E. Carlos Rodríguez-Merchán
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Editors

Joint Preservation in the Adult Knee

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Preface

The orthopaedic surgeon of today has access to an unprecedented selection of interventions to reconstruct knees damaged through trauma, infection, tumours or arthritis. Reconstructive treatments which were considered experimental within recent memory have now become commonplace; likewise, patients who may in the relatively recent past have had no alternative to arthroplasty now have access to treatments which allow the preservation of their native joint. Rapid progress has been made in terms of the development of new techniques, instruments and implants, through collaboration between orthopaedic surgeons, scientists and industry.

The rapid pace of innovation within orthopaedic surgery has been accompanied by a marked improvement in the quality of evidence available for the interventions that we use. Those wishing to introduce new interventions now have to demonstrate a sound evidence-base in terms of preclinical testing and post-market surveillance. Interventions that have been introduced are scrutinised to a much greater extent as evidenced by the rise in the standard of scientific methodology displayed within the major orthopaedic journals. Increasingly, interventions in widespread use are having their indications refined on the basis of high-quality randomised trials. The use of 'big data' within orthopaedics, with increased use and more sophisticated interpretation of institutional and national databases, has provided an additional source of information as to how our interventions are working in the real world.

These developments, both in terms of the introduction of new interventions and the growth of evidence-based practice within orthopaedics, represent a challenge to orthopaedic surgeons. Whilst we aim to provide our patients with the best and newest treatments, we are unable to change our practice without robust evidence that the new treatment is better than those already in use. Likewise, surgeons may be faced with evidence that what they currently consider to be best practice is in fact inferior to other surgical or non-surgical treatments.

The aim of this book is to help surgeons to negotiate this challenge. We have assembled a group of authors who between them have huge experience and knowledge on the practice and science of joint-preserving knee surgery.

Between them, they provide an overview of the state of the art of joint-preserving surgery of the knee, using the latest evidence together with insights from their practice. We hope that it will be of use to surgeons looking to develop and refine their practice to provide the best care for their patients.

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Contents

Examination of the Knee

1

Quen O. Tang and Chinmay M. Gupte

Abstract

The art of clinical examination is often forgotten with the advent of increasingly precise imaging modalities but in fact remains the most powerful tool in the surgeon's armamentarium and is at the heart of the patient–clinician relationship. A clear examination sequence forms a fundamental tool for the diagnosis and correct treatment of knee pathology. Whilst this is important, the advanced examiner together with the history will tailor a specific exam series depending on the suspected pathology. In general, there are three broad series: one for patellofemoral/extensor mechanism pathologies; one for meniscal and chondral (articular) lesions; and one for instability. This chapter will provide an overview of advanced physical examination of the knee and outlines the most commonly used tests. Images and detailed descriptions will provide the reader with a thorough understanding of hand positions and identifying a positive sign.

Keywords

Knee • Clinical examination • Static assessment • Dynamic assessment Assessment of gait

1.1 Introduction

The knee is amongst the most commonly injured large joint in the body [1], primarily because the tibiofemoral and patellofemoral articulations are inherently unstable and also due to the large loads that are transmitted through the joint when bearing weight.

The art of examining the knee should therefore involve consideration of the interplay between stabilising factors of the knee (muscles

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and ligaments) and the overall biomechanics of the lower limbs.

Whilst the examiner should have a logical and repeatable sequence of examination for each knee, the advanced examiner will develop the ability to adapt this protocol and add further tests to the specific knee condition suspected. For example, the tests employed to assess for patellofemoral instability in a young patient (tracking, apprehension, Q angle) may differ from the assessment of an elderly patient with medial osteoarthritis.

The general sequence of examination should be as follows:

(a) *Look*
(b) *Feel* (with knee in extension and 90° flexion)
(c) *Move*
(d) *Special tests*

This chapter is arranged according to the above sequence.

1.2 Look

1.2.1 Alignment

Alignment should be assessed in the static (patient standing) and dynamic (patient walking) modes and in all three planes (coronal, sagittal and axial).

1.2.1.1 Patient Standing

Coronal plane (Fig. 1.1) Examination with the patient facing the examiner: assessing for varus or valgus posture and the presence of tibial bowing. Further coronal assessment can be performed from behind, whilst assessing for popliteal masses or scars. Varus and valgus deformities are often more obvious from behind.

Axial plane This can also be assessed with the patient facing the examiner. Specific findings include a "squinting" (inward-tilting) patella [2], femoral anteversion or retroversion. Further assessment of axial (rotational) alignment can be performed in the case of patellofemoral instability using the "Staheli profile" technique with the patient seated [3].

Sagittal plane (Fig. 1.2) The patient is examined from the side assessing for flexed posture, and anterior tibial or femoral bowing.

1.2.1.2 Assessment of Gait

Full gait assessment is beyond the scope of this chapter. However, specifically with regards to orthopaedic knee examination, gait should again be assessed in coronal (frontal) and sagittal planes:

Coronal

Assess varus thrust for lateral collateral and posterolateral corner injury. Valgus thrust indicates medial collateral injury.

Fig. 1.1 Assessing coronal plane. Note the physiological valgus attitude of the lower limb

Sagittal

From the side, assess for flexed knee gait (suggesting fixed flexion of the knee or hamstring tightness) or back knee gait (suggesting hyperextension of the knee).

1.2.2 Examination of Knee with Patient Sitting on Couch, Legs Suspended from Side of Couch (Fig. 1.3)

It is the senior author's practice to examine patellofemoral tracking before laying the patient supine to order to avoid "forgetting" the patellofemoral joint.

The patient is asked to sit on the side of the couch with legs hanging down but not touching the floor. The examiner then faces the patient and asks the patient to slowly flex and extend each knee in turn. This allows assessment of:

(a) The extensor mechanism.
(b) Patellar tracking (Video 1.1): The arc of interest is mainly between 70° of flexion and full extension.

Pathology most commonly detected includes:

- "Inverse J sign" – lateral subluxation of the patella between 30° of flexion and full extension.
- Frank lateral dislocation of the patella. This most commonly occurs in chronic recurrent patellar dislocation in near extension. However, it can occur with the knee flexed.

1.2.3 Examination Supine (Fig. 1.4)

The patient is laid on the couch. Convention dictates that the patient should be fully supine in order to examine the hip joint first. However,

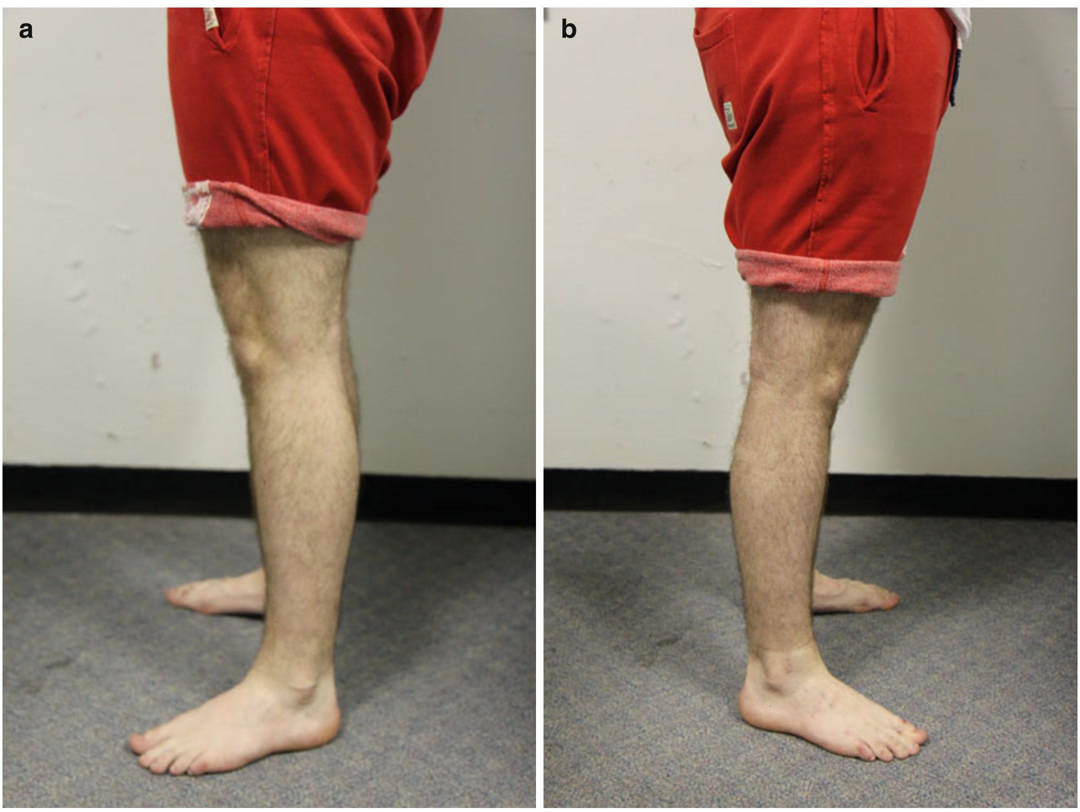

Fig. 1.2 (**a**) Assessing left lateral sagittal plane. (**b**) Assessing right lateral sagittal plane

Fig. 1.3 Examination of knee with patient sitting on couch, legs suspended from side of couch

Fig. 1.4 Assessing whilst supine on a couch. Note the valgus attitude is more obvious whilst supine

examination of the knee is more comfortable with the patient in the semi-supine position (approximately 45° flexed at waist). The key to supine examination is to ensure patient relaxation, by avoiding causing unexpected pain. The best way to assess for pain is to consistently look at the patient's eyes.

Alignment should be checked again from the end of the bed.

Muscle wasting The quadriceps group, in particular vastus medialis obliqus (VMO). VMO wasting is often best detected by palpation of the muscle belly whilst asking the patient to contract the quads group. "Push your knee down into the bed". Objectively, the quads can be assessed by measuring circumference of the thigh from a fixed bony point (e.g. 10 cm proximal to the tibial tubercle).

1.3 Feel

1.3.1 Warmth

Warmth is best palpated with the back of the examiner's hand. If there is warmth, is there a focus e.g. prepatellar bursa, tibial or femoral component of a total knee replacement?

1.3.1.1 Effusion

There are three grades of effusion:

- *Grade 1*: Small effusion: Best assessed by the "sweep" test. Fluid is gently moved from the lateral gutter by "sweeping" the hand over the gutter, into the medial gutter. The medial gutter is then pressed and the fluid is displaced back into the lateral gutter in a positive test.

- *Grade 2*: Patellar tap: A moderate sized effusion will lead to the patella floating up towards the skin. The patella can then be "tapped" against the femoral trochlea.
- *Grade 3*: Cross fluctuance: A very large effusion will lead to a fluid thrill demonstrated by cross fluctuance of the fluid when pressed.

1.3.1.2 Joint Palpation

The joint line is best palpated with the knee flexed to 80°. The examiner should visualise the anatomy being palpated through the skin and sequence of palpation should be consistent:

1. Medial joint line: medial meniscus, medial femoral condyle, and tibial and femoral insertions of the medial collateral ligament (MCL). If a thickened medial plica is suspected, this can be palpated over the medial femoral condyle with the knee at 30°. More distally, the pes anserinus bursa should be palpated for tenderness typical of pes bursitis.
2. Lateral joint line: lateral meniscus, lateral femoral condyle, and lateral collateral ligament. The fibula can also be palpated for tenderness and the superior tibiofibular joint can be balloted if instability is suspected.
3. Popliteal fossa for popliteal cyst, and to exclude popliteal aneurysm.

1.4 Move

With the knee extended, the patient is asked to dorsiflex the ankle and lift the leg up straight. If there is any flexion when this is done, there are two possibilities:

(a) Fixed flexion deficit due to joint contracture
(b) Quadriceps weakness/extensor lag

In order to distinguish between the two, the patient is asked to rest the leg relaxed into the examiner's hand. If full extension occurs, then there is a weakness of the quadriceps, known as extensor lag (Video 1.2). If the knee stays flexed, then there is fixed flexion.

Once this is performed, the patient is asked to flex the knee – "pull your heel towards your buttock". Active flexion is assessed first. If there is full active flexion, then no passive assessment is required. If there is any deficit, the heel can be gently held and the knee flexed further always watching the patient's face for pain.

It is important to note that full extension is termed as "zero degrees flexion", a right angle is "90° flexion" and full flexion will depend on the body habitus of the patient and can vary from 120° in a patient with large thighs to 160° in a very thin patient. Another way to quantifying flexion deficit between knees is to determine the "heel to buttock" distance.

It is best to assess flexion of both knees one after the other.

1.5 Special Tests

These can be divided into:

(a) Cruciate ligaments
(b) Collateral ligaments
(c) Meniscal tests
(d) Patellofemoral tests

As previously mentioned, not all tests have to be performed in every knee and the examination should be tailored to the pathology suspected.

Grades of laxity vary between authors and testers [4]. It is best to state the estimated:

(a) Distance (mm) of translation of the joint
(b) The degree of difference between sides
(c) The "end point". The firmness of resistance towards the extreme of the test. A less firm "end point" indicates a more severe injury and damage to secondary restraints.

If grades are used, the general convention is:

- Grade 1: 0–5 mm side to side difference with good end point
- Grade 2: 5–10 mm difference with soft end point
- Grade 3: gross laxity beyond 10 mm difference

1.5.1 Cruciate Ligaments

1.5.1.1 Tests with Knee at 30° Relaxed Over the Examiner's Thigh

Lachman´s test (for anterior cruciate ligament (ACL) injury) Best performed with the knee relaxed over the examiner's contralateral thigh, with the point of contact between the two approximately 5 cm proximal to the popliteal fossa. The thigh is stabilised anteriorly with the examiner's contralateral hand and the tibia is gently translated anteriorly with the ipsilateral hand placed cupping the tibial tubercle (Fig. 1.5 and Video 1.3).

Posterior Lachman's (for posterolateral capsular injury) This is a subtle sign that indicates posterior capsule laxity in the case of posterolateral corner injury. The tibia is translated posteriorly with the knee in the same position as for a Lachman's. Often the subtlest sign of laxity is a soft end point. More obvious laxity is demonstrated by more than 2 mm side to side difference.

1.5.1.2 Tests with Knee at 80° of Flexion

It is important to note that the knee should be between 80° and 90° of flexion for the following tests as higher angles of flexion can lead to false negative results.

Posterior sag and medial step off (*for posterior cruciate ligament* (*PCL*) *injury*):

Posterior sag The knees are flexed together to 80°. The examiner inspects from the side so that a tangential view of the tibiofemoral joint is obtained in the sagittal plane. A posterior sag is observed if there is "dip" in the tibiofemoral articulation. This is often confirmed using a pen with a straight edge on the area.

Medial step off In a PCL injured knee, there is loss of the normal medial step off. Normally the anterior aspect of the medial tibial condyle protrudes 3–5 mm anterior to the medial femoral

Fig. 1.5 Position of hands whilst performing Lachman's test

condyle. PCL injury results in loss of this protrusion, whereby the tibia sags posteriorly: grade 1 is fewer steps off than the normal side, grade 2 is tibia level with the femoral condyle and grade 3 is tibia posterior to the femoral condyle.

Anterior drawer (for ACL deficiency), posterior drawer (for PCL deficiency) and dial test (for PLC insufficiency):

Anterior drawer It is essential to ensure relaxation of the hamstring tendons with the examiner's middle fingers whilst performing this test. Otherwise, a false negative result is obtained. The examiner places their hands with the thumbs just below the joint line and middle finger behind the knee palpating the relaxed hamstring tendons on either side. The tibia is then brought forward. Again, it is best to assess for the number of millimetres of side-to-side difference and end point rather than grades of laxity (Fig. 1.6 and Video 1.4).

Posterior drawer The posterior drawer can be assessed in the same manoeuvre as the anterior drawer but by pushing the tibia posteriorly. It is important to assess for posterior cruciate deficiency as well as anterior cruciate as a posteriorly sagged tibia will lead to a "pseudo anterior drawer" when the tibia is brought back into its normal position.

1.5.1.3 Other Tests

Pivot shift test (for ACL injury) This test should only be performed if ACL insufficiency is suspected and only in the most comfortable of patients. If the patient is in significant discomfort, the pivot shift test should be reserved for examination under anaesthetic.

In the comfortable, relaxed patient, the pivot shift test should be performed as follows:

(a) Knee fully extended.
(b) Ipsilateral hand cupping the sole of the foot rotating the tibia into internal rotation.
(c) Contralateral hand holding lower leg at neck of fibula, again rotating the tibia into internal rotation. This will sublux the lateral tibia anteriorly, with the iliotibial band acting as an extensor of the knee. The medial tibia will remain in position.
(d) Flexing the knee from full extension into 30° flexion. Will convert the iliotibial band (ITB) into a flexor of the knee and the lateral tibial condyle will reduce back into the joint from its anteriorly subluxed position.

Fig. 1.6 Position of the hands whilst performing anterior drawer test. Note the examiners thumbs are just below the joint line

Quadriceps active test (for PCL injury) The patient is asked to rest the knee on the couch with the knee in 80° flexion. The tibia will sag posteriorly in the PCL deficient knee. The examiner then holds the foot on the couch and the patient is asked to kick the foot away (eliciting quadriceps contraction) against the examiner's resistance. The resulting quads contraction will lead the posteriorly subluxed tibia back into joint.

Test for anterolateral and anteromedial instability These tests, which are modifications of the anterior drawer test, are for the advanced examiner. For anteromedial instability (ACL and/or MCL) the tibia is rotated internally and then an anterior drawer is applied. The medial tibial plateau will sublux more anteriorly than the lateral in a positive test. For anterolateral instability, the opposite applies (Fig. 1.7 and Video 1.5).

Dial test The dial test was originally described with the patient in a supine position and the examiner on one side with an assistant on the other side. This has since been adapted so that the examiner can assess both sides together by placing the patient prone. The patient is asked to inform the examiner of pain as they are prone as the face cannot be inspected.

The test is performed ensuring:

(a) The knees are together and in neutral rotation.
(b) The ankles are fully dorsiflexed.
(c) The examiner is directly looking over both feet.

The dial test is performed initially with the knee at 30°. A 10° to 15° difference in external rotation indicates damage to the posterolateral corner. Excess rotation is caused by posterior translation of the lateral tibial due to lack of posterolateral restraint.

If the test is positive when also performed at 90°, this indicates a combined PCL and posterolateral corner injury.

Fig. 1.7 (**a**) Internal rotation of tibia allows assessment of anteromedial instability. (**b**) External rotation of tibia allows assessment of anterolateral instability

NB. False positive dial test

The dial test can be positive if the posteromedial corner is injured. In this case it is the medial tibia translating anteriorly and the lateral tibia staying in position. This also causes the excess external rotation.

1.5.2 Collateral Ligaments

The most reliable method of achieving muscle relaxation is to cradle the leg with the examiner's arms just beneath the examiner's axilla. It is helpful to place the examiner's four fingers on the medial and lateral joint lines in order to assess the degree of joint opening.

MCL (medial collateral ligament) – Valgus stress applied in full extension and 20° flexion.

LCL (lateral collateral ligament) – Varus stress applied in full extension and 20° flexion.

The difference between full extension and 20° is that in full extension the posterior capsular structures act as secondary restraints to the collateral ligaments, whereas in 20° only the collateral ligaments resist the stress. Thus, a knee that is lax in full extension and 20° flexion may indicate more damage to the posterior capsular structures than a knee that is only lax at 20° flexion.

1.5.3 Meniscal Tests

Thessaly test [5] A weight bearing meniscal test performed by the examiner supporting the patient and asking the patient to swivel to the left and right side whilst rising from crouching position (Fig. 1.8 and Video 1.6).

McMurray's test This should be performed only in the most comfortable of patients, and is of limited sensitivity and specificity [6]. This is best

Fig. 1.8 (**a**) Swivelling to the left during Thessaly test. (**b**) Swivelling to the right during Thessaly test

performed with the thumb on the joint line and the tibia externally rotated (posterior horn medial meniscus) and then internally rotated (posterior horn lateral meniscus).

1.5.4 Patellofemoral Tests

Patellofemoral joint (PFJ) tracking and assessment of lateral tilt and tightness is mentioned above.

Other tests include:

1. *The clinical Q angle* (Fig. 1.9). This is the angle subtended between: (a) a straight line from the anterior superior iliac spine and centre of the patella and (b) a line from the centre of the patella to the tibial tubercle. This is supposed to represent the resultant lateral pull of the patella tendon and the quadriceps tendon on the patella. A normal value is 12–15°, with the angle slightly greater in women than men.

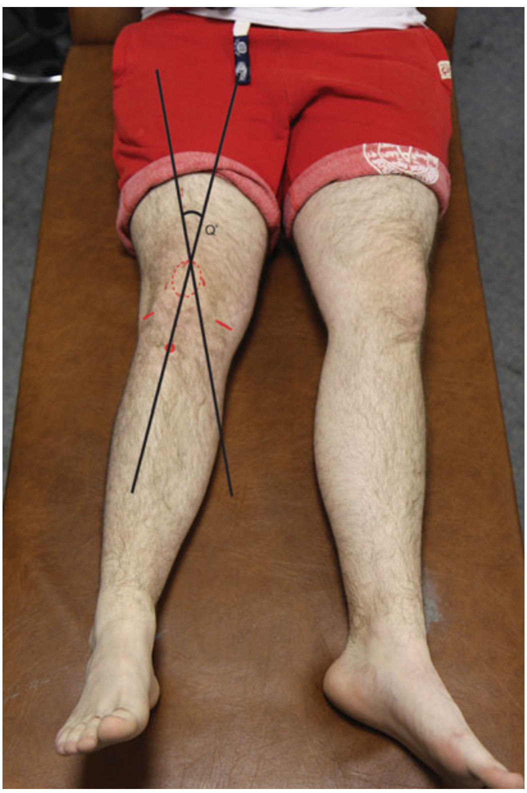

Fig. 1.9 The clinical Q angle. A line from the anterior superior iliac spine to the superior pole of the patella intersecting a line from the inferior pole of the patella to the tibial tubercle. The patella, joint line and the tibial tubercle are all marked in *red*

Increase in Q angle is associated with:
   - Femoral anteversion
   - External tibial torsion
   - Laterally displaced tibial tubercle
   - Genu valgum: increases the obliquity of the femur and concomitantly, the obliquity of the pull of the quadriceps
2. *Patellar apprehension*. In this test, the examiner applies gentle pressure on the medial side of the patella displacing it laterally as the knee flexes from full extension. The patient will contract their quadriceps as a reflex in order to avoid flexion and lateral displacement if the test is positive.
3. *Clarke's test* (Video 1.7) [7]. This, as classically described, is a painful test and should not be performed. However, a modified Clarke's test for irritability of the PFJ can be performed with the knee relaxed and flexed to 20° over the examiner's contralateral thigh much like the position for Lachman's test. The patella is then gently glided medially and laterally: significant pain or crepitus indicates PFJ irritability and chondral wear of the patellofemoral surface.

Conclusion

Clinical examination of the knee is an art that requires a combination of biomechanical thinking, static and dynamic assessment and delicate handling of the patient.

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Imaging Assessment of the Knee

2

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Abstract

Many imaging modalities and techniques are helpful for the diagnosis and prognostication of disorders within the knee. Plain radiographs remain the first line of investigation, however, MRI now plays an increasing role for imaging the knee in the setting of joint-preservation strategies. Whilst the imaging findings for specific conditions are discussed in each chapter of this book, this chapter aims to give an overview of the imaging modalities available and to discuss in detail the use of imaging techniques for the visualisation and assessment of early osteoarthritis within the knee joint.

Keywords

Knee • Imaging • Assessment

2.1 Introduction

The advance has not been the 'correct' use of imaging modalities. There have been scientific advances in imaging techniques. It would be more accurate to state that there have been 'advances in the field of imaging'. The widespread availability of MRI, and the increasing quality of the images that it produces, has allowed better visualisation of pathology in the knee joint. Alongside the diagnosis of acute joint injury, advances in imaging have facilitated the shift in focus toward disease prevention and the treatment of early osteoarthritis (OA) [1]. The development of joint-preserving strategies requires the

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ability to diagnose early joint degeneration prior to the onset of irreversible structural damage. It is at this early stage of disease when patients are most likely to benefit from intervention.

The aim of this chapter is to describe the imaging tools available and their optimal use in the knee. Individual imaging modalities and their findings relevant to specific pathologies will be covered in detail in the chapters relating to each pathology. In this chapter, we will concentrate on imaging protocols for specific knee tissues, as well as describing the current state of the art imaging of early osteoarthritis.

2.2 Radiography

Radiography is the first line of imaging in all pathologies of the knee. Whole-limb radiographic studies allow the assessment of malalignment and weight-bearing studies can demonstrate osteochondral lesions, as well as demonstrating secondary changes resulting from ligamentous insufficiency (see Chaps. 8 and 9). Plain radiographs allow visualisation of ossified structures and features of degenerative change. In OA, osteophyte formation is often the earliest sign on plain radiographs with narrowing of the joint space width, sclerosis of subchondral bone, and development of subchondral cysts Osteophyte formation is often the earliest sign of osteoarthritis, followed by narrowing of the joint space width, sclerosis of subchondral bone, and development of subchondral cysts. Kellgren-Lawrence [2] and Osteoarthritis Research Society International (OARSI) [3] grades can be used to score the severity of these features, but measurement of joint space width provides a more sensitive and reliable assessment of degenerative change [4]. Joint space width reflects cartilage thickness and meniscal integrity [5], but is not sensitive to localised cartilage lesions. MRI can detect chondropathy that is not evident on radiographs [6], as well as offering three-dimensional assessment of subchondral bone, meniscus, ligaments and synovium. However, radiography remains the first line investigation for knee pathology in most instances. It is readily available and relatively inexpensive and facilitates early identification of cases that are not amenable to joint preservation procedures.

