, NA and ACL injury (p<0,001). Type A notch in the ACL-injured group (79.75 %) was significantly higher than the control group (24%). NWI was lower in patients with ACL-injured group than in control group (0.249 ± 0.020 vs 0.281 ± 0.022) Notch angle was lower in patients with ACL-injured group than in control group (47.15 ° ± 5.63 ° vs 50.73 ° ± 5.44°). A significant association between stenotic notch type A and NWI (p <0,001). The α angle was lower in patients with ACL-injured group than in control group but it was not statistically different (41.9 ° ±2.79 °vs 42.06 ° ±2.53 °; p= 0.978).
Conclusion: This study showed that however low NWI, NA values are a risk factor for ACL injury, the strongest predictive factor was stenotic femoral notch type A. α angle had no significant correlation in ACL injury.

Key Words: Anterior cruciate ligament, femoral notch type, intercondylar notch angle, magnetic resonance imaging

ÖZ

Amaç: Bu çalışmanın amacı, sporcu olmayan, erkek, ön çapraz bağ (ÖÇB) yaralanmalı hastalarda femoral çentik tipi, çentik genişlik indeksi (NWI), çentik açısı (NA) ve α açısını manyetik rezonans görüntüleme (MRI) kullanarak değerlendirmek ve karşılaştırmaktır.
Yöntemler: Komplet ÖÇB yırtığı olan 79 hastanın ve 80 hastalık kontrol grubunun (19-43 yaş arası) diz MRI görüntüleri değerlendirildi. NWI, NA ölçümleri ve çentik şekli, eksenel yağa doymuş proton ağırlıklı sekanslar üzerinden değerlendirildi. Femoral çentik şekli A, U ve W tipleri olarak sınıflandırıldı.
Bulgular: Çentik tipi, NWI, NA ve ACL yaralanması arasında istatistiksel olarak anlamlı bir ilişki bulundu (p<0,001). ÖÇB yaralanmalı grupta; A tipi çentik (%79.75), kontrol grubundan (%24) önemli ölçüde daha yüksekti. ÖÇB hasarlı grupta NWI kontrol grubuna göre daha düşüktü (0.249 ± 0.020 vs 0.281 ± 0.022). Çentik açısı ÖÇB hasarlı grupta kontrol grubuna göre daha düşüktü (47.15 ° ± 5.63 ° vs 50.73 ° ± 5.44°). Stenotik çentik tipi A ile NWI arasında anlamlı bir ilişki mevcut idi (p <0,001). ÖÇB yaralanmalı hastalarda α açısı kontrol grubuna göre daha düşüktü ancak istatistiksel olarak fark yoktu (41.9 ° ±2.79 °vs 42.06 ° ±2.53 °; p= 0.978).
Sonuç: Bu çalışma, düşük NWI, NA değerlerinin ÖÇB yaralanması için bir risk faktörü gibi görünse de, en güçlü prediktif faktörün stenotik femoral çentik tip A olduğunu göstermiştir. α açısı ÖÇB yaralanmasında anlamlı bir korelasyon göstermemiştir.

Anahtar Kelimeler: Ön çapraz bağ, femoral çentik tipi, interkondiler çentik açısı, manyetik rezonans görüntüleme

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*Corresponding Author: Aybars Tekcan, Istanbul Medipol University, Medicine Faculty, Department of Orthopedic and Traumatology, İstanbul, Turkey, +905324314874, draybars@yahoo.com

ORCID: 0000-0003-3078-1285

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INTRODUCTION

Anterior cruciate ligament (ACL) is an important stabilizer of the most common injured knee joint. Approximately 70% of ACL injuries are non-contact and occur during a sudden change of footsteps or when an athlete slows down [1]. Previous studies have shown that ACL injuries and ACL deficiency lead to articular cartilage damage, chronic knee instability and early secondary osteoarthritis [2].

Multiple intrinsic and extrinsic predisposing factors such as biomechanical abnormalities, neuromuscular deficits, hormonal change and environmental factors may be effective in ACL injury. In many studies, the association between the risk of increased ACL damage and anatomical features of the knee has been shown [3]. These anatomic risk factors are factors such as knee and general joint laxity, knee geometry (intercondylar notch, tibial slope), ACL volume and body mass index. Although intercondylar notch morphology has been investigated with different imaging modalities, their results are contradictory.

