Anterior cruciate ligament graft tear

Primary and secondary magnetic resonance signs

Emam M. Kheder, *FACS, FRCS,* **Mohamed E. Abd El-Bagi,** *FFRRCSI, FRCR,* **Mohamed H. El-Hosan,** *MD, FACHRTZ.*

ABSTRACT

نستعرض في هذا التقرير علامات التمزق التي أظهرتها أشعة الرنين المغناطيسي، والذي حدث في ترقيع (رقعة) الرباط الصليبي الأمامي الذي تم إصلاحه. تعد أشعة الرنين المغناطيسي (MRI) وسيلة ناجحة لتقييم هذه الرقعة عندما تصبح سلامتها محل تساؤل. وعلى الرغم من وجود بعض القيود، فإن هذا النوع من الأشعة يمكنه أن يميز بين أن تكون مثل هذه الرقعة قد تم تمزيقها جزئياً أو بشكل كامل. كما تمت التوصية بإجراء العديد من العلامات الأولية المباشر والعلامات الثانوية الغير مباشرة من جل الحصول على مزيد من الدقة بواسطة التشخيص بأشعة الرنين المغناطيسي(MRI). يعتبر تواصل الرقعة في المستوى التاجي ومدى سماكة الرقعة الطبيعية في المستوى التاجي أو المستوى السهمي بمثابة أكثر العلامات الأولية قيمة في استبعاد تمزق في كامل سمك الرقعة، أما فيما يتعلق بالعلامات الثانوية فتعتبر علامات انتقال عظم الساق الأمامي وكذلك العلامات الدالة على الغضروف المفصلي الجانبي المكشوف بمثابة أكثر العلامات فائدة في التمييز بين أن تكون الرقعة ممزقة أو سليمة. من المقرر أن تكون بعض العلامات الأولية والثانوية الخاصة بتمزق الرباط الصليبي الأمامي الطبيعي بمثابة تقييم مدى الدقة في اكتشاف التمزق في الرقعة، غير أن هذه العلامات تكون أكثر وضوحاً، وخصوصاً إذا ما تم الأخذ بهم معاً. ويدخل ضمن تلك العلامات كل من أخدود الفخذ الجانبي العميق، زاوية الرباط الصليبي الخلفي وقيم انحناءات الرباط الصليبي الخلفي.

Magnetic resonance (MR) imaging is a useful tool for assessing the anterior cruciate ligament (ACL) graft when its integrity is in question, with some limitations. It can differentiate between a graft that is partially or completely torn. Several primary (direct) and secondary (indirect) signs have been described. Graft continuity in the coronal plane and normal graft thickness in the coronal or sagittal plane are the most valuable primary signs in excluding full thickness tear. Of the secondary signs, the anterior tibial translation and the uncovered lateral meniscus sign are the most useful in differentiating a torn from an intact graft. Some of the primary and secondary signs of a native ACL tear are yet to be assessed for accuracy in detecting grafts tear, but they are a helpful guide especially when combined. These include the deep lateral femoral sulcus, the posterior cruciate ligament (PCL) angle, and the PCL curvature values.

Arthroscopic reconstruction of the anterior cruciate ligament (ACL) using auto grafts is being performed with increasing frequency particularly in young athletes. Although the procedure is generally well tolerated with good success rates, unsatisfactory results in terms of continued instability, loss of extension, and pain in the knee have been noted in 10-25% of patients.[1] Recently, computer assisted surgical systems are being introduced to improve the accuracy of graft placement, and thereby reduce graft failure or tears.[2] The usefulness of magnetic resonance (MR) imaging in the diagnosis of ACL graft tears and other complications associated with ACL reconstruction such as arthrofibrosis (cyclops lesions) and graft impingement is now well established.[3] The sensitivity (100%), specificity (86%), and accuracy (86.5%) of MR imaging is an evaluative tool for ACL graft tears.[4] A normal ACL graft on MR should be posterior and parallel to the roof of the intercondylar notch. It should not be in contact with that roof. The graft should enter the tibial tunnel without angulations.[3] (**Figure 1**). The appearance of the graft itself on MR imaging depends on the type of substance used, its

