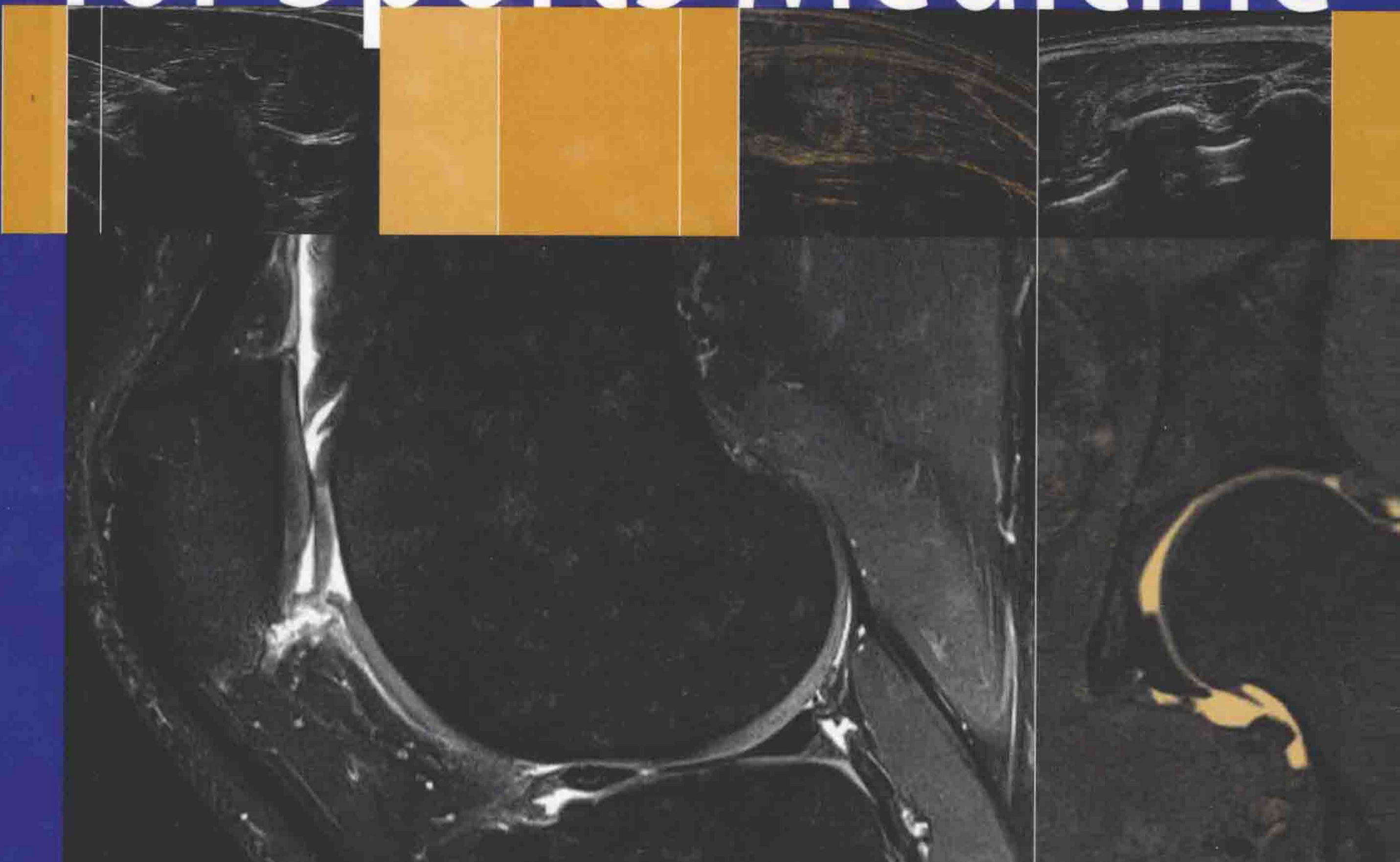
Philip Robinson
Editor

Essential Radiology for Sports Medicine



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Essential Radiology for Sports Medicine

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Essential Radiology for Sports Medicine

For my parents, Peter and Anwen, and my family Oonagh, Eve, Ted and Roddy for their constant love, support and belief

Preface

Imaging plays an increasingly vital role in the management of athletes aiding diagnosis, injury grading and prognosis, as well as guiding therapy. These processes apply equally to elite and recreational athletes young and old.

I have always found that understanding the relevance of imaging findings is easier when accompanied by knowledge of the anatomy, biomechanics and pathological processes involved in injury formation. This textbook has been developed with both radiologists and sports clinicians in mind and aims to bring all these processes together and illustrate the spectrum of injury and associated clinical features for specific anatomical areas. Internationally recognized musculoskeletal experts have contributed chapters which provide an imaging and clinical overview of the most relevant joint, bone and soft tissue athletic injuries. There is guidance for the reader on why specific injuries occur, how to identify the optimal imaging evaluation and how to interpret the subsequent imaging findings. Acute and overuse injuries are discussed as well as the premature degenerative processes that occur in athletes.

State-of-the-art imaging techniques and findings are presented including the use of musculoskeletal ultrasound, conventional MR imaging and MR arthrography. Therapeutic image-guided intervention using fluoroscopy, CT, and ultrasound is also discussed. This balance of techniques should allow a clinician whose practice focuses on one particular modality to become aware not only of that technique's abilities but other modalities and their capabilities and limitations.

