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Femoral Intercondylar Notch Stenosis and Correlation to Anterior Cruciate Ligament Injuries

A Prospective Study*

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ABSTRACT

To evaluate the possible relationship between femoral intercondylar notch stenosis and anterior cruciate ligament injuries in pivoting and cutting sports, a 2-year prospective study was performed on intercollegiate athletes at a Division I university. Daily practice times and athlete participation in practices and games were recorded for each sport during the 2-year period. Bilateral intercondylar notch view radiographs were taken of all athletes enrolled in the study. The notch width index, a ratio that measures the width of the anterior outlet of the intercondylar notch divided by the total condylar width at the level of the popliteal groove, was measured for each knee. A total of 213 athletes, representing 415 anterior cruciate ligament-intact knees, were enrolled in the study. There were 7 anterior cruciate ligament tears. Statistical analysis demonstrated a correlation between femoral intercondylar notch stenosis and anterior cruciate ligament injuries. No statistical difference was found between the sex of the athlete and notch width indices or rate of anterior cruciate ligament tears. Athletes with intercondylar notch stenosis appear to be at increased risk for noncontact anterior cruciate ligament injuries.

There is no ideal substitute for an athlete's normal ACL. Although numerous reconstructive procedures have been devised to treat an ACL tear,[3,7,11,17,28,35] little knowledge is available on the prevention of tears and the preservation of normal ACLs in athletes.

Up to this point, no effective means of predicting or preventing ACL injuries have been devised. Previous retrospective studies have suggested that there is a relationship between femoral intercondylar notch stenosis and ACL tears.[2,32] If this relationship exists, it could be an important variable to identify athletes at risk for ACL tears. Further investigation of this relationship could provide information on the prevention of ACL tears in those athletes found to be at increased risk. This study was designed to determine if the correlations suggested by retrospective studies could be validated prospectively. We chose to determine if there is a relationship between intercondylar notch stenosis and ACL tears in athletes participating in pivoting and cutting sports.

MATERIALS AND METHODS

This prospective study population consisted of varsity intercollegiate athletes in football, ice hockey, basketball, soccer, gymnastics, and volleyball at a Division I university. Daily practice times and athlete participation in practices and games for each sport were recorded by athletic trainers during a 2-year period. All participating athletes signed an informed consent form. In addition, the study protocol was approved by the Institutional Review Board at the participating institution. A total of 213 athletes, representing 415 ACL-intact knees, were enrolled in the study. Athletes with either an ACL-deficient knee, as determined by a preseason screening physical examination or who had undergone an ACL reconstruction had that knee excluded from the study. Athletes enrolled in the study had bilateral intercondylar notch view radiographs taken.

To obtain the most reproducible radiographic parameters for the femoral intercondylar notch view, radiographs

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were obtained of cadaveric knees and the uninjured knees of volunteers in various degrees of flexion and abduction-adduction. The primary authors of previous studies of this nature were also consulted to obtain their radiographic methods (A. F. Anderson, personal communication, 1989; T. O. Souryal, personal communication, 1989). Radiographs taken of cadaveric femurs revealed that any amount of abduction-adduction caused distortion of the outlines of the intercondylar notch. We chose to take a notch view radiograph with the subjects on their hands and knees and their knees flexed to 45°. The camera-to-housing distance was 1.12 meters (44 inches), and the knee was in neutral rotation. A template was then constructed to standardize all radiographs (Fig. 1), prevent any deviation from the neutral position, and to maintain the knees in a standard amount of flexion. Five volunteers had two notch radiographs taken both with and without the use of the template. No measurement differences were found between notch radiographs for each subject when a template was used, but there was a statistical difference when these were compared with radiographs where the template was not used (Wilcoxon signed rank test, $P = 0.03$). The same viewbox, radiolucent ruler, and radiology technician were used for all radiographs in this study.

Cadaveric femurs were also used to identify the outline of the anterior and posterior intercondylar notches on plain radiographs. Radiopaque threads were secured to the outlines of the anterior and posterior intercondylar notches to represent these outlines on radiographs (Fig. 2). These radiographs confirmed the findings of Good et al.[12] (that the anterior notch is narrower than the posterior notch) and allowed us to identify intercondylar notch landmarks accurately.