2.2.1 Joint Space Width

Joint space width measurements are dependent on the radiographic protocol [7] and radiographs may be performed weight-bearing or non-weight-bearing, with the knee flexed or extended, and positioned under fluoroscopic or non-fluoroscopic guidance. Radiographs that are non-weight-bearing or acquired with the knee extended are inferior to weight-bearing flexed-knee protocols for the assessment of joint space width [8]. Knee flexion aims to ensure joint space width on the radiograph corresponds to the site of load transmission across the joint when the medial femoral condyle is located in a central position on the articular surface of the tibia. Radio-anatomic alignment of the anterior and posterior margins of the medial tibial plateau is critical for joint space width measurements [5], and is aided by fluoroscopic guidance [9].

Several semi-flexed radiographic protocols are available, and two frequently adopted are the posteroanterior fixed-flexion (FF) protocol and its fluoroscopically guided equivalent, the Lyon Schuss (LS) protocol. FF images are acquired with patients standing with their patellae and thighs against a radiograph cassette in line with the tip of their great toes. This results in a fixed-flexion of approximately 20–30°. The X-ray beam is then directed caudally 10° to bring it parallel with the medial tibial plateau. LS images are acquired with the same positioning is as for FF views, but rather than directing the beam 10° caudally, the beam is aligned fluoroscopically to ensure the anterior and posterior aspects of the medial tibial plateau are superimposed. Although LS radiographs are more sensitive to change in joint space width, both techniques offer similar reproducibility [9], and the non-fluoroscopic FF technique is better suited to routine clinical practice. Posteroanterior views are combined with a lateral view to permit assessment of tibial translation and patella height, in addition to features of osteoarthritis. Assessment of the patellofemoral joint is best assessed with a skyline axial view.

2.2.2 Limb Alignment

Varus or valgus knee malalignment of the knee is a risk factor for ligamentous injury and for the development and progression of knee osteoarthritis [10]. Accurate assessment of the mechanical axis therefore provides value information on prognosis and potential treatment options. Full limb weight-bearing radiographs are considered optimal and the mechanical axis is measured with a line passing through the centre of the femoral head to the centre of the tibiotalar joint, and usually passes just medial to the tibial spine. It is further subdivided into the mechanical axis of the femur and tibia to determine the hip-knee-ankle angle, which is a measurement of overall lower limb mechanical alignment [11]. However, full limb radiographs are more technically demanding and expensive and deliver greater ionising radiation than short limb radiographs centred on the knee. Therefore, authors have explored the value of measuring the anatomical axis on anteroposterior knee radiographs as a surrogate for the mechanical axis. The anatomical axis passes along the centre of the femoral and tibial diaphysis, and anatomical alignment is the angle subtended by these two lines. Studies have reported variable agreement between mechanical and anatomical alignment, and the method of performing short limb radiographs is likely to be of importance [12].

2.3 Morphological MRI

Morphological MRI studies have become the mainstay of diagnosis of soft tissue pathologies within the knee, and are being used increasingly in the diagnosis and prognostication of early osteoarthritis [13]. In this section, we will describe the choices in terms of equipment and protocols for imaging of the knee, before describing the special considerations for different tissue types and pathologies.

2.3.1 Imaging Protocols

2.3.1.1 Sequences

Pulse sequences are the sets of pre-determined radiofrequency and gradient pulses which produce the final MRI image [14]. Different pulse sequences produce images of different characteristics which allow the examination of different structures and pathologies. The selection of sequences for imaging of the knee must be a balance between time and the quality of images required. Standard sequences include T1, T2 and Proton Density (PD) [15].

T1 weighted images have short repetition and echo times (TR and TE) and the resultant image produced as a function of relaxation time demonstrates tissue contrast where fat is bright and cortical bone, ligaments and tendons are dark; this is traditionally been considered to be the best view for assessing anatomy. T2 weighted images have a long TR and TE and demonstrate both fat and water to have high signal intensities. PD sequences have a short TE and a long TR to produce an image which represents the concentration of protons in each tissue; this is largely used for the imaging of both fibrocartilage and articular cartilage [15].

Fluid sensitive techniques are used to increase the available tissue contrast to demonstrate areas of oedema or abnormal tissue. These techniques are varied and include fat suppression, inversion recovery and newer techniques such as Dixon imaging. Fat suppression can be applied to T1, T2 and PD sequences and they each have their own benefits with fat suppression usually providing the better spatial resolution.

2.3.1.2 Coils and Magnets

The quality of the image produced relies upon many factors; however, the adequacy of B_0, or main field strength and the use of appropriate coils are very important [16]. The standard field strength for most MRI machines is now 1.5 T;

this field strength is adequate for most applications within the knee. Magnets of higher field strength have a higher signal to noise ratio and may be more sensitive for imaging cartilage in the context of early OA [16]. Direct comparisons of the ability of radiologists to diagnose chondral lesions in 1.5 and 3 T scanners have been undertaken with both animal and human subjects. Whilst the sensitivity of the two are similar, 3 T scanners have a higher specificity and accuracy for diagnosing chondral lesions [16]. Open MRI scanners are useful for claustrophobic patients and have been used in the research setting to study the knee during weight-bearing. However, the field strength is significantly lower than that of conventional closed scanners (around 0.5 T) and the quality of the images produced is significantly poorer. Ultra-high field strength (7 T) MRI is in use in the research setting and has the potential to deliver even higher quality images [17].

Image quality is also improved by the use of specific coils. Coils with higher numbers of channels and coils with more homogenous radiofrequency signals produce better images. Flexible coils, which may be necessary for larger patients, usually produce poorer quality images.

2.3.2 Bone

The medullary portion of bone is mainly composed of fat cells. This is best imaged on T1 weighted images. The assessment of bone marrow lesions can be difficult especially around the meta-diaphysis where there are commonly areas of haematopoiesis which leads to a marked reduction in fat cell content. Given this, it is important to compare the T1 signal to the adjacent muscle. If the signal is comparable to muscle, there is concern of a mass and further investigation is recommended. Newer techniques involve the automatic estimation of fat content using "in and out of phase" techniques using a region of interest [18]. T2 fat suppressed images allow visualisation of bone marrow oedema related to tumours or trauma (Figs. 2.1 and 2.2).

Fig. 2.1 Coronal T2 weighted fat-suppressed image demonstrating anterolateral bone bruising following rupture of the anterior cruciate ligament

Fig. 2.2 Coronal T2 weighted fat-suppressed image demonstrating bony oedema secondary to trauma resulting in posterolateral corner injury

2.3.3 Cartilage

In current practice, proton density imaging is the mainstay of morphological assessment of articular cartilage. Accurate assessment of articular cartilage is achieved through adequate spatial resolution, contrast resolution and orthogonal image acquisition, which allow for a fuller appreciation of curved articular surfaces. Assessment for bone marrow oedema subjacent to areas of cartilage irregularity is important to help recognise areas of full thickness fissure. As interest increases in the use of MRI for OA, new sequences are being employed including morphological and compositional techniques which are covered in more detail below [19].

2.3.4 Meniscus

The meniscus is rich in proteoglycans; this makes the inherent signal characteristics of the meniscus low on all sequences. PD and T2 sequences make for excellent tissue contrast with the adjacent joint fluid and articular cartilage and the addition of fluid sensitive techniques such as fat suppression makes the appreciation of tears better. The meniscus is depicted in two planes, coronal and sagittal, and although the orientation of the collagen fibres cannot be demonstrated on MRI, the type of meniscal tear can be. The stability of meniscal tears can be assessed in order to ascertain the requirement for surgical intervention. The findings of these on MRI include tears greater in size than 1 cm and displacement of meniscal tissue.

A three-dimensional appreciation of the meniscus is key to understanding the tear configuration and how this appears on MRI. Challenging areas include visualisation of the meniscal root, which can be easily overlooked, and the assessment of previously repaired menisci. In the case of diagnostic difficulty, the use of an arthrographic study can aid diagnosis.

2.3.5 Ligament

The assessment of ligament injury is one of the main indications for MRI examinations. The ligamentous anatomy is usually best assessed by fluid sensitive proton density or T2 images, in at least two planes. Sagittal images can be taken obliquely, to be oriented along the course of the ligament in question, to avoid averaging artefacts which may produce false-positive findings for ligamentous injury. High intrasubstance signal in T2 images suggests injury but in partial ruptures there may be some fibres which retain their normal signal (Fig. 2.3) [20].

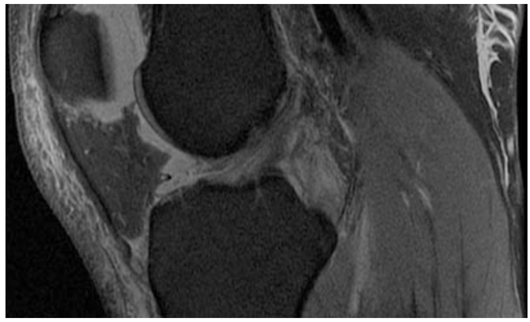

Fig. 2.3 Sagittal image demonstrating intrasubstance high signal following partial rupture of the ACL

2.3.6 Whole Joint Imaging (Semi-quantitative Scores)

Osteoarthritis is a disease of the whole joint. Whilst a broad understanding of the degree of joint involvement is possible using systems such as that of Kellgren and Lawrence, elements of the disease such as synovitis and degree of meniscal involvement are only visualised using MRI. Whilst the degree of cartilaginous damage is predicted using joint space width on plain radiographs, it is only possible to directly measure it using MRI. Likewise, the ability to predict disease progression is higher when there is co-localised non-cartilaginous pathology, such as bone marrow lesions and meniscal pathology [21].

A number of scoring systems have been devised to categorise the degree of damage to the joint on MRI [22]. These systems are important in the research setting as they allow standardisation of MRI findings in epidemiological and interventional studies in OA. They may have clinical relevance as predictors of progression, but as MRI is not in widespread use for the monitoring of OA, their direct clinical relevance is limited. Such systems include the Whole-Organ MRI Score (WORMS), the Knee Osteoarthritis Scoring System (KOSS), the Boston-Leeds osteoarthritis Knee Score (BLOKS) and the MRI

Osteoarthritis Knee Score (MOAKS) [23–26]. In all these systems, scores are attributed to a number of cartilage, synovial, subchondral, ligamentous and meniscal findings, subdivided by the area of the joint affected. All have excellent inter- and intra-rater reliability. Such scores have been used in randomised controlled trials and epidemiological studies of OA. They also appear to be clinically relevant, with the degree of bone marrow change and synovitis being related to the degree of pain in OA. They also appear to be of use in predicting progression of disease.

2.4 Compositional MRI

2.4.1 Imaging Protocols

Compositional MRI aims to assay the biochemical composition of tissues in order to detect early osteoarthritis prior to when it is evident on morphological MRI, at which point cartilage damage is likely irreversible. Potential applications include the identification of individuals who may benefit from early intervention, as well as an outcome measure to evaluate the efficacy of novel interventions within a short timeframe.

2.4.2 Cartilage

A plethora of MRI sequences are available that appear responsive to different cartilage properties [27]. The best validated compositional sequence is delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC), which provides a measure of cartilage glycosaminoglycan content. Several studies show that dGEMRIC correlates well with the histological severity of osteoarthritis [28] and may predict future knee osteoarthritis [29], however, clinical applicability is limited by a long scanning protocol and requirement for potentially nephrotoxic contrast agent. There are a number of sequences with potentially greater clinical value that do not require contrast agent or specialist hardware, and that have acceptable scan times. These include T2 mapping, T1rho, T2* mapping and diffusions protocols [30]. These sequences are responsive to a range of cartilage properties including glycosaminoglycan content, collagen fibre orientation and cartilage hydration. T2 mapping and T1rho are increasingly used in clinical studies, and like dGEMRIC, values correlate with histological degeneration [31] and baseline values are able to predict progressive osteoarthritis in the knee [32]. T2 mapping is more sensitive than morphological MRI for the identification of early cartilage degeneration [33], and T2 mapping has been frequently employed to monitor the outcomes of cartilage repair procedures [34]. Compositional MRI may therefore offer diagnostic and prognostic capabilities, as well as providing a measure of intervention efficacy.

2.4.3 Non-cartilaginous Structures

Compositional MRI has also been adopted for the evaluation of meniscus. There appears to be concomitant degeneration of the articular cartilage and meniscus in early osteoarthritis, supported by delayed Gadolinium Enhanced MRI of Meniscus (dGEMRIM) [35]. Meniscal T1rho and T2 mapping values also correlate with the severity of knee osteoarthritis [36]. Given the critical role played by the meniscus, addressing any associated meniscal pathology may be a critical step in delaying or preventing the development of osteoarthritis. Compositional MRI of non-cartilaginous structures is likely to represent an area for future development.

2.5 Computerised Tomography (CT)

CT has a limited but potentially valuable application for imaging early osteoarthritis. It offers excellent three-dimensional assessment of bone morphology, and bone shape is increasingly thought to have predictive value for the

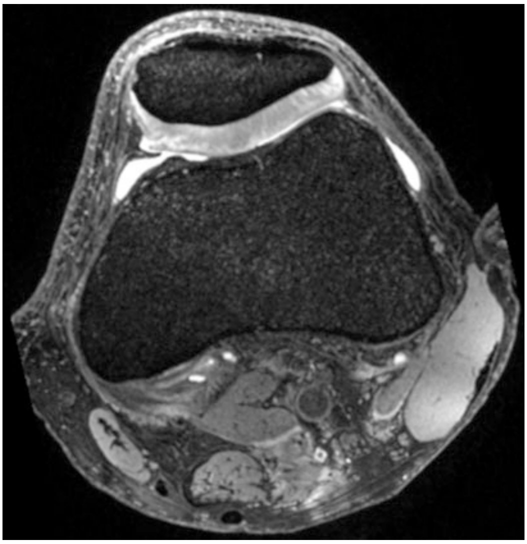

Fig. 2.4 Axial section of knee in 32 year old healthy volunteer – true fast imaging with steady-state free precession at 7 tesla MRI (Courtesy of Dr Daniel Park and Prof Neal Bangerter, University of Oxford)

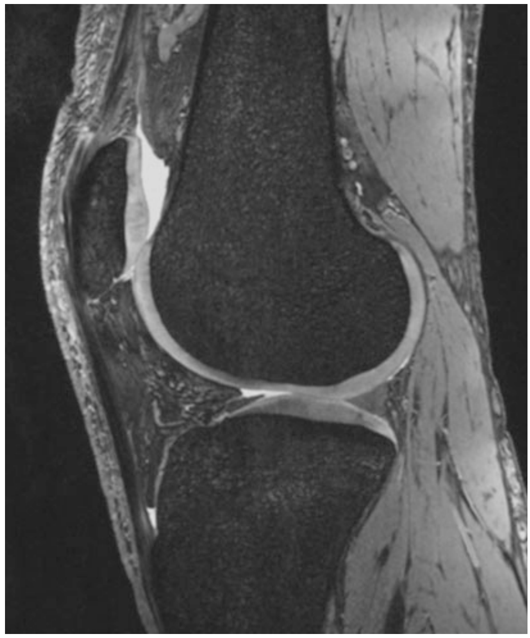

Fig. 2.5 Sagittal section of knee in 32 year old healthy volunteer – true fast imaging with steady-state free precession at 7 tesla MRI (Courtesy of Dr Daniel Park and Prof Neal Bangerter, University of Oxford)

development and progression of osteoarthritis. CT arthrography can be employed to both identify cartilage defects and estimate cartilage glycosaminoglycan content [37]. However, MRI has several advantages in that it permits the imaging of all joint structures alongside non-invasive compositional assessment. Combined single photon emission CT and conventional CT (SPECT/CT) may have a potential role in assessing loading of compartments in relation to leg alignment [38]. SPECT/CT tracer uptake in the medial and lateral compartment correlates with varus or valgus alignment, respectively.

2.6 Future Advances

Current clinical MRI platforms have field strengths of 1.5 Tesla or 3 Tesla, however, research is underway on 7 Tesla platforms (ultra-high field strength). Increasing the field strength allows improved image resolution and faster image acquisition [39], although there are also a range of associated technical challenges that must be overcome. The ability to diagnose early osteoarthritis is enhanced by the greater spatial resolution of images (Figs. 2.4 and 2.5), but also because additional compositional sequences are feasible at ultra-high field strength. These include sodium scanning and chemical exchange saturation transfer imaging of glycosamynoglicans (gagCEST), both of which assay glycosaminoglycan content [40]. Currently, 7 Tesla MRI is confined to the research setting, however, these platforms are likely to eventually enter clinical practice, and in the meantime, it may be possible to reverse engineer research findings onto current clinical MRI platforms.

Conclusions

Radiography continues to play an integral role in the assessment of knee pathology, however, MRI is now central in the assessment of joint injury and early osteoarthritis. Morphological MRI allows high-resolution three-dimensional imaging of all joint structures. Compositional MRI offers great promise for the biochemical assessment of tissues, but does require further validation.

There remains a lack of standardisation between compositional MRI protocols and this limits any comparison between studies. It may be this that explains the different conclusions reached as to which tissue property a compositional sequence is responsive. The influence of activity levels on compositional MRI readings is also poorly characterised and it is important to be able to differentiate adaptive from pathological signal [39]. Finally, post-processing remains very time intensive and automated tools will be required in order for these sequences to be used in routine clinical practice.

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3 Intra-articular Corticosteroids and Hyaluronic Acid in the Knee Joint

Carlos Kalbakdij-Sánchez
and Enrique Gómez-Barrena

Abstract

Degenerative knee osteoarthritis (OA) affects 35 % of the population older than 65 years. Before surgical treatment (total knee arthroplasty, TKA), there are many conservative strategies that may offer good clinical outcomes. The aim of this chapter is to describe the mechanism of action of corticosteroids and hyaluronic acid joint injections in knee's osteoarthritis physiopathology. The authors hope to improve reader's understanding on the role of corticosteroids and hyaluronic acid joint injections and how it can improve the quality of life of these patients, and eventually delay total knee arthroplasty.

Keywords

Knee • Injections • Corticosteroids • Hyaluronic acid

3.1 Introduction

Knee osteoarthritis (OA) is characterized by cartilage degeneration, pain and loss of function. OA leads to progressive loss of function, affecting the individual's capability to perform daily activities. Knee OA also leads to impaired work performance and early retirement, which has socioeconomic implications [1].

There is no therapeutic agent proven to modify disease progression in OA. Instead, there are many options which have uncertain effectiveness in the treatment of knee OA. However, pharmacologic therapies, non-steroidal anti-inflammatory drugs (NSAIDs) and intra-articular (IA) corticosteroid injections are commonly prescribed to control the symptoms of OA. NSAIDs and IA corticosteroid injections have inherent limitations: NSAIDs have potentially serious adverse events associated with their use; and corticosteroid injections often provide a relatively short period of effective pain relief. Although corticosteroid injections generally have a positive safety profile, they have been shown to cause a transient increase in

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Table 3.1 Differences between corticosteroids and hyaluronic acid joint injections.

Characteristics	Corticosteroids	Hyaluronic acid
Mechanism of action	Analgesic Anti-inflammatory Immunosuppressive effect	Analgesic Anti-inflammatory Mechanical improvement Chondroprotection Proteoglycan and glycosaminoglycan synthesis Subchondral bone compliancy
Duration of effects	±2 weeks	6–12 months
Viscoelasticity	None	High
Side effects	Hyperglycemia Infections (immunosuppression)	Limited pain for the infiltration IA local reactions
Price	Low	High

IA intra-articular

blood glucose, which may be a concern for diabetic patients [2]. IA injection of hyaluronic acid (HA) is another treatment option. HA is ubiquitous in the body, and is a molecule found intrinsically within the knee joint where it provides viscoelastic properties to synovial fluid [3]. Table 3.1 shows the main differences between corticosteroids and hyaluronic acid joint injections.

In aspirates from knee joints with OA, the molecular weight of the HA present is lower; lower molecular weights have been shown to correlate strongly with the degree of pain in OA. IA administration of HA thus aims to restore the concentration of HA and improve the mean molecular weight of the HA present [4].

There are many proposed mechanisms of action of IA HA, including shock absorption, joint lubrication, anti-inflammatory effects, chondroprotection and proteoglycan synthesis [5]. There is also evidence suggesting different mechanisms of action between HA products of varying molecular weights. Higher molecular weight HA (HMW HA) has been reported [6] to provide greater anti-inflammatory and proteoglycan synthesis effects, as well as joint lubrication and maintenance of viscoelasticity.

The safety profile of HA depends on the mechanism of synthesis. HA derived through a biological fermentation process (Bio-HA) is safer than avian-derived HA (AD HA), which has the potential for local inflammatory reactions [7].

3.2 Mechanism of Action

3.2.1 Corticosteroids

The anti-inflammatory and immunosuppressive effects of corticosteroids are well known. Corticosteroids act directly on nuclear steroid receptors and interrupt the inflammatory and immune cascade at different stages. They reduce vascular permeability and inhibit accumulation of inflammatory cells, phagocytosis, production of neutrophil superoxide, matrix metalloprotease (MMP), and metalloprotease activator, and prevent the synthesis and secretion of several inflammatory mediators such as prostaglandin and leukotrienes [8].

Clinically, corticosteroids reduce the erythema, swelling, heat and tenderness of inflamed joints, as well as stimulate an increase in the relative viscosity of synovial fluid due to a higher hyaluronic acid concentration [9].

3.2.2 Hyaluronic Acid

The mechanism of action of HA has six main effects: analgesia, an anti-inflammatory effect, a chondroprotective effect, encouraging of proteoglycan and glycosaminoglycan synthesis, improving subchondral bone compliancy and mechanical improvement.

HA does not directly bind to bradykinin receptors, but provides analgesic effects through interaction with HA receptors and free nerve endings within the joint tissue. This analgesic effect occurs at mechanosensitive stretch-activated ion channels, where channel activity is significantly decreased when HA binds, reducing the action of joint nociceptors. Sensitized nociceptive terminals within the joint tissue are affected by HA concentration, reducing the pain response exhibited by these terminals. HMW HA decreases the mechanical sensitivity of stretch-activated ion channels, blocking the pain response. Low molecular weight (LMW) HA seems to be less effective in blocking this response [10].

The anti-inflammatory effect is based on suppression of interleukin (IL) - 1 beta (IL-1β) expression, which is a key mediator of inflammation which is regulated through the binding of HA to CD44 (a cell-surface glycoprotein involved in cell-cell interactions, cell adhesion and migration). IL-1β suppression results in a down-regulation of MMPs, which also aids in the anti-inflammatory effect of HA. Further suppression of pro-inflammatory mediators IL-8, IL-6, PGE2 (prostaglandin E2) and tumor necrosis factor (TNFα) provides the anti-inflammatory effects of intra-articular HA. Degradation products of HA produce an inflammatory response mediated via interaction between CD44 and Toll-like Receptors (TLR). This pro-inflammatory response results in increased nuclear factor kappa-light-chain-enhancer of activated B cells (Nf-κB), IL-1β, TNFα, IL-6 and IL-33 production. HMW HA has been demonstrated to suppress numerous inflammatory mediators through TLR 2 (toll-like receptor 2) and 4 binding, including TNF-α, IL-1-β, IL-17, MMP-13 and inducible nitrogen oxide synthase (iNOS). A direct correlation between molecular weight and anti-inflammatory effects has demonstrated longer effects of PGE2 and IL-6 inhibition for HMW HA treatment. IL-6 is a pro-inflammatory cytokine, regulated by Nf-κB. HA binding to ICAM-1 (intercellular adhesion molecule-1) down-regulates Nf-κB, which in turn decreases the production of IL-6. Down regulation of TNFα, IL-1B and IL-8 is an additional contributory factor to the anti-inflammatory effects provided by HMW HA [11].

Intra-articular HA has direct chondroprotective effects. HA is thought to reduce chondrocyte apoptosis, while increasing chondrocyte proliferation. The binding of HA to CD44 inhibits interleukin (IL)-1β expression, leading to a reduction in matrix metalloproteinase (MMP) production [12]. This binding to CD44 has been shown to be of greater effect for HMW HA products. HA also binds to the receptor for hyaluronan mediated motility (RHAMM), which is thought to aid in chondroprotection in addition to the CD44-mediated effect. The inhibition of IL-1β expression through CD44 binding is carried out through induction of mitogen-activated protein kinase phosphatase (MKP) -1: a negative regulator of IL-1β [13].

Chondrocyte apoptotic events are further decreased by the binding of HA to CD44 through the reduction of a disintegrin and metalloproteinase with thrombospondin motifs (ADAMTS) expression. These peptidases are involved in the cleavage of important synovial components, including aggrecan, versican and brevican. ADAMTS expression has been shown to be reduced as a result of HA-CD44 binding, providing an additional mode of chondroprotection for HA treatment [14]. The production of reactive oxygen species (ROS), such as nitric oxide (NO), results in degeneration of cartilage through increased chondrocyte apoptosis. IA HA treatment leads to a reduction in IL-1β-induced oxidative stress, through inhibition of NO production within the synovium. Additional results of CD44-HA binding resulting in chondroprotective effects include reduction of prostaglandin E2 (PGE2) synthesis, and increase of heat shock protein 70 (Hsp70) expression. These effects provide therapeutic benefit through the reduction of chondrocyte apoptosis [15]. HMW HA products demonstrate more inhibition of PGE2 expression than LMW, resulting in a greater chondroprotective effect.

