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A radiographic analysis of the relationship between the size and shape of the intercondylar notch and anterior cruciate ligament injury

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Abstract Notch-view radiographs were obtained from 108 persons with anterior cruciate ligament (ACL) injuries (55 women, 53 men) and 186 with intact ACL (94 women, 92 men). Notch width, femur width, and notch width index were determined from each of the 294 radiographs. The notch was also categorized as either A-shaped or non-A-shaped. Intrarater and interrater reliability ranged from 0.82 to 0.99 for notch width and femur width, respectively. Reliability within and between raters for the classification of notch shape ranged from 0.80 to 1.0. Notch width was significantly influenced by a 10° change in knee angle when repeated radiographs were taken. Femur width was not affected by knee angle across this range. Analysis revealed a higher proportion of A-shaped notches among women than men. However, notch shape was not related to injury status. Results showed a smaller notch width and notch width index in ACL-injured patients regardless of notch shape or gender. A-shaped notches were smaller than non-A-shaped notches regardless of injury status or gender. Both notch width and notch width index were found to be significant indicators of ACL injury. Knowledge of the shape of the notch added no useful information in differentiating patients based on injury status. Thus, regardless of gender, individuals who possess smaller notch dimensions appear to be at greater risk of injury than individuals with larger notches.

Keywords Intercondylar notch width · Anterior cruciate ligament · Radiographic measurements · Reliability

Introduction

Several reports have noted a higher incidence of anterior cruciate ligament (ACL) ruptures among female athletes than their male counterparts [2, 3, 6, 11, 14, 15]. Using the National College Athletic Association Injury Surveillance System, Arendt and Dick [2] reported the incidence of ACL ruptures among male and female athletes for several sports. Over a 5-year period from 1989 to 1993, women showed an ACL injury rate that was 2.4 and 4.1 times higher than that of men in soccer and basketball, respectively. Several intrinsic anatomical differences have been identified that may play a part in the increased incidence of ACL tears in women, including lower extremity alignment, ligamentous laxity, hormonal influences, and intercondylar notch shape and width. The majority of the studies in this area have focused on the gender-specific differences in intercondylar notch dimensions.

At present there are conflicting reports regarding the relationship between intercondylar notch width (NW) and the risk of ACL injury. The notch width index (NWI), defined by Souryal et al. [20] as the ratio of the width of the intercondylar notch to the width of the distal femur at the level of the popliteal groove on a tunnel view radiograph, has been used most often to characterize the size of the intercondylar notch. Using such an index, LaPrade and Burnett [12] obtained radiographs from 213 athletes prospec-

tively. No differences were found in NWI between men and women; however, six of the seven ACL injuries that occurred during the 2-year period were to knees with a narrow notch (NWI <0.20). Several other authors have suggested a similar relationship between NWI and ACL injury [13, 20, 21].

Others have concluded that NWI alone is not the critical factor to be considered when evaluating the risk of ACL injury. Teitz et al. [23] retrospectively compared NWI in 40 men and 40 women. No difference in NWI was found between genders or between ACL-injured and uninjured knees. The absence of a relationship between NWI and ACL injury has been reported by previous investigators [6, 7, 16]. Studies by Shelbourne et al. [18, 19] have suggested that the absolute measure of notch width itself is a more useful indicator for risk of ACL injury. Their findings show that intercondylar NW is narrower in women than in men, as well as in patients who sustain ACL tears than in uninjured controls. Previous work supports these conclusions [5, 13], leading some authors to suggest that the narrower notch width is reflective of a smaller and weaker ligament [16, 18, 22].

The only study to address the potential influence of notch shape on the incidence of ACL injury was carried that by Anderson et al. [1]. From computed tomographic images of distal femurs these authors created composite tracings of the intercondylar notch in order to characterize their shape. In general five shapes were identified that varied along a continuum from an inverted U to a crested wave-shaped notch with a flattened superior medial corner. The authors claimed that only 6% of uninjured knees had a wave-shaped notch, while 35% of patients with unilateral ACL injured knees displayed such a characteristic. No effort was made to analyze these data statistically, and the reliability of their categorization scheme was not addressed.

