

Magnetic Resonance Imaging of Sports Injuries of the Knee

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Introduction

Sports-related knee injuries are common, with contact sports and sports involving twisting movements being the most frequent causes. Sports injuries may affect any of the knee structures, including ligaments, menisci, bones, cartilage and periarticular soft tissues. However, relatively few injuries involve isolated structures, with complex injuries affecting multiple structures being much more common. Magnetic resonance (MR) imaging is now widely used for imaging injuries of internal structures of the knee, and has replaced conventional arthrography and diagnostic arthroscopy. It is superior to computed tomography (CT) for imaging of soft tissue structures. Accurate MR imaging diagnosis and interpretation allow a more complete identification of the extent of injuries and aids clinical management.

Assessment of Individual Knee Structures

Menisci

The knee menisci act as shock absorbers by distributing compressive and torsion forces. They are C-shaped fibrocartilaginous structures attached to the condylar surface of the tibia. The periphery of the meniscus is thicker than the central portion, enabling a firmer attachment to the joint capsule. The meniscus periphery also has greater vascularity (known as the “red zone” arthroscopically) and hence greater healing potential, compared to the inner, avascular portion (“white zone”). Therefore, peripheral tears heal much better than central tears. This vascularity however decreases with age. The menisci are of low signal intensity on all MR imaging sequences, with the exception of children and young adults who have intermediate to high signal representing normal vascularity in the posterior horns near the meniscal attachment to the capsule. The menisci should be evaluated using sagittal and coronal MR images. On sagittal planes, 3 or 4 images should be seen through the anterior and posterior horns, with the peripheral sections showing a “bow-tie” configuration and the central sections showing 2 contiguous wedge-shaped structures. On coronal planes, the anterior and posterior horns span across the tibial plateau with a slab-like configuration

while the body has a triangular configuration.

Meniscal tears are common, most of which are a result of non-contact sports which involve twisting of the knee (for example, in skiing), deceleration and landing from a jump.¹ A varus or valgus force pinches the meniscus between the femoral condyle and tibial plateau. Abrupt rotation then disrupts the meniscus in the longitudinal plane, hence the term “trap and twist” mechanism.² On MR imaging, meniscal tear is diagnosed when there is a linear area of increased signal extending to the articular surface (Fig. 1).³ This finding has an accuracy of >90%.⁴

Meniscal tears occur in 2 primary planes: vertical and horizontal. Most acute traumatic tears are oriented vertically with 3 basic shapes: longitudinal (which includes bucket-handle tears), radial and oblique.¹ Longitudinal tears are parallel to the circumferential axis or outer margin of the meniscus, separating the meniscus into inner and outer fragments. Bucket-handle tears occur when the inner fragment displaces into the centre or intercondylar notch, with the latter creating a “double posterior cruciate ligament” sign (Fig. 2). Radial or transverse tears are vertical tears that propagate perpendicular to the main axis of the meniscus. Oblique tears begin like radial tears and then curve into a longitudinal orientation similar to longitudinal tears. Horizontal tears divide the meniscus into a top and a bottom portion, and are frequently degenerative in origin, while complex tears often have a branching pattern (Fig. 3).

Cruciate Ligaments

Anterior cruciate ligament (ACL): The ACL is the primary restraint to anterior tibial translation with a secondary role in resisting internal rotation, hyperextension, varus and valgus angulation. It is attached to the posteromedial aspect of the lateral femoral condyle and extends to the anteromedial tibial spine. On sagittal MR images, the normal ACL is parallel to the intercondylar roof (Blumensaat’s line) and has a striated appearance with some high signal within, especially at its insertion on the tibia, due to fat or synovium. The ACL is the commonest ligament in the knee to be injured, with numerous mechanisms of injuries described, occurring with or without contact, and with the knee in any

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position from flexed to fully extended.^{5,6} The commonest contact mechanism of injury is the valgus or “clipping” injury, common in football players, resulting from a lateral blow to the partially-flexed knee.⁶ The pivot-shift mechanism is the commonest non-contact mechanism, consisting of a valgus stress and internal rotation of the tibia or external rotation of the femur applied to a flexed knee.⁶ This twisting injury frequently occurs with rapid simultaneous deceleration and directional movements such as in skiing, soccer, basketball or tennis.