Proteoglycan and glycosaminoglycan synthesis are major pathways in cartilage restoration. As OA progresses, intrinsic proteoglycan and GAG (glycosaminoglycan) concentrations decline within the cartilage. Results demonstrate that IA-HA treatment stimulates proteoglycan synthesis, delaying the progression of OA [1]. Aggrecan is the primary proteoglycan within articular cartilage, and IA-HA treatment is shown to both suppress aggrecan degradation, as well as promote intrinsic aggrecan development. IA-HA treatment is shown to mobilize newly synthesized proteoglycans to the outer chondrocyte matrix, potentially providing protection from degradation. In vitro, extrinsic HA encourages movement of newly synthesized proteoglycans from the cell-associated matrix to the further-removed matrix, which suggests that IA-HA could provide therapeutic relief of OA by strengthening the interterritorial cartilage matrix. The biological pathway in which HA modifies aggrecan levels is through CD44 and intercellular adhesion molecule (ICAM)-1 binding effects [14]. HMW HA has shown to provide a greater effect of proteoglycan synthesis than LMW HA through stimulation of the insulin-like growth factor (IGF)-1 pathway. IA-HA treatment has also shown to increase endogenous GAG production. IA-HA treatment not only supplements the synovium with HA, it promotes HA intrinsic production [15].

In the subchondral bone, it has been previously shown that interaction between osteoblasts and articular cartilage chondrocytes in osteoarthritic joints modifies ADAMTS-4/5 and MMP-1, MMP-2, MMP-3, MMP-8, MMP-9 and MMP-13 expression and regulation, mediated by mitogen-activated protein kinase (MAPK) and extracellular signal regulated kinase 1 and 2 (ERK 1/2) signalling pathways [16]. IA-HA also affects the subchondral bone through suppression of MMP-13 and IL-6 via CD44 binding, which potentially prevents abnormal osseous tissue metabolism. The suppression of MMP-13 expression by IA-HA has been suggested as a critical factor in the effect on subchondral bone in OA. HA effectively changes subchondral bone density and thickness through trabecular structure alterations, resulting in greater subchondral bone compliancy [17]. This finally reduces stresses on the cartilage during impact loading. An indication of IA-HA stimulation of cartilage/bone interface type II collagen turnover is the increase of urine carboxy-terminal collagen cross-links (CTX)-II levels observed following IA-HA treatment, which demonstrated improvement in the osteoarthritic knee [17].

Finally, the viscous nature of HA treatment is thought to lubricate the joint capsule, preventing degeneration by reducing friction, and protecting the joint capsule through beneficial shock absorption effects. HA provides cushioning to absorb pressure and vibration within the joint that otherwise may lead to chondrocyte degradation. Osteoarthritic knees are considered to suffer from higher friction within the joint space than healthy knees, which is counteracted by the joint lubrication capabilities of HA. HMW HA has been demonstrated to provide a greater effect of friction reduction due to its viscous properties. The reduction of friction within the joint can provide therapeutic effects, as the cartilage is protected from mechanical degradation [18].

3.3 Evidence

In spite of the theoretical benefits of corticosteroid and HA joint injections, the clinical evidence base for its use is limited. Unlike in many surgical interventions, the barriers to performing randomized trials with injectable therapies are low and both corticosteroids and HA have been extensively studied. However, on the basis of the available evidence the UK National Institute for Health and Care Excellence (NICE) does not recommend the routine use of either modality of injectable therapy [19].

The last Cochrane review examining the use of HA was in 2006, when 76 studies were reviewed [20]. On the basis of the evidence at the time, it was felt that, given the favorable side effect profile, the beneficial effects HA had on pain and function, particularly in the period between 5 and 13 weeks following injection, were strong enough to recommend its use. This was in spite of the variable quality and risk of bias of the included studies. Since then, the evidence surrounding the subject has grown and two recent high-quality systematic reviews have been published in the last 4 years. Rutjes et al. performed a systematic review and meta-analysis of 89 randomized or quasi-randomized trials, including 12,667 patients, comparing HA to placebo [21]. They found moderate reductions in pain overall with HA but there was significant heterogeneity and an asymmetrical funnel-plot suggesting a publication bias in favor of positive results. When the analysis was restricted to high-quality studies, the effect size became so small as to be clinically meaningless [21]. They also reported a higher rate of serious adverse events with HA than with placebo. More recently, a separate systematic review, which had more stringent inclusion criteria (19 studies were included, comprising 4485 patients) found similar results [22]. Whether controls were placebo or other treatments, the size of the positive effect of HA failed to reach the threshold for minimum clinically important difference (MCID) in pain and function despite being statistically significant. Again, in higher quality studies the effects reported were smaller. The effect of HMW HA was greater than that of conventional HA. Strikingly, a separate network meta-analysis suggested that IA HA may have a significantly superior effect compared to non-steroidal anti-inflammatory drugs, but that the effect was largely due to the enhanced placebo effect associated with IA injection over oral therapy [23].

Corticosteroid was the subject of a more recent Cochrane review, in 2015 [24]. Again, this is an extensively studied intervention and the Cochrane review included 27 placebo-controlled randomized or pseudorandomized studies with a total of 1767 patients. Again, there was evidence of a small effect, which was strongest in the very short term (up to 2 weeks post-treatment), on both pain and function. As with HA, there was evidence of heterogeneity and publication bias, and the effect sizes became smaller the larger the included study. The best of the studies in terms of methodology reported no statistically significant effect. The results of this review suggest that there is little evidence to support the use of corticosteroid injections on the basis of the current evidence.

The evidence was summarized in the 2014 NICE guidelines for the treatment of OA [19]. The guidance suggests that intra-articular corticosteroid injections should be considered an adjunct to core treatments for the relief of moderate to severe pain in osteoarthritis patients [19]. HA injections are not recommended at all for the management of osteoarthritis.

Conclusion

Although corticosteroid and HA joint injections are non-surgical strategies that are intended to improve the quality of life in patients with knee OA, eventually delaying the requirements of total knee arthroplasty, there is no strong evidence to support and recommend the injections as a major treatment strategy. Patient selection and injection protocols still remain unclear. Although substantial knowledge on the therapeutic action mechanism is available, insufficient clinical evidence may jeopardize the particular benefits of this treatment. Independent, high quality evidence studies may eventually help to better define this controversial issue.

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4 Injection Therapy: Intra-articular Platelet-Rich Plasma and Stem Cell Therapy

Yusuf H. Mirza and Sam Oussedik

Abstract

Platelet-rich plasma (PRP) has been touted in the sports medicine and orthopaedic surgery communities as a remedy with the ability to bridge the gap between conservative, pain relieving therapies and surgical interventions. Its theoretical advantages include its ability to enhance wound healing, decrease pain and improve function.

There has also been much excitement about the multipotential nature of mesenchymal stem cells (MSCs), with the potential to regenerate different types of musculoskeletal tissue from cartilage to meniscus.

Problems with both therapies abound. As yet, there is no common consensus as to what constitutes PRP, its preparation, or the method of its activation. Similarly, MSCs can have multiple origins, be induced in different methods and delivered in a variety of forms. Thus, at present, the evidence to substantiate the claims of either therapy is sparse or fails to be robust enough to support the arguments for its use.

Our chapter provides an evidence-based insight into the background, preparation and clinical use of both PRP and MSCs, two therapies which have much to offer in regenerating and preserving tissue within the adult knee.

Keywords

Platelet-rich plasma • PRP • Mesenchymal stem cells • Stem cells • MSCs • Knee

4.1 Introduction

Platelet-rich plasma (PRP) and mesenchymal stem cells (MSCs) have the ability to bridge the gap between conservative, pain relieving therapies and surgical procedures to address

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diverse pathologies in sports medicine and orthopaedic surgery. This chapter provides an evidence-based insight into the background, preparation and clinical use of both PRP and MSCs, two therapies which have much to offer in regenerating and preserving tissue within the adult knee.

4.2 Platelet-Rich Plasma (PRP)

4.2.1 Introduction

PRP refers to a volume of blood with an overabundance of platelets. Its ready availability as a product of an autologous sample of blood and its theoretical potential to aid in both bone regeneration and wound healing have led to a spike in interest from both the sports medicine and orthopaedic surgery communities. PRP is administered a reported 86,000 times annually for sports-related injuries in elite athletes in the United States [1].

4.2.2 Definition

No single definition of PRP exists, owing to the variety of platelet products. These differ by method of manufacture and by red blood cell, leukocyte and platelet content. A general definition of PRP is a concentration of platelets, greater than that found within blood, within a small volume of plasma [2]. Others have suggested that PRP should have at least a concentration 1,407, 640 platelets per microliter, corresponding to around 10 % of the total volume (and being around five times the concentration found in normal blood) [3]. The American Association of Blood Banks defines PRP as “the resultant plasma fraction following a single light spin of whole blood, with platelets enriched in comparison with other cell types” [4].

Its use and application have been described in a number of surgical fields including orthopaedic, maxillofacial, plastic and cardiothoracic surgery.

Platelets are small, disc shaped structures derived from megakaryocyte progenitor cells. Although described by others, in the late nineteenth century, Bizzozero correctly identified the role of the platelet in both haemostasis and thrombosis [5].

The study of platelet physiology led to advances in understanding of how platelets facilitate haemostasis, recognise damaged endothelium and release cytokines to attract inflammatory cells such as macrophages and polymorphonuclear lymphocytes. The inflammatory response is also enhanced by the release of vasoactive substances such as histamine and serotonin, amongst others [6, 7].

The study of atherosclerosis began to shed light on the function of platelets, beyond their haemostatic capabilities. It was discovered that a composition including 10 % of platelets in serum encouraged in vitro cell growth and intimal smooth muscle proliferation. Smooth muscle growth failed to occur in the presence of plasma with lower concentrations of platelets [8]. However, it was not entirely clear which constituent of plasma aided growth. Ross and colleagues identified thrombin-activated platelets as a key component of cell proliferation. The work led to a quick succession of discoveries of different biologically active molecules within platelets.

These biologically active molecules are known as growth factors and include platelet-derived growth factor (PDGF), vascular endothelial growth factor (VEGF) and insulin-like growth factor (IGF-1) amongst others. These growth factors are found enclosed within organelles unique to the platelet known as dense granules. The dense granules are formed by an outpouching of vesicles from the trans-Golgi apparatus [9]. Dense granules are abundant within each platelet. Growth factors and their function in platelets are summarised in Table 4.1.

Three groups of granules have been described, according to structure, as visualised with the use of an electron microscope [10]:

(i) Dense, deriving their name from their opaque “dense” core, which promotes aggregation

Table 4.1 Growth factors and their function in platelets

Name of growth factor	Action of growth factor
Platelet-Derived Growth Factor (PDGF) [48]	Angiogenesis and blood vessel repair Cell growth and collagen production
Vascular Endothelial Growth Factor (VEGF)	Growth and de novo generation of vascular endothelial cells
Insulin Growth Factor 1 (IGF-1)	Triggers platelet aggregation
Transforming Growth Factor	Growth and de novo production of vascular endothelial and epithelial cells
Epidermal Growth Factor	Angiogenesis and promotion of wound healing

(ii) Alpha, the largest in both size and number, with a role in adhesion and repair
(iii) Lysosomal granules, which aid in the degradation of the platelet aggregate [10]

Alpha granules give rise to the therapeutic potential of PRP. The phenomenon of activation (also known as degranulation) describes the release of the growth factors to a bioactive state via the addition of histones and carbohydrate side chains. The process occurs within minutes of exposure to either clotting cascade factors or basement membrane and leads to the formation of a mature clot. The growth factors bind to transmembrane receptors on mesenchymal cells, osteoblasts and others, in turn stimulating cellular proliferation, collagen synthesis and matrix formation promoting tissue repair [11, 12].

4.2.3 Preparation of PRP

The first stage in preparation of PRP is the collection of autologous whole blood from the patient. This is collected via a large bore cannula to avoid trauma to the blood constituents whilst also preventing the activation of platelets [13]. Anticoagulant, usually citrate dextrose, is used to prevent activation and the onset of clotting [11–13]. Other anticoagulants that have been used include ethylene-diamine-tetraacetic acid (EDTA); however, EDTA has been noted to cause structural and functional damage to platelets [3, 14] and its use is not recommended by the United States Food and Drug Administration [15].

Three main techniques for the manufacture of PRP have been described [3, 16].

These include:

(i) Gravitational platelet sequestration technique
(ii) Cell saver/separator technique
(iii) Selective filtration technology or plateletpheresis

(i) Gravitational platelet sequestration techniques are among the most common techniques used. Three distinct layers, according to specific gravity, are created via the process of centrifugation. Plasma forms the top layer with a specific gravity of 1.03 with the middle layer composed of platelets and white blood cells, also known as the buffy coat. The heaviest layer is composed of red blood cells. The yield of PRP is approximately 10 % of the whole blood obtained [3, 11]. Gravitational platelet sequestration can be further classified according to the buffy coat method or the PRP method. In the buffy coat method, whole blood is chilled and then undergoes high speed, “hard” centrifugation. After the three layers have been created, the PRP layer is further refined, by being separated from the plasma and RBCs. The PRP then undergoes a second bout of “soft”, slower centrifugation. The white cells are further separated from the PRP or a leucocyte filtration filter is employed [11]. In the PRP method, differences include the whole blood being drawn into acid citrate dextrose tubes whilst the timing of the two types of centrifugation is reversed. The method forms platelet poor plasma (PPP) in the upper 2/3 of the test tube whilst the lower 1/3 is the platelet-rich plasma concentration. Platelet pellets precipitate at the bottom of the tube. After discarding the PPP, the platelet pellets are suspended in plasma [11].

The PRP method is falling out of favour. The reasons for this are twofold [17]. Firstly, the activation, which occurs both during the precipitation of platelet pellets and during storage is higher than that of the buffy coat method (although it is not clear whether this in vitro phenomenon affects biological performance in the body [17]). Secondly, the process of storage also appears to increase activation. Metcalf measured the change in a series of platelet surface markers, using antibodies to the surface markers after 8 days of storage. The changes were attributed to the component separation, rather than venesection [18]. The activation is a cause for concern, as it leads to the release of cytokines, which can later lead to febrile non hemolytic transfusion reactions at the point of transfusion [17].

(ii) Standard cell separators use a whole unit of blood for PRP manufacture. The manufacture involves two steps with the first being a separation technique using a continuous flow centrifuge bowl or a continuous disc separation technique. This is followed by a fast (hard) centrifugation with a later slow (soft) centrifugation. One benefit includes the ability to transfuse red blood cells and PPP back to the donor patient [3].

(iii) The process of plateletpheresis involves the filtration of platelets alone, from a unit of whole blood, with the use of a disposable single filter. Centrifugation does not play a role in this method [3].

4.2.4 Classification

There has been much confusion regarding the terminology governing PRP. PRP can be considered an umbrella term, encompassing a number of different platelet concentrates with a multitude of different constituents. Dohan Ehrenfest and colleagues [19] propose a clarification of the term, based upon:

(i) The presence of cellular (i.e. leukocyte) contents

(ii) Type of fibrin architecture

The clarification, in turn, permits classification into four main groups [19] (Table 4.2).

The method of preparation, and therefore of resultant cell concentrations alters the clinical outcome. A study by Sundman et al. aimed to define what biological effect the inclusion of growth factors and leukocytes would have [20]. Two commercial systems were examined, one offering a PRP solution, which is leukocyte deplete, whilst the other offered a leukocyte rich solution. The presence of growth factors was measured after preparation, with the use of an ELISA assay. In the leukocyte-deplete PRP group, increased levels of PDGF-AB and TGF-ß1 were noted whilst MMP 9 and IL1-beta were noted in the leukocyte rich PRP group.

The presence of these growth factors in the leukocyte deplete group is advantageous. There is evidence to suggest that both factors hasten wound healing. TGF-ß1 improves collagen synthesis and deposition whilst PDGF-AB is chemotactic to fibroblasts and encourages deposition of glycosaminoglycan and fibronectin. The presence of white cells was postulated to increase tissue breakdown and encourage leukocyte activation. One of the benefits of TGF-ß1 is its immunomodulatory function, with an ability to retard IL1-beta activity whilst also synthesizing an IL1-ß antagonist. In the presence of a leukocyte rich preparation, this may be hindered [20]. Anitua also describes reservations with the use of leukocyte rich preparations, highlighting the creation of a proinflammatory environment, which is unfavourable to successful wound healing. The study also noted a detrimental effect to the mechanical properties of fibrin scaffolds [21].

4.2.5 Applications

4.2.5.1 Osteoarthritis

Osteoarthritis (OA) of the knee and knee arthroplasty are forecast to increase in frequency until at least 2030 [22]. With some evidence suggesting sporting participation will increase in all age groups, sporting injuries are also likely to escalate

Table 4.2 A current general classification of platelet concentrates

Type of preparation	Appearance after activation	Form	Clinical application
Pure Platelet-Rich Plasma (P-PRP)	Preparations without leukocytes and with low density fibrin network	Liquid solutions, gel form	Ability to be used as injectable in sports medicine and orthopaedics
Leukocyte and Platelet-Rich Plasma (L-PRP)	Preparations with leukocytes and presence of low density fibrin network	Liquid solutions, gel form	Can improve skin healing
Pure Platelet-Rich Fibrin (P-PRF)	With leukocytes and high density fibrin network	Solid, gel	Treatment of ulcer wounds. Not suitable for orthopaedic application
Leukocyte and Platelet-Rich Fibrin (L-PRF)	Preparations with leukocytes and high density fibrin network	Solid, gel	Maxillofacial surgery for use as filling or interposition material. High strength and slow release of growth factors

Adapted from Doran Ehrenfest et al. Classification of platelet concentrates (Platelet-Rich Plasma-PRP, Platelet-Rich Fibrin-PRF) for topical and infiltrative use in orthopaedic and sports medicine: current consensus, clinical implications and perspectives [19]

[23–25]. Sporting injuries are more likely to occur in the lower limb with the knee particularly prone [26], and can lead to post-traumatic OA.

PRP has been suggested as a possible adjunct to conventional treatment in OA, occupying a therapeutic middle ground between conservative management and surgery. In the example of sporting injuries, there is some evidence to suggest a role for PRP in pain reduction and the improvement of function in cartilage damage, whilst PRP may also facilitate earlier recovery in tendinopathy [27].

A systematic review and meta-analysis carried out by Laudy and colleagues, sought to assess the role of platelet-rich plasma in decreasing pain, improving function and preventing the progression of radiographic changes in knee OA [28]. Ten studies were analysed, of which six were randomised controlled trials (RCTs) and the others non-randomised with a high degree of bias. Eight studies compared PRP with hyaluronic acid, one compared PRP to placebo whilst the final study compared single versus double spinning. The review concluded that PRP may have a beneficial effect on both pain and function at both 6 months and a year in comparison to placebo and hyaluronic acid. The study also concludes that the application of platelet-rich plasma for knee osteoarthritis may be safe although one study by Patel et al., recorded a number of systemic adverse effects including syncope, tachycardia and dizziness in 17 from 78 patients. The symptoms were recorded in those who were subject to a higher quantity of platelets and were limited, arising in the first 30 min after injection. The symptoms were ascribed to either the higher quantity of platelets or the use of calcium chloride as an activating agent [29].

4.2.5.2 Tendinopathy

Overuse activities such as jumping or running can be the trigger for patellar tendinopathy, producing inferior pole tenderness of the patella [30, 31]. Whilst its etiology was previously ascribed to inflammation, current thought suggests that neural, mechanical or vascular triggers lead to a failed healing response. In an effort to establish the mechanism underlying the impaired response, Andia and colleagues compared healthy semitendinosus cells to tendinopathic rotator cuff cells [32]. The study concluded that PRP influences tendon healing by immunomodulatory and pain reduction pathways. At present there is no gold standard treatment for the problem but PRP's ability to release growth factors has been advocated to encourage the healing process.

Dragoo and colleagues performed an RCT comparing PRP to dry needling in a population of patient who had failed conservative treatment [31]. From 23 patients, 13 were allocated to the dry needling group whilst 10 were allocated to the PRP group. Outcome measures were collected at 12 and 26 weeks. Results demonstrated a significant improvement in outcome scores at 12 weeks for PRP compared to dry needling $p=0.02$. However, at 26 weeks, the difference between the two groups was not significant. The study concluded that PRP might have a role to play but time weakens its therapeutic value [31].

These findings have been supported by a recent systematic review of studies relating to PRP in patellar tendinopathy [33]. This review, including two RCTs, one non-randomised comparative study and eight case series, concluded that PRP appears to be a safe intervention, and that all non-comparative studies that were included demonstrated improvement after its administration. However, comparative studies did not demonstrate a consistent effect of PRP compared to other treatments such as physiotherapy.

4.2.5.3 Meniscus

PRP may enhance regeneration of meniscal tissue. In animal models, the use of PRP in conjunction with gelatin hydrogel led to an improved healing with the healed tissue demonstrating a structural integrity comparable to the inner part of the meniscus [34]. These findings were contradicted by Zellner et al., who did not describe any improvement upon the use of PRP with hyaluronan-collagen composite matrix [35].

A case control study examined the use of PRP in addition to meniscal repair. Outcome measures included the need for subsequent menisectomy and patient outcome scores at 2 years [36]. No difference was found between the two cohorts in terms of either reoperation or patient related outcome measures, return to work or athletic activity. The study was underpowered, did not allow for subgroup analysis of the different types of meniscal tears and the two groups varied in important factors such as age and body mass index. Pujol et al., examining the use of PRP in the open repair of horizontal meniscal tears, suggest an improvement with PRP. In those patients to whom PRP was administered, a statistically significant improvement in both KOOS score and the normalisation of MRI appearances was seen [37].

4.2.6 Remarks on PRP

The use of PRP promises many potential theoretical benefits in the treatment of knee pathologies. However the evidence collected to date has not supported these hopes. Part of the problem lies in the lack of a standardised preparation of PRP. The preparation and activation of the therapy, as well as the inclusion of fibrin or leukocytes, also vary from study to study.

The pool of evidence for treatment is small whilst the studies are not robustly designed to definitively support the use of PRP. In the case of the use of PRP in osteoarthritis, there are six RCTS to draw upon, with multiple sources of bias, whilst the evidence for PRP in tendinopathy is similarly limited [33]. There is also marked variability of the types of outcome measures used to quantify function between studies.

4.3 Mesenchymal Stem Cells (MSCs)

4.3.1 Introduction

Stem cell research began with the work of the German pathologist Julius Cohnheim in the late nineteenth century. By labelling inflammatory cells, Cohnheim discovered serendipitously associated dye labelled cells derived from bone marrow migrating to sites of injury. The idea that cells derived from blood and consequently bone marrow permitted tissue regeneration became known as the Cohnheim theory. A year later, in 1868, Emile Goujon, a French physiologist, furthered this work. Osteogenesis was demonstrated by the ectopic implantation of autologous bone marrow into the bones of rabbits and chickens. After the flurry of early advances, progress was arrested for almost a century.

Tavassoli and Crosby confirmed bone marrow's ability to undergo de novo osteogenesis. Alexander Friedenstein extended this work and realised that this osteogenesis was attributable to a subset of bone marrow cells of fibroblast like-appearance. This appearance suggested that the cells precursors were of the stromal compartment of the bone marrow. Friedenstein demonstrated that with the ectopic implantation of an aggregation of bone marrow stromal cells, at clonal density, led to the formation of a variety of mesenchymal tissues. This led Friedenstein to christen these cells CFU F (colony forming unit Fibroblastic). However the cells are better known, somewhat misleadingly, as mesenchymal stem cells, owing to Arnold Caplan's work coinciding with the isolation of human embryonic stem cells [38, 39].

4.3.2 Definition

Stem cells can be defined as those cells with:

- The ability to self-renew
- The quality of multilineage differentiation
- The property of arising from a single cell

Stem cells can be classified on the basis of their origin (embryonic stem cells, adult stem cells and cancer stem cells [40, 41]), the degree of plasticity they exhibit, or the ability to form different tissues.

Embryonic stem cells are derived from the morula, the inner cell mass of the blastocyst. These cells have the ability to form cell types from all three germ cell layers of the embryo. It is this ability of embryonic stem cells which forms an important avenue of research, as they can be used to understand pathophysiology, and to trial the efficacy and safety of medications and other treatments of a multitude of diseases.

However, the morula can only be created via the fertilisation of a human oocyte resulting in a viable human embryo. The creation and destruction of the human embryo generates ethical questions and is controversial. Legislation has regulated but also restricted research.

Takahashi and Yamanaka discovered a means of circumventing the problem, with the Nobel Prize winning discovery of the human induced pluripotent stem cell (HiPS) in 2006 [42]. The experiment, in murine cells and adult fibroblast cells, combined four factors into these cells, demonstrating morphology equivalent to that of embryonic stem cells as well as a pluripotent ability and gene expression. Other advantages of human pluripotent stem cells include the ability to avoid issues such as graft versus host disease and immune rejection [43, 44]. However concerns include the tumorigenic potential of HiPS cells. In human subjects, de novo tumours attributable to the graft have been discovered at the site of cell transplantation. Moreover, the formation of liver and splenic teratomas have been described in immunocompromised mice secondary to HiPS implantation [43].