A notch width index (NWI) was measured for each knee. The NWI, as described by Souryal et al. (Ref. 32; T. O. Souryal, personal communication, 1989), is the ratio of the width of the anterior outlet of the femoral intercondylar notch divided by the total condylar width at the level of the popliteal groove. This ratio eliminates variations in magnification that may occur if the radiographic technique is not standardized (Fig. 3).

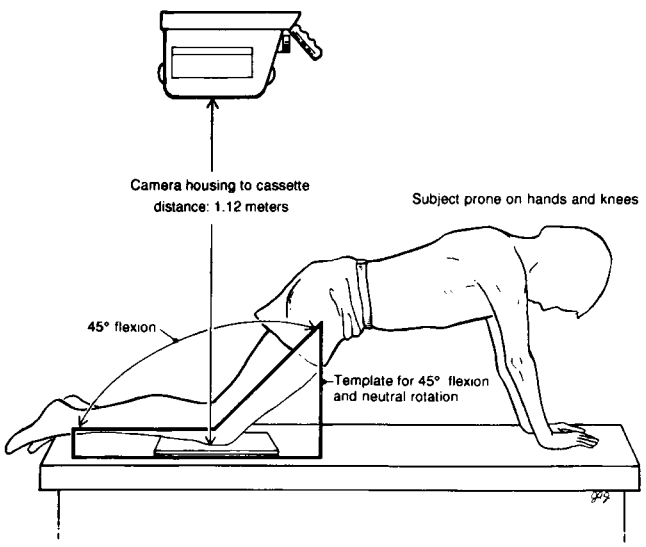

Figure 1. Standardized method of obtaining intercondylar notch radiographs on athletes in this study.

Figure 2. Radiopaque thread secured to outline of posterior intercondylar notch on this radiograph. The anterior notch is visibly narrowed.

Fisher's exact test, Student's t-test, Mantel-Haenszel inference, and Wilcoxon signed rank test statistical analysis were performed to analyze the data in the study. The 0.05 level of significance was used to accept or reject the null hypothesis tested.

In addition, four cadaveric knees were dissected anteriorly to expose the contents of the intercondylar notch. Steinmann pins were inserted perpendicular to the femur and tibia. The tibia was rotated with the knee in various degrees of flexion to determine qualitatively if impingement would occur on the ACL.

RESULTS

Analyses of the NWIs revealed an average of 0.243 ± 0.039 (1 SD). Breakdown of the NWI by sex showed an average NWI of 0.244 ± 0.036 for men and 0.238 ± 0.037 for women. The average NWI for all athletes and by sex did not change when only noninjured athletes were analyzed in each category. The average NWI for all injured athletes was 0.193 ± 0.013 (range, 0.17 to 0.21), with an average of 0.188 ± 0.013 for men and an average of 0.200 ± 0.010 for women.

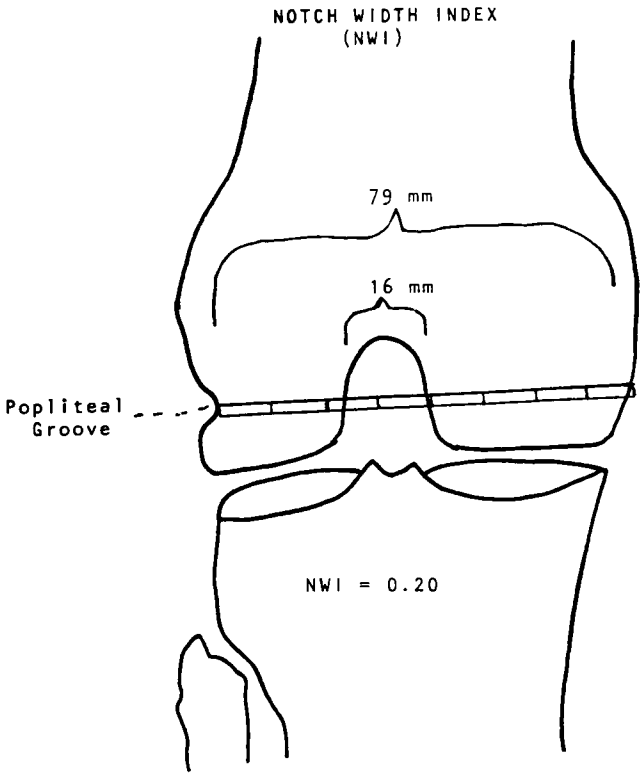

Figure 3. Outline of technique of measurement of the NWI. This ratio measures the width of the anterior outlet of the intercondylar notch divided by the total condylar width at the level of the popliteal groove.

