Validity of Indirect Ultrasound Findings in Acute Anterior Cruciate Ligament Ruptures

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Objectives—Ultrasound (US) is increasingly being used as an extension of the physical examination on the sidelines, in training rooms, and in clinics. Anterior cruciate ligament (ACL) injury in sport is common, but the literature on US findings after acute ACL rupture is limited. Three indirect US findings of ACL rupture have been described, and this study assessed the validity of these indirect signs.

Methods—Patients with an acute knee injury (<6 weeks) underwent US examinations to determine whether there was evidence of a femoral notch sign, posterior cruciate ligament wave sign, or capsular protrusion sign. Ultrasound findings were compared to magnetic resonance imaging.

Results—Sixty-nine patients were included (53 with ACL tears and 16 control patients). The posterior cruciate ligament sign had the highest sensitivity (84.9%), and the notch sign had the highest specificity (93.8%). If 2 or 3 of the signs were positive, the sensitivity was 86.8%, and the specificity was 87.5%.

Conclusions—A US examination is an easy-to-perform and noninvasive test, and the 3 indirect signs of an acute ACL tear had high positive predictive values ranging from 91.8% to 96.8%.

Key Words—anterior cruciate ligament; diagnostic ultrasound; knee ligaments; musculoskeletal

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Abbreviations

ACL, anterior cruciate ligament; MRI, magnetic resonance imaging; PCL, posterior cruciate ligament; US, ultrasound

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Anterior cruciate ligament (ACL) injuries have historically been poorly diagnosed outside of an orthopedist or sports medicine office.[1] A 2008 study demonstrated that only 26% of patients seen in an emergency department with an ACL tear had a correct diagnosis,[2] and another study found that only 14% of patients had a diagnosis at the initial presentation.[1] A separate study found that the mean delay from the time of injury to diagnosis was greater than 2 months.[3] Early diagnosis of ACL tears is important, and a delay in surgical reconstruction has been associated with a higher risk of damage to the menisci and articular cartilage[4–7] as well as a possible delay in return to sports and activities.

Most patients that sustain an ACL injury describe a sensation of a "pop" or "snap," rapid swelling, symptoms of instability, or a combination thereof. The diagnostic accuracy of these symptoms had a positive predictive value of 0.83 when all 3 clinical findings were present.[8] However, in many cases, not all elements are present, and when 2 of the 3 items were present, the positive predictive value dropped to 0.42. The validity of physical examination

findings is limited in the acute setting by pain, guarding, swelling, and hemarthrosis. In 1988, Decker and Ruf[9] found that clinical examination and surgical findings were concordant in only 48% of cases.

Magnetic resonance imaging (MRI) has become the noninvasive reference standard for the diagnosis of ACL ruptures. Magnetic resonance imaging is objective and effective, with sensitivity, specificity, and accuracy of 98%, 98%, and 97%, respectively.[10] In addition, MRI can also detect damage to the meniscus, collateral ligaments, and articular cartilage. However, MRI is expensive and not always available in the acute setting or at many medical practices. These limitations have led to an increased interest in ultrasound (US).

Direct US visualization of the ACL is challenging,[11–13] but US is increasingly being used as an extension of the physical examination on the sidelines, in training rooms, and in clinics. Ultrasound can be used to objectively measure the degree of laxity when combined with functional testing (ie, Lachman and anterior drawer tests).[14–19] These US-guided functional tests require 2 examiners, and it can be difficult to maintain the probe position while imaging the tibia, which may limit the reproducibility of these functional tests.

In addition to dynamic US examinations for measuring laxity, 3 static indirect signs of ACL rupture have been described in the literature.[20–25] The femoral notch sign has been the most studied. First described by Suzuki et al[26] in 1991, the femoral notch sign is characterized by the presence of a hypoechoic collection adjacent to the lateral femoral condyle, where the ACL should insert. The other indirect signs, the posterior cruciate ligament (PCL) wave sign and capsular protrusion sign, have only been described once in the literature by Chylarecki et al[23] in 1995. These clinical findings were translated into English in 2002, but the validity of the PCL wave sign and capsular protrusion sign have not been studied with high-resolution US. This study evaluated the validity of these 3 indirect US signs of ACL rupture and compared the US findings to clinical history, physical examination, MRI, and arthroscopic findings.