integrity, the extent of revascularization, and the time since surgery. With appropriate MR sequences, a well placed, intact graft can be differentiated from a partially or completely torn graft.[5] Contrast-enhanced MR imaging allows accurate evaluation of graft morphology and function. The distribution of contrast material within the substance of the graft may be of value in the identification of tears and whether or not they are partial or complete, however, this role has yet to be explored more.[6] The objective of this article is to highlight the diagnostic accuracy of the primary (direct) and secondary (indirect) MR ACL graft tear.

The diagnostic dilemma. 1. There are too many described signs for the native ACL tears, reaching over 20. Not all of those signs were reported in grafted ligament tears. 2. The exact type of graft used may not be known to the radiologist. Different grafts have different MR appearances. 3. Graft incorporation involves local complex biologic processes and its signal varies with the time since graft surgery. 4. A subset of patients seemed to have stable knees despite the lack of properly functioning ACL. Others might have morphologically normal, but functionally insufficient grafts. 5. Graft failure is of multifactorial etiology. Tunnel placement determines its biomechanical isometry. 6. An impinged graft against the intercondylar roof of a tunnel may have a bright signal without a tear. 7. Graft tension, which is important for proper function, cannot be quantified by static imaging techniques.

Primary (direct or intrinsic) MR signs of ACL graft tear. **Graft orientation.** Horizontal orientation or laxity of the graft is not diagnostic of a tear (**Figure 2**). An intact graft should be taut between the distal femur and tibial tunnel (**Figure 3**).[7] **Graft discontinuity**. Assessing completely discontinuous graft on both sagittal and coronal planes increases the specificity and positive predictive value in the diagnosis of a full thickness graft tear. However, agreement between observers in evaluating graft discontinuity in the sagittal plane was poor. Complete graft discontinuity in the coronal plane is the most accurate single indicator of disruption,[7] and is the most reliable primary or secondary findings when assessed individually (**Figure 4**).[8] **Graft thickness.** Assessing full graft thickness without focal thinning was more accurate in the coronal plane than the sagittal plane (**Figures 5a & 5b**).[7] **Graft signal.** The signal intensity of clinically stable ACL grafts increases for a few months after surgery and may persist well beyond 12 months. It starts to decrease over the subsequent months. The initial increase in graft signal intensity has been attributed to revascularization, cellular infiltration, or edema.[7] Focal increased signal in the distal aspect of ACL grafts has been reported with cases of graft impingement (**Figure 6**).[9] Fortunately, the commonly harvested auto graft
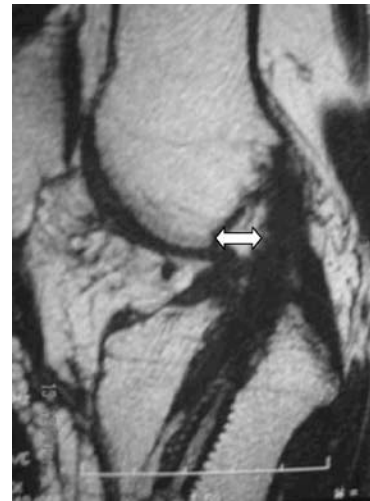

Figure 1 - A 27-year-old male with a clinically stable knee. The T2 sagittal shows an anterior cruciate ligament graft posterior to, and not in contact with the intercondylar roof (arrow).

Figure 2 - A 32-year-old male, post anterior cruciate ligament reconstruction with positive Lachman's test. Sagittal oblique image shows an intact, but lax graft fiber orientation in a clinically stable knee (arrow).

Figure 3 - A 30-year-old male, post anterior cruciate ligament reconstruction with bone-tendon-bone autograft showing a taut graft between distal femur and tibia on T2 with normal signal (arrow).

