

Using Femoral Notch Width Index and Medial Condyle-to-Lateral Condyle Ratio (M:L ratio) as Predictors in Subjects Prone to Anterior Cruciate Ligament Injury (ACL) Injury : An MRI Study

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Abstract

Purpose: This study was done to determine whether a) there is a correlation between the Notch Width Index (NWI) and notch volume, as measured by Magnetic Resonance Imaging (MRI), in patients with ACL-injured and non-ACL injured knees, b) there is a difference in NWI between patients with and without anterior cruciate ligaments tear, c) there is a relationship between ACL diameter, angle of ACL inclination and ACL injury and d) there are differences in distal femur morphology between the ACL-injured and non-ACL injured knees.

Materials and methods: In this study, 59 ACL-injured patients and 59 match-control ACL-intact patients were enrolled. MRI was used to measure the notch width, notch height and condylar widths. The thickness of ACL and ACL angle of inclination were also measured.

Results: Statistically, Notch Width Index (NWI) (0.47 +/- 0.07 vs 0.43 +/- 0.05, p < 0.05) and Medial-condyle to-lateral condyle ratio (M:L ratio) (1.07 +/- 0.11 vs 1.02 +/- 0.09, p = 0.023) were all significantly greater in the ACL-ruptured group compared to the ACL-intact group. However the ACL angle of inclination from the vertical axis is statistically significantly smaller in the ACL-injured group compared to the ACL-intact group (30.729 +/- 6.147 deg vs 43.339 +/- 12.950 deg, p < 0.0001).

In both the ACL-injured and ACL-intact groups, the Notch Width (NW), Notch Height (NH) and Notch Volume (NV) measurements were all statistically significantly greater in males compared to females. In both ACL-injured and ACL-intact groups, Notch width indices showed no statistical significant difference between the sexes.

Conclusion: In this MRI study, a high femoral notch width indices and high medial condyle-to-lateral condyle ratio (M:L ratio) serve as accurate predictors in subjects prone to ACL injury. The MRI findings can guide future routine radiological or ultrasound screening of ACL-injury prone knees.

Background

ACL is one of the most important and commonly injured ligaments in the knee. It originates from the posteromedial surface of the lateral condyle of the femur and inserts onto the anterior part of the proximal tibial intercondylar area. ACL injury can alter the biomechanics of the knee and cause subsequent secondary complications like osteoarthritis and chondromalacia.

Most ACL injuries are of the non-contact type. Many studies have investigated constitutional and physical properties of the ACL. The contribution of gender, diameter, volume and cross-sectional area of the ACL to ACL strength has been well established. Correlation between body weight, height and age to ACL strength has also been well studied.

However, there have been very few studies looking into how Notch Width Index (NWI) and notch volume would contribute to ACL injury. This study utilised MRI to measure notch width, notch height, notch width index, medial condyle-to-lateral condyle ratio and angle of ACL inclination to the vertical axis and to evaluate their impact on ACL injuries in the respective knees.

Materials and Methods

Subject population

This is a cross-sectional study performed in late 2010. All patients giving informed consent were from The Stadium Sports Medicine Clinic, Moore Park, Sydney.

The patients who satisfied the following inclusion criteria were studied between 1/1/2010 and 30/6/2010:

- a) Subjects in whom ACL injury had been diagnosed in MRI
- b) Self-reported non-contact ACL injury
- c) Subjects who were referred for knee MRI

The exclusion criteria were:

- a) Patients with morphologic knee anomalies
- b) Patients with open growth plates
- c) Patients with a history of prior knee ligament reconstruction (including ACL, meniscus and PCL) or notchplasty
- d) Patients with a history of distal femoral, proximal tibial or patellar fractures and
- e) Patients with knee arthritis (Grade 3 outerbridge or higher) with associated osteophytes seen on radiographs, MRI or arthroscopy. [1]

Ultimately, 118 patients were selected for the study.

MRI measurement

MRI examinations were performed using a GE Sigma 1.5T system. Sagittal 3D-SPGR MRI images with voxel size of 0.055cm x 0.15cm were obtained. The subjects were placed in supine position and MRI examinations were performed on the affected knees of interest.

The MRI technique of measurement was performed as in Charlton’s study [2], MRI Measurements (Figure 1 to Figure 3) of intercondylar height, epicondylar width –line A , Notch Entrance Width (NW)-line F , Bicondylar Width (BCW), Medial Condyle Width (MCW)-line C and Lateral Condyle Width (LCW)-line B at the level of popliteal sulcus and medial-to-lateral condyle ratio (M:L ratio), Notch Height (NH) were taken from 59 subjects with ACL injury and the other 59 subjects without ACL injury. We calculated Notch Width (NWI) Index from absolute measurements. The NWI is the width of the femoral inter condylar notch divided by the width of the femoral condyles.