Leeds, UK — Philip Robinson

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Chapter 1
Knee Injuries

Melanie A. Hopper and Andrew J. Grainger

Introduction

The knee is vulnerable to a wide variety of acute and chronic injuries sustained during sporting activity. Acute knee injuries most frequently involve the bone, menisci, articular cartilage and ligaments. They are particularly common in sports involving twisting movements and sudden changes of direction. Examples include soccer and rugby, skiing, basketball and volleyball. The knee transmits considerable forces and repetitive injury particularly to the cartilage and tendons is common, especially in sports involving running and jumping.

Anatomy

The knee comprises two joints, the tibiofemoral joint, with its medial and lateral compartments, and the patellofemoral joint. The menisci and ligaments are fundamental to the maintenance of joint stability.

Menisci

The fibrocartilaginous medial and lateral menisci have distinct morphology reflected in their imaging appearances. The medial meniscus is U shaped and larger than the more C-shaped lateral meniscus. Both menisci are triangular in cross-section with a 3–5 mm high peripheral rim, tapering to a thin free edge centrally. They comprise anterior and posterior horns separated by the meniscal body. The anterior horn of the medial meniscus is smaller than the posterior horn whereas the lateral meniscus is more uniform in shape. Both the medial and lateral menisci are firmly attached to the underlying tibia by anterior and posterior root ligaments (Fig. 1.1).

A number of ligaments are associated with the meniscal attachments and although they are very variable it is important to be aware of these and their potential to mimic meniscal injury on magnetic resonance (MR) imaging. They can be identified as meniscal ligaments by following their course on consecutive image slices between recognised points of origin and insertion. The transverse intermeniscal ligament links the anterior horns and may be seen as a fibrous band traversing Hoffa's fat pad. Posteriorly, the lateral meniscus may attach to the medial femoral condyle via the anterior and posterior meniscofemoral ligaments, the ligaments of Humphrey and Wrisberg, respectively. Frequently, one of the two ligaments is more prominent and most usually on MR imaging only one ligament is seen [1] (Fig. 1.2).

Ligaments have also been recognised passing from the anterior horn of one meniscus to the posterior horn of the opposite meniscus. These oblique intermeniscal ligaments are uncommon and are named after the meniscus of their posterior attachment [2].

The medial meniscus is firmly attached to the joint capsule and to the deep fibres of the medial collateral ligament via the meniscotibial and meniscofemoral ligaments making it less mobile than the lateral and more prone to injury. The lateral meniscus is more loosely attached to the capsule except posterolaterally where the inferior and superior popliteomeniscal fascicles extend from the lateral meniscus around the popliteus tendon attaching to the adjacent joint capsule. This connection allows the popliteus to pull the lateral meniscus posteriorly during knee flexion preventing meniscal entrapment. In this region, the appearance of the popliteus tendon separated from the meniscus by a thin line of fluid can mimic tearing of the posterior horn (Fig. 1.3a).

Although the medial meniscus has no direct muscle attachment, it is likely that indirect attachment to the semimembranosus muscle provides retraction of its posterior horn during knee movement.

In the foetus the menisci have intrinsic vessels, but from birth there is rapid restriction of blood supply so that by early adulthood only the outer third of a meniscus retains vascularity. This has important implications to the surgeon contemplating the viability of meniscal repair procedures.

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Cruciate Ligaments

The cruciate ligaments are intra-capsular but extrasynovial. The anterior cruciate ligament (ACL) is on average 4 cm long and 1 cm wide and arises from the medial aspect of the lateral femoral condyle. Proximally it runs parallel to the roof of the intercondylar notch fanning out to insert onto the anterior tibial eminence. The ACL comprises two functional bundles or units. The anteromedial (AM) bundle is smaller and more tightly packed than the posterolateral (PL) fibres. During knee flexion the AM fibres are taut; the larger PL bundle comes under tension in extension and provides the main resistance to hyperextension.

The posterior cruciate ligament (PCL) is thicker and stronger than the ACL and has a more robust blood supply. It takes its origin from the lateral aspect of the medial femoral condyle inserting into a small depression on the posterior aspect of the tibia. Again the ligament has two functional bundles of fibres. The anterolateral (AL) bundle is taut in knee flexion; the posteromedial (PM) fibre bundle becomes tight during knee extension.

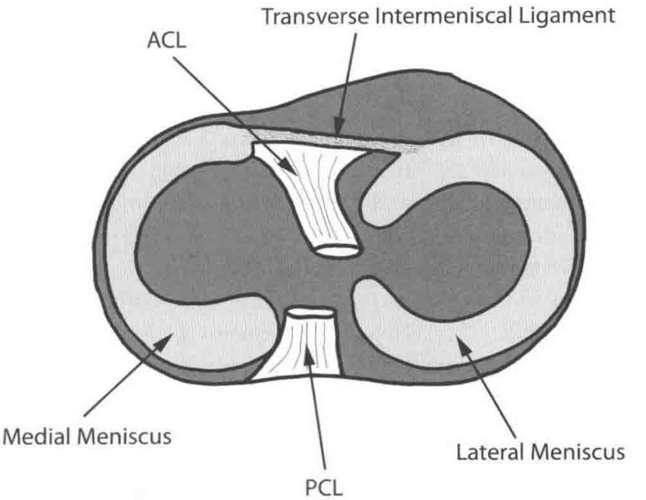

Fig. 1.1 Diagram showing the arrangement of meniscal attachments on the tibial plateau and their relationship to the cruciate ligament insertions. Note the medial meniscus has a "U"-shaped configuration while the lateral meniscus has a tighter "C" shape. The posterior horn of the medial meniscus is larger than the anterior horn in contrast to the lateral meniscus where the two horns are of similar size. Note also the transverse intermeniscal ligament

The Collateral Ligaments and Posterior Corners

The medial and lateral ligament complexes are functionally and anatomically complex and are essential for knee stability.