The controversy regarding the relationship between notch configuration and ACL injury may be related in part to the varying measurement techniques and questionable reliability of the methods used. Despite an effort to use anatomical structures when measuring notch width and shape, these measures are still somewhat ambiguous. For example, different authors have used different anatomical references when measuring notch dimensions from radiographs. The angle of knee flexion at the time that radiography is performed has not been rigorously controlled, and the effect this may have on radiographic measurements has not been examined. Further, the error inherent in the measurement, whether taken by the same or different examiners, has not been reported.

The purposes of this paper were threefold. First, the relationship between ACL injury and the measurements of NW, NWI, and notch shape were determined. Secondly, issues concerning inter- and intrarater reliability of radiographic measurements, including the categorization of notch shape were examined. Finally, the influence of patient positioning on measurements of radiographic notch dimensions was explored.

Materials and methods

This retrospective analysis evaluated all of the notch-view radiographs taken on patients examined in a single outpatient orthopedic practice between 1990 and 1997. Upon review of patient records, radiographs were divided into four categories based on gender and ACL injury status. Initially, patients were chosen such that an equal number of radiographs were included in each of the four categories. This selection process yielded a total of 528 radiographs with 132 patients in each group.

Because one of the aims of the study was to examine the ability to obtain reproducible measurements of the dimensions of the intercondylar notch, the quality of each of these radiographs was assessed on an individual basis. In order to minimize extraneous sources of measurement error those radiographs found to have excessive shadowing in the area of the intercondylar notch or along the margins of the femur were judged to be of poor quality and were eliminated from further analysis. As a result of this screening process a total of 294 radiographs remained that were used in the study.

The final number of patients comprising each of the four categories was: 55 ACL-injured women, 53 ACL-injured men, 94 ACL-intact women, and 92 ACL-intact men. The median age of the patients at the time that radiographs were taken was 17 years (range 14–21). The self-reported mean height and weight of the patients was 174.2±10.4 cm and 72.7±18.2 kg, respectively. The majority of ACL injuries occurred while participating in basketball (42%) or American football (21%).

Radiographic procedures

All of the notch-view radiographs used in this study were taken using the technique described by Holmblad [9]. With this procedure, the patient is placed on the radiography table in a kneeling position with the feet extended over the table's edge so that the long axis to the tibia is parallel with the table. The film holder lies under the knee, parallel with the long axis of the tibia and centered with respect to the patella. The long axis of the femur is positioned to form approximately a 70° angle to the horizontal. The central ray is directed vertically to the film's midpoint.

Radiographic measurements

For all of the 294 radiographs remaining in the study femur width (FW), NW, and NWI were determined by a single investigator according to the method of Souryal et al. [20]. An illustration of the method used to obtain these measurements is shown in Fig. 1. A line was first drawn onto the radiograph that bisected the femur at the level of the popliteal groove and was parallel to a line connecting the two most distal points of each femoral condyle. The distance along this line between the medial aspect of the lateral condyle, and the lateral aspect of the medial condyle was recorded as the NW. FW was defined as the distance along this line between the outermost borders of the femur. The NWI was determined by dividing the measurement of NW by that of FW.

After the measurements were obtained, the investigator categorized the shape of intercondylar notch as either A-shaped (AS) or non-A-shaped (NAS). An AS notch is characterized by a significantly larger notch base and a narrowed roof. A NAS notch has a more rounded appearance, resembling an inverted horseshoe.

