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The predictive value of radiographs in the evaluation of unilateral and bilateral anterior cruciate ligament injuries

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ABSTRACT

A review of 250 cases of surgical reconstruction of the anterior cruciate ligament identified 24 patients with bilateral complete tears of the anterior cruciate ligament. Twenty of these patients had previous reconstruction of one anterior cruciate ligament before rupture of the opposite ligament. Twelve injuries occurred during the same activity that was responsible for the initial opposite injury. The average time between surgical reconstruction and rupture of the opposite ligament was 29.3 months (range, 3 to 103). No significant demographic differences existed between patients with unilateral or bilateral ruptures of the anterior cruciate ligament.

Standardized measurements of intercondylar notch height and width and medial and lateral femoral condyle height and width were performed on routine notchview radiographs of 31 knees of patients with bilateral injuries, 30 with unilateral injury, and 30 with no anterior cruciate ligament injury. Statistical analysis revealed no significant differences between the three groups when comparing absolute measures or any of eight mathematical ratios calculated from these measurements. We concluded that measurements of the intercondylar notch made from radiographs may not be reliable predictors of injury to the anterior cruciate ligament. We found no significant clinical or demographic differences between patients with unilateral or bilateral complete ruptures of the anterior cruciate ligament.

Complete rupture of the ACL can be a devastating injury to a competitive amateur or professional athlete. Rupture of the ACL accounts for a significant number of knee injuries occurring during sporting activities. Over the past 20 years, an exhaustive amount of literature has been written about the anatomy, histology, and function of the ACL.[12] The natural history of the ACL-deficient knee has also been well studied.[3,5,8,10,11] Comparatively little, however, has been written about bilateral injuries to the ACL.[1,13] It is not yet clear if the small group of patients who sustain bilateral ACL injuries represent a subset of the population of all patients with ACL injuries or represent a distinct population in and of themselves.

The role the intercondylar notch plays in the development of these injuries has been studied to a limited extent.[1,6,7,13] Some evidence suggests that the shape or size of the notch may play a significant role in the development of complete tears of the ACL. However, this concept is not universally accepted and remains somewhat controversial.

To help clarify these issues, we undertook a retrospective review of a large series of patients with known ACL injuries. The goals of the present study are to determine the following information: 1) whether specific predisposing conditions, situations, or other factors exist that may increase the likelihood of bilateral injuries of the ACL, 2) the prevalence of bilateral ACL injuries within a population of patients with known ACL injuries, and 3) the role of radiographs and measurements of the intercondylar notch in the evaluation of patients with ACL injuries.

MATERIALS AND METHODS

A review of 250 randomly selected patients who had surgical reconstruction of the ACL performed by the senior author (GGW) over the 4-year period from 1984 to 1988 was undertaken. Data collected from this patient population included the sex of the patient, their age at the time of injury, the activity being performed at the time of injury, on which side the injury occurred, the time interval between injury and surgical reconstruction of the ACL, the type of surgical

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procedure performed, and associated injuries to the ipsilateral knee. From this population of patients, 24 patients were identified who had bilateral complete nonsimultaneous tears of the ACL. Additional information collected for this subgroup of patients included the time interval between the initial and opposite injury and the time interval between surgical repair of the initial injury and occurrence of the opposite injury.

Standardized measurements of the intercondylar notch height, anterior notch width, lateral femoral condyle height and width, and medial femoral condyle height and width were taken from standing notchview radiographs of 31 knees in 24 patients with bilateral ACL ruptures, 30 knees of patients with unilateral ACL ruptures, and 30 knees of patients with no clinical evidence of injury to the ACL (i.e., symptoms of functional instability of the knee, giving away, or demonstration of a significant lateral pivot shift or Lachman test). Anterior notch width was measured between the most medial projection of the lateral condyle and the most lateral projection of the medial condyle (i.e., the narrowest distal portion of the notch) according to a method similar to that described by Magill.[7] Notch height was measured from the top of the tibial spine to the superior most cortical margin of the anterior arch of the notch. The condylar width was measured from the widest portion of the lateral and medial condyles immediately above the joint line to the corresponding most centrally located portion of the condyle within the notch. The condylar height was measured from the inferior most edge of the condyle to the most proximal cortical margin of the anterior notch (Fig. 1).