The medial stabilising structures of the knee have a layered configuration first described by Warren and Marshall [3]. Deep crural and sartorial fascia provides the most superficial of the three layers. The middle layer is composed of the superficial medial collateral ligament (MCL). The deepest layer structures are the deep MCL, the patellomeniscal ligament and the posteromedial capsule.

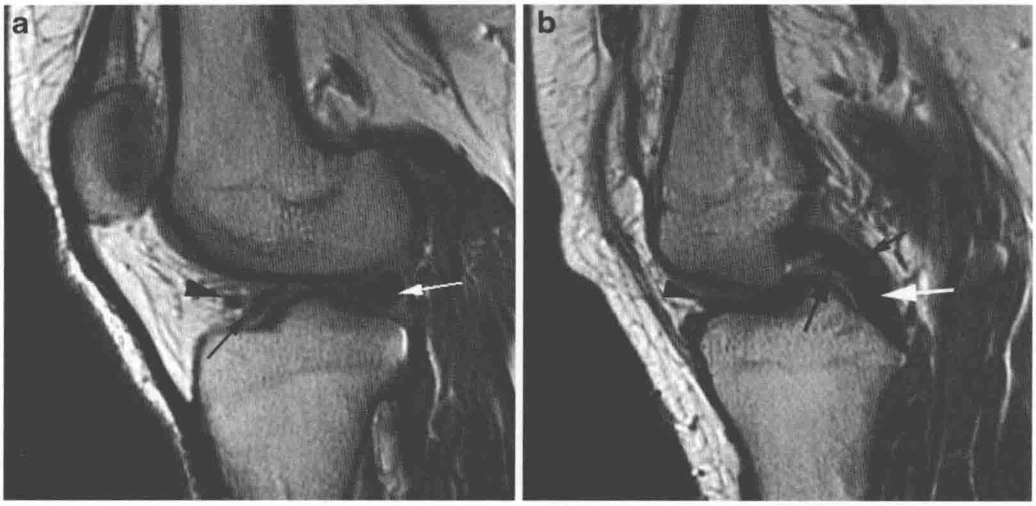

Fig. 1.2 Normal meniscal ligaments. Proton density sagittal images. (**a**) This section passes through the anterior (*black arrow*) and posterior (*white arrow*) horns of the lateral meniscus. The anterior intermeniscal ligament (*arrowhead*) is seen as a separate structure adjacent to the anterior horn of the meniscus. (**b**) This section is taken closer to the midline than **a** and passes through the intercondylar notch. The PCL is seen (*white arrow*). Anterior to it is seen the anterior meniscofemoral ligament of Humphrey (*large black arrow*) while posteriorly a rather smaller posterior meniscofemoral ligament of Wrisberg is seen (*small black arrow*). Anteriorly, the intermeniscal ligament seen in A continues across the midline (*arrowhead*)

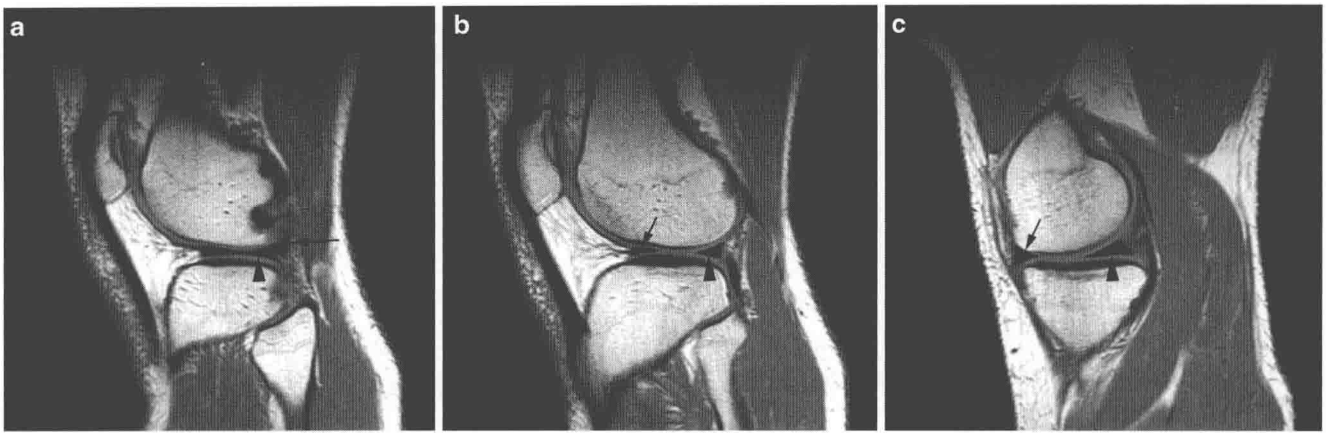

Fig. 1.3 Normal meniscal anatomy. Sagittal T1-weighted images. (**a**) This section passes through the far lateral aspect of the lateral meniscus which shows the classic "bow tie" configuration at this point (*arrowhead*). The popliteus tendon is seen passing posteriorly adjacent to the posterior aspect of the meniscus (*arrow*). (**b**) This section is more medial than **a** and passes through the anterior (*arrow*) and posterior (*arrowhead*) horns of the lateral meniscus. Note that the two horns are of similar size. (**c**) This image passes through the anterior (*arrow*) and posterior (*arrowhead*) horns of the medial meniscus. In contrast to the lateral meniscus the posterior horn is larger than the anterior

At its anterior aspect the superficial MCL runs from the medial femoral condyle to the medial aspect of the proximal tibia, attaching approximately 6 cm below the joint line. Posteriorly, fibres of the superficial MCL extend obliquely from the adductor tubercle to form the posterior oblique ligament (POL). The deep MCL attaches to the medial meniscus and comprises meniscofemoral and meniscotibial (coronary ligament) components. A bursa may exist between the superficial and deep MCL. Dynamic stabilisation for the medial aspect of the knee joint comes from the semimembranosus complex, the medial quadriceps and the pes anserinus muscle tendon units.