Although the number of ACL injuries is lower in women than in men, the prevalence of ACL injuries in women is significantly higher than in men. This difference can be explained by the anatomical differences between women and men. Therefore, studies on risks should be evaluated in separate groups [4].

In this study, non-athlete male patients with acute complete ACL injury were included to eliminate anatomical differences. The aim was to evaluate the femoral notch type, notch width index (NWI), notch angle (NA) and alpha 'α angle' components in these patients and to determine the most valuable risk factor among them.

MATERIALS AND METHODS

Ethical approval was obtained from the ethics committee of the health institution where the study was conducted (No:266/04.05.2018). Male nonathletic adult patients who were referred to our radiology department with clinical diagnosis of ACL injury between May 2016 and May 2018, were retrospectively evaluated. Patients whose history of swelling or pain started as a result of a trauma to the knee or sports injury within three weeks were included in the study. On physical examination, anterior drawer tests were positive in all patients. Inclusion criteria were defined as follows: (1) Male patients (2) Skeletal maturity > 18 years old (3) History of knee pain with sports injury or trauma in the last 3 weeks (4) no previous surgery (5) entire sequences are obtained and all images are clearly monitored. Exclusion criteria: 1- Female patients 2- Skeletal immaturity < 18 years old. 3- Any other ligament injury history 4- High energy trauma history 5- Fractures or tumors involving articular surfaces 6- Radiologic findings of osteoarthritis [5,6] (because of the effect on reducing NWI) 7- Partial ACL tear.

Physical examination and MR images of the control group patients were entirely normal. We selected 159 cases, 79 patients and 80 controls and our institutional review board approved the study.

All MR sequences were performed with a 1,5 Tesla scanner (MAGNETOM, Siemens, Erlangen, Germany) while the knee in the extension position. The regular knee MRI procedures in our hospital were includes: Axial proton density fat-saturated (PDFS): TR 4240 ms, TE 41ms, 160 mm FOV, slice thickness: 4 mm, sagittal T1-weighted: TR 606 ms, TE 9,4 ms, slice thickness: 4 mm and coronal T1-weighted: TR 471ms, TE 9.4 ms, slice thickness: 4 mm, Sagittal PDFS: TR 3540 ms, TE 31 ms, slice thickness:3 mm, Coronal PDFS: TR 3280 ms, TE 20 ms, slice thickness: 4 mm. The images were evaluated by a radiologist with 9 years of experience in musculoskeletal MRI, who had no knowledge of the patients' age, gender, type of trauma, medical history and physical examination findings, by using Picture Archiving and Communication System (PACS, General Electric, Chicago, IL, USA). Complete ACL tear was determined in sagittal fat-saturated MRI images. While the patients without ACL injury constituted the control group, those with complete ACL injuries constituted the study group. Complete tears of ACL were diagnosed based on the presence of non-visualization of normal intact fibers of the ACL.

Axial fat-saturated proton-weighted sequences were selected for femoral NWI measurement and

morphology evaluation. The femoral notch shape, described by Van Eck et al., was classified as type A, type U and type W [7]. Type A is the stenotic form that appears narrow from the middle to the apex. Type U also has a wider contour on the top than type A. In Type W, femoral notch has two apices of the notch roof and wider than type U (Figure 1) [7,8].

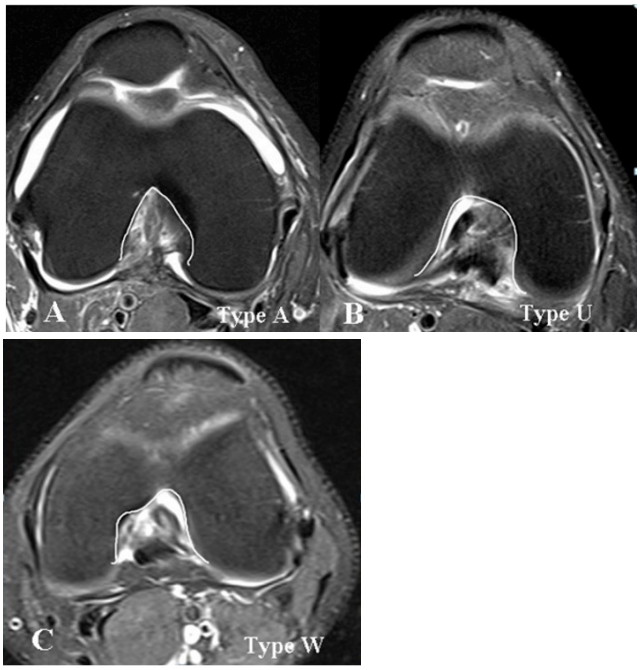

Fig.1. Axial PD (Fat Sat) MRI demonstrating femoral notch shapes; type A, type U and type W.