From the absolute measurements obtained from the radiographs, eight mathematical ratios were calculated. These included the ratio of notch width to medial condylar height (I), notch width to notch height (II), notch width to the sum of the medial condylar width and the lateral condylar width (III), the area of the notch to the sum of the calculated areas of the medial and lateral femoral condyles (IV), the notch width to the total width of the distal femur (V), notch width to lateral condylar height (VI), notch height to the sum of the medial condylar width and the lateral condylar width (VII), and notch area to the sum of the medial and lateral condylar width (VIII).

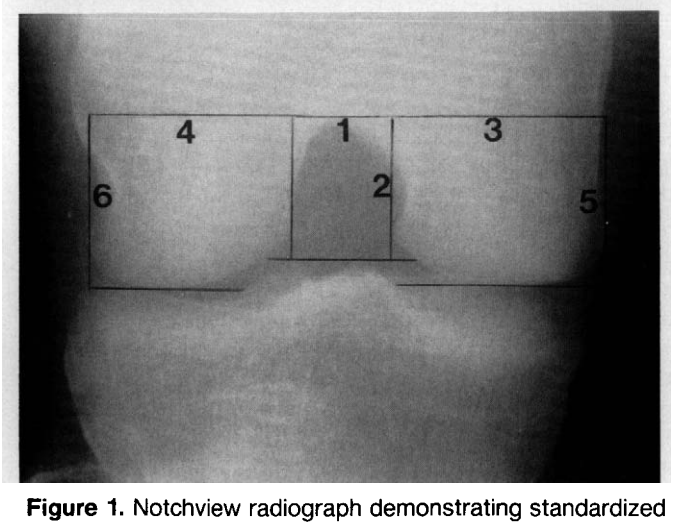

Figure 1. Notchview radiograph demonstrating standardized measurements. 1, notch width; 2, notch height; 3, medial condylar width; 4, lateral condylar width; 5, medial condylar height; 6, lateral condylar height.

Statistical analysis of the mathematical ratios obtained for each subset of radiographic data (knees with bilateral ACL injuries, knees with unilateral ACL injuries, and knees with no ACL injuries) was undertaken. Direct comparisons were made between all three groups. Because some subjects had both knees included in the study, standard analysis of variance was not appropriate. As such, an analysis of variance model that adjusts for the correlation that exists between right and left knees for the same subject was used.

RESULTS

A retrospective review of 250 surgical reconstructions of the ACL identified 24 patients (9.6%) with bilateral complete nonsimultaneous tears of the ACL. There were 17 male and 7 female patients in this group of 24. Thirteen patients experienced their initial injury to the right knee, while 11 experienced their initial injury to the left. Twenty of these patients had undergone previous reconstruction of one ACL before rupture of the opposite ligament. In this group of patients, the average time interval between surgical reconstruction of one ACL and complete rupture of the opposite ACL was 29.3 months (range, 3 to 103). Four of the 24 patients with bilateral complete ACL tears underwent nonoperative management of their initial ACL injury, consisting of physical therapy and bracing.

Thirteen patients underwent surgical reconstruction of the second, or contralateral, ACL injury while 11 chose nonoperative treatment modalities. Thus, fewer patients chose surgical reconstruction for treatment of their second injury.

The average age of the patients with bilateral injuries at the time of the initial injury was 20.75 years (range, 14 to 36). The average age of the entire population of 250 patients at the time of injury was 23.5 years. The mean time interval between rupture of one ACL and rupture of the opposite ligament was 48.2 months (range, 2 to 127).