Materials and Methods

In this prospective cohort study, patients were recruited from a single academic sports medicine center in Atlanta, Georgia. The Emory University Institutional Review Board approved the study. Patients between the ages of 16 and 50 years who had sustained an acute knee injury within 6 weeks of presentation were recruited. The referring orthopedic surgeon or a primary care sports medicine physician had to have a suspicion of internal derangement of the knee (ie, ACL or PCL injury or meniscus injury), and patients had to have MRI of the knee completed or ordered. Patients with a history of ACL injury or surgery to the effected knee were considered ineligible and excluded.

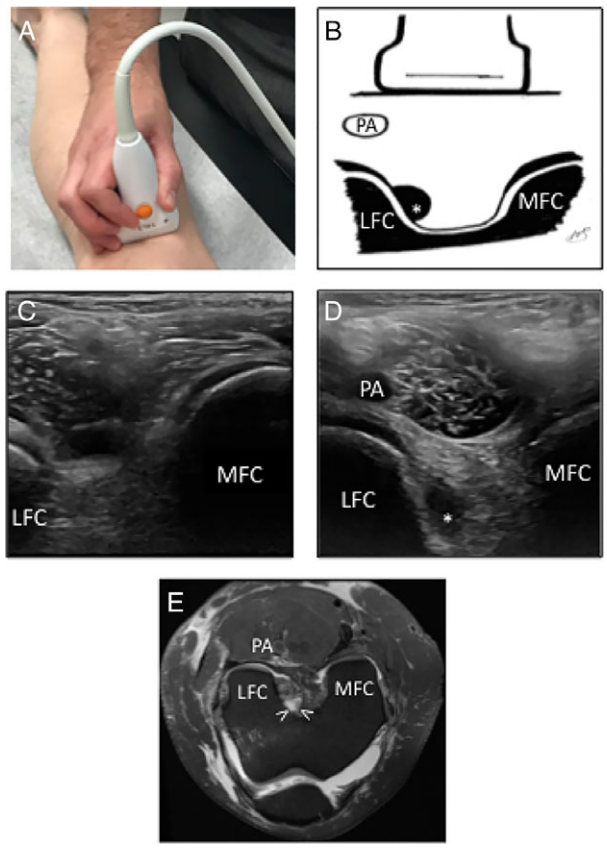
All patients underwent US examinations by a single primary care sports medicine physician (K.M.), with 8 years of US experience. The examiner was blinded to the mechanism of injury, clinical examination findings, and MRI findings. The US examination was performed within 6 weeks of the acute injury with an S8 12 L RS matrix probe (GE Healthcare, Milwaukee, WI). Patients were positioned prone with the knee in extension, and the US examination was performed over the posterior aspect of the knee, making specific note of the 3 indirect US signs of an ACL rupture. The knee was first examined in a transverse plane, assessing the ACL's femoral insertion for the presence of the hypoechoic intercondylar "notch sign." A positive sign is characterized by a round or oval hypoechoic collection at the femoral attachment of the ACL (Figure 1). This hypoechoic collection represents the hematoma that is formed when an ACL is torn from its proximal attachment on the femur.

The knee was then examined longitudinally, assessing the PCL and posterior joint capsule for the presence of the wavelike PCL sign and posterior capsule protrusion sign (Figure 2). On US imaging, the PCL appears as a hypoechoic wedge between the posterior capsule and bony outline of the tibia, and the posterior capsule appears as a slightly curved echogenic line. In complete ACL ruptures, the PCL can appear thickened and wavelike, and the posterior capsule protrudes posteriorly. A wavelike PCL (Figure 2, C and D) and a thickened PCL (Figure 3) were both considered pathologic and positive signs. The posterior joint capsule was examined above the PCL and typically appears flat or convex in this location. Protrusion of the capsule was defined as a convex appearance to the capsule (Figures 2 and 3).