NWI was measured as described by Domzalski et al. [9]. NWI was determined by the ratio between central notch width and intercondylar width at the level of popliteal groove. The values above 0.270 or more were considered normal and less than 0.269 was stenotic (Figure 2A).

The angle of the notch was defined as the line from the top of the intercondylar notch to the most inferior edge of the notch at the medial and lateral condyles (Figure 2B). Last, α angle was the angle between the longitudinal femoral axis and the Blumensaat line (BL) measured as described Fernandez et al. [10] (Figure 3). The same radiologist evaluated all MRI examinations twice, at two different sittings spaced three weeks apart.

Statistical Analysis

The statistical analysis was done by using the SPSS® version 17 (IBM Corp., Armonk, USA). Mean, standard deviation, median and minimum-maximum values were used to present descriptive analyses. Independent samples t-test was used for comparisons between the two normally distributed independent groups. Non-normally distributed variables were analyzed using the Mann-Whitney U test. The measurement data was analyzed using the Spearman Correlation test. Risk factors for ACL rupture were evaluated by binary logistic regression analysis. Odds ratios (ORs) and their 95 % confidence intervals (CIs) were estimated. P-values < 0.05 were evaluated as statistically significant results.

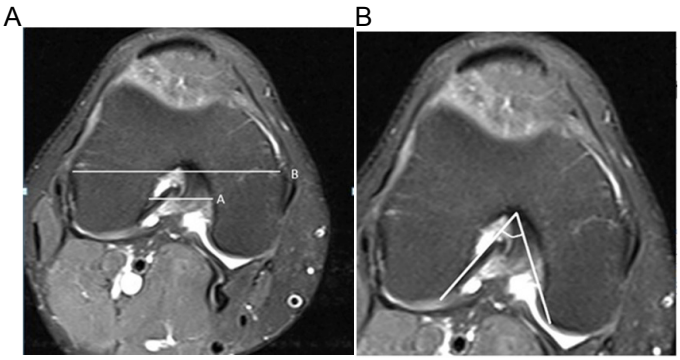

Fig. 2. A) Axial PD (Fat Sat) MRI demonstrating measurement of femoral NWI. A Femoral notch width B Intercondylar width. NWI= A/B, B) Axial PD (Fat Sat) MRI demonstrating notch angle measurement.

Fig. 3. Sagittal PD (Fat Sat) MRI image demonstrating α angle measurement.

RESULTS

The mean age of patients was 30.5 ±5.69 (range 19-43 years) and there was no statistical difference in age between groups. The comparison of notch

type, NWI, notch angle and α angle values among patients with ACL injured group and control group are summarized in Table 1. The coefficient of variation was < 10% for intraobserver analysis's.

Table 1. Comparison of NWI, NA, α angle and type of notches between the ACL-injured Group and Healthy Group

	ACL injury		Control		p
	Mean ± s.d.	Median	Mean ± s.d.	Median	
NWI	0.249 ± 0.02	0.251	0.281± 0.022	0.282	<0.001[1]
NA	47.15± 5.63	47.00	50.73± 5.44	51.00	<0.001[2]
α angle	41.97± 2.79	42.00	42.06± 2.53	42.00	0.978[2]
Type A	63	(79.75)	24	(30.00)	<0.001[3]
Type U	16	(20.25)	56	(70.00)	

[1]Independent t test [2]Mann-Whitney U Test [3]Chi-square Test (instead of mean ± s.d, n/% ratio is given)

In the control and patient groups, one patient each had notch shape type W. Type W and type U numbers are combined because type w is very small and close to type U. A statistically significant association was observed between notch type and ACL rupture (p<0,001). Type A notch rate was 79.75% in the ACL damaged group. It was significantly higher than the control group (24%). Type A ratio in the ACL-damaged group was 3.93 times higher than the type U ratio. NWI and NA values were statistically different between patients with ACL-damaged group and control group. NWI was lower in patients with ACL-damaged group than in control group (0.249 ± 0.020 vs 0.281 ± 0.022; p <0,001). NA was lower in patients with ACL-injured group than in control group (47.15 º ± 5.63 º vs 50.73 º ± 5.44º; p <0,001). Notch angle cut off value was determined as 49.5º (sensitivity %67.09 and specificity %61.25).