ACL tears most commonly occur in the middle portion of the ligament, although they can also occur at the proximal and less frequently, distal attachments. MR imaging has high sensitivity and specificity of >95% in diagnosing acute complete ACL tears.⁷ The primary signs are most valuable and include non-visualisation, discontinuity of the ACL by abnormal increased T1 and T2 signal due to oedema and haemorrhage (Fig. 4), abnormal morphology (such as angulation, thickening, a wavy or retracted appearance) and an abnormal flattened ACL axis (away from the Blumensaat’s line). The secondary signs of ACL tears are related to the mechanism of injury, associated injuries or sequelae of instability. Although these signs may increase diagnostic confidence, diagnosis should be made based on the primary signs.⁸ The secondary signs include: characteristic bone contusions in the mid-lateral femoral condyle and posterolateral tibia; anterior tibial translation (Fig. 5); uncovering of the posterior horn of the lateral meniscus; buckling of the posterior cruciate ligament (PCL); and deepening of the lateral femoral sulcus. In younger patients, avulsion of the tibial attachment with an intact ACL may be seen (Fig. 6). Acute partial ACL tears appear as a thickened ligament with T2-hyperintense signal (Fig. 7), while chronic partial tears may be difficult to diagnose accurately by MR imaging.⁹ In chronic ACL tears, the ACL is usually absent and is replaced by fat signal in the lateral intercondylar notch, the “empty notch” sign.⁶

Posterior cruciate ligament: The PCL functions as the primary restraint against posterior tibial translation. It also resists hyperextension, external rotation, varus and valgus angulation. It originates from the medial femoral condyle and inserts onto the mid posterior tibia, 1 cm below the joint line where it blends in with the posterior capsule. The ACL and PCL cross each other; hence, the term, the cruciate ligaments. On sagittal MR images, the normal PCL is seen to have a gentle curve with a uniform hypointense signal, in contrast to the ACL.

The PCL is twice as strong as the ACL, and is infrequently torn.¹⁰ The majority of PCL tears is associated with other injuries and has a more guarded prognosis than isolated PCL injury. The commonest mechanism of injury is hyperflexion of the knee from high-velocity forces that

have been applied on the tibia, such as in sliding-tackle occurring during soccer.¹¹ Other mechanisms include hyperextension, severe angulation and rotation. PCL injuries occur most frequently at the middle portion and are seen as diffusely-thickened lesions of increased signal (Fig. 8). There may be complete disruption in complete tears. Avulsion of its tibial attachment is least common. Partial PCL tears are seen as ligament thickening with areas of T2-hyperintense signal, particularly in the acute phase (Fig. 9).

Collateral Ligaments

Medial collateral ligament (MCL): The MCL functions as a resistance to valgus stress and external rotation of the tibia. It is a secondary restraint to anterior tibial translation. It consists of a superficial and a deep layer, separated by bursa and fibrofatty tissue. The superficial tibial collateral ligament originates from the medial femoral epicondyle and inserts on the medial aspect of the proximal tibia. The deep layer consists of the medial capsular ligament and meniscofemoral/meniscotibial ligaments which attach to the medial meniscus. A normal MCL can usually be visualised in its entirety in the coronal plane on MR imaging and is seen as a thin, taut, well-defined low signal structure surrounded by high T1-signal fibrofatty tissue throughout its full extent.

Injuries to the MCL often result from valgus stress, such as tackling from the side in American football. Repetitive stretching of the MCL among breaststroke swimmers can also result in injuries.¹² Signs of MCL injuries include disruption of fibres, thickening, increased T2-signal within and in the soft tissues medial to the MCL, and loss of its demarcation from adjacent fat (Fig. 10). Meniscocapsular separation often presents clinically in an identical manner to MCL injury.¹³ It is diagnosed when there is increased fluid between the MCL and medial meniscus.