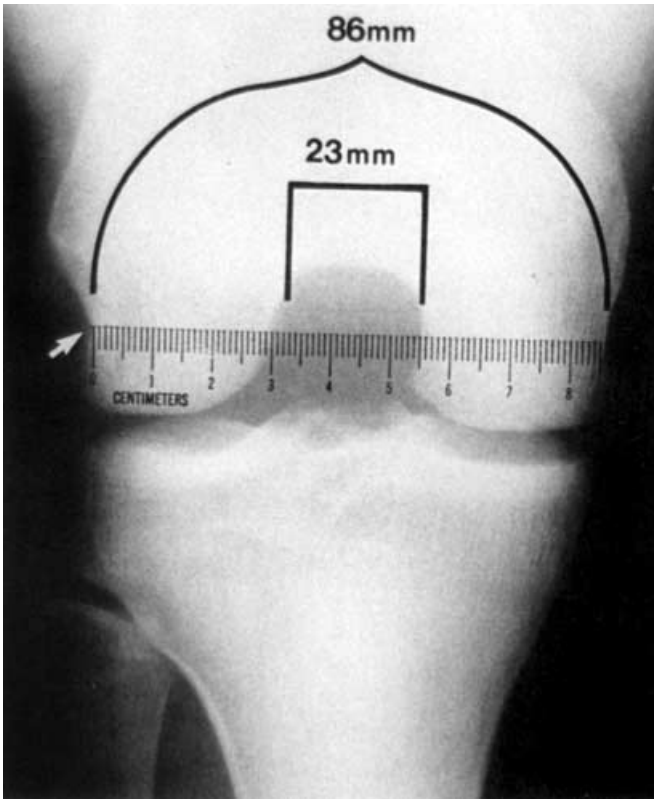

Fig. 1 Measurement of intercondylar notch width and femur width at the level of the popliteal groove. The ruler is placed parallel to the joint line. The narrowest position of the notch at the level of the ruler is measured. (From [20])

Measurement reliability

In order to assess intrarater reliability the same investigator repeated all of the measurements, including notch shape, on each of 20 randomly selected radiographs on three separate occasions. All lines were erased from the radiographs between measurement sessions. Interrater reliability was assessed by having a second investigator measure the same set of variables on a subset of 50 randomly selected radiographs.

Finally, to assess the effect of knee position on radiographic measurements, two additional notch-view radiographs were taken on each of ten healthy adult subjects. For the first radiograph the X-ray technician placed each subject in the standard position as described previously. Once the subject was appropriately positioned, a goniometer was used to measure the angle of the knee joint before the radiograph was taken. A second radiograph was obtained after repositioning the subject with the knee joint extended 10° from the original angle. The intercondylar NW, FW, and NWI were then measured by a single investigator from each radiograph.

Analysis

The χ^2 statistic was used to assess the relationships among notch shape, gender, and injury status. Separate three-way analysis of variance models were performed on the variables NW and NWI. The factors considered in each of these analyses were injury status, gender, and notch shape. Posthoc analysis was conducted for pairwise comparisons using Fisher's least significant difference procedure.

Backward stepwise logistic regression models were performed to determine the significant indicators of ACL injury. The two models considered contained either NW or NWI and notch shape, their respective interaction terms, height, and weight.

The κ statistic was used to assess intrarater and interrater reliability for the classification of notch shape (A versus non-A). The intraclass correlation coefficient ($ICC_{2,1}$) was calculated to estimate intrarater and interrater reliability for the measurements of NW and FW. In addition, the standard error of the measurement (SEM) was calculated to estimate the amount of error that can be expected when repeated measurements are taken by the same and different raters. The paired *t* test was conducted to determine the effect of knee angle on the radiographic measurements of FW, NW, and NWI. A *P* value less than 0.05 was used to indicate statistical significance.

Results

Reliability

Estimates of intrarater reliability for the measurement of NW and FW were 0.98 and 0.99, respectively ($ICC_{2,1}$). Based on the SEM, repeated measurements by the same individual can be expected to vary by only ±1.0 mm in NW and ±1.5 mm in FW. Interrater reliability was slightly lower for both NW and FW ($ICC_{2,1}$=0.82 and 0.98, respectively). Estimates of SEM showed that radiographic measurement of NW made by two different individuals may vary by as much as ±3.3 mm. The SEM for FW between two raters was ±2.0 mm. The κ values for the ability to classify the shape of the intercondylar notch were 1.0 and 0.80 for intrarater and interrater agreement, respectively.

Effect of positioning

Results indicated that a 10° change in knee angle between radiographs repeated on the same subjects produced significantly different measurements for both NW (*P*=0.034) and NWI (*P*=0.033). Measurements of FW were not affected by the change in knee angle.

Factors related to injury status

In the present sample a significantly higher proportion of AS notches was found among women (34.9%) than men (16.7%). However, notch shape was not significantly related to injury status since nearly the same proportion of AS notches was found among both ACL-injured (28.0%) and ACL-intact (24.7%) groups.