The mode of delivery of stem cells also poses problems. An estimated 90 % of cells are destroyed secondary to hypoxia, physical stress and inflammation [43]. It may be reasonable to suggest increasing the number of cells delivered to improve efficiency of uptake. However this benefit ought to be measured against the risk of teratoma formation.

4.3.3 Adult Stem Cells

Adult stem cells are a catch-all term for a number of cells discovered in the adult [45]. Such cells possess multipotentiality, described as the ability to form a limited number of cell types [43]. In the example of a mesenchymal stem cell, these have the ability to form bone, muscle, fat and cartilage [46, 47].

The first to be identified were marrow stromal cells, derived from the mononuclear layer of bone marrow. Later, other mesenchymal stem cells, so-called due to their mesodermal origin and presence of a stromal cell population, were discovered in adult tissue such as adipose tissue, synovial membrane and dental pulp. The absence of the major histocompatibility complex (MHC) ensures that MSCs are nonimmunogenic and thus immunosuppression is not necessary [48].

The therapeutic uses of MSCs are derived from their multipotent quality, with migration to the locus of injury and differentiation into the required cells.

However research has established that MSCs action is somewhat different.

Influencing cytokine activation, MSCs can suppress both B-cell and T-cell responses. The release of regulatory T-cells down-regulates the immune response to soluble mediators such as nitric oxide (NO) and human leukocyte antigen G (HLA-G) and prostaglandin E (PGE2) [49, 50]. A similar mechanism is seen with MSCs in the presence of natural killer cells (NK).

B-cell action is also subdued, with the cell cycle being impeded in the presence of MSCs.

Although some authors have suggested that cytokine activation alone may explain the action of MSCs, there is some evidence to indicate that direct cell-to-cell interaction may also mediate the immunomodulatory effect.

4.3.4 Applications

4.3.4.1 Cartilage Injury and Osteoarthritis

MSCs have received much interest both for their inherent properties and in the case of adipose-derived stem cells, abundance and ease of harvest. MSC therapy can be administered in two forms; direct injection or the implantation of the MSC on a scaffold like material.

In those studies in which MSCs were directly injected, the effect observed is initially an improvement in hyaline cartilage. Subsequently however, as the implanted MSCs are lost, cartilage quality deteriorates [51]. In studies, which used hyaluronic acid as a scaffold, the hyaluronic acid was thought to permit the embedding of collagen fibres and the sulphated proteoglycans. It is postulated that the use of a scaffold allows the graft to be able to adapt the shape of a defect more effectively whilst also being able to withstand mechanical and degradable processes. This in turn permits the delivery of MSCs, leading to later cell proliferation with later cartilage regeneration [51, 52].

Scaffolds may be natural or synthetic, with the former including collagen, alginate fibrin and hyaluronan amongst others. Synthetic scaffolds include polylactic acid and polyglycolic acid. Issues abound with both types of scaffold. In alginate, despite evidence of chondrogenesis, problems regarding biocompatibility remain whilst in synthetic scaffolds, there may be hydrolytic reactions, leading to inflammation and eventual chondrocyte death [51].

Veronesi and colleagues report a systematic review of the use of adipose-derived mesenchymal stem cells in the treatment of osteoarthritis and chondral defects in mice and rabbit animal models [52]. The study evaluated both the use of MSCs with scaffolds and culture-derived cells. With the studies concerning osteoarthritis, the conclusions are more equivocal to reversal of pathology. However, in the studies regarding osteochondral defects, all studies demonstrated good hyaline cartilage regeneration upon macroscopic and histological assessment [53].

Reports in human subjects are also promising. Waikitani et al. described a case control study of a group of patients with knee osteoarthritis. The study group underwent high tibial osteotomy with a repair of an osteochondral defect, using bone marrow-derived MSCs, embedded within collagen gel. The control group underwent a high tibial osteotomy without the inclusion of MSCs [54]. Outcome scores improved for both groups postoperatively. However, a second look arthroscopy, in the study group, suggested the presence of high grade, histological and arthroscopic de novo hyaline cartilage tissue [54].

In a further study, the same group report two patients with patellar chondropathy, undergoing repair to the defect with bone marrow-derived stem cells. At early follow-up, the patients described greatly improved functional ability and arthroscopy found evidence to suggest the presence of hyaline cartilage [55]. The studies described use bone marrow-derived stem cells, and there is limited higher evidence about mesenchymal stem cells.

4.3.4.2 Established Osteoarthritis

During early experiments employing MSCs, it was thought that the chondrogenic potential of the cells could be harnessed to form new cartilage. However, studies have demonstrated that de novo cartilage formation was limited and instead MSCs appeared to be behaving in a paracrine fashion [56], suppressing activated B- and T-cells.

Mesenchymal stem cells have had positive effects in animal studies. Qi et al. describe multiple MSCs promoting local meniscal regeneration whilst impeding changes associated with osteoarthritis including articular degeneration [57]. Xia et al. describe a meta-analysis of seven studies examining the effect of MSC injection on pain management and the functional improvement in following treatment for knee OA [58]. In two included studies, the control group underwent arthroscopic debridement alone, whilst in another two the control group was subject to a hyaluronic acid injection. The remaining studies involved control groups undergoing a combination of arthroscopy, high tibial osteotomy and PRP. Outcomes evaluated included visual analogue scores for pain and functional scores including Tegner, Lysholm and Western Ontario and McMaster University arthritis index (WOMAC) amongst others.

The study concludes that the use of MSCs does not have any effect on pain, ($p = 0.13$). However, there was a high degree of heterogeneity. After the omission of the studies of lower quality, a statistically significant improvement is described, $p = 0.001$, with no heterogeneity ($I^2 = 0\,\%$). Whilst an improvement in functional scores is reported, this should be interpreted with caution, as the meta-analysis was not adequately powered. The follow-up is short; the study with the longest follow-up included in the meta-analysis was reported at only 25 months [59]. A second review into the use of MSCs in knee osteoarthritis again drew attention to the lack of consistency in dosing or method of delivery [60].

4.3.4.3 Tendinopathy

There is little research available on the use of MSCs in patellar tendinopathy. The majority of studies are experiments in animal models, but these report positive outcomes. Xu and colleagues [61] describe the use of neural crest-derived stem cells being transplanted to patellar tendon defect in a rat model. The study demonstrated tissue repair at both a gross and histological level. One case report in a human subject reported the use of adipose-derived MSCs as a second line treatment for large interstitial tears in the patellar tendon following previous therapy with PRP. The stem cells, taken from a combination of bone marrow aspirate and autologous fat graft, was injected into the tendon with the patient commencing full practice within almost 4 weeks. At 6 months, the patient was able to play competitively without pain at any time. Serial ultrasound demonstrated a decrease in the length of linear hypoechoic areas, suggesting tendon repair.

A series of eight patients with chronic patellar tendinopathy who had failed at least 6 months of conservative treatment was reported by Pascual-Garrido et al. All patients received an injection of bone marrow-derived stem cells isolated from the iliac crest. Seven of eight patients reported excellent results with significant improvements in Tegner, knee injury and osteoarthritis outcome score (KOOS) and international knee documentation committee (IKDC) scores [62].

4.3.4.4 Meniscus

Mesenchymal stem cells are present in high concentrations in synovial fluid in knees with a damaged meniscus [63]. This suggests that MSCS may play an important role in meniscal healing; this has been supported by favourable results in animal models.

MSCs can be administered in three ways; by direct application, by intra-articular injection and using scaffold-free tissue engineered constructs [61]. Horie et al. demonstrated in a rat model with massive meniscal defects that synovial MSCs, delivered by intra-articular injection, migrated to the meniscal defect. Once in situ, the MSCs differentiated into meniscal cells [64]. The same authors confirmed this finding in a rabbit model [65]. Healing is promoted by promotion of angiogenesis, chondrogenesis and the infiltration of immune cells [66].

Although the evidence in animal models is promising there are few studies in humans and most are single case report. In one case, of a 32-year-old woman with a medial meniscal tear, injection of adipose tissue-derived MSCs led to a significant improvement in pain whilst MRI imaging also demonstrated complete resolution of the torn meniscus. [67].

A single randomized controlled trial (RCT) exists on this intervention, involving 55 patients undergoing partial meniscectomy randomised to three groups. Group A was randomised to treatment with mesenchymal stem cells alone; Group B received mesenchymal stem cells and hyaluronic acid, whilst Group C was treated with hyaluronic acid alone. The groups demonstrated an increase in meniscal volume in the MSC groups, with MSCs alone demonstrating greater increase in volume than the combined group. The authors suggest that the increase in volume as due to de novo tissue generation. The groups treated with stem cells also reported lower levels of pain [68].

4.3.4.5 Ligament

A recent systematic review examined the role of mesenchymal stem cells in anterior cruciate ligament (ACL) graft healing suggesting that mesenchymal cells promote bone tissue integration [69]. One included study was an RCT comparing patients undergoing ACL reconstruction with mesenchymal stem cells to those without. The study measures radiological outcome as well as some limited histological evidence. Silva described no radiological difference between the groups suggesting that MSCs do not accelerate graft to bone healing [70].

The use of MSCs in ACL injury has most extensively been investigated at a preclinical stage. Figueroa et al. describe the use of a collagen type 1 scaffold, seeded with MSCs in a rabbit model, with surgically transected ACLs. The animals were divided into three groups; those undergoing suture repair alone, suture repair in combination with type 1 collagen scaffold and the final group, suture repair with collagen scaffold impregnated with MSCs. In the final group, one third of patients demonstrated tissue comparable in macroscopic appearance to normal ACL. Histological evidence also suggested ACL regeneration, a feature not present in the other groups [71].

Other studies have disputed these findings [72].

In addition to direct injection, MSCs can be used in conjunction with scaffolds. Although preliminary uses of scaffolds were associated with a number of complications, there are many potential benefits. These include the ability to produce an implant, which is cheap and easy to manufacture, with a high intrinsic strength [73]. One animal study, in rabbits, describes the use of MSC loaded onto a silk scaffold to provide a synthetic ACL graft [74]. At 24 weeks follow-up, there were positive radiological and histological outcomes, with the authors describing MSC proliferation, with the morphology of fibroblasts. The tensile strength of the material was also described as sufficient for daily activities [74]. Significant tissue regeneration at 24 weeks was also described in a second study of a silk scaffold, impregnated with hydroxyapatite [75].

4.3.5 Remarks on MSCs

MSC research is hampered by heterogeneity of preparations and techniques. The optimal harvest site, the role of induction and the mode of delivery remain uncertain. The problem is exacerbated by a lack of full understanding of the mechanism of action of MSCs as well as how MSCs act on different tissues within the knee. Animal models suggest that MSCs have many benefits to offer. In the limited number of well-designed clinical studies available, MSCs can treat articular cartilage defects and meniscal damage. It is only with further research that we will fully realise the therapeutic potential of these interventions.

Conclusions

The use of injection therapy with platelet-rich plasma (PRP) and mesenchymal stem cells (MSCs) promises many potential theoretical benefits in the treatment of knee pathologies. However the evidence to date has not supported these hopes.

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5 The Patellofemoral Joint

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and Justin P. Cobb

Abstract

The patellofemoral joint has traditionally been poorly understood and interventions for patellofemoral joint problems have generally been less successful than those employed for the tibiofemoral joint. Pathologies affecting the patellofemoral joint in the adult can be largely divided into three groups: instability, osteochondral defects and osteoarthritis. These three conditions share a number of aetiological factors and all represent disorders of the normal mechanics of the patellofemoral articulation. As such, understanding the normal and abnormal anatomy and kinematics of the joint are vital to clinicians treating patellofemoral disorders. Treating the symptoms of these conditions without addressing the underlying disorder of kinematics will be likely to fail. In this chapter, the normal and abnormal anatomy and physiology of the joint are discussed as are the clinical features and treatments for the three commonly encountered pathologies of the patellofemoral joint.

Keywords

Patellofemoral joint • Disorders • Diagnosis • Treatment

5.1 Introduction

The patellofemoral joint is an important generator of symptoms within the knee joint in patients of all ages. In adults, the major pathologies are instability, osteochondral injuries and osteoarthritis. Common to all are disruptions to the complex biomechanics of the articulation. Understanding of the anatomy and physiology of the patellofemoral joint has lagged behind that of the tibiofemoral joint, but over recent years a

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great deal of research has been focussed on understanding the patellofemoral joint. The aim of this chapter is to describe the geometry and kinematics of the joint, and to apply these to the major pathologies encountered in the patellofemoral joint. By understanding the disorders of normal mechanics of the joint the surgeon can better understand the strategies for treatment of these traditionally difficult to treat pathologies.

5.2 Biomechanics

5.2.1 Geometry

While the bicondylar knee joint dates back to Eryops, an ancestor of reptiles, birds and mammals some 320 million years ago [1] the patellofemoral joint is a relatively recent development, dating back only 65 million years [2]. The patella is the largest sesamoid bone in the body and centralises the four converging heads of the quadriceps muscle group, transmitting their force and acting as a fulcrum. By extending the moment arm, it increases the power of knee extension [3–6].

The location and configuration of the intercondylar groove of the distal femur is clinically significant in the mechanics and pathomechanics of the patellofemoral articulation [5–8]. The traditional description of the femoral sulcus is that it lies midway between the femoral condyles, and this has informed many designs of total knee replacement. In fact, the native anatomy of the femoral sulcus is more complex than this. There is debate whether the femoral sulcus lies lateral to the midplane between the two femoral condyles [9] or central but with a distal-lateral deviation as the rotation of the femur increases during the arc of flexion [10]. The discrepancy may lie in the difference which is seen between bony and cartilaginous anatomy [11] or the fact that choosing different frames of reference while describing the circular trochlear groove would result in variable descriptions of its geometry [12]. Rotational variation is a key determinant of function and of predisposition to disease and the development of patellofemoral osteoarthritis has been related to increased external tibial torsion [13–15]. This rotation can be measured reliably using computed tomography (CT) scans [16].

5.2.2 Kinematics

The development of disease in the patellofemoral joint is influenced by abnormal joint kinematics [17] and knowledge of in vivo knee kinematics in healthy and arthritic knees is invaluable to understand the aetiology of patellofemoral disease and for surgical planning.

Patella tracking describes the motion of the patella relative to the femur during flexion and extension of the knee. There is a correlation between the anatomy of the patella and its facets with the trochlear groove of the femur [18], giving congruency and allowing the patella to move over the femur in a circular path [19]. Patellar maltracking can be a major contributor to knee pain in young knees [20–22] as well as leading to patellofemoral degenerative change and being one of the dominant causes of dissatisfaction following knee arthroplasty [23–25].

When the diaphysis of the femur is used as reference, lateral displacement of the patella has been observed with increasing knee flexion angle [26–32]. However, imaging studies have shown the opposite when relating the patella with the femoral trochlear groove (Figs. 5.1 and 5.2) [33, 34]. With three-dimensional tracking studies, there are difficulties in defining the groove axis and plane of reference as the trochlear groove is curved and different definitions of this axis have been used [35]. A reproducible axis has recently been defined between the centres of spheres in the femoral flexion facets [12].

5.3 Patellar Instability

5.3.1 Pathology and Diagnosis

The term patellar instability has been used in different contexts in the literature including abnormal tilting or positioning of the patella

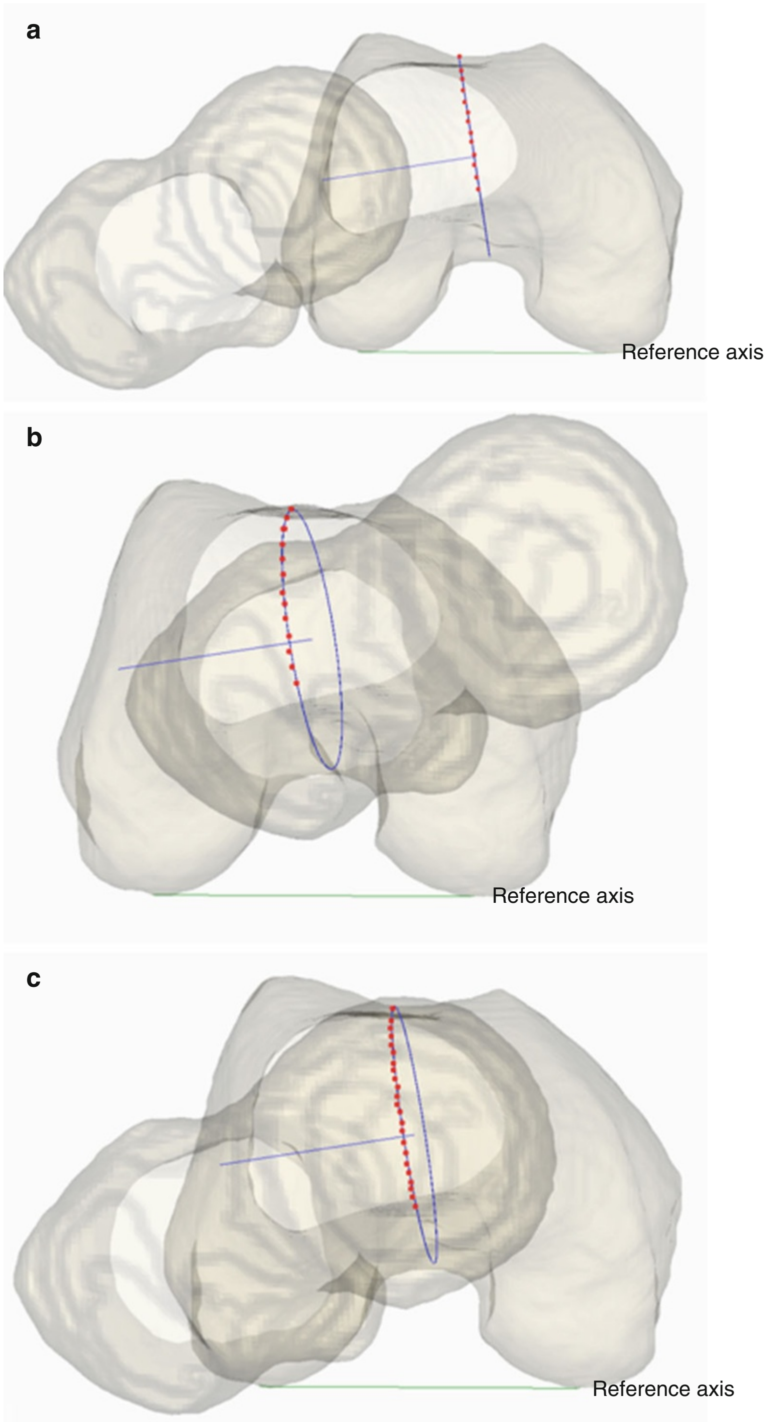

Fig. 5.1 Panels (**a**–**c**) demonstrate the effect of the femoral frame of reference on describing trochlear groove

[36, 37] but is here used to describe persistent maltracking which is associated with episodes of symptomatic subluxation or dislocation. Instability and malalignment of the patellofemoral joint are major causes of knee symptoms in young people [20, 22, 38].

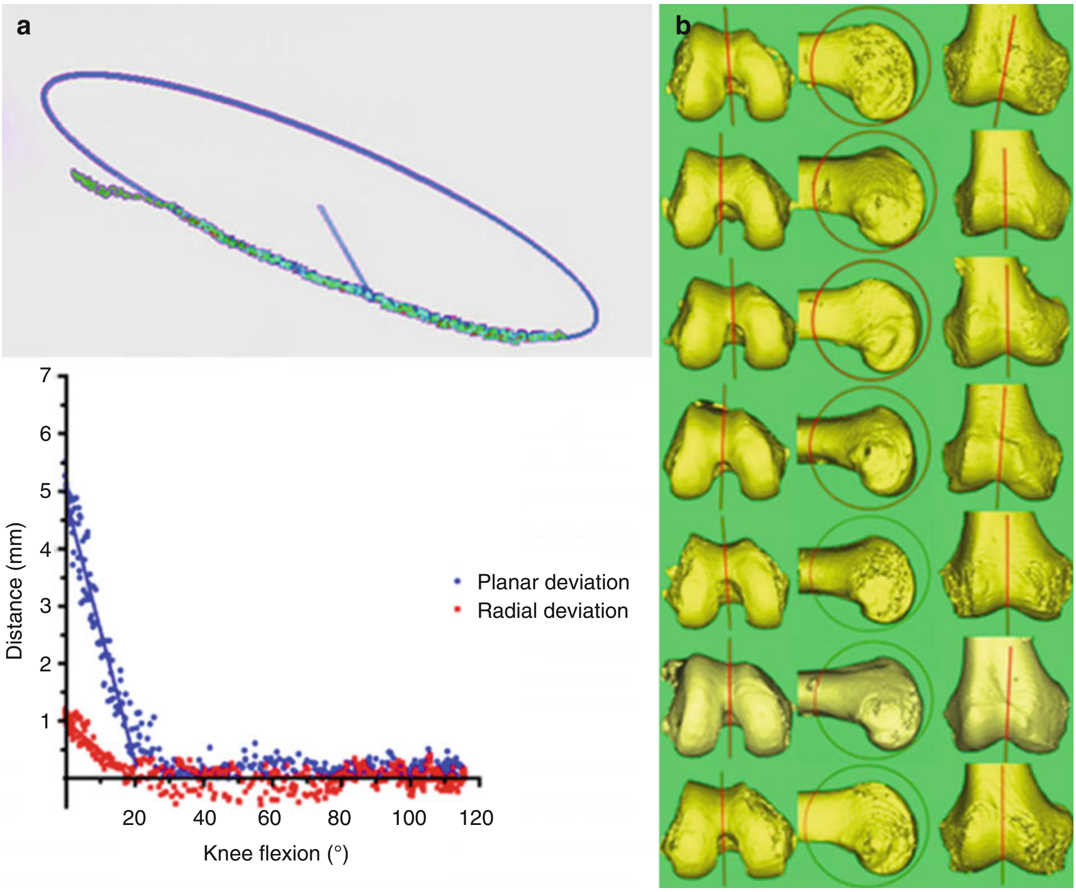

Fig. 5.2 (**a**) The moving landmark of the patellar centre during knee flexion for one knee is visualised and a best-fit circle is constructed to these points. The deviation from this circle is plotted against the knee flexion angle for two flexion-extension cycles. A *line* fitted to the graph crossed the x-axis at the flexion angle at which the path of the centre of the patella deviated from the circle. (**b**) The *circle* fitted to the path of the patella is illustrated in transverse, sagittal and coronal views

In full extension, the patella lies above the trochlea, and it is in early flexion that it articulates first at the distal pole and facets. As flexion progresses, contact occurs more proximally on the patella (and distally on the trochlea). Therefore, the contact surfaces and pressure on patellar facets changes throughout the range of motion, increasing the stabilising forces through the range of knee flexion [39].

Stability is provided by both bony and soft tissue stabilisers [8] and correlates with the geometry of the distal femur [40]. In the clinical evaluation of patellar tracking, it has been recommended that the patella is observed as it enters the femoral trochlear groove. In normal tracking, the patella moves smoothly into the femoral trochlea during initiation of flexion, and in terminal extension, there is minimal lateral displacement seen as the patella leaves the trochlea and occupies a supracondylar position. Exaggeration of this normal motion can be seen subjectively during clinical examination in the J-sign during initiation of flexion in patients with instability (see Chap. 1). This refers to the inverted “J” course of a patella that begins lateral to the trochlea then moves suddenly medially to enter the trochlea [41]. Although other patellofemoral pathological signs can be common in asymptomatic knees, the J-sign is almost universally associated with pathology [42]. A strong correlation has also been demonstrated between the presence of patellar tilt during clinical examination and tilt seen on magnetic resonance imaging (MRI) scans, such that patients with significant tilt on the physical examination can be expected to have an MRI tilt of 10° or greater whereas an angle of less than 10° is associated with the absence of significant tilt on the physical examination [38].

5.3.1.1 Bony Stabilisers

An increased trochlear sulcus angle is related to clinical instability [43]. Plain axial radiographs require accurate positioning [44, 45] and the true sulcus angle is difficult to measure as the "skyline" profile of the patellar contact area on the femoral groove changes with knee flexion [10]. Nevertheless, a degree of trochlear dysplasia can be seen in 85 % of patients with patellofemoral instability [46]. Lateral knee radiographs have also been used to describe abnormalities in the proximal-distal position of the patella relative to the knee [47–50]. The early part of the flexion cycle is critical because this is when the patella enters and engages the trochlear groove of the femur [51] and hence patella alta is related to instability [52, 53]. However, radiographic ratios of patellar position have significant inter-observer variability and rotational alignment of the knee affects these measurements [54].

Both computed tomography (CT) and MRI improve on the limitations of radiographs and are better at visualising the joint in early flexion. It is also possible to use newer techniques such as kinematic CT and MRI examinations to measure patellar tilt and translation in a moving knee [55–58]. However, the quadriceps muscles are relaxed during supine imaging and this may have an effect on the measurements [59]. In cadaveric studies, it has been shown that surgically flattening the lateral condyle can reduce the lateral stability of the patellofemoral joint [8] and that surgically flattening the anterior trochlea then subsequently deepening the sulcus with trochleoplasty caused decreased and then increased lateral patellar stability respectively [60].