At the anterolateral corner of the knee the iliotibial band (ITB) attaches to Gerdys tubercle and provides stabilisation along with the joint capsule. Behind the ITB the tendon of biceps femoris inserts onto the lateral margin of the fibula head as a conjoined tendon with the lateral collateral ligament (LCL) which originates from the lateral femoral condyle. The LCL is one of the structures of the posterolateral corner, also referred to as the arcuate complex, an important knee stabiliser. The other ligaments and muscles involved in the posterolateral corner include popliteus, the arcuate ligament, the lateral head of gastrocnemius, the fabellofibular ligament and the popliteofibular ligament.

The popliteus tendon is intra-articular as it passes from the lateral femoral condyle between the LCL and the lateral meniscus through the popliteal hiatus where the arcuate ligament lies on its superficial aspect. At this point it leaves the joint and the popliteus muscle belly attaches to the posteromedial proximal tibia. Fibres extend from the popliteus to the lateral meniscus (the popliteomeniscal ligament) and to the styloid process of the fibula (the popliteofibular ligament). The arcuate ligament is Y-shaped. From the posterior joint capsule the medial limb runs superficial to popliteus before blending with the oblique popliteal ligament, the lateral limb runs from the capsule laterally over the popliteus tendon and muscle to insert on the posterior aspect of the fibula head. 20% of the population have a fabella as an ossicle within the lateral head of gastrocnemius, when the fabella is present the fabellofibular ligament passes from the lateral femoral condyle to the fabella and onto the styloid process of the fibula.

The Menisci

Meniscal injury is common, particularly in the athletic population and meniscal tears represent the most frequent reason for knee arthroscopy. Signs and symptoms of meniscal injury are unreliable but a history of mechanical problems such as locking or giving way is suggestive. Although many clinical tests have been described, no single test has been shown to be specific and sensitive in the assessment of meniscal pathology. Joint line tenderness is thought to have the closest correlation [4].

Imaging

MR imaging is the imaging modality of choice for imaging meniscal injury with a reported diagnostic accuracy of between 90 and 95% [5]. A brief discussion later in the chapter will be given with regard to other modalities.

Magnetic Resonance Imaging

Short echo time sequences (conventional spin echo T1, PD or gradient echo) are the most sensitive at demonstrating linear meniscal tears and form the basis of MR imaging protocols. T2 sequences, with a longer echo time are less sensitive but more specific. There is controversy as to the role of fast spin echo (FSE) in meniscal evaluation. Several studies report comparable accuracy with conventional spin echo when an echo train length of 4 to 5 is used in addition to faster data acquisition [6, 7]. Other authors determine that the blurring inherent in short TE FSE sequences can obscure a tear or render it less conspicuous [8, 9].

Normal Meniscus

The normal meniscus is low signal on all sequences due to its fibrocartilaginous structure. In sagittal plane both menisci have a "bow-tie" appearance peripherally on at least two consecutive images. The anterior and posterior horns of the lateral meniscus are approximately the same size, whereas the posterior horn of the medial meniscus is roughly twice the size of the anterior horn (Fig. 1.3). These normal features are important to recognise as subtle abnormalities can represent a meniscal tear (Fig. 1.4).

Discoid Meniscus

A discoid meniscus can range from a complete disc to a circular ring and affects the lateral meniscus significantly more frequently than the medial. With a reported incidence of 4.5% a discoid meniscus should be asymptomatic unless torn [10]. There is an increased incidence of tears in a lateral discoid meniscus [10].

On MR imaging the typical finding is of a complete "bow-tie" on three or more contiguous sagittal images, the discoid nature of the meniscus can usually also be appreciated on coronal imaging (Fig. 1.5).

Persistent Meniscal Vascularisation

In the majority of adults only the outer third of the meniscus retains a vascular supply. In a small number of people meniscal vessels persist into adulthood, causing intra-substance high T2-weighted (T2w) signal which may be misinterpreted as meniscal degeneration. The altered signal does not extend to an articular surface and so should not be confused for a meniscal tear.

Classification and MR Imaging Appearances of Tears

Two key features should be looked for when examining the menisci for possible tear. First, signal abnormalities within the normally low signal meniscus and second, alterations in meniscal morphology.