Athlete enrollment by sport was recorded (Table 1). The total hours of participation for all knees was 87,705.5 practice hours and 9387 game exposures (number of games in which they participated). For injured knees, participation hours were 1611.25 practice hours and 228 game exposures. The amount of athlete participation on injured knees was affected by season-ending injuries and rehabilitation protocols.

There were seven ACL tears for athletes enrolled in the study (four men and three women) (Table 1). Six ACL tears occurred during cutting or planting maneuvers and one (in a stenotic knee) occurred through direct contact. The latter injury occurred in a hockey goalie who suffered a valgus force to his knee in a minor collision at the goal crease while his tibia was externally rotated on his femur.

Comparing the NWI of injured versus noninjured knees revealed a statistically significant correlation between intercondylar notch stenosis and ACL tears in contact and cutting sports (Student's t-test, $P = 0.0008$). There was no statistical difference between the NWI for men and women (Student's t-test, $P = 0.20$), but there was a trend toward women being more predisposed to ACL tears than men (Fisher's exact test, $P = 0.10$).

Results of cadaveric dissections demonstrated a qualitative difference between placing the knee in external or internal rotation. When the knee was externally rotated past 15° and flexed to between 30° and 40°, impingement occurred at the midportion of the ACL. No similar impingement was noted with internal rotation of the tibia on the fixed femur.

TABLE 1
Distribution of athletes and anterior cruciate ligament tears by sport

Sport	No. of athletes	Number of ACL tears
Football	101	1
Ice hockey	29	1
Soccer	22	0
Men's basketball	15	1
Softball	14	2
Women's basketball	10	1
Volleyball	8	1
Men's gymnastics	8	0
Women's gymnastics	6	0
Total	213	7

Previous retrospective studies have suggested that intercondylar notch stenosis is present when the NWI is less than or equal to 0.20 (Refs. 2, 32; T. O. Souryal, personal communication, 1989). Normal knees would then have an NWI of 0.21 or greater (Fig. 4). According to these criteria, we found 40 knees to be stenotic, with an NWI not greater than 0.20, and 375 nonstenotic knees. Six of the ACL tears occurred in stenotic knees and 1 in a nonstenotic knee. If this ratio breakdown proves to be true, a statistically significant difference was found between the rate of ACL tears in stenotic and nonstenotic knees (Fisher's exact test, $P < 0.0001$). In addition, Mantel-Haenszel inference would indicate that the odds of an ACL tear occurring in a stenotic knee are 66 times higher (range, 20 to 218, 95% confidence interval) than in a nonstenotic knee.

DISCUSSION

Only recently have studies been directed to the possible role played by the intercondylar notch in ACL ruptures.[2,10,16,21,23,24,32] Some authors have observed during ACL reconstruction that the intercondylar notch is stenotic in many patients.[6,16,21,28] Several authors recommend routine notchplasty to widen the anterior intercondylar notch during ACL reconstruction.[11,12,15,21,27] Retrospective studies have also demonstrated a relationship between anterior intercondylar notch stenosis and ACL tears.[2,32] The NWI was developed by Souryal et al.,[32] who found that athletes with bilateral ACL injuries had a significant narrowing of their intercondylar notches. Anderson et al.[2] demonstrated a significant narrowing of the anterior intercondylar notch outlet in patients with unilateral and bilateral ACL tears. Good et al.[12] also found that patients sustaining an acute tear of the ACL have a smaller intercondylar notch width than those with uninjured knees. Our prospective study demonstrated that there is a statistically significant correlation between anterior intercondylar notch stenosis and ACL injuries in pivoting and cutting sports. While the findings of this study may not identify all athletes who may sustain an ACL tear, especially in contact situations, it does identify a subset of athletes who may be at increased risk to sustain this serious injury.