Lateral collateral ligament (LCL) and posterolateral (PL) corner structures: The LCL and PL corner structures act as primary restraints to varus stress and internal rotation of the tibia, and secondary restraint to external rotation, anterior and posterior tibial translations. The PL structures are complex with considerable anatomical variation.¹⁴ The major constituents are the iliotibial band, biceps femoris tendon, fibular collateral ligament (FCL) or LCL proper, arcuate ligament, popliteal tendon, popliteofibular ligament, lateral gastrocnemius tendon and lateral joint capsule. The FCL originates from the lateral femoral condyle and inserts on the lateral aspect of the fibular head, having a common attachment with the biceps femoris tendon. The normal FCL is seen on coronal MR images as a thin, taut, well-defined low signal structure. While some of these structures such as FCL and biceps femoris tendon are readily evaluated, the small size and anatomical variation of the other structures



Fig. 1a.



Fig. 1b.

Fig. 1. Meniscal tear compared to normal meniscus. (a) Sagittal PD-W MR image shows an undisplaced oblique tear at the posterior horn of the medial meniscus, depicted as a linear area of hyperintense signal that extends to the inferior articular surface (arrow). (b) Sagittal PD-W MR image shows a normal posterior horn of the medial meniscus. It is completely hypointense and has a regular wedge shape.



Fig. 2a.

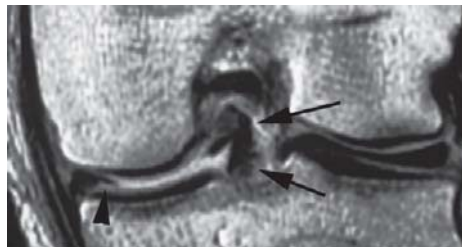


Fig. 2b.

Fig. 2. Bucket-handle meniscal tear. (a) Sagittal PD-W MR image shows a double PCL sign with the displaced bucket handle fragment (arrows) located anterior to the true PCL. (b) Coronal PD-W MR images shows the displaced bucket handle fragment (arrows) as well as a deficient posterior horn of the medial meniscus (arrowhead).

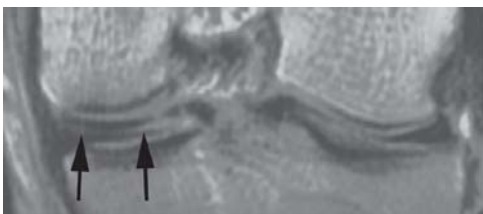


Fig. 3a.

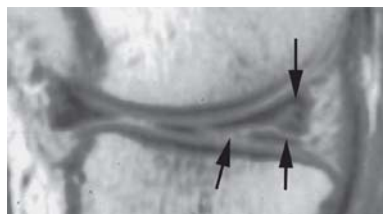


Fig. 3b.

Fig. 3. Different types of meniscal tears. (a) Coronal PD-W MR image shows an undisplaced horizontal tear (arrows). (b) Sagittal PD-W MR image shows a branching complex tear (arrows).



Fig. 4a.



Fig. 4b.

Fig. 4. Subacute complete ACL tear compared to normal ACL. (a) Sagittal PD-W MR image shows a complete ACL tear that is seen as discontinuity of the fibres with a cloud-like haemorrhagic mass at the site of tear (arrows). (b) Sagittal PD-W MR image shows a normal ACL. The intact ACL is oriented parallel to the intercondylar roof.

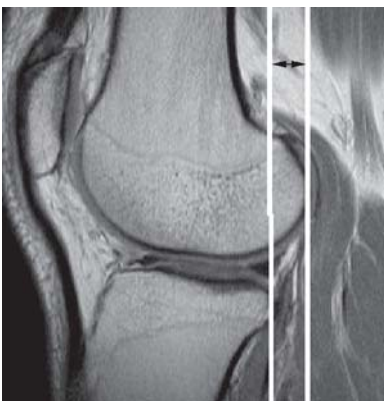


Fig. 5. Secondary sign of a complete ACL tear. Sagittal PD-W MR image shows the secondary sign of anterior tibial translation of the lateral femoral condyle. The degree of translation is measured by drawing vertical lines tangential to the posterior margins of the lateral femoral condyle and tibia, and occurs when there is ≥ 7 mm anterior translocation of the tibia relative to the femur. The tangential line of the posterior margin of the tibia also passes through the posteriorly-displaced posterior horn of the lateral meniscus.