Twelve of the contralateral injuries occurred while performing the same activity that was responsible for the initial opposite injury (Table 1). Associated injuries to the ipsilat-

TABLE 1
Mechanism of injury[a]

Activity	Initial	Opposite
Football	8	4
Basketball	2	5
Baseball/Softball	3	2
Downhill skiing	2	2
Gymnastics	4	4
Others	4	6
Unknown	1	1

[a] Twelve patients experienced both injuries while performing the same athletic activity.

eral knee were found to occur less frequently with rupture of the second opposite ACL (Table 2). Surgical reconstructions of the initial injury consisted of 19 intraarticular procedures using a modified Jones technique.[4] This technique uses a middle third patellar tendon graft with a bone block distally and a thin fragment of patellar bone proximally that is passed through a tibial tunnel and over the top of the lateral femoral condyle. Fixation is achieved with a press fit in the undersized tibial tunnel using a spiked staple. The proximal extent of the graft is fixed in a recessed bone slot in the lateral distal femoral metaphysis using a spiked staple. Notchplasty is routinely performed. An Andrews-type extraarticular augmentation was performed in all 19 cases.[4] One patient underwent primary surgical repair of his ruptured ACL.

Results of the radiographic analysis of the intercondylar notch are outlined in Table 3. No significant differences were found in any of the eight mathematical ratios calculated from the absolute measurements obtained from the radiographs of the knees of patients with bilateral ACL injuries, unilateral ACL injuries, or no ACL injuries. Specifically, the ratio of intercondylar notch width to the total width of the distal femur (Ratio V) was not statistically significant. Although patients with bilateral injuries did not have the smallest value for this ratio (0.2456 versus 0.2655 for unilateral ACL injuries and 0.2598 for uninjured knees), statistical significance ($P < 0.05$) did not exist.

TABLE 2
Associated injuries[a]

Injury	Initial	Opposite
Torn medial meniscus	**10**	2
Torn lateral meniscus	**4**	5
Torn medial collateral ligament	1	1
Total (%)	15 (63)[b]	8 (33)[b]

[a] Eight patients had no associated ipsilateral knee injuries with either ACL injury.
[b] Percent of 24 total patients.

TABLE 3
Analysis results and statistics used in the analysis

Ratio	Statistic	ACL injury			*P* value
		None ($N = 26$)	Unilateral ($N = 29$)	Bilateral ($N = 19$)	
I	Mean	0.7000	0.7008	0.6394	0.230
	SEM	0.0269	0.0257	0.0303	
II	Mean	0.8982	0.9204	0.8465	0.450
	SEM	0.0397	0.0379	0.0451	
III	Mean	0.3554	0.3659	0.3308	0.279
	SEM	0.0152	0.0146	0.0168	
IV	Mean	0.2930	0.2835	0.2616	0.208
	SEM	0.0122	0.0117	0.0133	
V	Mean	0.2598	0.2655	0.2456	0.246
	SEM	0.0083	0.0079	0.0091	
VI	Mean	0.7780	0.7254	0.6995	0.257
	SEM	0.0332	0.0319	0.0366	
VII	Mean	0.4015	0.4025	0.3946	0.885
	SEM	0.0117	0.0114	0.0128	
VIII	Mean	8.6668	9.2780	8.1592	0.148
	SEM	0.4011	0.3918	0.4212	

DISCUSSION

Although a tremendous amount of published literature exists concerning the ACL, very little has been written about bilateral ACL injuries. Anderson et al.[1] reported an incidence of 2% in a population of 1100 patients with ACL injuries. In a more recent article, Souryal et al.[13] found 4.01% of 1120 patients with ACL to have bilateral complete nonsimultaneous tears of the ACL. We found a prevalence of 9.6% (24 of 250) bilateral injuries in a population of patients with at least one surgically reconstructed ACL. Clinically and demographically, our patient population was nearly identical to that of Souryal et al. They found an average age of 19 years and 10 months at the time of initial injury and the mean time interval between initial and opposite injury was 47 months; 68% of their patients were male. In our series, we found an average age of 20.75 years at the time of initial injury and an average interval of 48.2 months between initial and opposite injury; 71% of our patients were male. Neither our series nor that published by Souryal et al. found significant clinical or demographic differences between patients with unilateral or bilateral ACL injuries.

Twelve of our 24 patients experienced complete rupture of their opposite ACL while performing the same activity that led to their initial injury. Eleven others experienced their second injury while performing another athletic activity. In one case, the mechanism of injury to the second ligament was not clear (Table 2). These results suggest that this group of patients had a good functional result after treatment of their initial injury, allowing them to again participate in athletic activities. It also suggests that the type of activity being performed does not necessarily predispose to or correlate with the occurrence of a second opposite complete rupture of the ACL since one-half of the patients were performing some other activity when the second injury occurred.