The contralateral knee was examined for comparison in all cases. After the US examination was completed, the patient's findings were recorded. The validity of the 3 indirect signs was then determined both individually and in combination, using the MRI and arthroscopic findings as the reference standards.

The diagnostic accuracy of each of the 3 US findings relative to MRI (the reference standard test) was summarized with point estimates of the test's sensitivity, specificity, negative predictive value, and positive predictive value using single-sample proportions. Ninety-five percent confidence intervals for a single-sample binomial proportion were 2 sided and calculated based on the Wilson score method.[27]

Figure 1. Femoral notch sign. **A**, Ultrasound probe position for visualizing the femoral notch sign. **B**, Anatomic drawing showing the positive US findings at the level of the femoral intercondylar notch. **C**, Normal knee sonogram of the femoral intercondylar notch. **D**, Sonogram showing a positive intercondylar notch sign with a hypoechoic collection (asterisk) at the origin of the ACL and a mass effect displacing the intercondylar fat pad medially. **E**, Fat-saturated T2-weighted coronal MRI of the same patient in **D** with the image flipped vertically to match the orientation of the sonogram. The hypoechoic collection (arrowheads) at the origin of the ACL corresponds to the positive intercondylar notch sign, a secondary sign of an ACL tear with a bone contusion at the lateral femoral condyle. LFC indicates lateral femoral condyle; MFC, medial femoral condyle; and PA, popliteal artery.



Results

Seventy-four patients were recruited (Table 1) during the inclusion period. Five did not meet eligibility criteria (Figure 4). The study group included 16 control patients (23.2%) and 53 patients with ACL injuries (76.8%).

One patient was excluded after not being able to position the knee in extension. Two patients never received MRI or came back for follow-up to confirm the diagnosis and were excluded. Two patients were excluded after it was found that they were recruited

Figure 2. Wavelike and capsular protrusion signs. **A** and **B**, Ultrasound probe position for visualizing the PCL and capsular protrusion sign. **B**, Anatomic drawing showing the positive US findings with a wavelike PCL (asterisk) and capsular protrusion (arrowheads). **C** and **D**, Sonograms of a control knee (**C**) and injured knee (**D**) showing the wavelike and capsular protrusion signs. **C**, Normal contralateral knee sonogram showing a normal concave posterior joint capsule (arrowheads) and PCL (asterisk) Arrows outline the PCL lying against the tibia. **D**, Abnormal knee sonogram showing a positive convex capsular protrusion sign (arrowheads) and wavelike PCL sign with arrows outlining the PCL bowing away from the tibia. FC indicates femur condyle; and T, tibia.

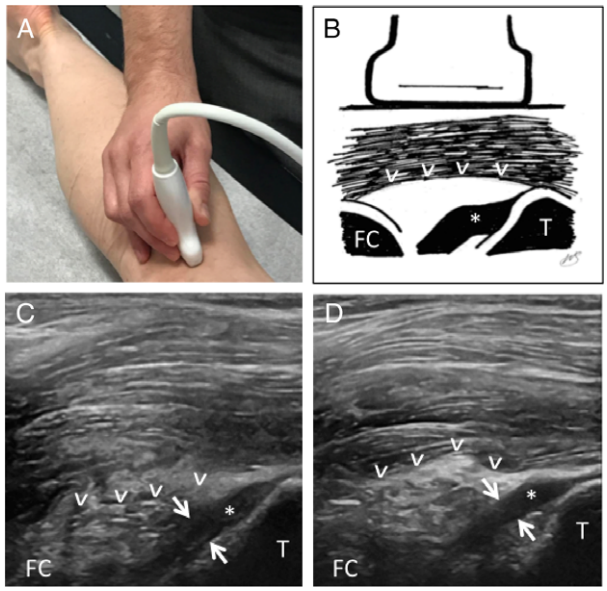


Figure 3. Thickened PCL and capsular protrusion signs. **A–D**, Sonograms of a control knee (**A** and **C**) and corresponding injured knee (**B** and **D**). **A** and **C**, Normal contralateral knee sonograms showing a normal concave posterior joint capsule (arrowheads) and PCL (arrows). **B** and **D**, Positive convex capsular protrusion sign (arrowheads) and thickening of the PCL (arrows). FC indicates femur condyle; and T, tibia.