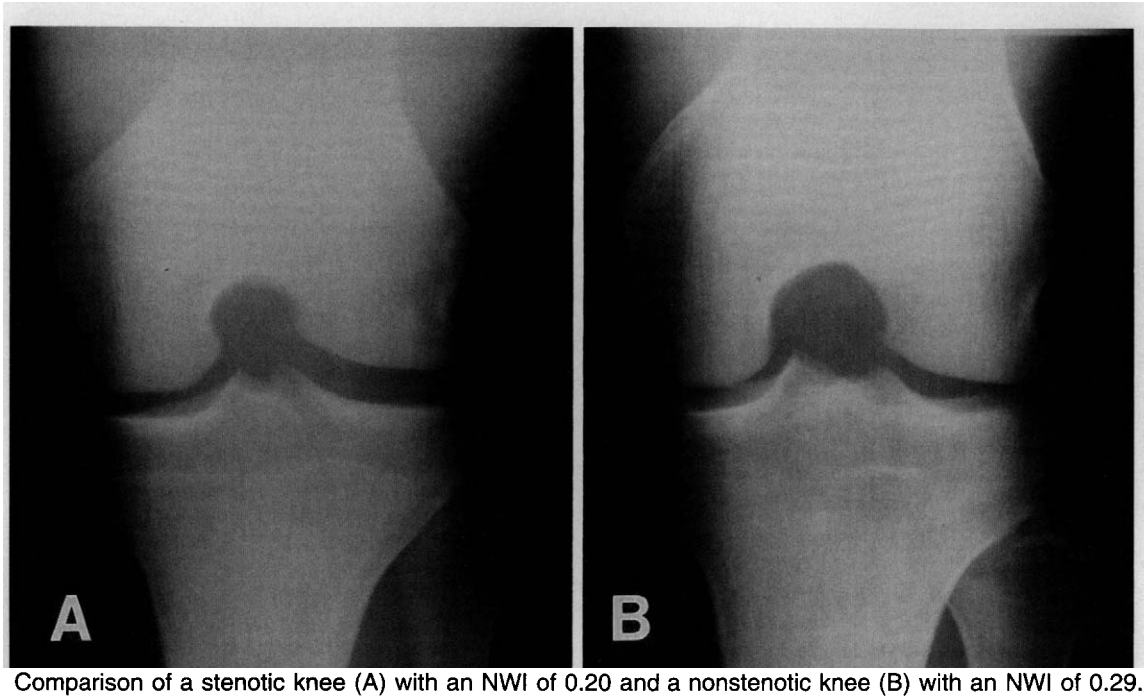

Figure 4. Comparison of a stenotic knee (A) with an NWI of 0.20 and a nonstenotic knee (B) with an NWI of 0.29.

Although we evaluated both contact and noncontact sports, the majority of the ACL tears in this study (six of seven) occurred in noncontact events. In addition, while this study did not find a statistically significant difference between sex and the average NWI or rate of ACL tears, it must be remembered that the *P* value of 0.05 is an arbitrary convention for the level of statistical significance. Since statistical significance may not be the same as clinical importance, further studies may prove these relationships to have clinically important differences since the *P* value was relatively close to 0.05.

When we established our study protocol, we planned to analyze our data based on the results of previous studies that suggested intercondylar notch stenosis is present with an NWI $\leq$0.20 (Refs. 2, 32; T. O. Souryal, personal communication, 1989). However, once we had compiled our data, we realized that while comparing stenotic and nonstenotic knees yielded statistically valid results, the designation of the NWI ratio of 0.20 as representing notch stenosis was based on qualitative findings rather than a true quantitative analysis. Keeping this in mind, we based our analysis on the comparison of the NWI for all athletes compared with the NWI of injured athletes. We found the NWI of 0.20 to be outside the range of 1 SD of the mean for all athletes. While these data add support to the suggestion that notch stenosis is present with an NWI of 0.20, we believe that further analysis is needed to define the parameters for when notch stenosis is present.