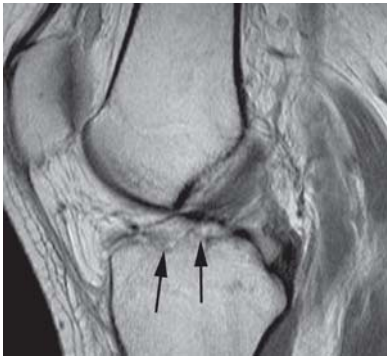


Fig. 6a.



Fig. 6b.



Fig. 6c.



Fig. 6d.



Fig. 6e.

Fig. 6. Avulsion of the tibial attachment of the ACL with a strained but intact ACL.

(a) Sagittal PD-W and (b) coronal fat saturated PD-W MR images show avulsion of the anterior tibial spine, seen as cortical disruption (arrows) at the ACL insertion site. The ACL is thickened with increased signal intensity, consistent with a strain. Collateral ligament injuries are also noted. Corresponding (c) sagittal and (d) coronal reformatted CT images confirm the avulsion fracture at the distal ACL attachment. (e) AP radiograph shows the tibial spine fracture clearly and should always be performed to compliment MR imaging.

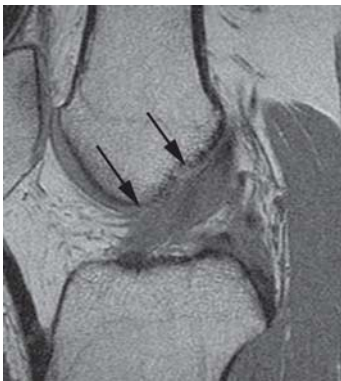


Fig. 7a.



Fig. 7b.

Fig. 7. Acute partial ACL tear.

(a) Sagittal PD-W and (b) coronal fat saturated PD-W MR images show thickening and diffuse hyperintense signal (arrows) within the ACL.



Fig. 8. Chronic complete PCL tear. Sagittal PD-W MR image shows a complete PCL tear which is seen as disruption of the midfibres of the PCL (arrows).

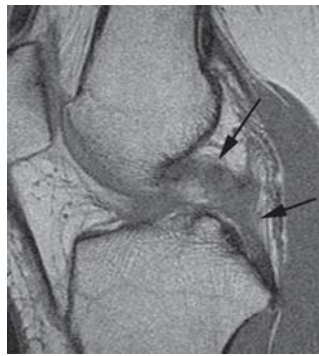


Fig. 9a.

Fig. 9. Acute partial PCL tear. (a) Sagittal PD-W and (b) coronal fat saturated PD-W MR images show thickening and diffuse hyperintense signal (arrows) within the PCL.



Fig. 9b.



Fig. 10a.



Fig. 10b.

Fig. 10. Acute complete MCL tear compared to normal MCL. (a) Coronal fat saturated PD-W MR image shows a complete MCL tear which is seen as discontinuity of the distal fibres, with the remnant fibres appearing wavy (arrow). There is also increased signal intensity in the MCL and in the surrounding soft tissue. (b) Coronal PD-W MR image shows a normal MCL, which is seen as a thin and taut hypointense structure (arrowheads).



Fig. 11a.

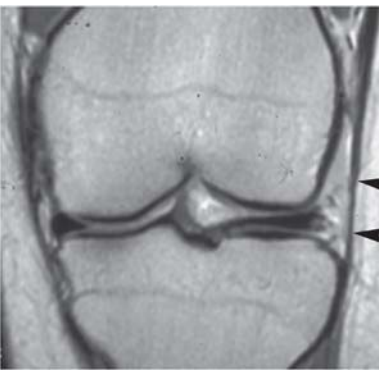


Fig. 11b.