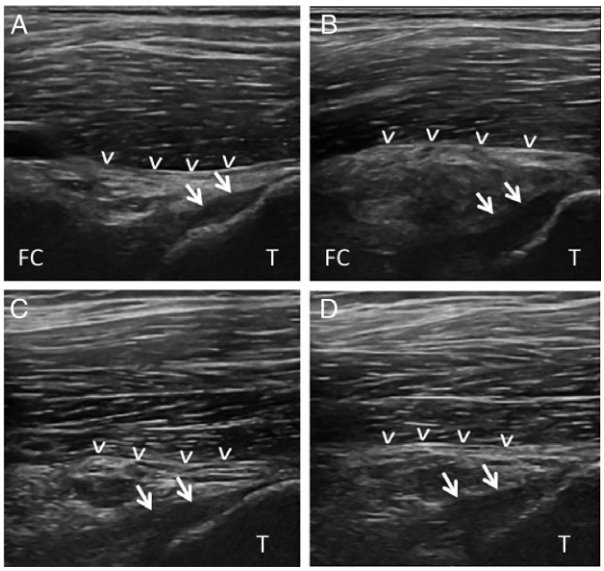
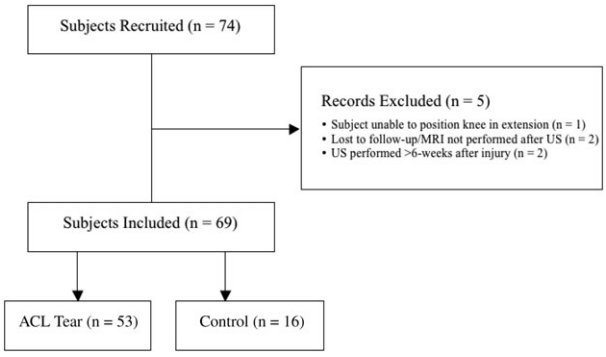


Table 1. Demographics and Characteristics

Characteristic	All Patients (69)	ACL Tear (53)	Control (16)
Age, y	26.5	27.2	24.4
Male/female, n	34/35	23/29	11/6
Body mass index, kg/m^2	25.3	24.4	27.9
Time of presentation, d	11.7	11.7	11.7
Time of US, d	13.0	13.1	12.4

Figure 4. Flow diagram depicting inclusion of patients.



44 days after the initial injury and outside the 6-week inclusion period.

All patients had MRI of the knee, with 31 patients having the MRI before being recruited for the study (ACL group, n = 30; control group, n = 1) and 38 getting the MRI after being recruited (ACL group, n = 23; control group, n = 15). The timing of the MRI study was dependent on scheduling and independent of the study. Fifty-three patients had an ACL tear on MRI. In the ACL tear group, 49 patients had a complete tear; 2 had a partial tear; and 2 had an avulsion of the ACL. Seventeen of these patients had an isolated ACL injury, and 36 had additional findings on the MRI (PCL tear, n = 3; collateral ligament injury, n = 17; meniscus, n = 27). The arthroscopic records were also reviewed in all cases, but documentation was inconsistent and lacked detail to exclude false-negative cases due to distal or midsubstance tears.

The validity of the indirect ACL signs is detailed in Table 2, with MRI as the reference standard. The PCL sign had the highest sensitivity (84.9%), and the notch sign had the highest specificity (93.8%). All 3 signs had high positive predictive values, ranging from 91.8% to 96.8%. If only 1 of the 3 signs was positive, the sensitivity was 90.6%, and the specificity was 68.8%. If 2 or 3 of the signs were positive, the sensitivity fell to 86.8%, but the specificity increased to 87.5%.