The mechanism of most ACL injuries is a sudden forceful twisting motion with the knee flexed and the foot planted in a noncontact episode.[8,9,13,22,25,26,29,36,37] Most of these injuries occur with external rotation of the tibia on the femur with the knee flexed. This position of risk, confirmed by our cadaveric studies and by others,[10,19,20] causes the ACL, even in normal cadaveric knees, to impinge over the lateral femoral condyle. The study of Good et al.[12] demonstrated that the medial aspect of the lateral femoral condyle forms an edge because of the concave dimension of the notch wall at that location. It has also been found that the absolute strength of the ACL decreases significantly with external rotation.[1] A stenotic intercondylar notch may contribute to the increased incidence of ACL tears. Another possibility may be that the ACL in a stenotic knee is inherently smaller than those with larger intercondylar notches. We propose that with sudden tension and tibial external rotation the stenotic notch itself, along with a possibly smaller diameter ACL, causes increased impingement and stress concentration on the ACL. This results in a ligament rupture. It appears that this was the mechanism of injury for noncontact ACL tears in this study. We did not have enough contact tears to comment on the mechanism for these tears. Further study is necessary to determine the contributing factors to ACL tears in stenotic knees.

In athletes with stenotic intercondylar notches who sustain an ACL tear, it is probably necessary to perform a notchplasty of the medial aspect of the lateral femoral condyle to prevent impingement of the ACL graft and to reduce the risk of reinjury. Several recent studies have been conducted to document the amount of notchplasty necessary to prevent graft impingement.[6,12,28,33] Berg[6] has stated that the notchplasty should simulate an NWI of at least 0.250. Tanzer and Lenczner[33] have also demonstrated that any ligament graft greater than or equal to 8 mm in diameter will impinge on the inferomedial border of the lateral femoral condyle, even in nonstenotic knees. On the basis of our findings and the results of the studies noted above, we recommend that notchplasties be considered during ACL reconstructions in athletes with stenotic notches to reduce

the risk of notch impingement and potential deterioration of the ligament reconstruction. The amount of the notchplasty would certainly depend on the amount of intercondylar notch stenosis present, but we recommend that, at the very least, the edge of the medial aspect of the lateral femoral condyle[12] be rounded off to prevent impingement and increased stress on the graft.

At this point, no proven, cost-effective method of prophylactic bracing of athletes' knees has been demonstrated to reduce the risk of ACL injuries. Paulos et al.[30] showed that the use of prophylactic braces resulted in a reduction of peak force applied to the ACL, while Sitler et al.[31] showed an overall reduction in the number of ACL injuries with prophylactic bracing. Other studies have demonstrated no beneficial effect to the ACL from bracing[14,18,34] and no benefit from either prophylactic or functional braces on reducing the forces on the ACL with an intact medial collateral ligament.[5] Baker[4] has advocated further epidemiologic studies to test the effectiveness of prophylactically bracing knees. We also suggest that further study be devoted to prophylactically bracing knees (with either prophylactic or functional braces) of athletes who are at increased risk of ACL injuries because of intercondylar notch stenosis. It is possible that the prophylactic bracing of those athletes at risk because of notch stenosis may prove beneficial in the prevention of ACL tears.

CONCLUSIONS

The relationship between femoral intercondylar notch stenosis and ACL injuries was found to be statistically significant in this study. Athletes with intercondylar notch stenosis appear to be at increased risk for ACL injuries. We recommend that notchplasties be considered on ACL reconstructions in athletes with stenotic knees to reduce the risk of notch impingement and potential deterioration of the ligament reconstruction.

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DISCUSSION

Dale M. Daniel, MD, *San Diego, California*: Dr. LaPrade has presented to us a prospective study on the incidence of ACL injury in competitive athletes, and has documented the relationship of the injury to intercondylar notch size. The authors measured notch width index by tunnel view radiographs. They report the index for male athletes was 0.24 and recorded a similar index for female athletes. The authors note that the majority of the ACL injuries occurred in noncontact events, which is consistent with other reports in the literature. The notch width index in the injured patients was 1 SD less than the average.

Should we counsel those patients with a narrow notch that they have a significant risk of ACL injury if they play a level one or two sport? Should a tunnel view radiograph become a part of the preparticipation physical? We hope that others will follow up on this study and present their findings to our society.