5.3.1.2 Soft Tissue Stabilisers

The medial patellofemoral ligament (MPFL) provides 60 % of the medial stabilising force with a smaller contribution from the other components medial retinaculum [61]. There is also a dynamising effect of the vastus medialis obliquus muscle (VMO) on the MPFL [62, 63].

5.3.2 Treatment

The first line of treatment of patellofemoral instability involves physiotherapy with strengthening of the quadriceps focusing on the VMO, although it is debatable whether this can be selectively isolated in practice [64, 65]. For patients without overt dysplasia, physiotherapy remains a good option [66] and newer techniques, such as biofeedback, can improve the results [67].

Lateral patellar dislocation is associated with MPFL rupture in 87–100 % of patients [36, 68–70] and in the longer term, patellar instability and dislocation are associated with chondral injury and osteoarthritis [69, 71]. Non-operative management may leave a third of patients with significant symptoms, two fifths with at least one episode of further dislocation and half unable to return to vigorous sports at long-term follow-up [70]. Surgery can correct recurrent dislocation which without treatment can occur in 42–49 % of patients [70, 72].

Surgical treatment must depend on the primary pathology and identification of this pathology is mandatory for successful treatment of instability. Repair or reconstruction of the MPFL is indicated when soft tissues rather than bony morphology are the primary pathological feature [73–77]. Tibial tubercle advancement transfer [53, 78–80] or sulcus deepening trochleoplasty [81, 82] are considered favourable treatments for pathoanatomy such as increased tibial tubercle to trochlear groove (TT-TG) distance or trochlear dysplasia respectively [83, 84]. Guided growth for deformity correction has been described [85] as instability can present prior to skeletal maturity although some surgeons will elect to wait until physes have closed to avoid complications such as growth arrest [86]. An isolated lateral ligamentous release will only work for a proportion of patients and has not shown as favourable results as the other options above [87] because it cannot alone resolve all of the causative factors listed. Further research is necessary to understand the best surgical treatment for patellar dislocation. A Cochrane review found only poor quality evidence supporting any surgical treatment for patellar instability, with no trials examining people with recurrent dislocations, which are those most likely to require surgical management [88].

5.4 Osteochondral Defects (OCD)

5.4.1 Pathology and Diagnosis

Patellofemoral osteochondral defects can be associated with osteochondral or bone marrow lesions on imaging studies. MRI can be used to detect bone oedema even in the absence of fracture or defect on plain radiographs. OCD may be the precursor to patellofemoral arthritis although further research is required to determine the risk factors for progression to OA [89, 90]. Osteochondral injuries are associated with patellar instability and dislocation [91–93]. This is important as missed or delayed diagnosis can lead to chronic pain, decrease in sports, social and working activities, with the associated socio-economic impact, even when the primary pathology leading to the instability is addressed.

5.4.2 Treatment

Before the OCD itself can be treated, firstly the stability of the patellofemoral joint must be restored. As mentioned in the previous section, the medial retinaculum is injured with rupture in nearly all patellar dislocations [94] and this will impact the ongoing patellar stability and will compromise any reparative techniques for the cartilage.

Cartilage lesions are described in detail in Chap. 11. Compared to the tibiofemoral joint, and in particular to lesions in the femoral condyles, the shear forces encountered at the patellofemoral joint often render traditional reparative strategies, such as microfracture, unsuccessful. Modern techniques such as stem cell or chondrocyte implantation are showing promising early results [95] and matrix-induced autologous chondrocyte implantation (MACI) may offer an alternative solution in experienced hands [96, 97]. With ongoing technological progress, the high costs of such procedures may continue their downward trend but in areas of larger cartilage defects there are proponents for alternatives such as inlay arthroplasty [98] or osteochondral allograft transfer [99].

5.5 Patellofemoral Osteoarthritis (OA)

5.5.1 Pathology and Diagnosis

Isolated symptomatic patellofemoral osteoarthritis has been reported in 2 % of men and 8 % of women older than the age of 55 [100] and a prevalence of 9 % was noted in a series of 174 patients presenting to an orthopaedic a single centre with knee pain [101]. The aetiology of patellofemoral joint (PFJ) OA can be divided into surface pathomorphology and soft tissue imbalance. Evidence of trochlea dysplasia has been shown in 78 % of knees with isolated patellofemoral arthritis [102, 103]. The same factors implicated in patellar instability can predispose to OA: the extensor mechanism can be affected by excessive Q-angle [104], patella alta and tibial tubercle malposition [105]. A laterally positioned tibial tubercle [106, 107] and valgus alignment have been associated with PFJ OA [20, 107–109].

5.5.2 Treatment

Physiotherapy to strengthen the quadriceps muscles has been shown to be beneficial [110].

Lifestyle measures including activity modification and weight loss should also be considered key parts of treatment, particularly for patients with malalignment [111].

Surgical treatments include tibial tubercle elevation, total knee arthroplasty and patellectomy [112–114] although the latter has been much debated [115] and has now largely fallen from favour due to associated loss of extension power [116]. Newer options such as chondrocyte implantation are also being used in PFJ OA [117] although this is a developing field with only early results.

Arthroplasty interventions are beyond the scope of this book but will be dealt with briefly. Total knee arthroplasty (TKA) has had good results although it requires more soft tissue releases for isolated PFJ OA compared to tricompartmental knee OA [112]. One of the main issues with the patellofemoral articulation in TKA may be the design of the trochlear groove [118]. Patellofemoral joint replacement is a bone preserving procedure [119] and has gained popularity in treating isolated PF osteoarthritis in young patients [120–123]. Although early designs suffered from higher revision rates of up to one third, this has now improved dramatically [124], with some surgeons reporting no revisions at 5 years follow-up in a group of 50 patients [125]. The most common cause for revision was progression of tibiofemoral arthritis [126] although significantly less frequently when the patellofemoral arthritis had been secondary to femoral trochlear dysplasia [127]. Patient selection is of paramount importance and younger patients, those with dysplasia or previous patellofemoral trauma are the most suitable candidates as opposed to those with idiopathic arthritis or disease in other compartments [119, 128]. Patellofemoral joint replacement is a complex procedure as not only is the pathomorphology varied as discussed above but also placing even a well designed prosthesis correctly is challenging. Most femoral implant designs show characteristics of trochlear dysplasia [129, 130] and traditional surgical instruments allow significant variability in implant positioning. Patient-specific implants [131] and computer-assisted patellofemoral arthroplasty with preoperative planning [132] may improve component placement and accurate restoration of joint surfaces.

Conclusions

Patellofemoral disease has traditionally been less well understood compared to conditions affecting the tibiofemoral articulation and procedures performed at the patellofemoral joint have generally been more challenging compared to the rest of the knee. A thorough understanding of the mechanics of the joint and the pathophysiology of patellofemoral disease are vital to successful treatment. Fortunately, a great deal of research has been performed in this area in recent years and surgeons now have greater tools at their disposal for treating the three interlinked pathologies which primarily affect the patellofemoral joint.

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Tendon Injuries of the Knee

6

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Abstract

Tendon injuries are common in the knee. The most commonly affected structure is the extensor mechanism. The main pathologies are tendonitis of the patella and ruptures of the patellar and quadriceps tendons, although other tendonopathies have rarely been described around the knee. Patellar tendinopathy can be difficult to treat, but the mainstay of treatment is physiotherapy, with injectable and surgical treatment reserved for recalcitrant cases. The diagnosis of quadriceps and patellar tendon ruptures requires a high index of suspicion and thorough history-taking to assess for medical comorbidities that may predispose patients to tendon degeneration. Radiographic assessment with plain films supplemented by ultrasonography (US) and magnetic resonance imaging (MRI) when the diagnosis is equivocal further aids diagnosis, however, advanced imaging is often unnecessary in patients with functional extensor mechanism deficits. Acute repair is preferred, and transpatellar bone tunnels serve as the primary form of fixation when the tendon rupture occurs at the patellar insertion, with or without augmentation depending on surgeon preference. Chronic tears are special cases requiring reconstructions with allograft, synthetic grafts or autograft. Rehabilitation protocols generally allow immediate weight-bearing with the knee locked in extension and crutch support. Limited arc motion is started early with active flexion and passive extension and then advanced progressively, followed by full active range of motion and strengthening. Complications are few but include quadriceps atrophy, heterotopic ossification, infection, stiffness and rerupture. Outcomes are excellent if repair is done acutely, with poorer outcomes associated with delayed repair.

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6.1 Introduction

The tendons about the knee, in particular those of the extensor mechanism, are subject to extreme loading during activities of daily living. As a result, tendon injuries are commonly encountered in both primary and secondary care. Tendon injuries can be subdivided into tendinopathy, which is related to low-intensity but repetitive traumatic phenomena, and acute rupture of the tendon, which may be a result of chronic tendinopathy.

The commonest sites for tendon disorders about the knee are the extensor mechanism, with patellar tendinopathy and ruptures of the patellar and quadriceps tendon being the most frequently encountered pathologies. Less commonly, tendinopathy of the quadriceps, gastrocnemius and popliteus have been described as rare causes of knee pain.

In this chapter, we will revise the current concepts on the diagnosis and treatment of tendon pathologies around the knee.

6.2 Basic Concepts

Tendons are structures that absorb and transmit loads generated by the muscles in their corresponding bony structures. The tendon is attached to bone by a direct insertion, characterised by its great resistance to injury, explaining the existence of avulsion fractures [1]. Tendons are principally composed of fibres of type I collagen. Such fibres predominate over elastic fibres, which are responsible for the flexibility and distraction capacity of tendons. The mission of collagen fibres is to resist the tension forces generated in tendons [1].

Ageing causes cellular changes in tendons, with a reduction in the number and size of cells, and a progressive failure of their functions in repair and protein synthesis [2]. A decrease in water and mucopolysaccharide content of the extracellular matrix renders the tendon less stiff and less able to glide, whilst the reduction in the numbers of capillaries within the tendon can cause a relative hypoxia, which in turn leads to mucoid degeneration and calcifying tendinopathy. The total content of collagen decreases, with type II collagen, which usually only predominates in the insertional part of the tendon, spreading into the main tendon body. The structure of the collagen also changes, with an increase in the number of irreducible cross-links present between fibres. This has the effect of decreasing the tensile strength and modulus of elasticity of the tendon, increasing the degree of mechanical stiffness and rendering the tendon significantly more likely to rupture when the tendon encounters increasing stress and strain [2]. Such a circumstance is clinically seen as an increased tendency to suffer tendon ruptures related to physical activities [1–3].

There are other factors involved in the development of tendon injuries, such as the frequency of tension forces to which tendons are exposed, the type of contraction (excentric or concentric) performed during physical activities or sporting activities, and the degree of vascularisation of the tendon. Vascularisation varies depending on the presence of a paratenon, or whether the tendon is contained within a synovial sheath (in which vessels go into the tendon through anatomical structures called vinculae) [1, 3].

Tendinopathy occurs in two main populations. The first and largest group includes weekend or occasional athletes who have musculoskeletal structures insufficiently prepared to resist the excessive mechanical loads they suffer. The second group is formed by professional and elite athletes who principally encounter problems if there is a sudden change in training regime (for instance a change of surface or change of shoes) or if their training regime is inadequate for the activities they are undertaking [3].

Most tendon injuries can be considered to be overuse injuries, which are especially frequent in the lower limbs. Such injuries may represent up to 50 % of the outpatient clinic consultations in our institutions. Overuse injuries occur when repetitive mechanical forces cause microtrauma to the mio-tendinous structures. Repeated microtraumas may exceed ability of the body to repair itself, leading eventually to pain and disability [3].

Garner et al. report on the risk factors and epidemiology of extensor mechanism injuries [4]. In a review of 726 patient records, they found that females with an extensor mechanism injury are more likely to sustain a patellar fracture compared with males [4]. Younger males are more likely to sustain a patellar fracture or patellar tendon rupture; however, in older males, patellar tendon rupture predominated, with 43 % of the patellar tendon ruptures being in patients over the age of 40. Medical comorbidities were common with tendon ruptures, and appeared to have a greater associated risk of rupture in females than in males. Garner et al. stated that orthopaedic surgeons treating female patients with a tendinous extensor mechanism disruption should have a low threshold to initiate a medical work-up in search of a possible undiagnosed medical comorbidity [4].

6.3 Patellar Tendon Injuries

In this section, the diagnosis and treatment of tendinopathy and rupture of the patellar tendon will be reviewed.

6.3.1 Tendinopathy

Tendinopathy of the patellar tendon is a form of overuse injury. The injury occurs at the attachment of the patellar tendon in the patella. Whilst it is known as “jumper’s knee”, and is very common in those participating in jumping sports, it is common in other athletes [3, 5]. Imaging studies of asymptomatic athletes have noted a high prevalence of patellar tendon changes on ultrasound [6].

In common with other tendinopathies, patellar tendinopathy is due to chronic repetitive traction forces in the patellar tendon that result in a cycle of injury and repair disrupting the microstructure of the tendon [3]. Some authors have reported a relationship between patellar tendinopathy and a friction area in the lower pole of the patella and the central part of the upper zone of patellar tendon, mainly in the initial degrees of knee flexion [3, 5]. Other risk factors related to patellar tendinopathy are patellofemoral mal-alignment, patella alta and hypermobility of the patella. Finally, some non-anatomical or extrinsic factors must be taken into account, such as an inadequate physical training (closed chain exercises), the use of inappropriate shoes or inadequate conditions in the training place (hard surfaces) [3].

Blazina categorised patellar tendinopathy into four stages [7]. In Stage I, symptoms are only present after performing physical or sporting activities. In Stage II, there is pain during and after the aforementioned activities but patients are still able to perform to their normal level. In Stage III, there is pain at rest and activity which interferes with sport. Stage IV is the most severe degree of tendinopathy, indicating rupture of the tendon associated with frank functional disability [7].

Stages I and II respond well to nonoperative treatment with eccentric exercises and modification of activity. The rehabilitation programme should include isometric strengthening exercises of the quadriceps muscle and stretching exercises of the ischiotibial muscles. Initially, exercises must be isometric and isotonic and isokinetic exercises will follow. As important is patient education, with modification of activity to avoid jumping and squatting until there is substantial change in symptoms [7]. As adjuncts to rehabilitation, NSAIDs, cryotherapy, thermotherapy (ultrasounds) and massage can be helpful.

By the time patients reach Stage III, patients are less likely to respond to these conservative measures and need a prolonged period refraining from sporting activity for as long as 8 weeks; rehabilitation without rest in such patients has been demonstrated to be ineffective [8].

For patients with patellar tendinopathy which is resistant to conservative measures, a number of therapies have been proposed [9]. Injections of corticosteroid have been frequently used historically, but in common with other tendinopathies and enthesopathies, such injections appear to have only positive results only in the very short term, and multiple injections carry the risk of precipitating tendon rupture [10]. Other injectable therapies, including platelet-rich plasma (PRP) injection, aim to stimulate a normal healing response within the abnormal patellar tendon. Platelet-rich plasma (PRP) is safe and promising therapy in the treatment of recalcitrant patellar tendinopathy. However, a recent systematic review has shown that its superiority over other treatments such as physical therapy remains unproven [11]. Other injectable therapies include dry needling, sclerosing polidocanol and stem cells, but the evidence for these remain weak [9]. Extra-corporeal shockwave therapy (ESWT) has been used for a number of tendinopathies, and there is some evidence of its effectiveness in patellar tendinopathy [12]. A recent systematic review identified five studies, two of which were randomized controlled trials (RCTs), comparing ESWT to placebo, usual therapy or, in one study, surgery. The outcomes were mixed, with two studies demonstrating superior results compared to conservative treatment after a year, and the remainder showing little benefit of ESWT at any time point [12].

Surgical treatment may be indicated in motivated patients if carefully-followed conservative treatment is unsuccessful after more than 3–6 months. Open surgical treatment includes longitudinal splitting of the tendon, excision of abnormal tissue (tendonectomy), resection and drilling of the inferior pole of the patella, closure of the paratenon. Postoperative immobilisation and aggressive postoperative rehabilitation are also paramount. Arthroscopic techniques include shaving of the dorsal side of the proximal tendon, removal of the hypertrophic synovitis around the inferior patellar pole with a bipolar cautery system, and arthroscopic tendon debridement with excision of the distal pole of the patella [9]. Both open and arthroscopic methods of treatment have excellent outcomes overall. Using a variety of outcome measures, a systematic review of the literature reported success rates of 91 % in arthroscopic surgery and 87 % in open surgery for patellar tendinopathy [13]. However, surgery is a substantial undertaking and it may take between 8 and 12 months to return to sporting activity, if this is achievable at all.

Physical training, and particularly eccentric training, appears to be the treatment of choice for patellar tendinopathy, particularly in the acute setting. Injectable therapies and ESWT may have a role to play but this is still uncertain. The literature does not clarify which surgical technique is more effective in recalcitrant cases. Therefore, both open surgical techniques and arthroscopic techniques can be used.

6.3.2 Patellar Tendon Rupture

Patellar tendon rupture is the third most frequent cause of disruption of the extensor mechanism of the knee joint, after patellar fractures and ruptures of the quadriceps tendon. It has been reported that in a healthy person the rupture of patellar tendon requires a force 17.5 times greater than the body weight [14]. From the etiological point of view, trauma is the most common cause of patellar tendon rupture. It generally occurs in athletes of less than 40 years of age because they put their extensor mechanism under intensive forces that exceed its resistance and repair capability [14, 15]. There are other non-traumatic causes of patellar tendon rupture such as corticosteroid injections, rheumatic diseases, renal insufficiency, and infectious and metabolic diseases. Exceptionally, some bilateral ruptures have been reported in patients with systemic disease or previous surgical procedures on the knee [14].

Patients with patellar tendon rupture usually present with pain, swelling and impossibility to raise their leg with the knee in extension [14, 15]. It is not unusual that the rupture is not initially seen, mainly when it is related to trauma [14].

The main challenge in differential diagnosis is to distinguish a rupture of the patellar tendon from that of the quadriceps tendon. It can be made by observing the location of the tendon gap and the position of the patella. Diagnosis can be confirmed with a single lateral radiograph (in patellar tendon ruptures, the patella is located higher than the contralateral patella). Ultrasonography (US) and MRI can also help to confirm the diagnosis [14, 15].

Treatment usually will be surgical. Nonsurgical treatment will be considered only in elderly patients with debilitating or chronic diseases (Table 6.1). Surgical treatment consists of reconstruction of the ruptured tendon. The type of surgical procedure to perform will depend on the location of the rupture and the timing of the injury (Table 6.2).

Table 6.1 Conservative treatment of patellar tendon injuries

Therapeutic exercises (eccentric training)
Extracorporeal shock wave therapy (ESWT)
Different injection treatments (platelet-rich plasma, sclerosing polidocanol, steroids, aprotinin, autologous skin-derived tendon-like cells, and bone marrow mononuclear cells)

Table 6.2 Surgical treatment of patellar tendon injuries

Open surgical treatment
Longitudinal splitting of the tendon
Excision of abnormal tissue (tendonectomy)
Resection and drilling of the inferior pole of the patella
Closure of the paratenon
Arthroscopic techniques
Shaving of the dorsal side of the proximal tendon
Removal of the hypertrophic synovitis around the inferior patellar pole with a bipolar cautery system
Arthroscopic tendon debridement with excision of the distal pole of the patella

In acute tears of the substance of the tendon, direct repair should be reinforced with a cerclage wire passing through a patellar osseous tunnel, the distal part of the quadriceps tendon and an osseous tunnel at the level of the tibial tuberosity. When the rupture is located in the osteotendineous junction, the tendon must be re-attached to the bone by means of sutures going from the tendon to the bone via transosseous tunnels. An alternative to the aforementioned bone tunnels is the use of anchors. They provide a solid re-attachment and allow an earlier and more aggressive rehabilitation programme (similar to that employed for treatment of ruptures of the quadriceps tendon) [16]. In acute ruptures, El-Desouky et al. described a technique of primary repair of the patella tendon augmented by a semitendinosus autograft, which was strong enough to permit early motion and weight-bearing with achievement of good and excellent results [17].

After a primary suture the knee must be initially immobilised in extension. In our practice, the sutures are removed at 2 weeks and at that point an orthosis is provided allowing isometric exercises. Active flexion exercises are prohibited for 4 weeks after surgery. Until the sixth postoperative week, active flexion of the knee must be maintained in a range of 0°–90°. Then, a greater range of knee flexion will be allowed. The aim will be getting a full range of knee motion at 8–10 weeks after the procedure. Finally, the patient will perform isokinetic closed-chain exercises to strengthen the quadriceps muscle and then exercises of eccentric contraction to recover the preinjury level.

In chronic ruptures, a direct repair is usually insufficient [18]. A number of reconstructive procedures have been described using autograft, allograft or synthetic grafts for reinforcement of the primary repair. The Kelikian procedure uses semitendinous tendon, which is sectioned proximally to preserve its distal attachment. Two tunnels are made, one proximally at the level of the lower pole of the patella, and the other one distally at the level of the anterior tibial tuberosity. This way, a square can be formed with the semitendinous tendon that will finally be attached on its own in its distal attachment [15]. Jain et al. modified this procedure by performing a percutaneous reconstruction of the patellar tendon using semitendinosus tendon, reporting excellent results. Picrusting of quadriceps along with lateral release may be required to pull the patella down [19]. Maffulli et al. report results of an open hamstring reconstruction technique at over 5 years' mean follow-up [20]. They found that hamstring tendon reconstruction of chronic patellar tendon rupture provided good functional recovery and return to preinjury daily activities. Sundararajan et al. modified this technique by using both gracillis and semitendonosus tendons, detached from their tibial insertions and threaded through bone tunnels in a figure of eight, reporting excellent results [21].

Alternatives to hamstrings reconstruction include other autografts such as vastus lateralis, allograft, xenograft or artificial grafts. However, the evidence base for each are limited. A recent systematic review of the literature suggested that for chronic ruptures, autograft-augmented repair was the treatment of choice [18].

In contrast to acute ruptures, rehabilitation programme must be more conservative, maintaining the knee immobilised until 6 weeks, going then to the protocol previously outlined for acute ruptures.

6.4 Quadriceps Tendon Injuries

The quadriceps tendon is part of the extensor mechanism of the knee joint together with the quadriceps muscle, medial and lateral retinacular ligaments, patellotibial and patellofemoral ligaments and patellar tendon. All the aforementioned structures are exposed to great mechanical loads, both concentric and eccentric [15]. Quadriceps tendon rupture is uncommon in young people, being more frequent in elderly persons [15, 16, 22].

There are many risk factors associated with quadriceps tendon rupture, most importantly diabetes mellitus, renal dialysis, hyperthyroidism, gout, and in younger people, previous corticosteroids injections. There are also local factors, such as poor vascularisation associated with the normal ageing process [2, 15, 16, 22].

The structure of quadriceps tendon is trilaminar, formed by the expansions of the muscle bellies that form the quadriceps muscle. Quadriceps tendon injury may affect to the full thickness of the tendon or a part of it, starting in the most central area and extending peripherally. Histological analysis of the ruptured tendon usually shows chronic inflammation associated with fibrinoid necrosis and fatty degeneration [15].

The main clinical finding of a quadriceps tendon rupture is pain associated with a clear functional deficit. Nonetheless, its diagnosis is not always easy, because the integrity of retinacular ligaments may mask the quadriceps tendon injury. Clinical examination will depend on the degree of tendon rupture, sometimes with existing swelling or hemarthrosis making palpation of the tendon difficult. An extension lag of the knee suggests a quadriceps tendon rupture, particularly as the patient tries to extend the knee from the position of knee flexion [15, 16, 22]. Clinical suspicion can be confirmed with complementary studies, such as US and MRI (Fig. 6.1). Plain radiographs may show patella baja in comparison with the contralateral patella (Fig. 6.2). MRI can confirm the injury, mainly its size and depth, and also differentiate a full rupture from a partial one. Tendon rupture will be seen as a lack of continuity of its fibres and the presence of edema or fluid in the adjacent soft tissues [15]. Swamy et al. have suggested that US is not a reliable method in establishing the diagnosis of acute injuries to the extensor mechanism of the knee, particularly for quadriceps tendon ruptures in obese or very muscular patients. If there is clinical ambiguity, MRI scan is a better investigation tool before undertaking surgical treatment [23].

Treatment will depend on the extent of the rupture. Partial ruptures may be managed conservatively, immobilising the lower limb in extension for 4–6 weeks. At 3–4 weeks, the patient will start isometric exercises. Then, a progressive rehabilitation treatment will be started with the aim of recovering active extension and ultimately full range of movement [15].

Complete ruptures of quadriceps tendon require surgical repair. Such a repair must be solid and include all the thickness of the tendon. The particular surgical technique to use will depend on the exact location of the injury. Borders must be approximated by means of a nonabsorbable suture and reinforced using tran-

Fig. 6.1 Tendinopathy of quadriceps tendon (arrow) on MRI

Fig. 6.2 Radiographic view of a quadriceps tendon rupture (arrow)

sosseous tunnels or bone anchors [24]. Scuderi's technique, a v-shaped turn-down of the central quadriceps tendon, can be used to augment the repair [25].

Late diagnosis complicates the technique for repair as the tendon may be retracted. The tendon may be lengthened using a V-Y plasty or Codivilla's technique or by using autografts or allografts [15, 26]. Compared to the excellent results of acute ruptures, longer rehabilitation times and poorer long term results have been reported for chronic ruptures [24].