In the control group, MRI findings included meniscus tears (n = 8), patella dislocation/medial patellofemoral ligament tears (n = 3), PCL tears (n = 3), collateral ligament tears (n = 3), and a bone contusion (n = 1). One patient in the control group had a chronic ACL tear with an acute bucket handle meniscus tear. In this case, the bucket handle meniscus tear was the acute injury, and the chronic ACL tear was an incidental finding. The US examination was performed before the MRI, and the patient was included in the control group, as the objective was to assess the validity of indirect US signs of acute ACL tears. The 3 control patients with PCL tears had a false-positive PCL wave sign, and 2 of these patients had a false-positive capsular protrusion sign. The other control patient with a false-positive PCL sign had a bucket handle meniscus tear. There were 2 other bucket handle meniscus tears that had a negative PCL sign. One patient with a lateral meniscus tear also had a false-positive femoral notch sign.

Discussion

Direct US imaging of the ACL is challenging given the intra-articular position and bony anatomy of the intracondylar notch. With the knee in maximal flexion, the tibial attachment of the ACL can be seen with the US probe positioned inferior and medial to the patella.[11,26,28] In complete ACL ruptures, interruption of the ligament fibers can sometimes be seen on an anterior US examination.[28] In a normal knee, the ACL fibers appear to elongate and thin as the knee is moved from flexion to extension on a dynamic anterior knee US examination.[28] In an ACL rupture, the ligament may remain thick and shortened[28] or adhered to the fat pad with the tendon and fat pad moving together when the knee is moved from flexion to extension.[11] The femoral attachment of the ACL where most tears occur is challenging to see.

Dynamic US has also been used to confirm laxity and indirectly assess the integrity of the ACL. Ultrasound-guided anterior drawer and Lachman tests have been reported in the literature[14–19] but require 2 examiners and can be challenging to perform. Dynamic tests require patients to relax, which can be difficult in acutely injured knees. Indirect methods may be better suited for acute ACL ruptures, and 3 signs of an acute ACL rupture have been described in the literature (Table 3).

Of the 3 static indirect signs, the femoral intercondylar notch sign has been the most studied. Normally, the origin of the ACL is not visible on US imaging, with the intercondylar notch primarily filled with echogenic fat and connective tissue. Most ACL disruptions are proximal at the femoral attachment (43%) or midsubstance (52%) of the ligament.[29] The cruciate ligaments are intra-articular, but an extrasynovial structure and a hypoechoic collection along the lateral femoral intercondylar notch are thought to represent a soft tissue hematoma. This finding is also commonly seen on coronal MRI and is known as the empty-notch sign. For complete ACL tears, the empty-notch sign on MRI has sensitivity of 92% and specificity of 83%.[30]

The validity of the US femoral notch sign has been well studied, with sensitivity and specificity ranging from 88% to 96.2% and 65% to 100%, respectively. The validity improves when the symptomatic knee is compared to the asymptomatic side.[22,24] In our study, the femoral notch sign had sensitivity and specificity of 56.6% and 93.8% respectively. In 2 of the studies, the authors stated that the femoral notch sign was valid only in cases of acute rupture.[21,22] Although it is reasonable to assume that the femoral notch sign disappears with time, Ptasznik et al[24] found no statistical correlation between the size of the hematoma and time since injury within the first 10 weeks after injury. It is not clear when or whether the hematoma completely resolves. Our study excluded chronic ACL tears but included patients up to 6 weeks after injury. Of the 53 patients with an

Table 2. Diagnostic Accuracy of 3 Indirect US Signs of ACL Rupture With Reference Standard MRI

