Original Article

Knee Surg Relat Res 2012;24(3):180-185
http://dx.doi.org/10.5792/ksrr.2012.24.3.180
pISSN 2234-0726 · eISSN 2234-2451

KSRR
Knee Surgery & Related Research

Measurement of Knee Morphometrics Using MRI: A Comparative Study between ACL-Injured and Non-Injured Knees

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Purpose: The purpose of this study is to find out the differences of distal femur morphology between the anterior cruciate ligament (ACL)-injured and the non-ACL injured on an magnetic resonance imaging (MRI), and the difference of bone structure by gender.
Materials and Methods: MRI Measurements of notch width (NW), bicondylar width (BCW), medial condyle width (MCW), lateral condyle width (LCW), medial-to-lateral condyle ratio (M:L ratio), and notch entrance width (NE) were taken from 120 subjects with ACL injury and the other 106 subjects without ACL injury, by three independent observers, at two different times. The measured values from MRI figures between the ACL-injured and the non-ACL-injured were compared and analyzed, with consideration of the differences by gender. Both intra and inter-observer reliability were calculated.
Results: There were significant differences of NW, BCW, MCW, LCW and NE by gender ($p<0.001$). While NW and MCW in male group were different ($p<0.001$), NW, MCW, M:L ratio and NW index (NWI) in female group were significantly different ($p<0.001$) in the bone morphology between the ACL-injured and non-ACL-injured. The intra- and inter-observer reliability was satisfying.
Conclusions: If necessary to take an MRI, female patients with small NWI and NW injury should be carefully treated because of possibility of ACL injuries.

Key words: **Knee morphology, Anterior cruciate ligament injury, Magnetic resonance imaging.**

Introduction

The anterior cruciate ligament (ACL) is the most frequently injured ligament of the knee, which is, 50% of all knee injuries[1]. Some people are at greater risk of tearing their ACL than others. In general, women have a higher injury risk compared with men, and the volume of the femoral notch was found to be statistically smaller in women than in men[2-5]. Beside the morphometric parameters of the intercondylar notch and tibial slope, morphometric parameters of the ACL are the most important anatomical risk factors regarding the ACL-injuries[6].

Several studies have tried to identify the risk factors contributing to ACL injury with different results. Factors that have been proposed to contribute to the development of an ACL tear are notch width (NW) and notch width index (NWI), but the results of studies on this topic are not unanimous[7-15]. Several studies reported that the ACL injured group had significantly narrow NW, while others reporting no significant difference[12,16,17]. Most of these studies were not successful to resolve these controversial debates.

Furthermore, there are few studies about the bony morphology of ACL injured and non-injured groups in Korea. Thus, it is necessary to show accurate data concerning some differences of the bony morphology of the ACL injured and the non ACL-injured groups using an magnetic resonance imaging (MRI), the anatomical bone structures of men and women. The purpose of this study is to compare the bony morphology between men and women, and to compare the bony morphology in subjects

Received April 26, 2012; Revised (1st) June 4, 2012; (2nd) July 6, 2012; Accepted July 16, 2012.
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with and without ACL injury. Our hypothesis was that there are differences in bony morphology between men and women, and there are differences in bony morphology between the ACL-injured and non-injured subjects.

Materials and Methods

This study was a retrospective case control study. The MRI scans were obtained from patients who had received a reconstruction operation for ACL injuries, between January 2004 and January 2011, while, the control group had an MRI for other knee problems, rather than ACL injury. They were either found to have isolated meniscal injuries, or no pathology. The exclusion criteria were performed following the results from an MRI scan with bad quality (other hospitals), greater than grade II Outerbridge osteoarthritic changes, patient's age older than 55-year-old, multiple ligamentous injury and foreigner. Following the rules above, total of 226 patients' MRI images were obtained. Among them, the ACL injured group was composed of 120 patients; 76 male with the average age of 37.9 years (range, 19 to 50 years) and 44 female with the average age of 42.5 years old (range, 20 to 55 years old). The causes of ACL injuries were traffic accidents for 38 patients, playing soccer for 23, playing basketball for 15, and some other reasons for 44. Non-ACL injured group consisted of 106 patients, and among them, there were 71 male patients with an average age of 40.5 years (range, 17 to 53 years) and 35 female patients with an average age of 47.2 years (range, 21 to 54 years).