Fig. 11. Acute partial LCL tear compared to normal LCL. (a) Coronal fat saturated PD-W MR image shows a partial LCL tear which is seen as increased signal intensity at its proximal end (arrow). There is also a tear of the MCL. (b) Coronal PD-W MR image shows a normal LCL, which is seen as a thin and taut hypointense structure (arrowheads).



Fig. 12. Pivot shift injury, which is a flexion injury with valgus and external rotation. Coronal fat saturated PD-W MR image shows non-contiguous bone marrow oedema in the mid-lateral femoral condyle and posterolateral tibia.

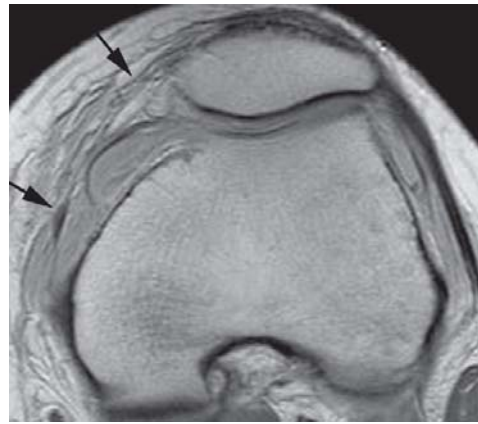


Fig. 13. Knee injury with valgus component. Axial PD-W MR image shows a tear of the medial patellar retinaculum, seen as discontinuity of the fibres (arrow).



Fig. 14a.



Fig. 14b.

Fig. 14. Recent patellar dislocation with osteochondral fragment. (a) Axial T1-W MR image shows a relocated patella which is irregularly truncated at its medial aspect (arrowhead). The medial patellar retinaculum is disrupted. (b) Sagittal fat saturated SPGR MR image shows a large osteochondral fragment (arrows) which arose from the medial patella.

of the PL corner makes assessment difficult.²

PL corner injuries are infrequent, and are often associated with injury of the cruciate ligaments.^{2,10,15} Hyperextension-varus injury is the commonest mechanism for PL corner injuries, for example during tackling of an American football player from anteromedially.¹² An acute LCL tear is seen as a serpiginous or lax ligament with discontinuous fibres (Fig. 11). Unlike MCL, the LCL is completely extracapsular and does not result in extravasated joint fluid to demonstrate high T2-signal surrounding the ligament.¹²

Extensor Mechanism Structures

As the name suggests, this group of structures function as the knee extensors. Contraction of the quadriceps while the foot is on the ground stabilises the knee, acting as a decelerator. The extensor mechanism consists of the quadriceps muscle group and tendon, patella, patellar tendon, Hoffa's fat pad, medial and lateral patellar retinacula, patellofemoral and patellotibial ligaments. The quadriceps tendon inserts on the superior pole of the patella. The patellar tendon originates at the inferior pole of the patella and inserts onto the tibial tuberosity. These are best assessed on sagittal MR images. The patellar retinaculum is an important stabiliser of the patellofemoral joint, and is best evaluated on axial MR images.

There are numerous extensor mechanism injuries, which are often due to chronic repetitive sports.¹⁶ Jumper's knee, often seen in jumping sports such as basketball, volleyball, high- or long-jump, refers to pain in the inferior patellar region from proximal patellar tendinosis. Tears of the quadriceps tendon in older patients are usually due to minor trauma, such as weight lifting, but with predisposing risk factors such as diabetes mellitus and rheumatoid arthritis.^{16,17} In young healthy patients, injuries are often due to violent deceleration, as occurs in running when the leading foot is planted.¹⁷ The injured tendons are seen as thickening with increased signal or discontinuity.