Figure 1: Line A: Epicondylar Width; Line B: Lateral Condyle Width; Line C: Medial Condyle Width; Line D: Lateral Condyle Height; Line E: Medial Condyle Height; Line F: Notch Width



Figure 2: Line G: Notch Height

We determined the course of the ACL, the thickness of the ACL at mid-length and the angle of inclination of ACL to the vertical axis on sagittal plane MRI and the intercondylar notch configuration on the coronal plane magnetic resonance images in 59 adult cruciate ligament-intact knees (37 males, 22 females ; age range, 15 to 59 years) and in 59 adult cruciate ligament-injured knees (39 males, 20 females; age range, 15 to 59 years old). The intercondylar notch widths were measured at the notch entrance.

Statistical analysis

The Pearson correlation coefficients between a) the NWI and notch volume and b) NH and notch volume, were calculated.

An independent t test was performed to determine the differences in NWI and notch volume between male and female specimens, in both the ACL intact and ACL injured groups. The differences in medial-to-lateral condyle ratio and in the angle of inclination of ACL were also compared, for both the ACL injured and ACL intact group, using the independent t-test.



Figure 3: Line H: ACL; Angle I: Angle of Inclination subtended by the ACL and Vertical Axis

Table 1

	NW	NWI	NH	NVolume
ACL Rupture Group	M > F p = 0.011	M ~ F p = 0.219	M > F p = 0.007	M > F p = 0.001
ACL Intact Group	M > F p < 0.001	M ~ F p = 0.116	M > F p = 0.002	M > F p < 0.001

(NW – Notch Width, NWI – Notch Width Index, NH – Notch Height, M:L Ratio – Medial Condyle to Lateral Condyle Ratio , ACL-R – ACL-Injured Group, ACL-I – ACL Intact Group)

Table 2

	M:L Ratio	ACL Angle Inclination
ACL Rupture Group	M ~ F p = 0.293	M ~ F p = 0.840
ACL Intact Group	M ~ F p = 0.420	M ~ F p = 0.122

(NW – Notch Width, NWI – Notch Width Index, NH – Notch Height, M:L Ratio – Medial Condyle to Lateral Condyle Ratio , ACL-R – ACL-Injured Group, ACL-I – ACL Intact Group)

Results

In the ACL-injured group, Notch Width was found to be significantly wider in men than in women (24.23 +/- 2.56 mm vs 22.45 +/- 2.2 mm, p = 0.011). Notch Height was also found to be significantly higher in men than in women. (32.18 +/- 3.87 cm vs 29.05 +/- 4.55 cm, p=0.008).

In the ACL-intact group, Notch Width was also found to be significantly wider in men than in women (24.54 +/- 2.50 mm vs 20.59 +/- 2.15 mm, p < 0.001). Notch Height was also found to be significantly higher in men than in women. (32.41 +/- 4.91mm vs 28.45 +/- 3.61mm, p = 0.002).

However, there was no significant difference in Notch-Width between the ACL-injured group and ACL-intact group (23.63 +/- 2.57 mm vs 23.07 +/- 3.04 mm, p = 0.283). There was also no significant difference in Notch-Height between the ACL injured group and ACL intact group (31.12 +/- 4.34 mm vs 30.58 +/- 4.69 mm, p = 0.516).

Notch-Width Index was found to be significantly larger in the ACL-injured group compared to the ACL-intact group (0.47 +/- 0.07 vs 0.43 +/- 0.05, p = 0.003).

Within the ACL-injured group, men had significantly larger notch volumes than women (780.00 +/- 135.17 mm³ vs 584.59 +/- 86.26 mm³, p = 0.0008), but there was no significant difference in NWI between men and women. (0.46 +/- 0.07 vs 0.48 +/- 0.07, p = 0.219).

Similarly, within the ACL-intact group, men had significantly larger notch volumes than women (779.05 +/- 122.62 mm³ vs 654.40 +/- 136.77 mm³, p < 0.001), but there was no significant difference in NWI between men and women. (0.44 +/- 0.06 vs 0.42 +/- 0.05, p = 0.116).

Table 3

NW	NWI	NH	M:L Ratio	ACL Angle of Inclination
ACL-R ~ ACL-I	ACL-R > ACL-I	ACL-R ~ ACL-I	ACL-R > ACL-I	ACL-R < ACL-I
p = 0.283	p = 0.003	p = 0.516	p = 0.023	p < 0.001

(NW – Notch Width, NWI – Notch Width Index, NH – Notch Height, M:L Ratio – Medial Condyle to Lateral Condyle Ratio , ACL-R – ACL-Injured Group, ACL-I – ACL Intact Group)

Notch-Width Index was found to be positively correlated to the three-dimensional notch volume (Pearson correlation coefficient, R= 0.258, p < 0.005) Notch-Height was also found to be positively correlated to the three-dimensional notch volume (Pearson correlation coefficient, R = 0.512, p < 0.001).