For each included patient, the 1.5 Tesla Knee MRI (Magnetom Avanto-Siemens, Image J program ver. 1.44, JAVA, California, CA, USA) was collected and the slice spacing was 3 mm. The NW, bicondylar width, medial condylar width, and lateral condylar width of each patient were measured at an intermediate imaging, among the obtained ones, where popliteal grooves are seen under the T1 coronal view of MRI. The medial-to-lateral condyle size ratio (M:L ratio) was calculated by dividing the medial condyle width by the lateral condyle width, and the NWI was calculated by dividing the NW by bicondylar width (Fig. 1).

The axial T2 sequence was used to measure the width of the notch entrance (NE). This width was measured at each slice containing the notch, from the first slice with cartilage on both condyles to the last slice with bony connection between the medial and the lateral condyle (Fig. 2).

The widths of the subjects in each group were measured twice with three observers. The descriptive statistics were used for the calculation of notch entrance width, medial condyle width, lateral condyle width, M:L ratio, bicondylar width, and the NWI. The first study was performed with the differences of bony morphology between men and women, and the differences between the ACL injured and the non ACL-injured were analyzed. All comparisons were performed with a student t-test and the alpha level was set at 0.01. All MRI measurements were performed with three observers. Each observer measured

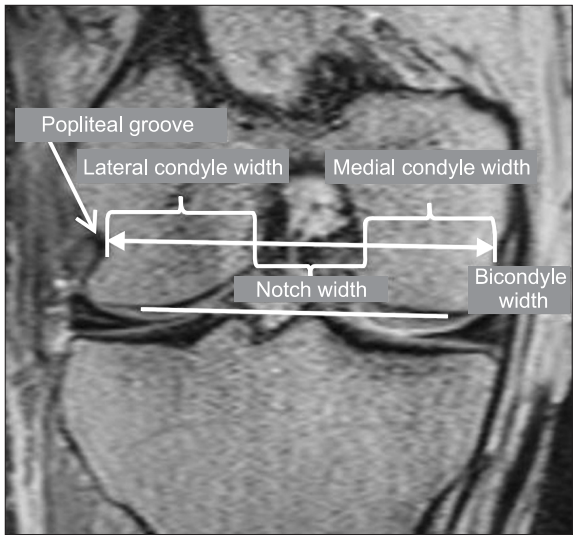

Fig. 1. T1 coronal view of knee magnetic resonance imaging. A line is shown along the most inferior part of the femoral condyles and a line parallel to this line at an intermediate imaging among the obtained ones where the popliteal grooves are seen, where the indicated morphometric values were measured.

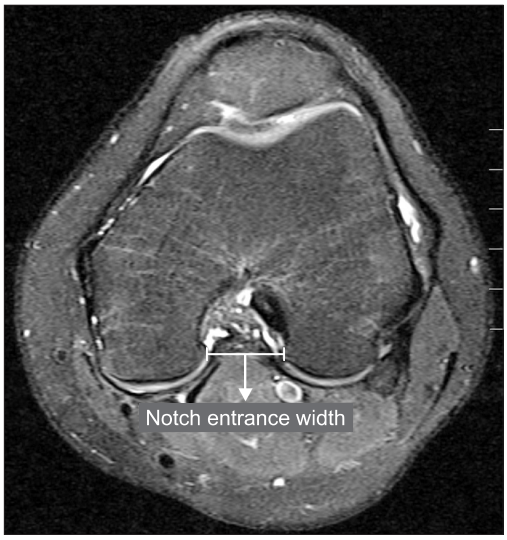

Fig. 2. T2 axial view of knee magnetic resonance imaging. The notch entrance width was measured at each slice containing the notch, from the first slice with cartilage on both condyles to the last slice with bony connection between the medial and the lateral condyle.

the values twice. The intra and inter observer reliability were calculated using the interclass correlation coefficient (ICC), and the statistical analysis was made with SPSS ver. 18 (SPSS Inc., Chicago, IL, USA).

Results

The subjects were 226 in total, and there were 147 men and 79 women, with average age of 42.3 years. Table 1 shows the values measured in men and women, as well as the differences of the bony morphology. Among the 7 measuring values (NW, bicondylar width, medial condyle width, lateral condyle width, M:L ratio, and notch entrance width), M:L ratio and NWI were not statistically significant, while the others were significantly larger in males than females.