Bones

Bone marrow oedema, seen as patchy areas of T1-hypointense and T2-hyperintense signal, may be secondary to microtrauma (i.e. bone contusion or bruise), radiographically- occult fractures or osteochondral injury.² Assessment of the pattern of bone marrow oedema may yield useful information on the specific mechanism of knee injury. Impaction injuries produce fairly large areas of oedema, while avulsions result in smaller abnormalities localised beneath the avulsed structures.² Contiguous bone contusions indicate an injury occurring in extension, while non-contiguous contusions indicate rotation and abnormal translation of one bone over another, usually occurring in flexion.¹⁸ For example, hyperextension results in the

“kissing” contusion pattern involving the anterior aspect of the distal femur and proximal tibia.¹⁹ Pivot shift injury, a flexion injury (with valgus and external rotation), results in contusions in the midportion of the lateral femoral condyle and posterolateral tibial plateau (Fig. 12).¹⁹

Hyaline Cartilage

Hyaline cartilage functions as a low friction, wear-resistant and avascular shock absorber. It covers the articular surfaces of opposing bone ends. It is assessed in 3 planes – sagittal, coronal and axial MR images – using fine resolution specialised cartilage sequences, appearing as hyperintense signal while the rest of the structures are hypointense. In the acute setting, hyaline cartilage can be destroyed as a result of fractures involving the articular surface, or more commonly due to dislocation or subluxation, particularly of the patellofemoral joint (which is described later).² In adults, injuries are usually confined to the cartilage, while in adolescents, osteochondral fractures occur more frequently due to stronger anchorage of the cartilage to the bone. More typically, chondral injuries are usually related to chronic repetitive trauma such as in weightlifting and running.

Periarticular Soft Tissues

These can be hints to the mechanism of injury. Localised soft tissue swelling or haematoma may denote the site of a direct blow force. Haemarthrosis and lipohaemarthrosis indicate significant intra-articular injury. Localised deep soft tissue swelling can be a sign of adjacent ligamentous, capsular or meniscal injury.

Mechanism-based Pattern Approach to Knee Injuries

When the mechanism of injury can be deduced, additional “at risk” structures can be re-evaluated. Examples of several well-described patterns include the O'Donoghue triad (injuries to ACL, MCL and medial meniscus) and Segond fracture (avulsion fracture of the lateral tibial plateau, frequently with tears of the ACL or menisci). The major injury-producing forces at the knee include translation (anterior, posterior), angulation (varus, valgus), rotation (internal, external), hyperextension, axial load and direct blow.¹⁸ Most injuries occur as a result of two or more forces exerting simultaneously or in succession. Contact sports, like football, rugby and hockey, can result in any injury pattern. Basketball, skiing and other sports that involve “twisting” movements often produce a rotational and angulation injury pattern. Some patterns of injuries are described below, based on the direction of the force. Identification of injuries to various individual structures on MR imaging is useful, particularly when correlated with the clinical information about the mechanism of injury in a specific sporting activity.

Translation

Anterior translation^{2,20}: This involves an anteriorly directed force applied to the posterior aspect of the tibia, resulting in anterior translation or anterior instability. An example is forceful kicking in football with resultant stress on the posterior aspect of the opposite leg on the ground. Injury patterns include ACL tear, medial and lateral capsular ligamentous disruption, bone marrow oedema in the anterior femoral condyle and posterior tibial plateau.

Posterior translation^{2,20}: This is the result of a posteriorly directed force applied below the patellar tendon, causing posterior instability. For example, when an American football player is tackled from the front, or when an athlete falls onto the flexed knee. Injuries include disruption of the PCL, posterolateral and/or posteromedial corners, and posterior capsule. There is bone marrow oedema in the femoral condyle, anterior tibia and patella. If severe, posterior knee dislocation may occur.

Angulation

Lateral or valgus (or clipping injury)^{2,20}: This injury involves a force applied to the lateral aspect of the knee, for example when an American football player is tackled from the side, resulting in medial instability. There are resultant injuries to the medial supporting structures (Fig. 13), predominantly the MCL, and possibly avulsion of its insertion sites at the medial femoral condyle or medial tibia. Contiguous bone marrow oedema is often present in the lateral femoral condyle and lateral tibia. With severe valgus force, there may be additional ACL and medial meniscus injuries, forming the O'Donoghue triad.