The intercondylar notch has been implicated as a factor in the development of complete tears of the ACL. Anderson et al.[1] reported results of CT scan evaluation of the intercondylar notch of patients with bilateral ACL injuries, unilateral ACL injuries, and knees with no known ACL injury. Comparison of notch dimensions determined by CT scan revealed statistically significant differences between normal knees and those with ACL injuries with regard to the opening notch angle, the ratio of notch width at two-thirds of the notch length to condylar width, and the ratio of maximum notch width to condylar width. They concluded that an association exists between anterior outlet stenosis of the intercondylar notch and rupture of the ACL and recommended notchplasty for patients with documented notch stenosis. Houseworth et al.[6] designed a computer graphics study to determine the area of the anterior opening and posterior arch of the intercondylar notch based on notchview radiographs. They suggested that narrowing of the posterior arch of the notch may predispose the knee to ACL injury.

In a more recent study, Souryal et al.[13] evaluated the

intercondylar notch as seen on notchview radiographs. A statistical comparison, using Student's *t*-test, of notch width (the width of the notch versus the total distal femur width at the level of the popliteal groove) obtained from 35 knees of patients with bilateral injuries, 50 knees of patients with unilateral injuries, and 50 knees with no injury, revealed a significant difference between patients with bilateral injuries and those with one or no ACL injuries. They suggested that a notch width index of 0.2 or less may represent critical notch stenosis. They recommended that young athletes who sustain ACL injuries through a noncontact cutting maneuver and demonstrate a relatively narrow notch on tunnel view radiographs be "counseled strongly" regarding the possibility of rupture of the opposite ligament.

Our standardized measurements of the intercondylar notch included the notch width at the most narrow distal opening of the notch and condylar width at the greatest width above the joint line (Fig. 1). Such a method should provide the smallest possible ratio of notch width to total femoral condylar width.[7] Using a modified analysis of variance statistical model, we found no significant differences between comparable groups of patients with bilateral ACL injuries, unilateral ACL injuries, and no ACL injuries. We interpret this to mean that measurements of the notch as seen on standard notch or tunnel view radiographs[9] may not be reliable or reproducible predictors of clinically significant notch stenosis as previously suggested by other authors. Thus, information obtained from such measurements should be used carefully and selectively in counseling patients regarding activities and future risk for rupture of the ACL.

There are two possible explanations why our results differ from those of Souryal et al.[13] Our method of measurement of the notch width and distal femoral condylar width was different; we chose to measure the condylar width at the widest level above the joint line. Our measure of notch width was similar to theirs. Our method, however, should provide for the smallest possible ratio of notch width to distal femoral width and as such, if biased, should be biased in favor of finding statistically significant notch stenosis.

The other possible explanation is our statistical method. We chose to use an unbalanced, repeated-measures analysis to statistically analyze our data.[2] Such a method adjusts for the correlation that exists between right and left knees for the same subject. A moderate to high degree of correlation (0.29 to 0.78) was found for subjects with both knees included in our study. Thus, knees from the same subject cannot be treated as independent and, as such, a standard analysis of variance is not an appropriate statistical method. We believe the Student's *t*-test, used in some other studies,[13] is an inappropriate statistical model for analyzing this type of data.

Although the size or shape of the intercondylar notch is probably a factor in the development of ACL injuries, we do not feel that plain radiographs can be used to reliably diagnose clinically significant notch stenosis. As such, it should not be used as a basis for counseling patients regarding the risk for future ACL injuries. Computed tomography scans and other more elaborate imaging studies (e.g., magnetic resonance imaging) are more likely to reproducibly demonstrate significant differences in notch morphology between patients with unilateral, bilateral, and no ACL tears. However, the practical value of performing such elaborate studies of the intercondylar notch on all patients with ACL injuries for the purpose of counseling is low. Our data also suggest that the patients who experience bilateral ACL injuries represent a small subset (9.6%) of the total population of patients who experience ACL injuries and does not constitute a demographically unique population in and of itself.

Further studies of the radiographic evaluation of the intercondylar notch need to be performed before the information obtained from such radiographs can be used reliably to counsel patients at presumed risk for ACL rupture.

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