Table 2 shows the bony morphology differences and demographic information of the ACL injured, in addition to the non ACL-injured of men and women. In the male subjects, the mean value of NW measured 17.37 mm in the ACL injured patients, and 20.33 mm in the control population, signifying a smaller NW among the ACL injured patients. This difference was statistically significant (p<0.001). In the female subjects, the mean value of NW measured 15.76 mm in the ACL injured patients, and 18.52 mm in the control population, signifying a smaller NW among the ACL injured patients (p<0.001). In the male subjects, NW and medial condyle width were significantly different between the ACL injured and the non ACL-injured, while NW, medial condyle width, M;L ratio and NWI were significantly different between the ACL injured and the non ACL-injured of the female subjects.

The intra- and inter-observer reliability of the MRI measurements is displayed in Table 3. The MRI measurements showed an average of 0.987 in the intra-observer relationship, and 0.994 in the inter-observer relationship, which is relatively high in reliability.

Table 1. Knee Morphometry Differences in Men and Women

Parameter	Male (n=147)	Female (n=79)	p-value
Mean age (yr)	39.9	44.7	
NW (mm)	18.56 (±2.41)	17.50 (±2.09)	0.001
Bicondylar width (mm)	76.59 (±3.53)	67.92 (±3.02)	0.001
Medial condyle (mm)	26.93 (±2.50)	23.38 (±1.99)	0.002
Lateral condyle (mm)	31.09 (±2.19)	27.02 (±1.71)	0.002
M:L ratio	0.90 (±0.07)	0.91 (±0.05)	0.114 (NS)
NWI	0.23 (±0.03)	0.24 (±0.02)	0.03 (NS)
NE (mm)	20.81 (±2.44)	18.86 (±1.67)	0.001

Alpha<0.01 was found significant.
NW: notch width, M:L ratio: medial-to-lateral condyle ratio, NS: non specific, NWI: notch width index, NE: notch entrance.

Table 2. Knee Morphometry Differences in Anterior Cruciate Ligament-injured and Non-injured Subjects

Parameter	Injured mean	Non-injured mean	p-value
Male (n=147)	76	71	
Age (yr)	37.9 (19-50)	40.5 (17-53)	
NW (mm)	17.37.00 (±2.12)	20.33 (±1.60)	<0.001
Bicondylar width (mm)	76.00 (±3.74)	77.46 (±3.02)	0.013 (NS)
Medial condyle (mm)	27.83 (±2.62)	25.60 (±1.58)	<0.001
Lateral condyle (mm)	30.80 (±2.45)	31.53 (±1.65)	0.033 (NS)
M:L ratio	0.91 (±0.08)	0.88 (±0.04)	0.012 (NS)
NWI	0.23 (±0.03)	0.24 (±0.02)	0.083 (NS)
NE (mm)	20.45 (±2.41)	21.36 (±2.42)	0.026 (NS)
Female (n= 79)	44	35	
Age (yr)	42.8 (20-55)	47.2 (21-54)	
NW (mm)	15.76 (±1.70)	18.52 (±1.56)	<0.001
Bicondylar width (mm)	67.47 (±3.37)	68.17 (±2.81)	0.323 (NS)
Medial condyle (mm)	25.00 (±1.92)	22.45 (±1.32)	<0.001
Lateral condyle (mm)	26.71 (±1.84)	27.20 (±1.61)	0.215 (NS)
M:L ratio	0.94 (±0.06)	0.89 (±0.05)	0.001
NWI	0.23 (±0.02)	0.25 (±0.02)	0.001
NE (mm)	18.72 (±1.63)	18.95 (±1.70)	0.561 (NS)

Alpha<0.01 was found significant.
NW: notch width, M:L ratio: medial-to-lateral condyle ratio, NS: non specific, NWI: notch width index, NE: notch entrance.

Table 3. Intra- and Inter-observer Reliability (n=226)

	Observer 1	Observer 2	Observer 3	Mean	Observer 1 vs. 2	Observer 2 vs. 3	Observer 3 vs. 1	Mean
Intra-observer (ICC)	0.991 (p<0.001)	0.982 (p<0.001)	0.981 (p<0.001)	0.987	0.992 (p<0.001)	0.994 (p<0.001)	0.997 (p<0.001)	0.994

ICC: interclass correlation coefficient.