The medial-to-lateral condyle ratio (M : L ratio) is significantly higher in the ACL-injured group compared to the ACL-intact group (1.07 +/- 0.11 vs 1.02 +/- 0.09, p = 0.023).

Within the ACL-injured group, there was no statistical significant difference in the medial-to-lateral condyle ratio (M : L ratio) between male and female subjects. (1.05 +/- 0.09 vs 1.08 +/- 0.14, p = 0.293).

Within the ACL-intact group, there was no statistical significant difference in the medial-to-lateral condyle ratio (M : L ratio) between male and female subjects. (1.03 +/- 0.09 vs 1.01 +/- 0.07, p = 0.783).

The thickness of the ACL was not significantly different in both the ACL-injured and ACL-intact groups. However the angle of inclination of ACL ligament to the vertical axis was significantly more acute in the ACL-injured group compared to the ACL-intact group(30.73 +/- 6.15 deg vs 43.34 +/- 12.95 deg, p<0.001).

Discussion

The most important finding was that there was significant difference in bone morphology between the ACL-injured and ACL-intact group. Notch Width Index (NWI) and medial condyle-to-lateral condyle ratios (M:L ratio) were statistically significantly higher in ACL-injured groups.

However, there was no statistical significant differences in Notch Width (NW) and Notch Height (NH) between the ACL-intact and ACL-injured groups. Studies by Van Erk CF and Shelbourne showed the opposite findings [3,4]. Domzalski et al [5], in the comparison of ACL intact and ACL injured using MRI images, found that intercondylar NW of the ACL-intact knee (mean = 26.91 mm) and the ACL injured group (mean = 24.15 mm) to be significantly different (p<0.001).

It can be inferred therefore it is the relative proportions of the distal femoral morphology, in particular the notch width index (NWI) and M:L ratios, rather than the absolute measurements, which predict ACL injuries in an individual.

In both ACL-injured and ACL-intact groups, our study showed that the notch-width, notch-height and notch volumes were significantly greater in men than in women. This is in accordance

with Murshed et al. results [6] which showed that men had much larger size of the distal femur morphology than women. This is also supported by Chandrashekar et al [7].

However in both the ACL-injured and ACL-intact groups, there was no statistical significant differences in NWI, M:L Ratio, ACL angle of inclination between the men and women. Our results are in contrast to the findings by Shelbourne KD and Stijak L [8,9].

Vrooijink et al. [16] 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. [10] also showed that the width of male intercondylar notch was statistical significantly greater than the width of female intercondylar notch.

We found that NWI notch-width index (NWI) was significantly greater in the ACL-rupture group and this increases the risk of ACL rupture. Our findings differed from Jin finding [11] which suggested the contrary. This is also in contrast to Anderson et al. [10] findings which suggested that a smaller condylar notch increases the incidence of ACL rupture. This is also in contradistinction to Lombardo's finding [12] that there was no association between critical notch stenosis and predisposition to ACL injury.

Our study showed that a larger Notch-Width Index (NWI) correlates positively with a larger Notch Volume (NV). Similarly a larger Notch Height (NH) correlates positively with a larger NV. This is in contrast with Carol F. van Eck findings [13] which found no positive correlation between NWI and NV. A larger NWI would translate into smaller contact surface areas between the femoral condyles and tibial plateau and this meant increasing translational and rotatory instability.

Medial condyle-to-lateral condyle ratio (M:L ratio) is also statistically and significantly greater in the ACL-injured groups. Similar to NWI, it is the relative proportion of the medial condyle to lateral condyle in an individual, rather than the absolute measurements, which predict ACL rupture. In this study, the width of the medial condyles were consistently found to be larger than the width of the lateral condyles in the ACL-ruptured group.

This suggested that the sizes of condyles affected the motor mechanics and that the discrepancy in condylar sizes increases the magnitude of unstable rotation.

Medial Condylar Width (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.

The angle of inclination of ACL ligament was also found to be greater in the ACL-ruptured group compared to the ACL-intact group. The result was statistically significant. However, there was no statistical significant difference in the thickness of ACL between ACL-ruptured and ACL-intact groups. This is in contrast to Paraq et al findings [14] which indicated that a small anterior cruciate diameter is a predictor of subjects prone to ligament injuries.

In conclusion, this MRI study showed that a high femoral notch width indices and high medial condyle-to-lateral condyle ratio (M:L ratio) serve as accurate predictors in subjects prone to ACL injury [15]. The MRI findings can guide future routine radiological or ultrasound screening of ACL-injury prone knees.

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