The stenotic notch type A and NWI had a significant cooperation. The NWI measurements of type A is lower than that of notch type U (0.254 ± 0.024 vs 0.278 ± 0.023; p <0,001). Notch stenosis was found in 90 patients (56.6 %). Stenotic type A notch was observed in sixty-six (73.33 %) of these patients (Table 2). This 66 people (73,33%) were type A and 24 people (26,67%) were type U with NWI less than 0,269. Similarly, there is a strong partnership between stenotic notch type A and NA. NA measurements of type A is lower than that of type U (47.55 º ± 5.43 º vs 50.64 º ± 5.82 º; p <0,001). The α angle was lower in patients with ACL-injured group than in control group but it was not statistically difference (41.9 º ±2.79 ºvs 42.06 º ±2.53 º; p= 0.978).

When the factors affecting ACL injury were examined by regression analysis, it was shown that the strongest connection was associated with the notch type and it was determined that the probability of rupture in A-type notches increased 8.13 times (% 95 G.A. = 3.84-17.301) (Table 3).

Table 2: Correlation between NWI and notch type (p<0,001)

	NWI<0.269		NWI≥0.270	
	n	%	n	%
Type A	66	(73,33)	21	(30,43)
Type U	24	(26,67)	48	(69,57)

Table 3. Binary logistic Regression Analysis to determine the factors affecting ACL injuries

Factor	Coefficient (B)	Std. Deviation	Odds Ratio	%95 CI		p
				Min.	Max.	
Type A	2.096	0.385	8.134	3.824	17.301	<0.001
Notch angle	0.095	0.035	1.099	1.026	1.178	0.007
α angle	-0.058	0.072	0.943	0.819	1.086	0.419
Constant	-3.0926	3.226	0.045			0.338

CI: Confidence interval

DISCUSSION

Our study showed that NWI was significantly smaller in patients with ACL injury, than in the healthy ACL group. Subjects with an ACL tear also showed to have stenotic form of notch and a smaller femoral notch angle. On the other hand, increased α angle was not associated with the risk of ACL tear. In our study, stenotic type A notch shape had the greatest risk of ACL injury.

Van Eck et al. and Sutton et al. reported that type A shape of femoral notch was easy to affect notch stenosis in ACL ruptured patient [7,11]. In addition, Sutton et al. showed that the A-type ratio in women was greater than in men. Al-Saeed et al. reported that type A patients had a higher risk than other types [8]. In the study of Basukala et al., 30% of the patients with U type notch had ACL rupture, on the other hand, 74% of the patients with A-type notch had rupture [12]. Shen et al. compared 125 patients who underwent ACL reconstruction and 125 patients without ACL rupture. They found that there is no significant difference in notch shape

[13]. Huang et al. compared 61 patients who underwent ACL reconstruction with a 78-patient control group. They found no significant difference about notch shape [14]. In our study, we found that type A in the ACL injured group was 3.93 times higher than type U, and type A was higher in the ACL injured group than the non-injured matched controls.

NWI has been measured on x-ray, CT, and MR images in several studies. Souryal et al. measured NWI using tunnel view radiographs and reported smaller NWI measurements in the ACL-ruptured group with male and female population [15]. Since MRI provides easier, faster and repeatable evaluation, many studies have used MRI to measure NWI but no clear NWI cut-off value could be found to detect notch stenosis. Uhorchak [16], LaPrade [17], Domzalski [9] and Souryal et al. [15] determined 0.18, 0.19, 0.27, 0.2, respectively. Basukala et al. NWI cut off value was taken as 0.27 in their study. While NWI decreased in 40% of the group with ACL injury, it was 13% in the group without ACL injury. This was statistically significant. On the other hand, 40.67% of the group with ACL injuries had narrow NWI while 59.32% had wide NWI [12]. Huang et al. found that the NWI was significantly smaller in both axial and coronal MR images in the ACL damaged group compared to the control group [14]. Furthermore, Shen et al. found smaller NWI in ACL injured group. The cut off value of NWI was determined as 0.252 [13]. In contrast, Van Diek et al. and Vrooijink et al. reported in their studies with both male and female population that NWI is unrelated to ACL rupture [18,19].