Discussion

The most important finding of this study was that there are differences in bony morphology between the ACL-injured and the non ACL-injured subjects. These differences in bony morphologic characteristic varied for men and women. Anderson et al.[16,17] analyzed the computed tomography (CT) data to compare and study the bony morphology between men and women, in addition to the ACL injured and the non ACL-injured. It concluded that a knee with a small condylar notch might increase the rate of ACL rupture. Domzalski et al.[18] used MRI images to compare the ACL injured with the non ACL-injured, and found that intercondylar NW of the normal knee (mean=26.91 mm) and the ACL injured group (mean=24.15 mm) were significantly different ($p<0.001$). A narrower intercondylar notch was found to be associated with the risk of ACL rupture. Lombardo et al.[7] showed a different result, compared with the previous studies. After measuring the NW from notch view radiograph of 615 male basketball players, they concluded that critical notch stenosis between the ACL injured and the non ACL-injured had no associations. NW affecting ACL injury has been identified in various studies, but the results are still controversial because of the differences in the measurements and subjects. Results on NWI, as a risk factor for ACL tear, are also contradictory[7,8,18]. In our study, the average NW values of the male ACL-injured were significantly smaller than the non ACL-injured, while NWI was not significantly different between the two groups. In the same comparison in females, NW and NWI were significantly smaller in the ACL-injured than the non ACL-injured. We discovered that the narrow NW could be a risk factor in men and women. In case of narrower NWI, it could be another risk factor in female. The difference methods to measure the condylar notch and 2-dimensional structures, instead of 3-dimentional structures, were the limitation of our study. Therefore, more advanced 3-dimensional research method showing more precise anatomy is considered to be needed.

One of our hypotheses is that there would be differences in bony morphology between men and women. Murshed et al.[19] showed that men had much larger size of the distal femur morphology than women, and our study also showed the same result. Vrooijink et al.[20] showed that significant differences were found for bicondylar width ($p=0.001$), medial condylar width ($p=0.002$), and lateral condyle width ($p=0.002$) between male and female subjects. Stijak et al.[14] showed that the width of male intercondylar notch was greater with statistical significance than the width of female intercondylar notch. Male with greater width of intercondylar notch have wider ACL than female. There were other studies reporting that men possessed larger volume of condylar than women[9-12]. Male knee bony morphology was larger than female in our finding. It was the same as NW, which means the absolute size of NW in female is smaller than in male. This difference cannot statistically support the idea of the associations with ACL injury and the size of female bony morphology.

The second hypothesis was that there would be differences in bony morphology between the ACL-injured and the non ACL-injured between the different genders. Vrooijink et al.[20] compared MRI images of 45 subjects, with two independent observers, to analyze the bony morphology of ACL injured and the non ACL-injured groups. The bicondylar width ($p=0.002$) and medial condyle width ($p=0.008$) of male groups, and the bicondylar width ($p=0.009$) and lateral condyle width ($p=0.002$) of females were significantly different in this study. Our finding was also the same as Sharon's. For instance, NW was significantly narrower in the ACL-injured for both men and women groups. Medial condyle width of the male ACL-injured was quite different from the non ACL-injured. The result of the MCW of our finding should be focused on. Vrooijink et al.[20] reported that the difference of the MCW in the male ACL-injured was significantly smaller, while our result was quite different from his. MCW in the ACL-injured was significantly greater than the non ACL-injured in the male groups. In case of the female groups, MCW in the ACL-injured was significantly greater in our finding. This suggests that the size of condyle affect the motor mechanics, and the size difference of the condyle could be the risk factor of ACL rupture, since the difference of condyle width affects the knee joint rotation, causing more rotations[19]. The reason why our result differed from Sharon's is thought to be due to unclear criteria for measurement method and differences among the races. Thus, further studies are needed to check this thought.

This study has several limitations. First of all, we didn't use power analysis before the study design. Second, there was no consideration of the relationship between the age and the ACL (non ACL)-injuries. Third, 2-dimensional MRI measurement could not produce better images than the ones which 3-dimensional MRI might have produced. If possible to use better technical methods to get the values of morphology, there must be some significant different raw data. Last, measuring methods and its values of bony morphology and structures could not be the universal way.

Conclusions

The study shows the differences in bony morphology between men and women, and significant differences in bony morphology between the ACL injured and the non ACL-injured groups. In addition, there was one more significant difference at NW, NWI between the ACL injured and the non ACL-injured in female. The MRI measurement was proven to be effective, and orthopedic surgeons need to be more cautious when seeing and diagnosing, especially, female outpatients with small NW, NWI in MRI, because patients with small NW, NWI tend to have higher possibility of ACL injuries.

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