Outcomes of acute tears of the quadriceps tendon are good, but require a long period of immobilisation and full return to sport in athletes may not be possible. Complications of repair include infection (in around 1 %), loss of strength, re-rupture and heterotopic ossification (in around 6 %) [24]. Following a period of immobilisation, flexion should be commenced in a hinge orthosis. If bone anchors are used, more rapid rehabilitation can be attempted, immobilising for only 2 weeks before starting controlled active flexion exercises, so that the patient can achieve 90° of flexion at 6 weeks [15, 27–32]. Boublik et al. reported that, even with timely surgical repair, there is a low rate of return to play for high-level athletes with quadriceps ruptures [33]. Fourteen unilateral distal quadriceps tendon tears were treated with surgical repair, one of which was delayed after failure of nonoperative treatment. Only 50 % of players returned to play.

6.5 Other Tendinopathies About the Knee

Whilst the extensor mechanism is the main site of tendon injury about the knee, other tendinopathies have been more rarely described. Whilst rupture of the quadriceps is common, symptomatic quadriceps tendinopathy is rare. Imaging findings are similar to those seen in patellar tendinopathy, but lesions are often asymptomatic [34]. Popliteus tendinitis or tenosynovitis is becoming increasingly recognised as a cause of knee pain following total knee arthroplasty [35], but has also rarely been described in the native knee [36, 37]. Symptoms are similar to those of a lateral meniscus tear and may include anterolateral or posterolateral knee pain in the absence of trauma. Gastrocnemius tendinopathy is a common incidental finding on MRI scans of the knee, and occurs frequently alongside more major pathologies such as anterior cruciate ligament (ACL) rupture [38]. The medial head is more commonly affected than the lateral and in symptomatic cases, there is pain around the medial head; however, symptomatic tendinopathy is rare and few reports exist in the literature.

Conclusions

Tendinopathies and tendon ruptures are common in the knee, particularly affecting the extensor mechanism. Tendinopathy of the patellar tendon is common in jumping athletes and can be difficult to treat. In acute cases, physiotherapy and anti-inflammatories remain the mainstay of treatment. In chronic cases, various treatment modalities including injectable therapies, ESWT and surgery have been described. Surgery has excellent results overall but requires a long period of rehabilitation. The less invasive therapies such as PRP injection and ESWT have only moderate evidence at best supporting their use. Corticosteroids provide only short term relief and repeated injections should be avoided due to the risk of tendon rupture.

Patellar and quadriceps tendon ruptures are both common in weekend athletes, particularly in older people and those with comorbidities such as diabetes. Results of acute repair with or without augmentation are predictable but chronic cases have worse outcomes. For these cases, augmentation techniques are mandatory.

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The Meniscus

7

Luke D. Jones and Sean O'Leary

Abstract

Damage to the menisci of the knee represents the commonest indication for orthopaedic surgical intervention. Their complex role within the knee must be appreciated by all surgeons who aim to preserve tibiofemoral chondral surfaces. This narrative review considers the anatomy and microscopic structure of the menisci and relates this to function. Mechanisms of injury are considered, and strategies for managing patients in both the short and long term are presented in light of current evidence.

Keywords

Knee • Meniscal injuries • Diagnosis • Treatment

7.1 Anatomy of the Meniscus

7.1.1 Morphology

The menisci, historically known as the semilunar cartilages, were originally described by anatomists as vestigial structures of limited significance. Found in all mammals, in the human knee they are formed of fibrocartilage and are crescent-shaped in the axial plane and triangular in cross section. The menisci are attached at their ends (horns) to the intercondylar area of the tibia and peripherally they are attached to the fibrous capsule of the knee joint.

The medial meniscus is C-shaped and occupies approximately 60 % of the articular contact area of the medial compartment. The posterior horn of the medial meniscus is significantly wider than the anterior horn. The medial meniscus is wider in the anterior posterior plane than the medio lateral plane. The anterior horn can have a variable site of attachment but the commonest is into intercondylar region of the tibial plateau anterior to the anterior cruciate ligament (ACL). The posterior horn attaches to the tibia just anterior to the attachment of the posterior cruciate ligament (PCL). Peripherally, the coronary ligament attaches the meniscus to the upper tibia.

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The lateral meniscus, in contrast, is smaller, almost circular and much more mobile. It covers a greater proportion of the articular surface, approximately 80 %, and in a common variation known as discoid meniscus can cover the articular surface in its entirety. The anterior horn of the lateral meniscus is attached to the intercondylar fossa next to the broad foot print of the ACL and posteriorly, the posterior menisco femoral ligament (of Wrisberg) and the anterior menisco femoral ligament (of Humphrey) attach the posterior horn to the PCL and the medial femoral condyle [1].

7.1.2 Blood Supply

The menisci are relatively avascular structures that obtain their blood supply from the periphery via the medial and lateral inferior and middle geniculate arteries that are themselves branches of the popliteal artery. Radial branches from a perimeniscal plexus enter the meniscus with the anterior and posterior horns having the greatest blood supply. Endoligamentous vessels proceed into the body of the meniscus from the horns forming terminal loops that provide potential for vascularisation [2]. The remainder of the meniscus receives nourishment via synovial diffusion or mechanical motion. As a result of this, the lateral meniscus is vascularized in the peripheral 10–25 % and the medial meniscus in the peripheral 10–30 % only. This has led to the concept of vascularization zones within the menisci that are used to guide treatment algorithms. The peripheral 10–20 % of the meniscus is described as the red–red zone and is fully vascularized [3]. The border of the vascular area is described as the red–white zone and the white–white zone is found within the avascular area of the meniscus.

7.1.3 Microscopic Structure

The menisci are composed of cells (fibroblast-like and chondroblast-like cells) and extra cellular matrix (ECM). The dense ECM is composed of water (approximately 75 %), type I collagen (20 %) and 5 % of other substances including proteoglycans, glycosaminoglycan, elastin and type II collagen with the precise makeup of the ECM varying with age, injury and presence of pathological conditions. Collagen is the main fibrillary component of the meniscus. Different collagen types exist in various quantities in each region of meniscus. In the red–red zone, Type I collagen is predominant (80 % composition in dry weight), but other collagen variants (e.g., type II, III, IV, VI, and XVIII) are present at less than 1 %. In the white–white zone, collagen makes up to 70 % dry weight, of which 60 % is type II collagen and 40 % is type I collagen [4]. Collagen fibres appear to be organized peripherally in a highly aligned circumferential direction, with a woven, less organized and aligned structure in the inner meniscus. This arrangement acts to convert compressive forces into radially directed forces that are distributed throughout the meniscus and subsequently resisted as hoop stresses.

7.2 Meniscal Function

Meniscal function is closely related to its anatomical and microscopic structure. The lateral meniscus is considerably more mobile than the medial meniscus with twice the extrusion of the medial side during range of movement and rotation [5]. The key biomechanical functions of the meniscus include load transmission, shock absorption, stability, nutrition, joint lubrication and proprioception. In addition, they act to decrease contact stresses and increase congruency of the knee particularly in the lateral compartment where the relatively convex tibial plateau and narrow femoral condyle predispose to high contact stresses. The surgeon, when considering their role in preserving or reconstructing the menisci, does so with the distribution of contact stresses and prevention of osteoarthritis (OA) foremost in their mind.

The role of the meniscus in the pathogenesis of osteoarthritis of the knee has been understood for some time. Loss of meniscal function, whether due to trauma, degeneration or iatrogenic causes, increases peak stresses and contact pressures at the articular surface by up to nine times their physiological normal [6]. Similar biomechanical studies have demonstrated that the greater the loss of meniscal volume, the greater the increase in articular contact pressures [7]. In human studies, total meniscectomy [8] has been demonstrated to lead to increased rates of cartilage volume loss compared to controls (6.9 % greater loss per year). Meniscal tears and damage in those with existing OA of the knee has been demonstrated to lead to increased cartilage loss over 2 years compared to those without [9, 10]. Other retrospective studies of knees with previously normal cartilage surfaces followed for the development of OA over time [11, 12] have established correlation between a history of meniscal injury and the development of OA. What is not clear from these studies, which tend to be small and retrospective, is whether the underlying injury that leads to the meniscal damage played a role in the development of the OA, or whether it is the loss of meniscal function itself that leads to the disease. A key step in this debate was the demonstration that defunctioning the medial meniscus leads to the development of medial compartment OA in animal models [13]. In this study on ten mice, lesions reliably developed on the central weight-bearing portions of the medial tibial plateau and the medial femoral condyle at 4 weeks post-surgery. Subsequent prospective studies in larger groups of patients with no history of OA who undergo medial meniscectomy have confirmed these findings in humans [14, 15]. The development of cartilage degeneration and osteoarthritis following trauma or resective surgery to both the medial and lateral meniscus is a well-established phenomenon.

7.3 Meniscal Injury

Meniscal injury can be classified as acute or degenerative.

Degenerative meniscal tears occur in older patients in the presence of osteoarthritis. These tears tend to be complex in nature, and irreparable. The incidence of degenerative meniscal tears detected on magnetic resonance imaging (MRI) in patients with asymptomatic knees is as high as 33 % [16]. The presence of underlying osteoarthritis can commonly lead to symptoms such as swelling, pain and catching sensations that can be misinterpreted as arising from the degenerative meniscal injury. Management of these patients requires careful thought and consideration of the underlying states of the chondral surfaces as arthroscopic debridement of the degenerative meniscus has been shown to be no better than sham procedures in blinded randomized trials [17, 18].

Acute meniscal injury is a very common occurrence with over a million surgical procedures performed in the USA per year for this problem [19], and an estimated 35 surgeries to the meniscus per 100,000 people in the United Kingdom NHS [20]. As these numbers refer to only those who required surgery for the injury, the true number of injuries is likely to be greater. Overall, males are four times more likely to sustain a meniscal injury than women, with a peak incidence occurring between 21 and 30 years of age in men and 11 and 20 years of age in women [21]. Medial meniscal injuries are more common than lateral tears with lateral tears seen more frequently in association with ACL tear.

The mechanism of meniscal injury tends to be due to a combination of axial loading and rotational forces that lead to a shear load on the meniscus. These shear forces exceed the elastic limit of the collagen fibres resulting in lesions with the meniscus that can propagate to the surface of the meniscus, manifesting as a tear.

Symptomatically, the patient will typically experience an immediate onset of pain and may describe a tearing or grinding sensation within the knee at the time of injury. Swelling secondary to a haemarthrosis typically occurs after 1–2 h in contrast to the immediate massive swelling of an ACL injury. Many patients will describe being able to complete the game or activity they were undertaking with loss of function occurring typically 1–2 days later. Following the acute injury, patients will complain of mild to moderate swelling, pain over the medial or lateral compartment of the knee as appropriate, and mechanical symptoms such as catching, locking and giving way. On examination, wasting of the vastus medialis is often present, sometimes as soon as 5 days post injury. The typical quartet of effusion, joint line tenderness, pain on full flexion and pain on full extension are found.

As with many aspects of knee surgery, classification of acute meniscal injuries is useful as it guides not only treatment but prognosis. The International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports medicine have produced a validated classification system for meniscal injuries [22] that evaluates tears based on the following criteria:

1. Tear depth: partial or complete.
2. Rim width: Zone 1 tears are tears with a rim of less than 3 mm, Zone 2 tears have a rim width of 3≤5 mm, Zone 3 tears have a rim width of greater than 5 mm.
3. Radial location: posterior, mid body or anterior in location.
4. Lateral meniscal tears that extend partially or completely in front of the popliteal hiatus should be graded as central to the popliteal hiatus.
5. Tear pattern: longitudinal-vertical (the extension of which is the bucket handle tear), horizontal, radial, vertical flap, horizontal flap or complex.
6. Quality of the tissue: degenerative characteristics include cavitation, multiple tear patterns, softened meniscal tissue, fibrillation or other degenerative changes
7. Length of tear: should be measured from the arthroscopic ruler in millimetres. The length of a radial tear is the distance the tear extends into the meniscus.
8. Amount of meniscal tissue that has been excised.
9. Percentage of meniscus excised.

Despite the validated nature of this classification system, its cumbersome nature means its primary use is in clinical studies of meniscal surgery to stratify injuries. Most surgeons, including the senior author of this chapter, follow the classification system devised by Cooper that provides consistent clinical documentation of tear patterns and locations. In this system [23] the menisci are divided into three radial zones (posterior, middle and anterior) and then four circumferential zones running from peripheral to central (0 – mensicosynovial junction, 1 – outer third of meniscus, 2 – middle third of meniscus, 3 – central third of meniscus). In addition, the senior author then further classifies tears according to their morphology.

Vertical longitudinal tears occur between the circumferential collagen fibres in the long axis of the meniscus. They are most commonly traumatic and occur commonly isolated in the medial compartment and in association with ACL tears in the lateral compartment. As the integrity of the collagen fibres is often not disrupted the meniscus can maintain its function. In addition, due to their amenability to suture fixation they are the most commonly repaired subtype of tear.

Radial tears are transverse tears which most commonly occur at the junction of the middle and posterior third. Radial tears disrupt collagen fibres impairing ability to resist hoop stresses. In addition they are usually not repairable.

Horizontal (cleavage) tears are parallel to the tibial plateau and thus divide the meniscus into superior and inferior flaps. The mechanism of injury is secondary to shear forces between the upper and lower meniscal surfaces leading to an intra substance disruption that then extends to the free edge of the meniscus. Excision of the unstable portions of these tears is usually recommended as they are not amenable to repair.

Complex (degenerative) tears usually have two or more tear configurations and are therefore not easily classifiable. They are the commonest type of tear and, if symptomatic, should be treated with a gentle resection as they are not suitable for repair.

Bucket handle tears [24] are longitudinal tears that extend from the posterior to anterior horn with displacement of the free edge of the tear into the joint toward the intercondylar notch. They are named for their appearance with the free edge representing a handle and the remaining circumferential edge representing the bucket. The inner flap can be intact or disrupted and in the intact situation is amenable to repair.

Meniscal root tears (MRTs) are unique injuries with severe biomechanical consequences in terms of load bearing and subsequent progression of arthritis. Some have suggested that MRT is similar in effect to total meniscectomy in terms of biomechanical disruption of the joint [25]. Often missed at arthroscopy, the anterior and posterior roots of both menisci must be inspected for bony avulsion, radial tears and degeneration of the roots. Patients who have acute traumatic MRTs with extrusion and minimal compartment chondral disease are amenable to repair, theoretically restoring the critical biomechanics of the meniscus.

7.4 Imaging of the Injured Knee

A minimum of two orthogonal plain weight-bearing radiographs of the affected knee are essential to exclude the presence of a fracture in a painful swollen knee. In addition, the underlying joint must be inspected for the presence of degeneration. The presence of any irritability on hip examination necessitates an AP pelvis radiograph particularly in the presence of a minimally swollen knee. Long leg alignment films are useful in the varus or valgus knee as repairing a meniscus in the presence of an unfavourable biomechanical environment may predispose to failure. The development of MRI scanning, in particular the advent of 3 T scanning, has transformed the diagnosis of meniscal injuries. MRI is important for characterizing the tear pattern and tissue quality. It has a sensitivity and specificity of 89 % and 88 % respectively for medial meniscal tears and 75 % and 98 % for lateral meniscal tears [26]. In addition, other intraarticular lesions may be identified. In the presence of clear history and examination findings, the senior author may decline MRI scan of the knee in order to expedite surgical treatment.

7.5 Treatment Options

A common treatment algorithm of compression, anti-inflammatory medications, extensive icing of the affected joint and early quadriceps and hamstring activation exercises are employed by the senior author irrespective of and prior to the subsequent management of injury.

7.5.1 Physiotherapy

Physiotherapy as an isolated treatment strategy in the setting of degenerative meniscal tears has a clear role as no randominsed controlled trial (RCT) has been able to demonstrate the superiority of partial meniscectomy over physiotherapy [27]. Fewer high quality studies are available in the setting of acute tears; however a small RCT has demonstrated a greater improvement in symptoms following arthroscopic partial meniscectomy than physical therapy. It is important to note that 75 % of patients with an acute meniscal injury who underwent physiotherapy still experienced an improvement in their knee pain [28].

7.5.2 Open Meniscectomy

As far back as 1948 [29], Mc Murray advocated total open meniscectomy and criticized those who performed "incomplete removal of the injured meniscus". This historical procedure has been abandoned due to an increase in understanding of the biomechanics of the meniscus, and a 40-year follow-up study has demonstrated a 132 fold increase in rate of arthroplasty in total meniscectomized patients compared to matched controls [30].

7.5.3 Arthroscopic Partial Meniscectomy (APM)

As discussed previously, role for arthroscopic meniscectomy in degenerative tears with or without the presence of OA is limited [17, 18] and in the future it is unlikely that healthcare payers will reimburse surgeons who perform this procedure. In patients with acute tears, APM is attractive to surgeons as it preserves as much meniscus as possible whilst creating a stable meniscal remnant. Most surgeons recognize the good short term results of APM with rapid symptom resolution and early return to function. Unfortunately, the quality of long term follow up studies is poor in terms of understanding radiographic progression to OA [27, 31]. However, it does appear that patient who undergo APM progress to OA over time in terms of radiographic rather than symptomatic OA and there is convincing evidence that preserving as much meniscus as possible is beneficial with worse clinical outcomes when more meniscus is removed [11]. Whilst the discussion regarding the role of the initial injury in the development of OA continues, the development of degeneration in these knees is likely to be multifactorial rather than attributable to single surgical episodes.

7.5.4 Meniscal Repair

Meniscal repair has been enthusiastically adopted by the orthopaedic community as a logical progression of the understanding of the role of the meniscus in distributing forces across the joint. There has been a 34 % increase in the incidence of meniscal repair over the last 8 years [32]. This is likely to increase further as specialist knee surgeons begin to take ownership of this group of patients who have, in the past, been managed by general orthopaedic surgeons.

Whilst the evidence for its efficacy in preventing OA is yet to be demonstrated in large scale trials, many cohort studies have suggested that it does delay or prevent the onset of degenerative change within the joint. Whilst it is broadly accepted that meniscal repair is the treatment of choice for the young athlete with a history of acute injury, indications for meniscal repair have been described in detail [33].

Patient-related indications include positive symptoms of meniscal injury, physical findings on clinical examination and positive provocative signs such as pain on deep squat. Contraindications include poor tissue vascularity and degeneration, advanced patient age, poor patient compliance with rehabilitation, and the presence of either knee instability or osteoarthritis.

Tear-specific indications include reducibility of the tear, favourable tear characteristics (e.g., single vertical tear in one plane in the red–red region, or a red–white tear in the middle third region). Tear characteristics considered unsuitable for repair by the authors include chronicity of the tear, tears less than 10 mm long, radial tears limited to the inner 2/3 (avascular) region of the meniscus and degenerative tears. The key factors appear to be firstly the vascularity of the tear site, so whilst peripheral, red–red zone tears have high propensity for repair, white–white tears do not, and should not be repaired [34]. Secondly, the stability of knee is integral to the survival of the repair, with approximately an 80 % long term success rate of repairs in stable, ACL intact knees and only 40 % in ACL deficient unstable knees.

When performing arthroscopic repair of the meniscus three main techniques exist: outside-in, inside-out and all-inside. In all cases, loose and damaged fragments of meniscus are gently removed. Fibrous tissue is removed from the opposing edges of the repair typically using either a rasp or shaver. Biological augmentation of the repair attempts to overcome the inherent limitations to healing conferred by poor vascularity and heterogeneous cellularity by aiming to promote chemotaxis, cellular proliferation and matrix production at the repair site. These techniques include fibrin clot, platelet rich plasma, limited notchplasty and the surgical creation of vascular access channels. The evidence for these interventions remains limited and they are not required when concomitant ACL reconstruction is performed.

All repair techniques require the surgeon to understand the site of neurovascular structures with posterior horn repairs placing the popliteal artery at risk, the common peroneal nerve being at risk with lateral repairs and saphenous nerve at risk with medial repairs. All repairs, other than the all-inside, require an open approach to part of the joint, even if only mini open.

Inside-out repair: this technique requires a suture with long flexible needles on each end to be passed through the meniscus via curved cannulae, and then out through the capsule utilizing a mini open approach. The sutures are then tensioned outside the knee joint and tied down onto the capsule under direct vision to avoid trapping of the neurovascular structures. Typically, tears in the posterior aspect or body of meniscus are suitable for this technique. Whilst cheap, its use has diminished following the introduction of easier to use, no incision all-inside repairs.

Outside-in repair: Typically used for anterior horn tears where arthroscopic access is particularly difficult, this technique uses an open approach to the joint, but leaves the capsule unviolated. Sutures are passed via a spinal needle into the knee through the open incision over the tear site. The sutures are then drawn out of the knee via a portal, sliding interference knots are tied, and then the knot is pushed back into the knee to snug down onto the torn meniscal fragment of the meniscus. The free ends of the suture on the outside of the knee are then tied over the capsule.

All-inside repair: the use of all inside repairs using popular commercial devices such as Fast-Fix 360 has dramatically increased over the last few years. They avoid the requirement of further incisions and therefore reduce the risk of neurovascular damage. These devices work by passing anchors loaded on an introducing needle through the tear and capsule. The anchors are connected by a pre tied, sliding 2–0 ethilon suture that is then snugged down to bring the edges of the tear together. A suture cutter is then slid over the free end of the suture and the suture is clipped flush to the knot.

Despite multiple trials comparing these techniques, heterogeneity of tear types and the presence or otherwise of additional injuries to the knee means that good quality evidence to determine the most successful technique is limited.

Different surgeons have varying rehabilitation protocols that they may personalize to the patient depending on tear type, location and reliability of patient. Typically, the senior author will not brace the knee, but will make the patient touch weight bearing only for the first 2 weeks with increase to full weight bearing at 6 weeks. Quads activation is started early with range of movement from 0 to 90° from day one. Irrespective of the protocol used, an experienced sports physiotherapist must be used to monitor and guide rehabilitation to minimize the risk of retear.

7.5.5 Meniscal Allograft Transplantation

The role of meniscal transplant has increased since first described in 1989 by Milachowski et al. [35]. The primary indication is to treat the symptomatic compartment of the knee in a patient with a history of sub or total meniscectomy. The knee must be ligamentously stable or a concurrent ligament reconstruction must be performed, the mechanical alignment must be neutral and chondral surfaces must be a maximum of grade 2 articular changes. A cadaveric meniscus matched by size and site are implanted using a variety of methods, including free soft tissue implantation, separate anterior and posterior bone plugs and bone bridges. Commonly, the periphery of the meniscal allograft is sutured to the remaining peripheral rim or the joint capsule. Whilst this surgery remains highly specialized, it is becoming increasingly common. However, patients must be counselled that this is salvage, not restorative surgery and it unlikely that a return to pivoting sports can be anticipated. Medium term results do suggest that a beneficial improvement in symptoms will be seen in 70 % at up to 10 years [36]. Whilst it is clearly plausible that meniscal transplantation may offer a role in protection of chondral surfaces, this has not been established clinically yet [4].

Conclusions

When managing a meniscal injury, the surgeon must be careful to consider the patient in their entirety. An increased understanding of the function of the menisci has transformed our approach to these common lesions. A good understanding of the vascularity of the meniscus is key to guiding treatment. Logically, reconstruction and preservation of meniscal tissue would appear to be important in promoting long term joint survival. Whilst high quality trials are yet to demonstrate this, it is likely that the meniscus will continue to play a key role in our understanding of the complex function of the knee joint.

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The Anterior Cruciate Ligament

8

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Abstract

The anterior cruciate ligament (ACL) is the most common surgically treated ligament rupture in the adult knee. Disruption of the ACL has important consequences for knee kinematics, activities of daily living, return to sport and progression to symptomatic knee osteoarthritis in later life. While reconstructive procedures have good evidence for improving symptoms following ACL rupture, there is no strong evidence that reconstruction prevents osteoarthritis and selection of patients for reconstruction should be made on the basis of their clinical picture. Several controversies persist regarding surgical technique, including the use of single- or double-bundle techniques, the method of fixation and the selection of appropriate graft material. In this chapter, we discuss the natural history of ACL rupture, the evidence base for surgical interventions and the long-term outcomes of ACL reconstruction.

Keywords

Anterior Cruciate Ligament • Rupture • Reconstruction • Techniques Outcome

8.1 Introduction

The anterior cruciate ligament (ACL) is a key driver of the normal kinematics of the knee. Rupture of the ACL is common, affecting over 80,000 patients each year in the USA, and ACL injury is the most common surgically treated rupture of knee ligaments [1]. However, there remains debate over when reconstruction of the ACL is indicated and which techniques to use when it is [2]. In this chapter, we aim to describe

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the anatomy, physiology and natural history of ACL rupture, before going on to discuss the evidence available to guide the surgical management of this common injury.

8.2 Anatomy and Physiology of the Anterior Cruciate Ligament

The ACL consists of multiple fascicular units, measuring between 0.5 and 3 mm in diameter, and enveloped in synovium [3]. It is generally accepted that these fibers form two main bundles: the anteromedial (AM) bundle, which is roughly isometric throughout the range of knee flexion, and the larger posterolateral (PL) bundle, which is taught in extension but slackens in flexion [4, 5]. The ACL is present from around 9 weeks of gestational age and even in mid-term fetuses two distinct bundles are distinguishable [6]. Other authors have proposed alternative hypotheses for the organization of the fibers within the ACL (Amis and Dawkins proposed a third, intermediate bundle, while other authors have suggested that, rather than being divided into bundles, the ACL forms a 'ribbon' of parallel fibers [3, 7]), however, the two-bundle model is very widely used for the purposes of discussing the physiology of the ACL and its reconstruction, and as a result, will be used within this chapter [8].