Sign	MRI+(n = 53)	MRI–(n = 16)	Sens, %	Spec, %	PPV, %	NPV, %
Notch sign						
+ (n = 31)	30	1	56.6	93.8	96.8	39.5
– (n = 38)	23	15	(43.3–69.0)	(71.7–98.9)	(83.8–99.4)	(25.6–55.3)
Capsule sign						
+ (n = 43)	41	2	77.4	87.5	95.3	53.8
– (n = 26)	12	14	(64.5–86.5)	(64.0–96.5)	(84.5–98.7)	(35.5–71.2)
PCL sign						
+ (n = 49)	45	4	84.9	75.0	91.8	60.0
– (n = 20)	8	12	(72.9–92.1)	(50.5–89.8)	(80.8–96.8)	(38.7–78.1)
2 or 3 + signs						
+ (n = 48)	46	2	86.8	87.5	95.8	66.7
– (n = 21)	7	14	(75.2–93.5)	(64.0–96.5)	(86.0–98.9)	(45.4–82.8)
At least 1 + sign						
+ (n = 53)	48	5	90.6	68.8	90.6	68.8
– (n = 16)	5	11	(79.8–95.9)	(44.4–85.8)	(79.8–95.9)	(44.4–85.8)

Values in parentheses are 95% confidence intervals. NPV indicates negative predictive value; PPV, positive predictive value; Sens, sensitivity; and Spec, specificity.

ACL tear, 38 had a US examination within 14 days of an injury, and 52.6% had a positive hematoma sign. Of the 15 patients who had US examinations in the subacute period (≥15 days after the injury), 66.7% had a positive hematoma sign.

The validity of the femoral notch sign in chronic ACL tears is unknown. In addition to chronic ACL ruptures, false-negative femoral notch signs can also occur with a distal ACL rupture at the tibial insertion[23] or with an ACL avulsion injury of the tibial eminence.[24] In this study, there were 2 cases of ACL avulsion injuries diagnosed on MRI and initially missed on plain radiographs. The femoral notch sign can also be missed in partial midsubstance tears.[20] The arthroscopic records were not detailed enough to exclude false-negative cases due to distal or midsubstance tears.

The other 2 indirect signs, the PCL sign and capsular protrusion sign, have not been well studied. The PCL sign has been reported in only 2 articles[23,31] and the capsular protrusion sign in 1 article.[23] When observing the appearance of a torn PCL on a sonogram, it can look similar to how it would look with a torn PCL (thickened and "wavelike"), and in the 3 control patients with a PCL tear in our study, all 3 had a positive PCL sign, and 2 of them had a positive capsular protrusion sign. A "double-PCL sign" has been described in the MRI literature as a predictor of a bucket handle meniscus tear, and in the 3 bucket handle meniscus tears, 1 had a false-positive PCL sign. Dynamic testing has been shown to be helpful in distinguishing between an isolated ACL tear or PCL insufficiency but was not performed in this study.[32]

In 1990, Hawe[31] first noted the wavelike appearance of the PCL in an ACL-deficient knee. As the patient lies prone during the US examination, the origin and attachment of the PCL are near each other, leading to an "S-shaped" PCL. Chylarecki et al[23] examined the validity of the PCL sign (sensitivity, 54%; specificity, 71%) and capsular protrusion sign (sensitivity, 68%; specificity, 77%). In comparison, clinical tests of stability in the study by Chylarecki et al[23] had sensitivity of 70% and specificity of 65%. In our study, the sensitivity and specificity of these US signs were higher (PCL sign: sensitivity, 84.9%; specificity, 75%; capsular protrusion sign: sensitivity, 77.4%; specificity, 87.5%). Advances in US resolution since the study by Chylarecki et al[23] in 1995 may have accounted for the differences in sensitivity and specificity.