MR imaging meniscal signal abnormalities correlate well with pathology [11] (Table 1.1). Grade 1 signal change seen as globular high signal is not clinically significant and

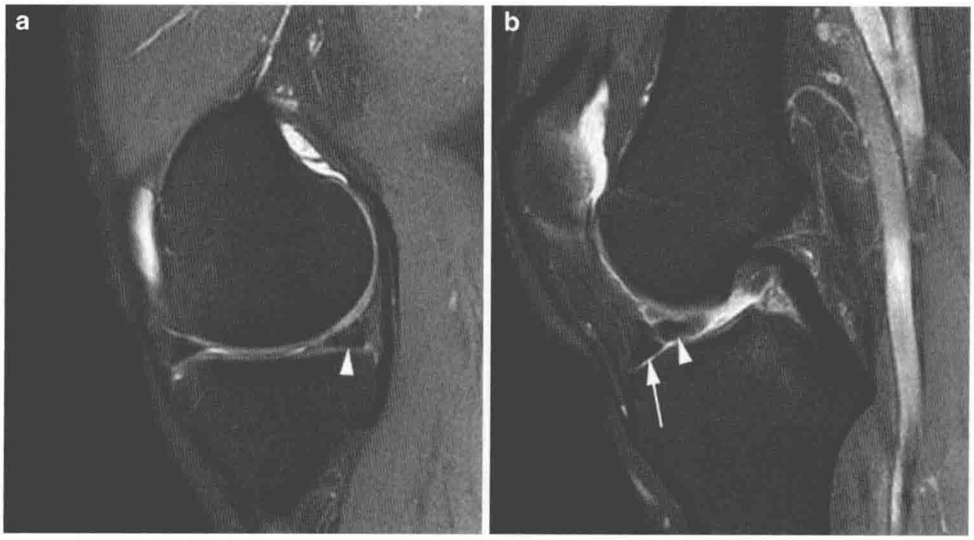

Fig. 1.4 Displaced tear of the medial meniscus. Sagittal proton density images with fat saturation. (**a**) This section passes through the anterior and posterior horns of the medial meniscus. Although no tear is evident the posterior horn (*arrowhead*) should be larger than the anterior but in this case looks to be of similar size. (**b**) This section passes through the intercondylar notch and is lateral to **a**. The cause of the small posterior horn is identified. The meniscus has torn and a fragment of the posterior horn has flipped anteriorly (*arrowhead*) to lie adjacent to the root of the anterior horn (*arrow*)

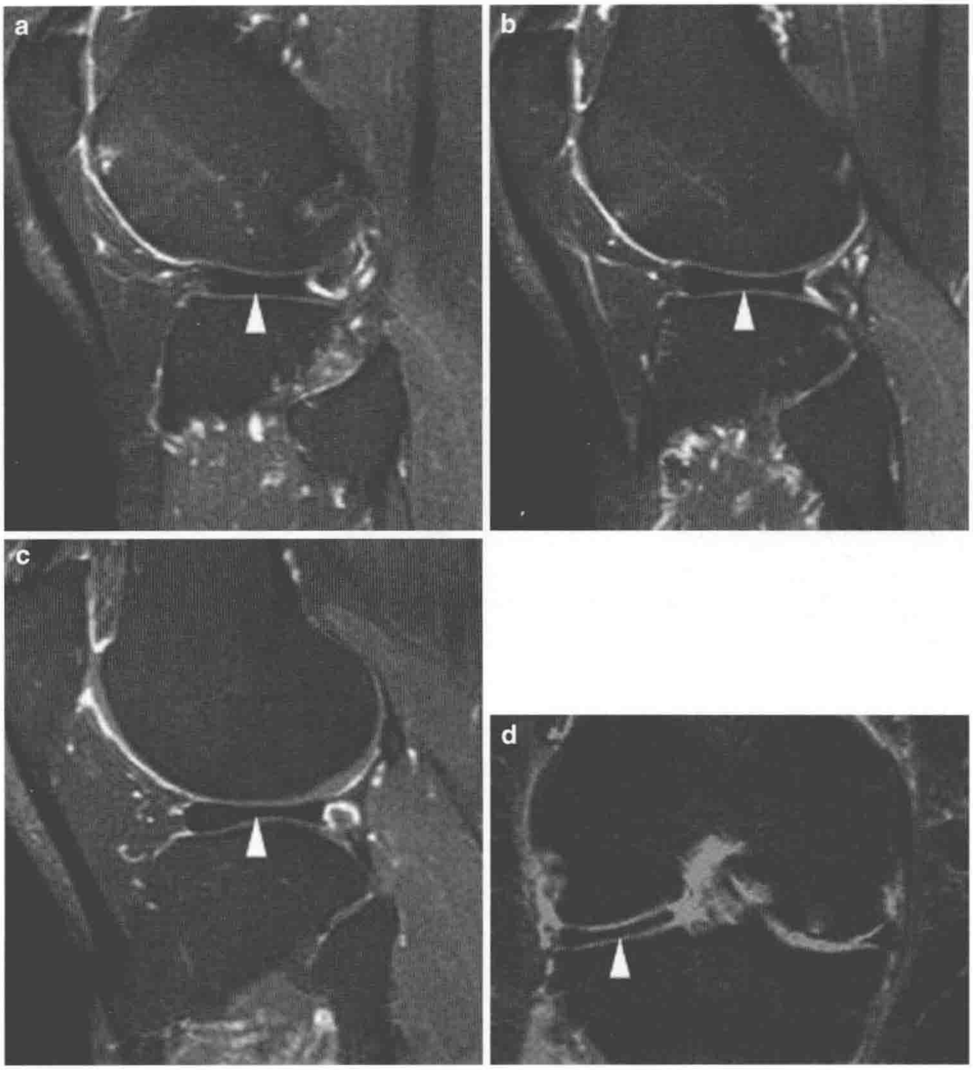

Fig. 1.5 Discoid meniscus. (**a–c**) Proton density sagittal images with fat saturation. The lateral meniscus has a "bow tie" configuration on multiple slices suggesting a discoid meniscus (*arrowheads*). (**d**) Coronal proton density fat-suppressed imaging. This section passes through the mid-plane of the lateral joint compartment and confirms the discoid meniscus (*arrowhead*)