Figure 4 - A 30-year-old male with clinically unstable knee after anterior cruciate ligament reconstruction. Coronal T2 showing complete graft discontinuity (arrow), an accurate indicator of disruption at its tibial attachment.

Figure 6 - A 44-year-old male with clinically stable knee, but with 10 D extension lag. The T2 with fat sat shows increased signal due to graft impingement and anterior positioning of tibial tunnel (arrow).
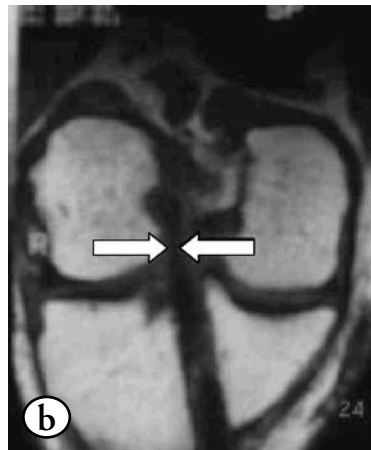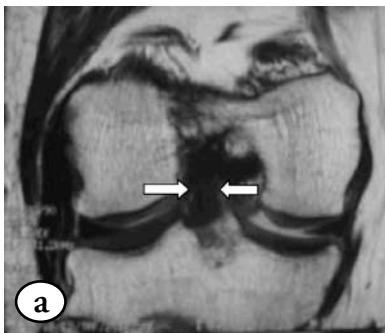

Figure 5 - Graft thickness: **a**) A 34-year-old male 15 months post anterior cruciate ligament reconstruction. Coronal T2 shows full graft fiber thickness in the coronal plane (arrow). **b**) A 30-year-old male with clinically stable knee. Oblique coronal T2 showing continuous, but thinned graft fibers (arrows).
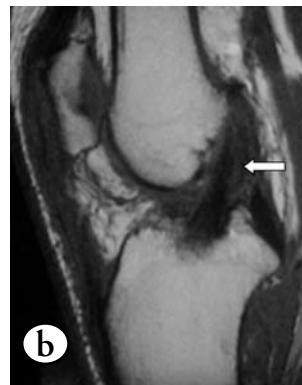

Figure 7 - Graft signal: **a**) A 33-year-old male who had an anterior cruciate ligament (ACL) reconstruction using bone-tendon-bone shows Rak's type 1, well defined graft with continuous band and low signal (arrow). **b**) A 22-year-old male with anterior knee pain 5 months post ACL reconstruction shows Rak's type 2, increased signal intensity with low signal only in a part of the graft (arrow).

(bone-patellar tendon-bone, or hamstring) is thicker than the native ligament, and therefore easier to image. Its appearance on MR can be categorized into 3 types by signal intensity and continuity of the ligament according to Rak's method:[10] 1. Well-defined type: the graft is visualized as a smoothly continuous band with low signal over the entire course, 2. Intermediate type: increased signal intensity with a low-signal band in part of the graft, 3. Indiscernible type: the graft is not identified at all due to markedly increased signal intensity (**Figures** 7**a** & 7**b**). The graft signal intensity can also be evaluated using the grading system described by Howell et al;[11] namely, the intra-articular portion of the ACL graft is divided into 3 areas (proximal, mid, and distal). The signal intensity of each area was graded from 0 to 3 points (0 - the graft has a homogeneous low signal intensity indistinguishable from the posterior cruciate ligament or patellar ligament, 1 - the graft on multiple slices retains at least 50% of the normal ligament signal (**F**igure 8), 2 - <50% of the graft exhibits normal low signal, and 3 - the graft consists of diffuse increased signal intensity with no normal appearing fibrous strands. However, small amounts of increased intra-substance graft signal intensity on intermediate and T2-weighted images can be seen after ACL reconstruction at long term follow up of 4 years or longer, and do not necessarily correlate with findings of joint instability or functional limitation.[12]

According to Recht et al,[13] findings that are crucial for detection of graft disruption include absence of intact graft fibers, and increased signal intensity similar to that of fluid within the expected anatomical site of the graft on T2 weighted images.