The analysis of NW demonstrated a significant main effect due to injury status as well as a significant interaction effect between gender and notch shape. Follow-up tests showed that smaller notches were found in ACL-injured patients regardless of notch shape or gender (see Fig. 2A). The mean NW was 18.9±4.0 mm in ACL-in-

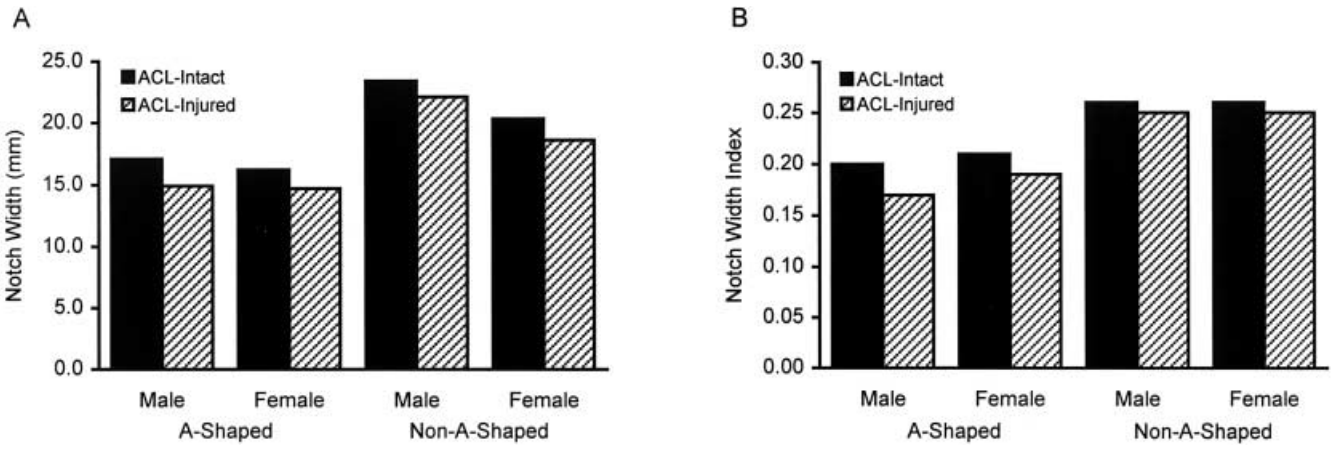

Fig. 2 Intercondylar notch width (**A**), and intercondylar notch width index (**B**) measurements based on ACL injury status, notch shape, and gender

jured patients and 20.7±3.9 mm in ACL-intact patients. In addition, AS notches were smaller than NAS notches in both men and women. A difference in NW between the genders was found only among NAS notches, with notches in women being significantly smaller than those in men. No such difference between the genders existed for patients with AS notches.

The analysis of NWI was similar to that described for NW in that we found both a main effect of injury status and an interaction effect between gender and notch shape. The results are displayed in Fig. 2B. Follow-up tests showed that on average ACL-injured patients had significantly lower NWIs than patients in the ACL-intact group. The mean NWI was 0.23±.04 in ACL-injured patients and 0.25±3.9 in ACL-intact patients. As with the analysis of NW alone, AS notches had a lower NWI than NAS notches in both men and women. In contrast to NW, differences in NWI between the genders were found only in AS notches, with the index in men being significantly smaller than that in women. No difference in NWI was found between men and women with NAS notches.

In the regression analysis (model 1) that included NW, notch shape, height, and weight only NW was identified as a significant indicator of injury status ($P<0.001$). Thus the inclusion of notch shape in the model did not provide additional information useful in differentiating between ACL-injured and ACL-intact patients. Similarly, only NWI was a significant indicator of injury status ($P<0.001$) in the analysis of regression model 2.

Discussion

Numerous studies have utilized radiographic measurements to examine the relationship between notch size and the risk of ACL injury [7, 12, 13, 17, 18, 19, 20, 21, 23]. However, none of these studies has reported the reliability of the techniques being used. In the present study radiographic measurements of NW and FW were found to be highly reliable both within and between examiners.

In this retrospective review of 294 radiographs, both NW and NWI were found to be smaller in ACL-injured than in ACL-intact patients. Thus individuals who possess smaller notch dimensions appear to be at greater risk of injury than those whose notch dimensions are larger. Because the number of injuries was chosen to be the same in both men and women, the relationship found between NW, NWI, and injury status is independent of gender. Since women tend to have smaller notch dimensions than men, this may partially explain their higher incidence of injury.