Table 1.1 MRI classification of meniscal tears

Grade 0	Normal
Grade 1	Globular intra-substance intermediate signal not extending to an articular surface
Grade 2	Linear intra-substance intermediate signal not extending to an articular surface
Grade 3	Intermediate signal extending to an articular surface
Grade 3a	Intermediate signal reaches 1 articular surface
Grade 3b	Intermediate signal reaches both articular surfaces

is seen in asymptomatic athletes. Grade 2 meniscal changes represent part of a continuum of changes occurring in meniscal degeneration. It is seen as linear high signal within the meniscal substance and is typically asymptomatic occurring most frequently in the posterior horn of the medial meniscus (Fig. 1.6). High/intermediate signal within a meniscus that extends to one or both articular surfaces represents a meniscal tear and is termed a Grade 3 abnormality (Fig. 1.7). Only grade 3 signal abnormalities represent a meniscal tear and Grade 1 and 2 abnormalities are not prognostic for Grade 3 change [12].

In addition to the signal characteristics within a meniscus, it is vital to assess meniscal morphology in order to recognise displaced or absent meniscal tissue.

Tear Orientation

Meniscal tears can be subdivided according to their orientation.

1. Horizontal tears are parallel to the tibial articular surface.
2. Longitudinal tears are vertically oriented and extend along the circumferential axis of the meniscus.

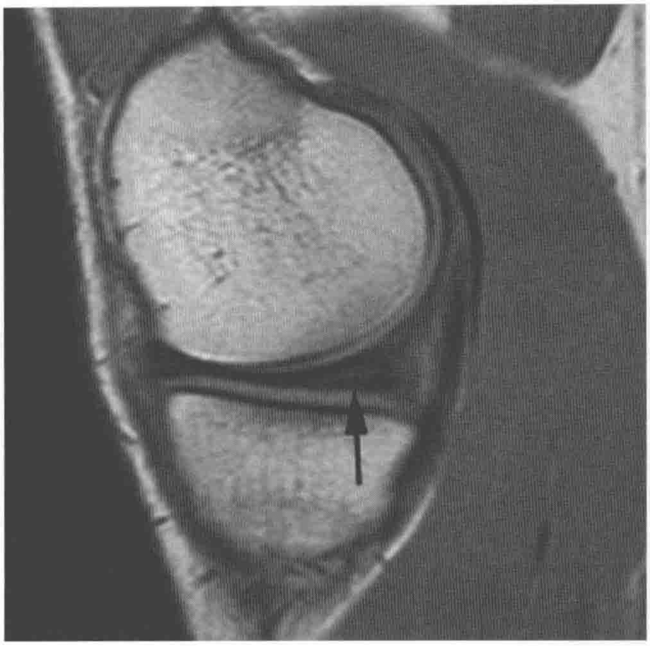

Fig. 1.6 Type 2 intra-meniscal signal change. Sagittal proton density image. The posterior horn of the medial meniscus is seen to contain linear increased signal. This does not contact the articular surface of the meniscus and represents type 2 signal change in the meniscus in keeping with intra-substance degeneration. No tear is shown

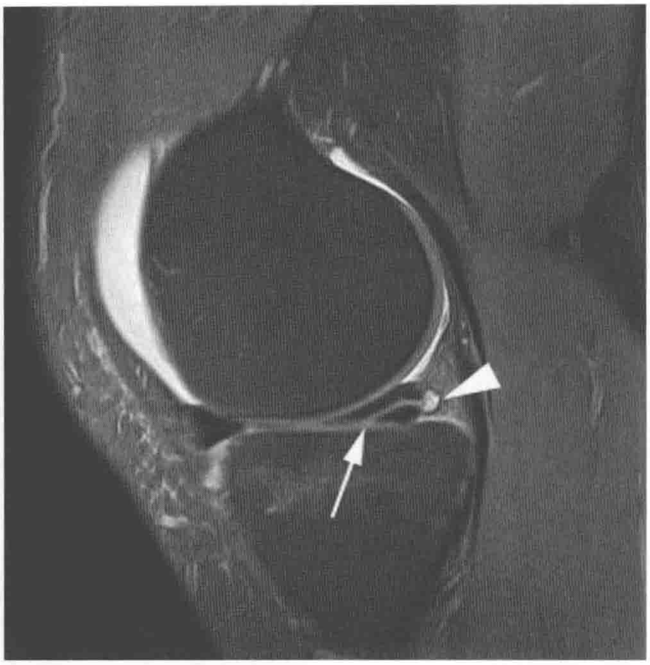

Fig. 1.7 Horizontal meniscal tear with small meniscal cyst. Sagittal proton density image with fat saturation. Linear high signal is seen extending horizontally to the inferior surface of the posterior horn of the medial meniscus (*arrow*) in keeping with a horizontal tear. A small parameniscal cyst (*arrowhead*) has formed at the outer edge of the meniscus