The ACL originates from a roughly oval 'footprint' on the lateral wall of the intercondylar notch of the femur, which measures between 13 and 18 mm in the vertical plane and between 7 and 9.5 mm in the anteroposterior plane [4, 9]. As surgeons have aimed to perform anatomically consistent reconstructions of the ACL, the precise position of the ACL footprint has been extensively studied [10]. In 2012, Piefer et al. performed a systematic review of studies published since 2000 pertaining to the position and morphology of the femoral footprint [9]. They placed the center-point of the femoral footprint at 43 % along a vertical line 2.5 mm proximal to the posterior surface of the femoral condyle (Fig. 8.1). When divided into AM and PL bundles, the PL bundle is half way along this line, while the AM bundle is 29.5 % along it, with the AM bundle lying slightly anterior to the PL bundle.

On the tibia, the footprint is situated approximately 10 mm posterior to the anterior border of the tibia and is roughly triangular, with the apex posterior, extending anteroposteriorly for between 15 and 19 mm [8]. The mediolateral extent of the tibial footprint is limited by the medial and lateral tibial spines. At the tibia, the anteromedial bundle lies adjacent to the anterior horn of the lateral meniscus, directly anterior to the posterolateral bundle [8]. Fibers of the ACL insertion fan out under the intermeniscal ligament and some may blend with the posterior horn of the lateral meniscus [11].

The ACL ranges in length from 22 to 41 mm, depending on the patient, and have an irregular shape in cross-section, which changes by position. Overall, the ACL becomes broader from proximal to distal, although the narrowest point is slightly distal to the femoral insertion [11]. As it approaches the tibial insertion, the ligament becomes broader; the cross sectional area of the

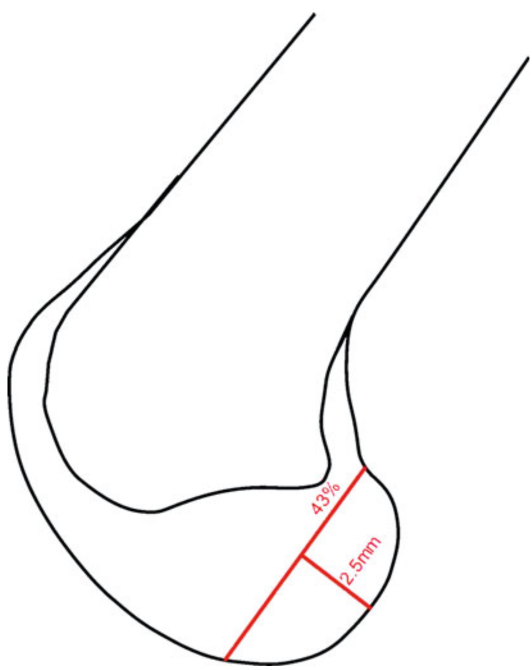

Fig. 8.1 Mean center point of the femoral insertion of the anterior cruciate ligament (After Piefer et al. [9])

ligament is one third greater at the tibial insertion than at the femur [12]. While the bundles are parallel to one another in extension, in flexion the AM bundle spirals around the PL bundle.

The primary roles of the ACL are to resist tibiofemoral rotation and anteroposterior translation. The two bundles contribute differently to these two roles depending on the degree of knee flexion. At full extension, the AM bundle is vertical within the notch and has therefore not been considered to provide a great deal of rotational constraint; by contrast, the PL bundle is more transverse and so would be likely to provide more rotational stability [13]. In fact, the evidence for either bundle providing a clinically meaningful degree of rotational stability is limited: while cadaveric studies have demonstrated statistically significant increases in rotational laxity when one or other of the bundles are cut, neither appears to produce a clinically detectable effect (and even cutting the entire ACL produces only 4° of additional internal rotation) [5]. More recent work has highlighted the role of the anterolateral ligament (ALL), together with extra-articular structures such as the iliotibial band, in conferring rotational stability [14]. In terms of anteroposterior stability, both the AM and PL bundles are important, but the AM has a more important role in the flexed knee and the PL is more important in extension [5].

The ACL is innervated from a branch of the posterior tibial nerve. Nerve fibers within the ACL are associated with mechanoreceptors which are important in giving the ACL its proprioceptive function. It takes its vascular supply from the medial geniculate artery, with the blood supply predominantly entering the ligament proximally in the intercondylar notch; as a result, the proximal part of the ACL has a more comprehensive vascular supply than the distal part [11].

8.3 Mechanisms and Risk Factors for ACL Injury

Around 70 % of cases of ACL rupture result from non-contact injuries, and the predominant mechanism of injury appears to be a valgus and rotational force exerted on a part-flexed knee [15]. As a result, sports which exert these pivoting forces across the knee are those which carry the highest risk of ACL injury: a recent meta-analysis of ACL injuries amongst American high school athletes demonstrated that the sports with the highest risks of ACL injury were basketball (other studies have found a similarly high risk in netball [16]), association football, American football and lacrosse [17]. Similarly, the new UK National Ligament Registry reports that 42 % of cases resulted from association football, 13 % from Rugby football and 8 % from skiing [18]. While ACL injuries are commoner in men (due to their higher level of participation in sport) [1], women have a higher rate of injury per sporting episode [17]. The reasons for this are poorly understood but are likely to be due to differences in limb alignment and a lower rate of muscle development in women during puberty [19]. Other non-sex-specific risk-factors include environmental factors (injury is more common in dry conditions or on artificial turf), anatomical factors (a narrow intercondylar notch and a greater tibial slope predispose to injury, as do generalized or knee-specific joint laxity) and neuromuscular/biomechanical factors such as a reduced range of motion of the hips [20]. Understanding of these risk-factors has led to increased research into the use of neuromuscular training to prevent ACL injury. Amongst such studies, the largest is a randomized study of 4,564 footballers in Sweden, where a neuromuscular warm-up program led to a statistically significant decrease the relative risk of cruciate ligament injury by 64 % compared to controls, although the absolute difference in rate of injury was non-significant [21].

8.4 Clinical and Radiological Examination in ACL Injury

The process of clinical and radiological examination of the knee is covered in detail in Chaps. 1 and 2 and it is beyond the scope of this chapter to provide more than a broad overview of these topics.

8.4.1 History and Clinical Examination

The diagnosis of ACL injury is often made on the basis of the mechanism of injury. As described in Sect. 8.3, ACL injury is commonly the result of non-contact twisting injuries during sport. Patients will often describe an immediate large haemarthrosis and will normally not be able to continue playing. Sometimes, an audible ‘pop’ is reported [22]. The acute injury is painful, probably as a result of the haemarthrosis and associated bone bruising, but this pain will subside over the early post-injury period.

Examination in the acute setting is hampered by the haemarthrosis, which may mask knee instability [22]. Three main clinical tests have been described for the assessment of ACL injury: the Lachmann test, the Pivot Shift test and the Anterior Drawer. The method of performing these tests are covered in Chap. 1; of the three, the Lachmann test has the highest intra-rater and inter-rater reliability, with the inter-rater reliability being highest when it is performed in the prone position [23]. The Lachmann test is also the test with the highest sensitivity for detecting complete ACL rupture when measured against magnetic resonance imaging (MRI) (with a sensitivity of 96 % in awake examination), but pivot-shift is also highly accurate (95 %). The accuracy of both is much lower in detecting partial tears, and both are made more sensitive by examining the patient under anaesthetic [24].

8.4.2 Imaging Examination

In most cases of acute rupture of the ACL, the diagnosis will be made on the basis of clinical findings [25]. In practice, however, most patients will undergo a plain radiograph and an MRI before surgery, to confirm the diagnosis and to exclude other coexisting pathologies within the knee joint.

Radiographs will often demonstrate a haemarthrosis, may show other pathology such as associated osteochondral defects and may demonstrate a Segond fracture (an avulsion fracture from the lateral border of the tibia, which may represent an avulsion of anterolateral capsule or the anterolateral ligament [26]) in up to 13 % of cases [27].

Characteristic MRI findings following ACL injury include discontinuity of the fibers of the ligament, with increased signal on T2 weighted images. Secondary signs include bucking of the PCL (Fig. 8.2), uncovering of the posterior horn of the lateral meniscus and anterior displacement of the tibia (which may also be seen in plain radiographs) [27]. Acute imaging will often demonstrate a characteristic pattern of bone bruising. Most commonly, this represents the ‘pivot shift’ mechanism of injury with bruising seen in the lateral femoral condyle and the posterolateral tibial plateau, although other patterns of bone bruising have been described [28]. Finally, other injuries to ligament, cartilage or meniscus, may be present. A recent meta-analysis of diagnostic accuracy studies of MRI in traumatic knee pathology has reported a pooled sensitivity and specificity for MRI in diagnosing ACL injury at 87 % and 93 % respectively [29], although some studies suggest both figures are as high as 100 % [30]. More details of imaging protocols and findings are given in Chap. 2.

Fig. 8.2 Sagittal MRI image demonstrating absence of the ACL in a chronic tear with bucking of the PCL

8.5 Consequences and Natural History of ACL Injury

8.5.1 Clinical Outcomes

As covered in Sect. 8.1, the ACL is an important driver of knee function and rupture of the ACL leads to a change in the kinematics of the knee during activities of daily living [31]. However, changes in kinematics can be tolerated; the outcomes of interest after ACL rupture are pain and loss of function as measured by patient-reported outcome measures [32], failure to return to sport, further injury and progression to osteoarthritis.

Studies examining the outcomes of conservatively treated ACL rupture are hampered by the selection bias resulting from the removal from study of those treated surgically (which may logically be the more symptomatic or those in higher-demand individuals). To our knowledge, there is only one randomized, controlled trial comparing non-operative to operative management for ACL rupture [33], and the evidence base for this section includes this trial and a small number of series of conservatively treated patients [34].

Frobell et al. randomized 121 patients to receive either early reconstruction or initial conservative management with the option of later reconstruction if symptomatic, publishing 5-year results in 2013 [33]. Half of those in the delayed group opted to undergo later reconstruction; results were presented both on an intention to treat basis and as treated. While knee stability to examination (Lachman and pivot shift tests) was significantly superior in those who underwent reconstruction, patient-reported outcome knee injury and osteoarthritis outcome score (KOOS) was similar. The incidence of radiographic osteoarthritis (OA) was similar in both groups on both analyses and the rate of subsequent meniscus surgery again did not vary between groups. Taking the cohort of 29 patients who were treated with rehabilitation alone, at 5 years, while only one had a normal Lachman test, the overall KOOS score was good at 82/100 and 3/26 (12 %) had radiographic evidence of OA. In a separate study of the same patients, 3 years postinjury, found that muscle strength and performance was similar in patients who had undergone reconstruction compared to those who were treated non-operatively [35].

Kostogiannis et al. in 2007 published the 15-year results of 100 patients with ACL rupture treated non-operatively [36]. Patients were actively persuaded not to undergo reconstruction primarily and all underwent arthroscopic examination at 10 days to confirm the diagnosis and treat concomitant injuries (which were present in 85 %). Reconstruction was only performed in patients who had unacceptable knee function; patients were excluded from the study if they sustained a contralateral tear (six patients) or were lost to follow-up (six patients). Of the remaining 88 patients, 21 underwent delayed reconstruction, leaving 67 available for analysis at 15 years. Unreconstructed patients displayed a significant decrease in Tegner activity scale but in many cases returned to competitive sports and attained good Lysholm, International Knee Documentation Committee (IKDC) and Knee Osteoarthritis Outcome Scores (KOOS) at least in early follow-up (1–3 years). In spite of this, 49/67 patients had good or excellent Lysholm scores at 15 years. No information is given about radiographic progression of arthritis.

A reduction in activity level following ACL rupture in conservatively-treated patients was observed in the systematic review of Muaidi et al. Fifteen studies met their inclusion criteria of which five were included in a meta-analysis of outcomes with respect to activity level [37]. They report an approximate reduction in level of activity of 21 % following ACL injury. However, good patient reported outcomes were achieved in the short term after injury in conservatively managed patients. Again, it should be re-iterated that in most studies there is inherent selection bias due to removal of patients (who may be the most symptomatic) who elect to undergo reconstruction.

8.5.2 Progression to Osteoarthritis

Long term studies of radiographs following ACL rupture have demonstrated OA in between 24 % and 86 % of cases [34]. Lohmander et al.

interviewed 84 female footballers a mean of 12 years following rupture of the ACL, 62 % of whom had undergone reconstruction [38]. Half had never returned to competitive football following their injury, and only 8 % participated at the time of interview. KOOS scores were significantly worse in ACL-injured subjects compared with a reference group of un-injured footballers. Radiographic analysis (performed in 67 subjects) demonstrated half (34 knees) to have tibiofemoral or patellofemoral OA in the affected knee compared to only 8 % with radiographic evidence of OA in the contralateral knee. Neither symptoms nor radiographic changes were affected by whether or not reconstruction was performed.

However, the systematic review of Øiestad et al. has suggested that we may have overestimated the incidence of OA following ACL rupture [39]. Their study included 31 studies, each having a minimum of 10 years' follow-up with radiographic analysis. For isolated injury to the ACL, between 0 % and 13 % of patients had radiographic evidence of OA, rising to between 21 % and 48 % of patients with associated meniscal injuries. Reasons for the overestimate of OA in previous studies may include the inclusion of patients with associated injuries or selection bias related to symptomatic patients returning to follow-up appointments [34].

The presence of associated meniscal injuries appears to be important in determining whether patients develop later OA. Hart et al. performed single-photon emission computed tomography (SPECT) scans on a cohort of 31 patients, 10 years following ACL reconstruction [40]. Only one of the 16 patients with an isolated ACL rupture showed any evidence of knee degeneration on SPECT, while five of the 15 who had undergone meniscectomy did, a significant difference. The systematic review of van Meer et al., while describing the overall quality of the evidence as being poor, found reasonable evidence of the importance of medial but not lateral meniscal injuries in predicting the development of OA. They found no evidence that increasing time to surgical reconstruction increased the risk of OA in the longer term [41].

Overall, the literature supports conservative management as a viable treatment option in the ACL injured individual. In practice, the decision to offer surgical treatment will depend on the patient, their symptoms and their aspirations. Some patients will be able to return to full sports in spite of their injury while some will be happy to adapt to a lower level of function [42]. Several authors have attempted to quantify these factors; in Kostogiannis' study, those with a positive pivot at three months were more likely to go on to reconstruction [36], while Fithian et al. defined patients as being at low, moderate or high risk of a poor result following ACL injury on the basis of whether they participated in high level sport and the extent of their arthrometer-measured knee laxity [43], offering early surgery to those deemed high risk. On the basis of the literature, in all but high level sportspeople or those with clearly symptomatic laxity preventing activities of daily living, it appears that initial conservative management with a structured rehabilitation program is a reasonable treatment strategy, with reconstruction being offered to those who are unable to return to their desired level of activity over the months following injury [44].

8.6 Surgical Management of ACL Injuries

Arthroscopic reconstruction of the ACL has been the gold standard for surgical management since the 1980s. Reparative procedures have largely been abandoned as they have a significant rate of re-rupture [45]. Similar principles are followed in all types of ACL reconstruction: a graft is secured in transosseous tunnels placed to recreate the functional anatomy of the native ACL. However, there remains controversy over several aspects of surgical management, including choice of graft, positioning of tunnels, choice of fixation and the use of single- or double-bundle techniques [46]. The aim of this section is to describe the evidence base on which these choices can be made; the techniques themselves are described in detail elsewhere and this is not intended to be a practical guide for those performing the surgery.

8.6.1 Choice of Graft

In both the USA and Europe, most ACL reconstructions are performed using autograft, mainly bone-patellar tendon-bone (BTB) or hamstrings (HS; semitendinosus +/− gracilis tendons) [18, 47, 48]. Allograft and synthetic grafts are rarely used in the primary situation but are more frequently used in revision surgery.

Both BTB and HS grafts are widely used and each has their advantages and disadvantages. Disadvantages to each largely concern donor site morbidity – anterior knee pain and a rare incidence of patellar fracture in BTB grafts, and hamstring weakness in when semitendinosus and gracilis are used [49, 50]. In the patellar tendon, bone blocks are present at each end of the graft which confer theoretical advantages in terms of primary fixation [51]; the size of hamstring grafts is more variable than the size of patellar tendon grafts and small grafts can predispose to failure [52]; hamstrings may provide biomechanical superiority and allow double-bundle reconstructions [53], while BTB grafts may be stiffer, conferring greater knee stability [54].

A 2011 Cochrane review examining this topic reported that, allowing for a lack of long term studies, there were no significant differences in patient-reported outcome between the two techniques [54]; however, they report greater static stability when BTB was used, at the cost of a higher rate of anterior knee pain and loss of range of motion compared to HS. Since then, there have been a number of good-quality studies that have reported, including four randomized controlled trials (RCTs). Sajovic et al. report an RCT comparing 32 patients with BTB grafts to 32 patients with HS grafts at 11 years. They report similar rates of graft failure, radiographic changes and patient-reported outcome, with a statistically significantly higher rate of positive pivot shift in the BTB group [49]. Barrett et al. analyzed a series of 1,131 ACL reconstructions and reported that BTB grafts had a lower failure rate amongst patients under the age of 25 years compared to allograft or hamstrings. This is supported by data from the Norwegian registry which suggests a lower revision rate following BTB grafts compared to hamstrings [55].

Wipfler et al. randomized 62 patients to receive either BTB or HS reconstruction [56]. No significant difference was reported in terms of patient-reported outcome or knee stability at 9 years following surgery; however, more anterior knee pain was reported in the BTB group. Likewise, the study of Björnsson, with 193 patents randomized to receive BTB or HS reconstruction, reported no difference in patient-reported outcome or knee stability (in terms of Lachmann or arthrometer measurements) at 16 years' follow-up. Patients in the HS group were more likely to have a normal pivot shift ($p = 0.048$) and had less anterior knee pain, but differences between the groups were small and only of borderline significance [57]. Kautzner et al. report another RCT comparing BTB with HS reconstruction, with a larger study group (150 patients) but at only 2 years' follow-up, and including only women [58]. No differences were reported in terms of Lysholm score, knee stability or graft failure; again, there was less anterior knee pain in the HS group. The final RCT, of Mohtadi et al., randomized 330 patients to receive either BTB, single-bundle HS or double-bundle HS [59]. Patient-reported outcome measures were similar for all techniques, but BTB grafts demonstrated superior post-operative static stability.

The traditional technique for HS reconstruction has involved the harvesting of both semitendinosus and gracilis, each being doubled to create a four-strand graft. Recently, attention has been paid to gracilis-sparing ACL reconstruction, where the semitendinosus tendon graft is quadrupled. This has the advantage of maintaining a greater level of hamstring function; however, it is more technically demanding and there are few perceptible differences in clinical outcome compared to traditional techniques [60, 61]. Alternative autografts, including iliotibial band (ITB) and quadriceps tendon, have been proposed and appear to have similar long-term results compared with more frequently used grafts [62, 63]. Both may be useful alternatives but lack the weight of evidence supporting the use of more traditional grafts.

The use of allograft is attractive in that it eliminates the problem of graft site morbidity. Achilles allografts share the benefits of patellar tendon autografts in that they have an integral bone block, at least at the distal end (Fig. 8.3). The previously reported high rate of failure for allograft may be due to the use of gamma irradiation, which has a deleterious effect on the biomechanics of the tendon, even at low doses [64, 65]. A number of recent systematic reviews have suggested that the results of non-irradiated allograft are similar to autograft [66, 67], although the majority of studies are of older patients and there is some doubt as to the applicability of these results to younger patient groups [68]. Synthetic devices have the potential to eliminate graft site morbidity without the risks associated with the use of allografts; however, previous generations of synthetic ligament had high rates of failure related to non-infective synovitis [69]. These risks seem to be substantially lower in modern devices such as the Ligament Augmentation and Reconstruction System (LARS; Surgical Implants and Devices, Arc-sur-Tille, France), which have encouraging published results, at least in the short to medium term [70]. There is, however, little long-term evidence to support its routine use in the primary situation.

8.6.2 Single Versus Double-Bundle Reconstruction

Double-bundle reconstruction was proposed in order to more closely mimic the biomechanics of the native ACL [71], and biomechanical studies have demonstrated improved biomechanics in knees with double-bundle reconstructions compared to those with single-bundle, particularly in terms of rotational stability [72, 73]. Alongside the development of double-bundle techniques came the introduction of the term 'anatomical' ACL reconstruction, implying an attempt to position tunnels in the footprints of the ruptured ligament, hence restoring normal or near-normal ACL anatomy and physiology [74]. Anatomic reconstructions can be performed with either a double- or a single-bundle technique and even proponents of single-bundle reconstructions suggest that a single-bundle anatomical technique is more appropriate in smaller knees [75].

Various techniques of anatomical single- and double-bundle ACL reconstruction have been described. One of the best known is that of Fu, who reported a technique using two tibialis anterior allografts placed in two separate tunnels in the footprints of the native AM and PL bundles [76]. He suggested first drilling the femoral PL tunnel via an accessory anteromedial portal, then the tibial PL and AM tunnels in turn and then the femoral AM tunnel using a transtibial technique. Tibialis anterior grafts are doubled and fixed in the femur using suspensory fixation devices (Endobutton, Smith and Nephew, Endover MA) and fixed in the tibia with a combination of interference screws and staples. The PL bundle is tensioned at 45° while the AM bundle is tensioned at 10°.

A 2012 Cochrane review found little evidence for the superiority of double- or single-bundle techniques, although they reported that there was weak evidence of superior rotational stability and

Fig. 8.3 Achilles tendon allograft, demonstrating the long length of graft available and the presence of a distal bone block

a lower re-rupture rate with double-bundle [77]. Subsequently, several RCTs have reported results at early to mid-term time points. Koga et al. reported a study of 78 patients randomized to receive hamstring double- or single-bundle reconstructions, reporting improvement in subjective knee stability in the double-bundle group with little difference in clinical outcome at 3 years [78]. Suomalainen et al. reported an RCT at 5 years comparing 30 patients with double-bundle reconstruction to 60 with single-bundle [79]. They report superior results in the double-bundle group in terms of re-rupture rate but no differences in any other end-point. Sun et al. reported 3-year results of a large RCT randomizing patients to receive either single-bundle allograft reconstruction (142 patients), double-bundle with allograft (128 patients) or double-bundle with autograft (154 patients). They reported greater stability in the double-bundle group with fewer progressing to osteoarthritis (42.3 % in the single-bundle allograft group compared to 29.2 % in the double-bundle allograft group, $p < 0.05$). By contrast, Mohtadi et al. reported a similar study randomizing 330 patients to receive PT, HS or double-bundle HS grafts, finding no difference in patient reported outcome or static stability at 2 years [59]. A 2015 systematic review reported that overall, clinical outcomes and graft failure are similar with single- and double-bundle techniques, but double-bundle techniques confer greater static knee stability [80].

Double-bundle reconstruction is challenging and time consuming [81]. The results reported by high-volume centers are encouraging but do not suggest clinically meaningful differences between single- and double-bundle techniques. It may be that attention paid to anatomical placement of the graft is more important than whether single- or double-bundle techniques are used.

8.6.3 Techniques of Graft Fixation

Many implants are available for graft fixation in ACL reconstruction but they can broadly be divided into aperture fixation devices (interference screws), suspensory fixation devices, staples and transosseous pins, used alone or in combination. In the tibia, aperture fixation is overwhelmingly used, with or without staple supplementation, while suspensory fixation is the most common fixation device in the femur [18, 48]. Bioabsorbable interference screws have the advantage of not needing to be removed if revision is necessary, but adverse local reactions and screw breakage have been reported [82]. Similar clinical results have been reported with both types of screw [83]. Likewise, the Intrafix screw-and-sheath device provides similar results to simple interference screws [84].

In the femur, transosseous pins and interference screws appear to give similar results in the medium term [85], and the RCT of Ibrahim et al. suggests that such pins confer superior stability compared to suspensory devices in double-bundle reconstructions [86]. The Norwegian ligament registry has raised concerns regarding the EndoButton device, reporting higher revision rates compared to transosseous pins and interference screws [55]. However, a number of smaller studies have found similar results for EndoButton compared to other devices [87, 88].

8.6.4 Partial Tears

Partial tears are estimated to comprise up to a quarter of all ACL tears [89]. There is little consensus in their definition, but clinically, they present with an increased Lachmann with a firm endpoint and evidence of disruption of fibers on MRI. The majority are treated non-operatively, and many patients will have good outcomes with conservative treatment [90]. However, in symptomatic cases, selective (i.e., isolated AM or PL bundle) or total reconstruction may be necessary. Selective reconstruction may allow preservation of the proprioceptive qualities of the ligament and restore greater rotational stability compared to single-bundle reconstruction, but is technically demanding [91]. Overall, there is little evidence to suggest that the outcomes of augmentation are significantly superior to those of primary reconstruction [92].

8.6.5 Rehabilitation

There is agreement in the literature of the importance of a structured rehabilitation program following ACL reconstruction [93]. In most cases, this would be achieved with range of motion, strengthening and functional exercises [94]. There is now strong evidence against the use of functional bracing following ACL surgery [93, 95, 96]. Accelerated rehabilitation programs may be viable and RCTs have demonstrated similar results to conventional rehabilitation [97]. Neuromuscular training may improve outcomes but the effect appears to be small [94].