Secondary (indirect) MR signs. Deep lateral femoral sulcus. This sign, which might have existed from the initial pre-grafting injury of the native ACL, was described in patients with an ACL tear. It is due to an impaction fracture similar to the Hill-Sachs lesion anterior dislocation of the humerus. It occurs when the tibia becomes displaced anteriorly, and the lateral sulcus pushes against the posterior rim of the tibial plateau. It is measured according to the method of Cobby et al.[14] A line drawn tangent to the articular surface serves as the reference. The depth of the sulcus was measured perpendicular to this line. No patient with a normal native ACL had a sulcus greater than 1.2 mm (**Figure** 9).

Posterior cruciate ligament curvature value (PCL bowing ratio). The curvature of the PCL can be quantified by means of 2 measurements: a) the distance between the anterior most tibial and femoral insertion points of the PCL ligament (line y), and b) the maximal distance of perpendicular line (line x) drawn between line y and the undersurface of the PCL. Positioning of the patient
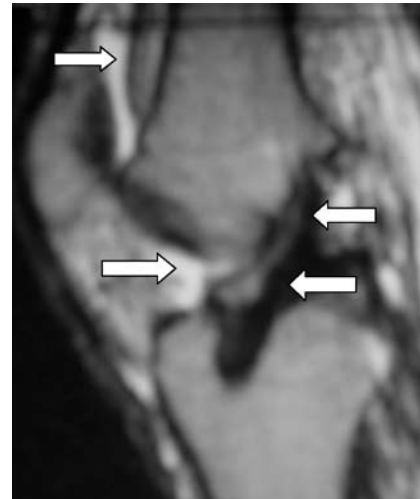

Figure 8 - A 36-year-old male with recurrent swelling of his right knee 7 months post anterior cruciate ligament reconstruction with bone-tendon-bone (arrows). Howell type 1, shows that the graft retain more than 50% of the normal ligament signal and an increased signal (fluid) within the joint.
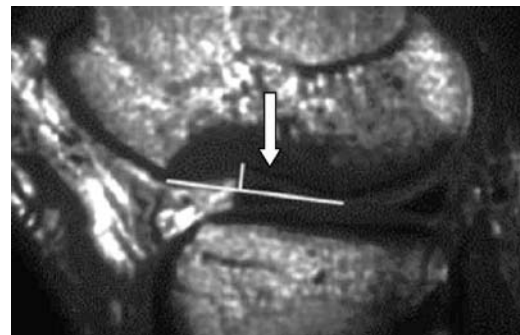

Figure 9 - Deep lateral femoral sulcus measures 4 mm, a sign of anterior displacement of the tibia with the lateral sulcus (arrow) pushes against the posterior rim of the lateral tibial plateau.
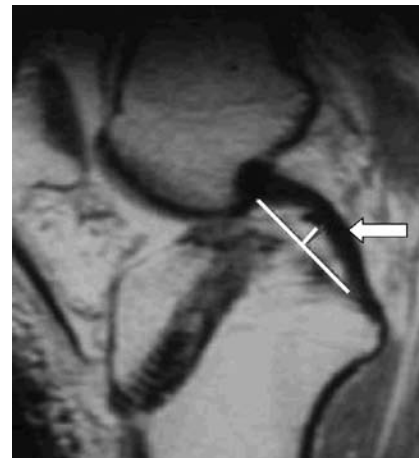

Figure 10 - A 30-year-old male post reconstruction using bone-tendon-bone with posterior cruciate ligament curvature value (index) of 0.2 (x=3 mm/y=15 mm) an indirect indication of an intact anterior cruciate ligament graft (arrow).