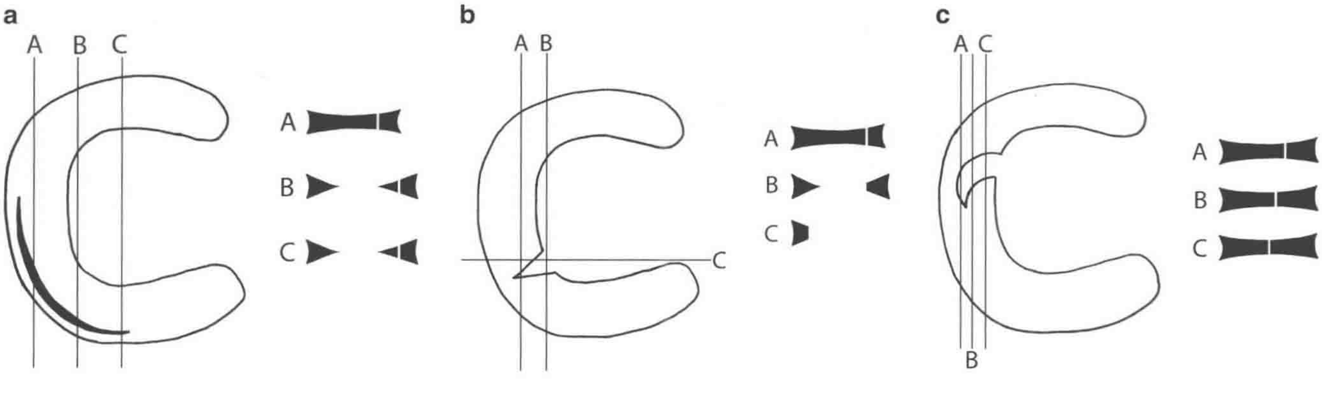

Fig. 1.8 Diagrams demonstrating the appearance of different meniscal tears on sections taken through the tear. (**a**) Peripheral longitudinal tear. (**b**) Radial tear. (**c**) Parrot beak tear

3. Radial tears are also vertically orientated but propagate perpendicular to the main meniscal axis.
4. Complex tears consist of components of two or more configurations.

Horizontal Tears

Tears running parallel to the tibial articular surface are also known as cleavage or horizontal tears. These tears may disrupt the superior or inferior surface of the meniscus, extending for a variable length into the substance of the meniscus (Fig. 1.7).

Longitudinal Tears

Typically longitudinal tears occur peripherally within the meniscus. Undisplaced peripheral longitudinal tears are characterised by abnormal high signal in the meniscus extending to both superior and inferior articular surfaces of the meniscus (Figs. 1.8a and 1.9). Displacement of the central meniscal fragment may occur and is referred to as a bucket handle tear; these are usually acute and represent approximately 10% of all meniscal tears [13]. The fragment usually displaces into the intercondylar notch. The sensitivity of MR imaging for the detection of bucket handle tears is less than that for other meniscal lesions [14]. Use of a coronal STIR sequence has been reported to significantly increase detection rates [15] and the authors find a coronal fat-suppressed PD or T2 sequence similarly helpful (Fig. 1.10). Several signs have been described to aid in the diagnosis of bucket handle tears (Table 1.2). In the sagittal plane, loss of the normal peripheral bow-tie configuration, or an inadequate number of bow-ties, suggests some of the meniscus is missing and should prompt further evaluation to identify displaced meniscal material. A double posterior cruciate ligament (PCL) sign has been described with bucket handle tears of the medial meniscus, the fragment lies in front of the PCL and is readily recognisable on sagittal imaging (Fig. 1.10b). Bucket handle tears of the lateral meniscus are associated with pseudo-tears of the anterior cruciate ligament as the meniscal fragment may lie just lateral to the ACL suggesting a tear (Fig. 1.11). Instead of displacing centrally into the intercondylar notch the meniscal fragment may flip anteriorly giving the appearance of a large anterior horn, the so-called flipped meniscus sign [13] (Fig. 1.4).

Fig. 1.9 Peripheral longitudinal meniscal tear. Sagittal proton density image with fat saturation. There is linear high signal extending from the superior to the inferior surface of the posterior horn of the medial meniscus (*arrow*). This represents a peripheral longitudinal tear

Table 1.2 Imaging findings in bucket handle tears

- Absent bow-ties
- Fragment in the intercondylar notch
- Double PCL sign
- ACL pseudo-tear
- Flipped meniscus

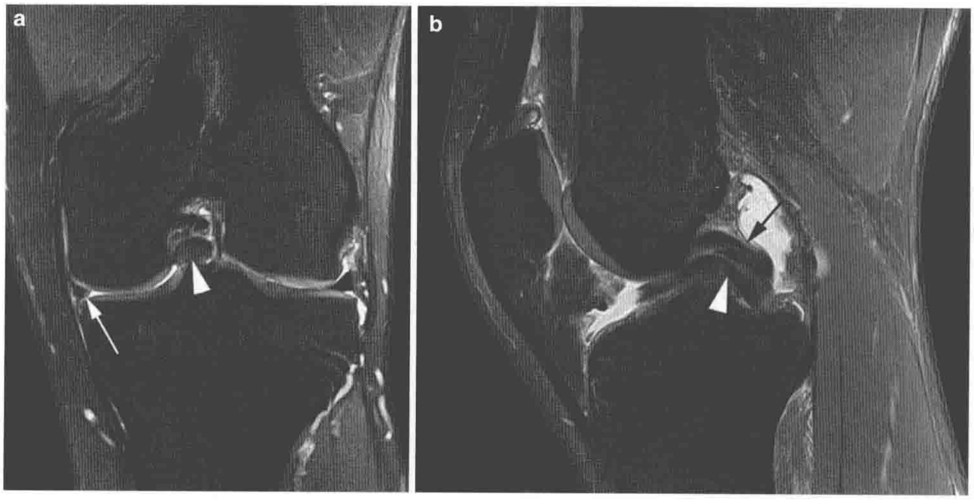

Fig. 1.10 Bucket handle meniscal tear with double PCL sign. Coronal (**a**) and sagittal (**b**) proton density images with fat saturation. (**a**) There is a bucket handle tear of the medial meniscus. The displaced meniscal material is seen in the intercondylar notch (*arrowhead*) while the body of the medial meniscus (*arrow*) is too small compared with the lateral meniscus. (**b**) The displaced meniscal material (*arrowhead*) lies in the intercondylar notch alongside the PCL (*arrow*) giving the impression of a double PCL, a characteristic sign