Table 3. Literature Review of Indirect US Findings

Reference	Study Design	Patients	ACL Rupture[a]	Acuity	Reference Standard	Sens, %	Spec, %	PPV, %	NPV, %
Hypoechoic intercondylar notch sign									
Skovgaard Larsen (2000)	PCS	62	16	Acute, <3 wk (mean 9 d after injury)	Arthroscopy (11/62) or clinical follow-up (51/62)	88	98	93	96
Richter (1996)	PCS	74	58	Acute 1 and 8 wk after injury	Arthroscopy and arthrotomy	88	87.5	96	NR
Kelsch (1996)	PCS	65	15	Acute and chronic ruptures, NOS	Arthroscopy	65	90	79	83
Chylarecki (1995)	PCS	193	NR	Acute, average 7 d, median 4 d	Arthroscopy	91	80	NR	NR
Ptasznik (1995)	PCS	37	32	Acute, <10 wk from injury	MRI (37/37) and arthroscopy (30/37)	91	100	100	63
Wittner (1991)	PCS	117	51	Not specified	Arthroscopy	96	75	75	96
Posterior capsule protrusion									
Chylarecki (1995)	PCS	193	NR	Acute average 7 d, median 4 d	Arthroscopy	54	71	NR	NR
Wavelike PCL sign									
Chylarecki (1995)	PCS	193	NR	Acute average 7 d, median 4 d	Arthroscopy	68	77	NR	NR

NOS indicates not otherwise specified; NPV, negative predictive value; NR, not reported; PCS, prospective cohort study; PPV, positive predictive value; Sens, sensitivity; and Spec, specificity.
[a]Partial or complete rupture.

To our knowledge, no study has looked at the validity of the PCL sign and capsular protrusion sign in acute versus chronic ACL injuries, and in theory, they would be present in both acute and chronic cases. The capsular protrusion sign may also be exacerbated by laxity but may also be due to hemarthrosis in the acute period. In some cases, we found that the PCL was thickened compared to the contralateral side. This finding has previously not been reported and was counted as a positive sign.

The study by Chylarecki et al[23] is the only other study in the literature that has looked at all 3 of the indirect static US findings of ACL ruptures. In their study, the femoral notch sign and posterior joint capsule protrusion sign reached sensitivity of 98%, but on average, the time to the US examination was 7 days (median, 4 days). When taken together, the false-negative findings were reduced, but the rate of false-positive findings increased. Our data are concordant with the sensitivity and specificity reported by Chylarecki et al.[23]

Limitations

Limitations of this study included a selection bias. The study depended on referrals from the orthopedic surgeons and primary care sports medicine physicians in the practice. Most of the patients had an ACL tear (79%). The referral bias may have been secondary to the fact that the study was associated with acute ACL tears. It may also have been secondary to the delay in presentation and advanced imaging of other intra-articular injuries, especially if there were no associated mechanical symptoms.

In the ACL group, only 33.1% had an isolated ACL tear. Most of the patients had additional internal derangement (PCL tear, collateral ligament injury, or meniscus injury) in addition to an acute ACL tear. Patients who presented with additional internal derangement to the ACL tear added a potential confounding variable. The PCL is ideally examined with the knee in hyperextension, but because of the acute and subacute periods and patient tolerance, it was examined with the patient prone and the knee in extension. A linear probe was used in all cases. Although that type of probe allows for adequate assessment of the caudal PCL, it can also result in underdiagnosis of injuries at the cranial potion of the ulnar collateral ligament.[33]

The US findings were compared to MRI findings, which served as the reference standard in this study. In past studies, US was compared to arthroscopy, but recent studies have shown MRI to have higher sensitivity for diagnosing ACL tears than in the 1990s, when many of the studies on indirect signs were performed. The arthroscopic records were also reviewed in all cases, but the records lacked detail. Records often did not document where the ACL was torn and could not exclude false-negative cases due to distal or midsubstance ACL tears.

Conclusions

Ultrasound does not and cannot replace MRI but can help clinicians decide on further diagnostic tests and treatment in patients with acute knee injuries. These US signs are easy to determine noninvasively, especially in cases in which the clinical examination is difficult or equivocal. Ultrasound may help decrease the number of undetected ACL injuries and can spare patients unnecessary treatment for a presumed diagnosis of a knee contusion, sprain, or strain. In addition, point-of-care US is cost-effective compared to MRI and can potentially give patients a diagnosis the same day while avoiding unnecessary anxiety and worry.

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