in the MR coil and the choice of which sagittal plane to use can affect the degree of PCL bowing. Care should be exercised to exclude the anterior menisco-femoral ligament of Humphrey's, if present. No patient with a normal ACL has a PCL curvature value >0.42, and no patient with ACL tear has a value <0.21.[15,16] With ratio more than 0.39, the sensitivity of this sign will be 34% and its specificity is 100% (**Figure 10**).[17]

The abnormal PCL line. A line is drawn tangential to the posterior margin of the linear portion of the distal part of PCL and extended proximally. It is considered negative if the proximal extension of that line crosses the medullar cavity of the distal 5 cm of the femur on mid sagittal images (**Figures 11a & 11b**).[9] It has 41% sensitivity, 75% specificity and 50% accuracy in the diagnosis of ACL graft tear.[7]

PCL angle. It is the angle between a line through the center of the proximal and a line through the center of the distal portion of the PCL (**Figure 12**). The mean PCL angle in normal subjects is 123°. This angle is decreased in patients with ACL tear to <106°. The PCL angle together with PCL line and PCL bowing ratio have been introduced to make assessment of PCL bowing less subjective. These 3 signs have a high specificity of 91-100%, but only a moderate sensitivity of 34-52%.[17]

Anterior tibial translation (anterior drawer sign). It is measured by drawing a line tangent to the posterior margin of the cortex of the lateral femoral condyle and parallel to the long axis of the tibia.[16,17] This sign is considered positive if the posterior cortex of mid lateral tibia is translated >5 mm anterior to the posterior cortex of the femur on sagittal images (**Figure 13**). It has 46% sensitivity, 90% specificity, 93% positive predictive value, and 50% accuracy in differentiating any graft tear from an intact graft.[7]

Uncovered posterior horn of lateral meniscus (posterior displacement of the lateral meniscus). This sign together with the PCL curvature value are manifestations of abnormal forward shift of the tibia. A line drawn superiorly from posterior cortex of lateral tibial plateau intersects the posterior horn of lateral meniscus on sagittal images (**Figure 14**). This sign has 23% sensitivity, 100% specificity, and 100% positive predictive value, and 52% accuracy in differentiating any graft tear from intact graft.[7]

Posterior cruciate ligament hyper buckling. Hyper buckling is defined as a posterior concavity of PCL on sagittal images. It is seen in most of the patients with complete or partial rupture of the graft. As in the non-reconstructed knee, it indicates laxity of ACL substitute (**Figure 15**).[4] It has 41% sensitivity, 70% specificity, and 50% accuracy.[7]
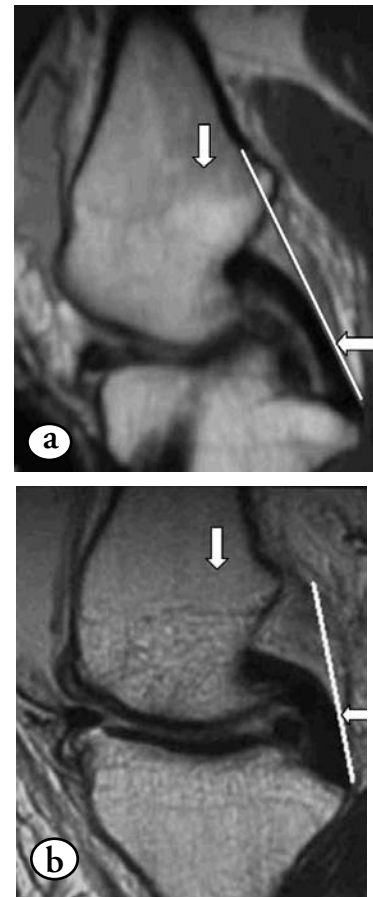