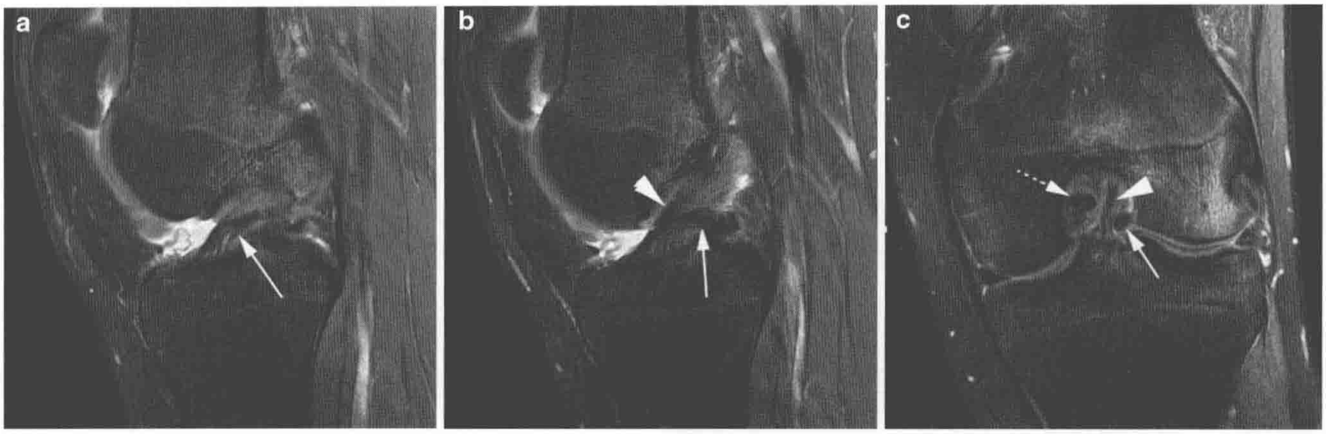

Fig. 1.11 Bucket handle meniscal tear with ACL pseudo-tear. Sagittal (**a** and **b**) and coronal (**c**) proton density images with fat saturation. (**a**) There is an abnormal appearance in the intercondylar notch (*arrow*) which was initially thought to represent a torn ACL. (**b**) The adjacent sagittal slice in fact confirms the ACL to be intact (*arrowhead*) but abnormal material is seen adjacent to the ACL in the intercondylar notch (*arrow*). (**c**) The coronal image confirms a bucket handle tear of the lateral meniscus with the displaced meniscal material (*arrow*) lying adjacent to the ACL (*arrowhead*). The PCL (*broken arrow*) is also seen in the intercondylar notch. The body of the lateral meniscus has an abnormal appearance as a result of the tear and there is extensive marrow oedema seen in the lateral femoral condyle

Table 1.3 Imaging findings in radial tears

- Truncated triangle
- Cleft sign
- Marching cleft
- Ghost meniscus

Radial Tears

Radial tears are purely vertical, orientated at 90° to the meniscal surface (Fig. 1.8b). The majority involve the posterior horns and bodies of the menisci [16]. MR imaging findings depend upon the position of the radial tear and four imaging signs have been described (Table 1.3). On sagittal and coronal images a radial tear can truncate the normal triangular shape of the meniscal horns (Fig. 1.12). A linear vertical cleft of high signal within the meniscus may also be evident (Fig. 1.13). Depending on position of the tear this may be present over successive images as the tear extends peripherally (Fig. 1.8c). When a radial tear is orientated in the plane of an image the meniscal signal may not be apparent, typically volume averaging causes a triangle of high signal not representative of the normal meniscus, termed the ghost meniscus (Fig. 1.12b).

Radial tears can have a more oblique orientation with respect to the main meniscal axis when they may be termed parrot beak tears. This subset of radial tears is unstable as they are prone to displacement of the meniscal fragment.

Meniscocapsular and Meniscal Root Injury

Tears may occur at the meniscal attachment to the joint capsule (meniscocapsular injury) or attachment to the tibia (meniscal root injury) (Fig. 1.14). When evaluating the MR imaging scan, it is important to follow the meniscus down to its tibial attachments to ensure they are intact. On MR imaging, meniscocapsular separation is seen as an increased distance between the capsule and the outer meniscal border and fluid is seen to separate the structures. It has been pointed out that these signs have a relatively high false-positive rate [17].

Meniscal Imaging with Other Modalities

Conventional Radiography

Although not able to demonstrate meniscal pathology, plain radiography remains a useful initial investigation following knee trauma. While suspected fracture is a clear indication, plain radiographs may also demonstrate loose bodies, chondrocalcinosis and other degenerative changes which may mimic meniscal symptoms.

Ultrasound

Ultrasonography (US) has low sensitivity and specificity in the diagnosis of meniscal tears and is generally not helpful in the assessment of acute meniscal trauma. The normal meniscus can be identified at the joint line as a triangular hypoechoic structure. However, the deeper components of the meniscus including the intra-articular free edge are not visualised. Meniscal tears are seen on US when they are peripheral and posterior. They typically appear as fluid-filled