NW has been shown to be related to increased risk of ACL tear in several previous reports [5, 8, 13, 18, 19]. Good et al. [5] measured NW perioperatively in 93 knees and found that patients with both acute and chronic ACL tears had a mean NW (18.1 and 16.1 mm, respectively), which was smaller than that found in a group of cadaveric ACL-intact knees (20.4 mm). Using radiographic measurements similar to those described in the present study, Lund-Hanssen et al. [13] showed that female handball players with a NW of 17 mm or less were six times more likely to tear their ACL than those with notches wider than 17 mm. Using weight-bearing radiographs at 45° knee flexion, Shelbourne et al. [18] reported that NW measured at one-half notch height was narrower in women than men and in those with unilateral or bilateral ACL tears than in controls.

Herzog et al. [8] compared radiographic measurements of NW in a group of 20 ACL-deficient skiers to a similar group of uninjured subjects. This was the only study to show no difference in NW measurements between injured and uninjured knees. Given the limited sample size, however, the authors acknowledged that small differences in notch size may not have been detected.

Much less agreement exists regarding the relationship between NWI and ACL tear rate. Shickendantz and Weiker [17] derived eight different mathematical ratios of

notch size, including NWI, from radiographs of 29 patients with unilateral injury, 19 with bilateral injury, and 26 with no ACL injury. Statistical analysis revealed no significant differences between the three groups for any of the measurements taken. These findings have been supported in the previously mentioned works by Tietz et al. [23], LaPrade and Burnett [12], and Herzog et al. [8].

In contrast, the retrospective analysis by Souryal et al. [20] compared NWI among 41 patients with bilateral ACL tears, 50 patients with unilateral ACL tears, and 50 normal knees. The authors reported a significant difference between the bilateral group and both the normal and unilateral ACL-injured groups. There was no difference between the normal and unilateral ACL-injured groups. In a later prospective study Souryal and Freeman [21] reported that women have a smaller NWI than men, and that athletes who sustain noncontact ACL injuries have a smaller NWI than athletes who did not become injured.

The rationale for utilizing NWI has been to eliminate errors due to magnification and to normalize to patient size. The NWI assumes that both NW and FW are related to patient size. However, Shelbourne et al. [19] have shown that FW increases in proportion to patient height, whereas NW is not directly related to height in either men or women. Subsequent analysis of the results from the present study support the findings by Shelbourne et al. [19]. A much stronger correlation was found between FW and body height (r=0.73) than between NW and body height (r=0.42). Therefore the NWI may not be an effective method of normalizing patient size either within or between sexes. These findings may explain some of the inconsistency of the results in the index-referenced literature.

Information regarding the shape of the notch does not appear to be useful in differentiating between patients based on injury status since the same proportion of AS notches was found among both injured and ACL-intact knees. Even though women showed a higher incidence of AS notches than men, the narrowness of the notch in women rather than the shape was the important factor determining injury status. These results therefore do not support the suggestion by Anderson et al. [1] that notch shape is related to ACL injury.

In ten healthy adult subjects the angle of knee flexion during the acquisition of notch-view radiographs was shown significantly to influence the resultant measures of notch dimensions. The lack of a standardized knee position could explain much of the variability in notch dimensions reported in the literature.

Some authors have suggested the use of a template for positioning the knee during notch-view radiographs. LaPrade and Burnett [12] chose to take radiographs with subjects positioned on hands and knees with their knees flexed to 45°. Based on their pilot work, the authors found that any amount of abduction-adduction of the lower leg caused distortion of the margins of the intercondylar notch. Therefore a template was used to position the knee in a standardized degree of flexion and prevent any deviation from the neutral position. Such variations in patient positioning may have been responsible for the large number of radiographs (45%) that were excluded from analysis in the present study due to poor quality. Although the precise knee position was not controlled in the present study, the use of such a standardized knee position would have made the differences between ACL-injured and ACL-intact patients even more apparent since the effect would be to further reduce the sample standard deviations.

Conclusions

Based on the methods used here, radiographic measurements of NW and FW are reliable both within and between examiners. The shape of the notch can also be reliably categorized, but the value of this type of information is questionable since the width of the notch rather than its shape appears to be more important in determining injury status. We recommend the use of a template to position the knee during acquisition of notch-view radiographs whenever quantitative comparisons are to be made within and between patients.

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