Figure 11 - Posterior cruciate ligament line: **a**) A 33-year-old man 2 years post anterior cruciate ligament (ACL) reconstruction with clinically stable knee and a normal posterior cruciate ligament (PCL) line crossing the distal 5 cm of the femur, an indirect sign of an intact ACL graft (arrow). **b**) A 30-year-old male with recurrent giving way 4 years post ACL reconstruction. Sagittal T2 shows an abnormal PCL line not crossing the distal 5 cm of femur (arrow).
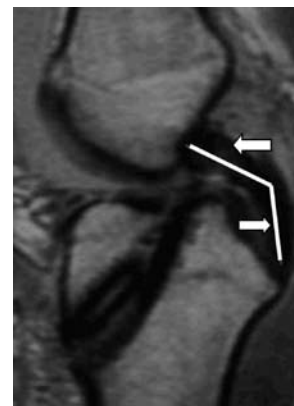

Figure 12 - A 27-year-old male with a clinically stable knee 1 ½ years post reconstruction with bone-tendon-bone autograft. Sagittal T2 shows a posterior cruciate ligament angle of 124° (arrows).

Figure 13 - A 30-year-old male with clinically unstable knee, 3 years post anterior cruciate ligament reconstruction with bone-tendon-bone autograft. Sagittal T2 shows anterior tibial translation of 5.5 mm.

Figure 14 - A 42-year-old male, 18 month post reconstruction using bone-tendon-bone Sagittal T2 shows intersection of the posterior horn of the lateral meniscus (arrow), a sign of forward shift of the tibia.
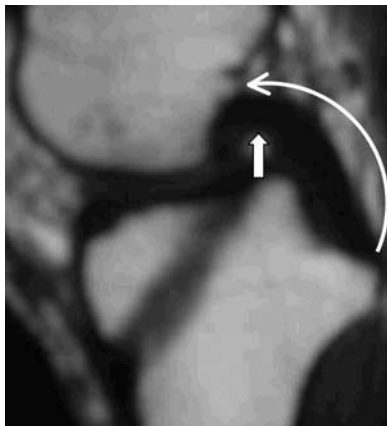

Figure 15 - A 31-year-old male with clinically unstable knee, almost 7 years post anterior cruciate ligament (ACL) reconstruction using bone-tendon-bone. Sagittal T1 shows increased posterior concavity (hyper buckling) of the posterior cruciate ligament (arrows), an indirect sign of torn ACL autograft.

In summary, MR imaging is indispensable when the ACL graft integrity is in question. As in non reconstructed knee, the primary signs of ACL graft tear includes: diffuse increased graft signal intensity, focal increased graft signal at its proximal, middle, or distal third, horizontal graft orientation on sagittal images, and complete ACL graft discontinuity. Numerous indirect signs have been described including: deep lateral femoral sulcus, abnormal PCL curvature value (PCL bowing ratio), PCL angle, abnormal PCL line, anterior tibial translation, uncovered posterior horn of lateral meniscus, and PCL hyper buckling. Some of these signs can assist in differentiating graft tear "partial or full thickness" from intact graft, but none of them are accurate on their own. It is unclear why many of these secondary signs associated with native ACL tears are present in intact ACL grafts. Perhaps these findings raise the question that the intact grafts may not provide the same degree of physiologic stability as seen with a native ACL. Of the primary signs, mildly hyper intense signal on T2 weighted images can occur without a tear, but a markedly hyper intense signal equivalent to fluid is the clue for a tear. Complete graft discontinuity in the coronal plane is the most accurate single indicator of disruption. The secondary signs, anterior tibial translation and uncovered posterior horn lateral meniscus can assist in differentiating graft tear (partial or full thickness) from intact graft.