Medial or varus^{2,20}: This rare injury is produced by a force applied to the medial aspect of the knee, for example tackling during American football, resulting in lateral instability. The lateral supporting structures, such as FCL, iliotibial band, arcuate-popliteus complex and biceps tendon, are injured. There may be ACL injuries. Contiguous bone marrow oedema is present in the medial femoral condyle and medial tibia.

Flexion-Angulation-Rotation

Flexion injuries typically produce non-contiguous bone oedema or small avulsions due to concomitant rotation and angulation movement. In rotation and angulation, there is a higher incidence of meniscal tears due to the “trap and twist” mechanism described earlier.²

Valgus and external rotation on flexed knee (or pivot shift injury)^{2,20}: This is a common injury, for example during skiing as described earlier, produced by a combination of lateral and external rotation forces applied to the flexed knee, resulting in anteromedial rotary instability. There is disruption of the ACL and medial

supporting structures, usually the MCL. There may be tears of the medial and lateral menisci. Non-contiguous bone marrow oedema is present in the mid-lateral femoral condyle and posterolateral tibia (Fig. 12). Occasionally, “counter-coup” impaction or avulsion of the medial femoral condyle and posteromedial tibia is present.

Varus and internal rotation on flexed knee^{2,20}: This injury is produced by a combination of medial and internal rotation forces onto the flexed knee, resulting in anterolateral rotary instability. Examples of causes include “cutting” (as described in American football), deceleration occurring in the absence of a fall (during skiing) and direct blow. There is resultant injury to the ACL, lateral supporting structures such as the PL corner, and lateral meniscus. Typically, non-contiguous bone marrow oedema is observed in the lateral femoral condyle and posterolateral tibia. There is avulsion at the lateral capsule insertion on the tibia, the well-described Segond fracture.

Hyperextension-Angulation-Rotation

Hyperextension injuries characteristically produce pronounced contiguous bone contusions at the site of entry, with small avulsions or ligamentous tears at the exit site of force.² There is resultant distraction of the posterior knee, and may involve ligamentous injuries at the posterolateral and/or posteromedial corner.

Varus and external rotation on hyperextended knee^{2,20}: This is produced by a force applied to the anteromedial aspect of an extended knee while the tibia is internally rotated or in a neutral position. An example is during tackling of an American football player. There is resultant posterolateral instability with injuries of the PCL and PL corner. There is bone marrow oedema in the anteromedial femoral condyle and anteromedial tibia.

Valgus and internal rotation on hyperextended knee^{2,20}: This is due to a force applied to the anterolateral aspect of an extended knee while the tibia is externally rotated or in neutral position, resulting in posteromedial instability. An example is during tackling of an American football player. Injuries include the PCL, MCL and possibly avulsion of the semimembranosus tendon at the posterior medial tibial rim. There is bone marrow oedema at the anterolateral femoral condyle and anterolateral tibia.

Patellar Dislocation

Lateral patellar dislocation occurs when the flexed knee contracts while subjected to valgus and internal rotation of the femur on a fixed tibia.^{2,19} For example, when one foot of a rock climber slips, the opposite foot which remains planted is injured. It produces non-contiguous bone marrow oedema at the anterolateral aspect of the lateral femoral condyle and medial patella. There is frequent association

with chondral or osteochondral injury to the medial patella and ligamentous injury to the medial retinaculum (Fig. 14). The medial patellofemoral ligament may also be injured, resulting in elevation of the vastus medialis muscle away from the adductor tubercle. Clinically, it is often missed as the dislocated patella frequently reduces on its own.

Direct Blow

This is characterised by impaction contusions with bone marrow oedema at the site of injury. Adjacent soft tissues may show oedema or haematoma, if recent. Typically, there is no significant associated internal derangement.²

Summary

Knee injuries are common at all levels of sporting activities and MR imaging plays an important role in evaluating the individual internal structure of the knee. A mechanism-based approach to the injury patterns, using both clinical and MR imaging findings, helps to optimise clinical management.

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