Bouras et al. showed a significant relationship between NWI and stenotic notch type A but no correlation was found between NWI and ACL rupture in female ACL-injured population [20]. In our study in ACL-injured group, NWI was statistically lower than the controls. In stenotic type A group, NWI values were lower than type U. In ACL-ruptured group patients the ratio of patients whose NWI values <0,269 were higher than healthy matched controls.

In the literature, the relationship between ACL injury and femoral notch angle has been rarely investigated [22-24]. Herzog et al. found femoral notch angle of 45.7 º ± 10.9 º in the patient group and 49.8 ° ± 7.2 º in the control group [21]. The most important reason for not finding a difference between the groups as Herzog et al. said that the study population consists of a limited number of individuals. Whereas Anderson AF et al. [22] with CT, Cha JH et al. [23] and Alentorn-Geli E. et al. [4] with MRI, reported that NA <50º would lead the risk of ACL injury, Stein et al. [6] showed no association between ACL injury and femoral notch angle <50º. Huang et al. and Shen et al. found that the NA was significantly smaller in the case group than that in the control group [13,14]. NA was determined as 50.36º ±5.70º by Huang et al. and it was significantly different with control group (p>0.018) [19]. In our study, femoral notch angle (47.15 º ± 5.63 º) was significantly lower in the ACL damaged group than in the control group (50.73 º ± 5.44º).

Fernandez-Jaen T et al. first described α angle and measured higher α angle values in ACL injured patients with male and female population with 57.5º ± 5.5º, compared than control group with 56.2 º ± 4.5 º [10]. Bouras et al. reported no significant difference in patients with ACL-injuries than controls in the female population (44 º ±3 º vs 43 º ±4) [20]. In these two studies, 13º of contradiction was found in the measurements of both the ACL-injuries and healthy groups. In contrast, Shen et al. found increased α angle (described as β angle) was the most crucial component for ACL injury. They indicated that more than 38.5 º α angle was associated with an increased risk of ACL injury (41.48 º ± 2.22 º vs. 38.30 º ± 3.16 º) [13]. On the other hand, Huang et al. observed that the risk of ACL injury increased with the decrease in α angle (described as INA). In the study, it is stated that decreased α angle creates a sharp edge on notch outlet, thus facilitating the ACL injury [14]. In our study there was no statistically significant difference between the two groups in terms of α angle (41.9 º ±2.79 º vs 42.06 º ±2.53 º).

Our study has several limitations. First, this was a retrospective study, therefore we could not achieve all the clinical information such as height, weight, physical examination findings and activity frequency. Second, while evaluating the femoral notch stenosis, we excluded the stenosis-associated ACL laxity and thinning and did not

measure ACL volume. Third, while evaluating the femoral notch morphology, we did not evaluate the notch volume and made measurements in only two dimensions. Finally, the risk factors for ACL injury are multifactorial, which aims to evaluate only femoral notch morphology.

CONCLUSION

In our study, there was a strong relationship between ACL injury and notch type, NWI and NA. The type A notch has been shown to be the most powerful factor in the prediction of anterior cruciate ligament rupture. Notch angle cut off value was determined as 49.5º in our study. Although there are studies reporting different results about alpha angle, it was not found as a risk factor in our study.

Description of risk factors can enable the implementation of preventive measures for people at risk. Many intrinsic factors such as NWI and femoral notch morphology were examined and it was observed that they cause variability according to gender, ligament laxity and race. We tried to evaluate these intrinsic factors in Turkish population and these results emphasize the importance of notch morphology and will also contribute to both prevention programs and knee surgery in ACL injuries. Therefore, more studies are required to explain different results about risk factors of ACL injuries.

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ORCID and Author contribution: **A.S.A.(0000-0002-9610-2209):** Concept and Design, Literature search, Analysis and Interpretation, Manuscript Writing, Critical Review. **A.T. (0000-0003-3078-1285):** Concept and Design, Data Collection, Analysis and Interpretation, Manuscript Writing, Critical Review

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