References

1. Musahl V, Burkart A, Debski RE, Van Scyoc A, Fu FH, Woo SL. Anterior cruciate ligament tunnel placement: Comparison of insertion site anatomy with the guidelines of a computer-assisted surgical system. *Arthroscopy* 2003; 19: 154-160.
2. Recht MP, Kramer J. MR imaging of the postoperative knee: a pictorial essay. *Radiographics* 2002; 22: 765-774.
3. Recht MP, Piraino DW, Applegate G, Richmond BJ, Yu J, Parker RD, et al. Complications after anterior cruciate ligament reconstruction: radiographic and MR findings. *AJR Am J Roentgenol* 1996; 167: 705-710.
4. Schatz JA, Potter HG, Rodeo SA, Hannafin JA, Wickiewicz TL. MR imaging of anterior cruciate ligament reconstruction. *AJR Am J Roentgenol* 1997; 169: 223-228.
5. Vogl TJ, Schmitt J, Lubrich J, Hochmuth K, Diebold T, Del Tredici K, et al. Reconstructed anterior cruciate ligaments using patellar tendon ligament grafts: diagnostic value of contrast-enhanced MRI in a 2-year follow-up regimen. *Eur Radiol* 2001; 11: 1450-1456.
6. Horton LK, Jacobson JA, Lin J, Hayes CW. MR imaging of anterior cruciate ligament reconstruction graft. *AJR Am J Roentgenol* 2000; 175: 1091-1097.
7. Stöckle U, Hoffmann R, Schwedke J, Lubrich J, Vogl T, Südkamp NP, et al. Anterior cruciate ligament reconstruction: the diagnostic value of MRI. *Int Orthop* 1998; 22: 288-292.

8. Collins MS, Unruh KP, Bond JR, Mandrekar JN. Magnetic resonance imaging of surgically confirmed anterior cruciate ligament graft disruption. *Skeletal Radiol* 2008; 37: 233-243.

9. Howell SM, Berns GS, Farley TE. Unimpinged and impinged anterior cruciate ligament grafts: MR signal intensity measurements. *Radiology* 1991; 179: 639-643.

10. Rak KM, Gillogly SD, Schaefer RA, Yakes WF, Liljedahl RR. Anterior cruciate ligament reconstruction: evaluation with MR imaging. *Radiology* 1991; 178 : 553-556.

11. Howell SM, Clark JA, Blasier RD. Serial magnetic resonance imaging of hamstring anterior cruciate ligament autografts during the first year of implantation. A preliminary study. *Am J Sports Med* 1991; 19: 42-47.

12. Saupe N, White LM, Chiavaras MM, Essue J, Weller I, Kunz M, et al. Anterior cruciate ligament reconstruction grafts: MR imaging features at long-term follow-up--correlation with functional and clinical evaluation. *Radiology* 2008; 249: 581-590.

13. Recht MP, Parker RD, Irizarry JM. Second time around: evaluating the postoperative anterior cruciate ligament. *Magn Reson Imaging Clin N Am* 2000; 8: 285-297.

14. Cobby MJ, Schweitzer ME, Resnick D. The deep lateral femoral notch: an indirect sign of a torn anterior cruciate ligament. *Radiology* 1992; 184: 855-858.

15. Gentili A, Seeger L, Yao L, Do HM. Anterior cruciate ligament tear: indirect signs at MR imaging. *Radiology* 1994; 193: 835-840.

16. Tung GA, Davis LM, Wiggins ME, Fadale PD. Tears of the anterior cruciate ligament: primary and secondary signs at MR imaging. *Radiology* 1993; 188: 661-667.

17. Schweitzer ME, Cervilla V, Kursunoglu-Brahme S, Resnick D. The PCL line: an indirect sign of anterior cruciate ligament injury. *Clin Imaging* 1992; 16: 43-48.

Related topics

Piskin A, Gulbahar MY, Tomak Y, Gulman B, Hokelek M, Kerimoglu S, Koksal B, Alic T, Kabak YB. Osteoarthritis models after anterior cruciate ligament resection and medial meniscectomy in rats. A histological and immunohistochemical study. *Saudi Med J* 2007; 28: 1796-1802.

Ozkayin N, Aktuglu K. Avulsion fractures of tibial tuberosity in adolescents. Treatment with closed reduction and percutaneous screwing, using MRI to identify combined intraarticular lesions. *Saudi Med J* 2005; 26: 1636-1639.

Hasan HA. Tegner and Lysholm scores in brace-free rehabilitation. *Saudi Med J* 2004; 25: 761-765.