8.6.6 Other Controversies and Future Directions

A number of technical factors remain controversial in ACL reconstruction. The use of trans-tibial or trans-portal techniques for drilling the femoral tunnel is linked to the practice of 'anatomical' ACL reconstruction (rather than simply relying on anatomical landmarks for tunnel placement). Using the anteromedial portal to drill the femoral tunnel allows unconstrained identification of the anatomical footprint, but increases the margin for error, resulting in a higher risk of subsequent revision, particularly in inexperienced hands [98]. However, the use of the anteromedial portal allows more accurate placement of the femoral tunnel [99]. Whether this results in superior stability or functional results is uncertain and it would seem sensible for surgeons to continue to use the method with which they are familiar [100–102].

Recent studies have suggested that preservation of the ACL remnant at the time of reconstruction could have potential benefits in terms of vascularization and ligamentization of the graft [103]. However, there is little convincing clinical evidence of improved outcomes with remnant preservation [103].

Extra-articular stabilization procedures were once widespread before arthroscopic ACL reconstruction became the gold standard for treatment of ACL rupture. In recent years, given a greater understanding of the incidence of residual instability after ACL rupture and the detailed description of the anterolateral ligament, there has been renewed interest in the results of combined intra- and extra-articular techniques [104]. Hewison et al. performed a systematic review of such lateral extra-articular stabilization procedures, including eight RCTs comparing isolated ACL reconstruction with combined procedures [105]. They performed a meta-analysis which suggested superior objective measures of stability but no difference in clinical outcomes. Likewise, the systematic review of Rezende et al. found no difference in re-rupture rate or clinical outcome, but enhanced stability in the combined group with a similar rate of complications [104]. It may be that a proportion of patients (perhaps those with a deficient anterolateral ligament) may benefit from combined procedures but more research is necessary to identify such patients.

Finally, there has recently been renewed interest in the use of reparative techniques for ACL rupture. Proponents suggest that repair will restore the proprioceptive functions of the ACL as well as producing a true anatomical restoration [106]. Augmentation devices, known as Dynamic Intraligamentary Stabilisation (DIS) may prevent the early failures reported in earlier series of ACL repair [107], but data is lacking and given the high rate of success of reconstructive procedures, a significant body of evidence is needed to change practice.

8.7 Outcomes Following ACL Reconstruction

The data we have relating to graft survival following ACL reconstruction is largely from single center cohort studies. However, with the emergence of multicenter studies and ligament registries, we have the tools to build a larger evidence base for what we do in ACL reconstruction.

A single center cohort study from Pinczewski's group in Sydney reports 15 year results of 200 patients (equally divided between men and women) who underwent hamstrings ACL reconstruction. They report a graft failure rate of 17 % at 15 years with a rate of osteoarthritis of 7 %, with no increase of laxity overall. Young patients and those with early laxity fared the poorest [108]. Shelbourne et al. reported the outcomes at a mean of 14 years of 502 patients who had undergone reconstruction using bone-patellar tendon-bone autograft [109]. Of the initial study cohort of 1773 patients, 54 patients (3 %) were excluded as they had undergone revision surgery, but no formal survival analysis was undertaken. They reported a normal IKDC score in 48 % and nearly normal in 42 %; 98 % of those with no other injury demonstrated normal radiographs at latest follow-up. Lebel et al. reported outcomes of bone-patellar tendon-bone reconstruction in 101 patients at 11 years reported re-rupture in 9.8 %, most of which occurred during return to sport [110]. A total of 74 % were participating in sports at latest follow-up with 91 % being normal or near-normal on the IKDC. Overall, 17.8 % of patients had developed radiological signs of OA.

Magnussen et al. collated the results of 10 year studies of ACL reconstruction in a systematic review [111], reporting good patient-reported outcomes overall. Patients who had undergone meniscectomy had worse results but no radiographic outcomes were studied. Likewise, the systematic review of Filbay et al. reported inferior health-related quality of life in patients with meniscal injuries, although this only became apparent in later follow-up (probably as a result of progression to OA) [112]. While gender is related to risk of ACL rupture, none of the cohorts studied suggested that gender was a risk for revision: this is supported by a systematic review of 13 studies which suggested no increased risk for graft rupture in women [113].

Grassi et al. performed a systematic review of return to sport following ACL reconstruction [114]. Using data from 16 studies, they estimated that 85.3 % of patients returned to sport at 4.7 years following ACL reconstruction, with 53 % returning to their pre-injury level at that timepoint. Very similar results were reported in the separate systematic review of Ardern et al. in 2013 [115]. Patients are more likely to return to sport if they have greater quadriceps strength, and if they are more motivated and confident and have higher levels of peer support [116, 117].

The large cohort studies and registries are only now reporting short-term outcomes. The most established registry is the Swedish registry which has been collecting data for 10 years [48]. However, no formal ligament survival analysis is presented in their annual report. A separate study of patients from the same database reported a 2 year revision rate of 1.82 %, with a higher rate in younger patients and football players [118]. A study using data from the Multicenter Orthopaedic Outcome Network (MOON) reported graft failure in 4.4 % of patients at 2 years, with failure again being more likely in younger patients [47]. In neither case is data available to provide information about longer-term results.

Conclusions

While a large proportion of patients may be managed non-operatively, ACL reconstruction is a well-established technique with a strong base of evidence. Surgeons have a number of choices to make as to their technique. However, there is little evidence that the use of single- or double-bundle techniques, the choice of graft or method of fixation have a large effect on outcome. Familiarity with the technique, a strong rehabilitation program and good patient selection are the strongest determinants of success following ACL reconstruction.

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9

Posterior Cruciate Ligament, Posterolateral Corner and Multiligament Knee Injuries

Jonathan J. Negus and Fares S. Haddad

Abstract

While injuries to the posterior cruciate ligament (PCL) and the posterolateral corner are less common than those to the anterior cruciate ligament (ACL), a missed diagnosis can have severe consequences for the patient. They are often injured in combination with each other or the ACL and without adequate assessment and management; a missed diagnosis can compromise any reconstruction surgery. The anatomy and management of the PCL has been well described for many years although the specifics of the surgical reconstruction are still debated such as inlay, single or double-bundle techniques. The anatomy and biomechanics of the posterolateral corner remain less well understood and the management options even more so. The key to managing both these injuries is a high index of suspicion, a thorough clinical assessment and appropriate imaging. It is also essential to remember the possibility of a dislocated knee that has spontaneously relocated, with a multiligament injury, which may have relatively benign initial clinical and radiographic findings considering its severity.

Keywords

Knee • Injury • Posterior cruciate ligament • Posterolateral corner Diagnosis • Treatment

9.1 Anatomy and Biomechanics

9.1.1 Posterior Cruciate Ligament

The anatomy of the posterior cruciate ligament (PCL) has been well described, being composed of an anterolateral (AL) and a posteromedial (PM) bundle named after their femoral attachments. The AL bundle is thicker and stronger and is tight in flexion. The smaller PM bundle is tight

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in extension. Together they make up a very strong ligament with a maximal tensile load in the range of 739–1627 N (Newtons). The distances between the centres of the femoral and tibial attachments of the 2 bundles are 12.1 and 8.9 mm, respectively [1].

The femoral footprint of the PCL is more than 20 mm in the AP direction across the roof and medial side of the intercondylar notch (Fig. 9.1). The distal border of the attachment is the articular cartilage while the superior and posterior borders are more variable. The AL bundle attaches mainly to the roof of the notch, sitting more anteriorly and distally on the femur than the PM bundle, which attaches mainly to the medial wall. The anterior meniscofemoral ligament of Humphrey, present in 75 % of cases, attaches adjacent to the articular cartilage of the femoral condyle, passing anterior to the PCL. The posterior meniscofemoral ligament of Wrisberg, present in 59–80 % of knees, passes posteriorly to the PCL with both attaching to the posterior horn of the lateral meniscus.

The tibial footprint lies in an upright oval on the posterior tibia that sits between the posterior horns of the menisci and passes from the posterior tibial shelf distally (Fig. 9.2).

9.1.2 Posterolateral Corner

The posterolateral corner (PLC) is complex and probably the least well-understood region of the knee. The major components of the PLC are the iliotibial band (ITB), lateral collateral ligament (LCL) and the popliteus complex, which has both static and dynamic components. The static components are the popliteofibular ligament (PFL), popliteotibial and popliteomeniscal fascicles. The dynamic component is the popliteus muscle-tendon unit. The other structures comprising the PLC are the patellofibular ligament (popliteofibular ligament), posterolateral joint capsule, arcuate ligament, lateral coronary ligament and posterior horn of the lateral meniscus (Fig. 9.3). Cadaveric studies have found some of these structures to be more variable than others. Sudusna and Harnsiriwattanagit found the PFL to be present in 98 % of 50 cases, the FFL in only 68 % and the thin membranous arcuate ligament in 24 % [3]. Watanabe et al. examined 155 cadavers and found seven different anatomical variants depending on

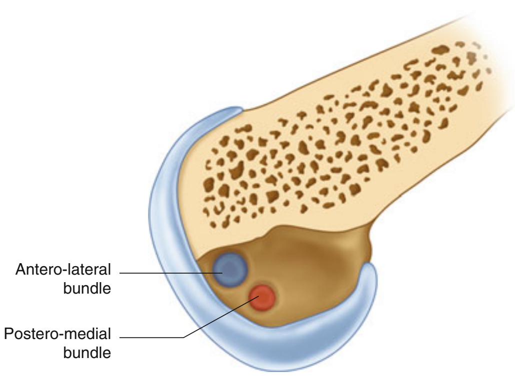

Fig. 9.1 Schematic illustration of the femoral attachment of the PCL bundles [2]

Fig. 9.2 Illustration of posterior tibia showing the PCL insertion site and the site of the drill hole [2]

the presence or not of the PFL, arcuate ligament and FFL. The LCL and popliteus were found in all and the PFL was found in 94 % of cases [3, 4].

The femoral insertions of the LCL and the popliteus tendon sit either side of the lateral epicondyle. The LCL femoral attachment is extracapsular and sits 1.4 mm proximal and 3.1 mm posterior to the lateral epicondyle [5, 6].

The popliteus muscle originates from the posteromedial aspect of the proximal tibia and is obliquely orientated in its course as it gives rise to the popliteus tendon at the lateral one third of the popliteus fossa in the PLC. It continues proximally through the popliteal hiatus in the coronary ligament, where it is intra-articular and inserts into the lateral femoral condyle. Its insertion point is 18.5 mm anteroinferior to the femoral insertion of the LCL, on the anterior one fifth of the popliteus sulcus on the femur [5]. The popliteus is a dynamic internal rotator of the tibia and contributes to dynamic stability of the lateral meniscus.

The PFL arises from the musculotendinous junction of the popliteus tendon and forms a "Y" configuration to anchor the popliteus to the fibula. The anterior division inserts 2.8 mm distal to the anteromedial aspect of the tip of the fibular styloid process and medial to the LCL. The posterior division is larger and is typically reconstructed in PLC surgery. It originates from the popliteus tendon and inserts 1.6 mm distal to the tip of the fibular styloid process on its posterior medial downslope. Its insertion site is just anterior to the fabellofibular ligament.

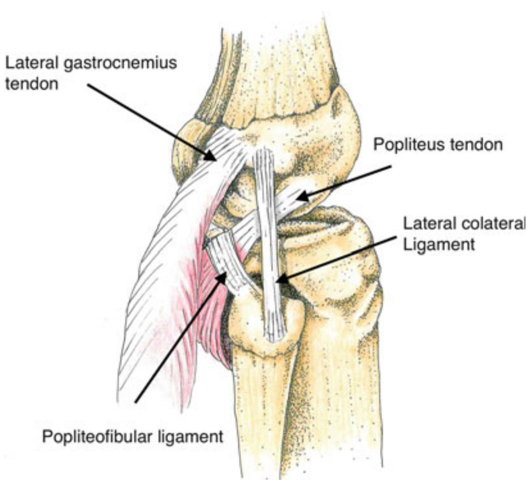

Fig. 9.3 Illustration of the anatomy of the posterolateral corner

The blood supply to this area is mainly from the lateral superior geniculate artery. There is also some supply from the posterior tibial recurrent artery and directly from the popliteal artery.

The innervation of the PLC arises from the posterior articular nerve from the posterior tibial nerve, the popliteal plexus and the lateral articular nerve.

9.1.3 Biomechanics

The primary function of the PCL is to resist posterior translation of the tibia throughout flexion. It has a secondary function of resisting varus when the knee is externally rotated, especially between 90° and 120° of knee flexion [6–8].

Various biomechanical studies have shown that an isolated tear of either PCL bundle results in a clinically meaningful increase in posterior tibial translation [9].

Studies that have previously looked at the forces within the individual bundles have contradicted each other as to which flexion angle of the knee produced the largest forces in each bundle. Fox et al. reported the in situ forces increasing in both bundles as the flexion angle increased during applied posterior tibial loads [10]; Harner et al. found the posteromedial bundle (PMB) graft of a double bundle reconstruction experienced its largest load at 30° of flexion [9]. However, both studies were working on the principle that each bundle was independent of the other (superposition). The work by Kennedy et al. shows that the bundles are interdependent and therefore using the superposition principle may not be valid [8].

Kennedy et al. have measured direct anterolateral bundle (ALB) and posteromedial bundle graft forces in double-bundle reconstructions. They reported that the Anterolateral bundle graft force peaked during mid flexion and the posteromedial bundle graft force peaked at both full extension and deep flexion during a posterior tibial load from 0° to 120° of knee flexion [11].

Complete sectioning of the PCL leads to a significant increase in posterior tibial translation throughout the knee's range of motion (0–120°) but a significant increase in internal rotation only between 90° and 120° of knee flexion [8]. A sectioned PCL results in significantly increased internal and external rotation when subjected to rotational torques [8]. The literature supports that the PCL has more of a role in rotational stability than previously thought and therefore it is important to examine for internal and external rotational stability when assessing a PCL injury. In biomechanical studies, there is a significant increase in external rotation after PCL resection under an applied posterior tibial load [12, 13].

The primary function of the PLC is to resist varus, external rotation and posterior translation of the tibia [14–16]. The relative importance of the LCL, popliteus and PFL has been demonstrated in studies that sectioned them in combination with the PCL [14–19].

The LCL is a primary static restraint to varus opening in the initial 0–30° of flexion [14–16]. It has an ultimate tensile strength of 295 N (Newtons).[21] An isolated tear of the LCL causes a mild (1–4°) increase in varus angulation that is maximal at 30° of knee flexion. It also shows loading response at all angles of knee flexion, but a greater response at 30° than at 90.

The PCL is a secondary restraint to varus opening and if sectioned with the PLC intact, varus opening is unaffected [14, 16]. If the PLC is sectioned with an intact PCL, the maximal increased varus occurs at 30° of flexion as well as maximal external rotation and posterior tibial translation.

The PLC is a primary restraint to external tibial rotation at all angles [14, 16]. If the PLC is sectioned, with the knee flexed to 30°, 13° of external rotation is present but with the knee flexed to 90°, the external rotation was only 5.3°. Sectioning the PCL in isolation had no effect but if the PCL and PLC were both sectioned, the external rotation at 90° of flexion was 20.9° [16]. This is because of the strongest fibres of the PCL becoming taut at 90° of flexion allowing them to form a secondary restraint against a varus moment or external rotation torque. These studies form the basis for the rationale behind the dial test [20, 21].

LaPrade et al. found that when the knee was externally rotated both at full extension & 30° of knee flexion, the LCL load response was higher than the responses of popliteus & PFL [22]. However, in 60° of knee flexion, the load responses of popliteus and PFL to external rotation (ER) were higher. They concluded that LCL, popliteus tendon and PFL perform complimentary roles as stabilizers to ER. While the LCL assumes a primary role at lower knee flexion angles, the popliteus complex does so at higher degrees of knee flexion.

Isolated sectioning of PLC increased posterior tibial translation at all angles with the maximum in early flexion. Isolated sectioning of the PCL produces increased posterior tibial translation at all angles of flexion with the maximum effect (11.4 mm) occurring at 90° of knee flexion. While the PCL is the dominant restraint to posterior tibial translation, the PLC is very important at near full extension [16, 23].

Combined sectioning of the PLC and PCL produces a significant increase in posterior tibial translation (21.5 mm) at 90° of knee flexion compared to a normal knee or isolated sectioning of the PLC. It also leads to increased varus and external rotation at all degrees of knee flexion [14, 16, 18].

The popliteus is a static and a dynamic stabilizer [17, 19–24]. The popliteal tendon attaches to the lateral meniscus via anteroinferior and posterosuperior popliteomeniscal fascicles [25]. These provide dynamic stability to the lateral meniscus and prevent medial entrapment of the lateral meniscus with functional varus forces to the knee [6]. The PFL is a static stabilizer resisting varus, external rotation and posterior tibial translation. It is relatively isometric and remains functional throughout a full range of motion. In contrast, the area from the posterolateral corner of the tibia to the lateral femoral epicondyle is only tensioned near full extension. An intact popliteus muscle belly will usually tension this portion of the popliteus tendon.

A competent posterolateral corner is important in protecting a cruciate graft. When the PLC is sectioned in a knee that has had an ACL reconstruction, there is an increased load on the ACL grafts during varus and varus-internal rotation moments [26]. This puts the grafts at risk of failure in these patients. For patients with a PCL reconstruction, a deficient posterolateral corner causes the forces on the PCL graft to be increased by 22–150 % [27–29].

In a combined PCL/PLC injury, a combined reconstruction is recommended. Sekiya et al. found that when both structures were reconstructed, the knee kinematics were nearly normal [28].

9.2 Clinical Assessment

9.2.1 Injury Mechanisms

Historically, 50 % of isolated PCL ruptures were the result of a flexed knee hitting a dashboard in a head-on motor vehicle accident. Since the widespread use of seatbelts, this is now an uncommon cause. In sporting injuries, isolated PCL injuries can be caused by the impact of a flexed knee onto the ground pushing the tibia back on the femur as well as hyperflexion or hyperextension injuries. Unlike the pop reported by patients at the time of ACL injuries, patients with an acute PCL rupture tend to report vague symptoms of unsteadiness or discomfort. In the chronic cases, symptoms include vague anterior knee pain, pain with deceleration and descending hills or stairs and pain when running at full stride [30].

In the trauma setting, PCL injuries are associated with ACL injury in 46 %, MCL in 31 % and the PLC in 62 % of cases [31].

The natural history of an untreated PCL injury is for medial compartment and patellofemoral wear which has been corroborated by in vitro PCL sectioning studies showing increased contact pressures in these areas. However, much like in the ACL literature, there is no evidence that reconstruction changes the natural history of degenerative disease.

An isolated injury to the posterolateral corner is uncommon (<2 % of all acute ligamentous knee injuries) because it tends to occur in combination with a cruciate or multiligament injury [32, 33]. There was a 16 % incidence of grade III PLC injuries in a consecutive series of 187 patients with an acute knee injury and complete ACL and/or PCL ligament tear on MRI [34].

The force causing an injury to the posterolateral corner is usually a posterolateral blow to the anteromedial proximal tibia at near full or full knee extension. This causes hyperextension and combined with a varus moment, disrupts the posterolateral structures [33, 35–37]. This can be a non-contact hyperextension and rotation twisting injury, a direct blow to the flexed knee or a high-energy trauma such as a motor vehicle accident or a fall.

The combined PCL/PLC injury can be caused by an impact to the medial side of the knee with the knee extended and the foot planted. The result is a varus force combined with hyperextension. Another common cause is landing heavily from a jump or mogul in skiing.

If there is associated sagittal plane laxity then a knee dislocation with multiligament injury must be considered. The knee may have spontaneously reduced. In all these injuries including the PLC, the status of the peroneal nerve must be checked.

In cases of chronic PLC laxity, patients can complain of joint line pain as well as posterolateral pain. Their functional instability is often in extension with their knee giving way into hyperextension on stairs, slopes or pivoting/cutting manoeuvres.

9.2.2 Examination

The aims of the examination are to diagnose all ligamentous and associated intra-articular injuries, rule out neurovascular pathology and then assess for anatomy or pathology that may interfere with the success of future reconstruction. For an overview of a full knee examination, see Chap. 1 (clinical assessment) but the following points are specific to assessing PCL and PLC injuries.

The patient must be evaluated for varus malalignment or hyperextension with varus thrust during stance phase [21, 38]. In chronic PCL injuries, they may walk with slight flexion in mid-stance phase to avoid posterior capsule stress [39].

Tenderness and ecchymosis in the posterolateral area is often present especially if there is a segond or arcuate fracture. An abrasion, laceration or ecchymosis over the tibial tubercle should raise the suspicion of a PCL injury [40].

The PCL should be tested with the well-described clinical tests:

- Posterior sag
  - With the foot place on the examination table and the knee at 90°, the tibia sags backwards on the femur, best seen from the side [41, 42].
- Posterior drawer
  - Patient supine with hip flexed at 45° and knee flexed to 90°
  - After assessing for sag, a posterior force is applied to the proximal tibia and the grade of injury as well as an end point is assessed.
  - Patients can develop an end-point in a chronic rupture as the PCL scars down [43].
- Quadriceps active test [44]
  - Place the knee at 90° of flexion and hold the foot in place against the examination table. Instruct the patient to try and slide the fixed foot anteriorly along the table.
  - The resultant quadriceps contraction causes a posteriorly subluxed or sagging tibia to be drawn anteriorly. Anterior movement of the tibia >2 mm is a positive test for a PCL tear.
- Reverse pivot shift test [45]
  - Be aware that this test has been shown to be positive in up to 35 % patients under anaesthesia with no PCL/PLC pathology [46].
  - The foot is externally rotated with the knee in 90° of flexion. A valgus load is applied to the knee which is then extended to assess for reduction of the posteriorly subluxed tibia at 20–30° of flexion.

The PLC should be tested with the following specific tests. The grading of the injury follows this section:

- Varus stress at full extension and 30° of flexion
  - Varus opening at full extension signifies a severe PLC injury
- Dial test (posterolateral (PL) rotation test for external rotation)
  - >10° side to side difference
  - If positive at 30°, only the PLC is injured.
  - If positive at 90°, both the PCL and PLC are injured.
  - It has been validated with biomechanical studies for assessment of medial and posterolateral knee injury [16, 18, 47].
  - Its clinical diagnostic accuracy has been questioned [48].
- ER recurvatum
  - With the femur fixed to the examination table with one hand, passively lifting the extended leg up by the great toe leads to recurvatum and relative varus through external rotation.
  - Positive in severe injuries – PLC injury with rupture of one or both of the cruciates [41, 49].
- Posterolateral drawer
  - Same patient position as the posterior drawer
  - Externally rotate the tibia 15° and apply a posterior force to the proximal tibia similar to a posterior drawer.
  - Positive if the lateral tibial plateau rotates posteriorly and externally relative to the medial tibial plateau.
- Reverse pivot-shift
  - See above

In assessing a knee with ligamentous rupture, the clinician should always be suspicious of a relocated knee dislocation. The vascular examination must be thorough with popliteal artery injury a significant risk. An ankle-brachial index should be measured with a cut-off of <0.9 for further investigation with arteriography. Selective arteriography is now accepted as a non-flow limiting intimal flaps rarely become occlusive. In the presence of a normal examination and ABIs, 48 h of observation and serial physical examination is sufficient.

The function of the peroneal nerve needs thorough examination and documentation [50–52].

9.2.3 Grading

PCL injuries are usually classified according to Clancy and Sutherland [53]. The normal femorotibial step-off is 10 mm with the anterior medial tibia plateau lying in front of the anterior medial femoral condyle with the knee at 90°. Applying a posterior drawer test:

- Grade I injury demonstrates 0–5 mm of posterior tibial translation but the tibia is still anterior to the femur.
- Grade II injuries are where the tibia translates 5–10 mm and the anterior surfaces of the two bones are now in line.
- Grade III injury is where there is at least 10 mm of posterior translation. It is important to check for an end point and critical in grade III injuries to check for a PLC injury.

PLC grading is less well defined. The dial test has been discussed but while a side-to-side difference of >10° indicates a PLC injury, there is no reliable classification system to indicate the degree of injury.

The grading system of Hughston is the most commonly used, but does not evaluate rotational instability [53]. It defines LCL injuries as:

- Grade I with varus opening of 0–5 mm
- Grade II with 6–10 mm
- Grade III is >10 mm, which signifies associated cruciate ligament tears.

Fanelli and Larsen addressed rotational instability with their grading system [54].

- Type A – An isolated rotational injury to popliteofibular ligament and popliteus complex. Increase in external rotation with minimal or no varus component.
- Type B – Rotational injury plus mild varus instability with firm end point at 30°.
- Type C – Significant rotational and varus components without a firm end point at zero degrees and 30° of knee flexion with varus stress. This occurs secondary to complete disruption of the PFL, Popliteus complex, LCL, lateral capsule and cruciate ligaments.

Stress radiographs can be used but there are unresolved issues surrounding consistency of set-up, stress application and interpretation.

9.2.4 Imaging

Standard radiographic imaging of the knee is essential, not only to rule out associated pathology such as tibial plateau fractures but also injuries specific to the PCL and PLC such as avulsion fractures. For further details on imaging, see Chap. 2.

PCL avulsion fractures tend to occur from the tibial insertion. Radiographs should be examined closely for a 'peel-off' lesion in the intercondylar notch. Other signs to look for are the medial capsule avulsion fracture or 'medial Segond fracture'.

The more commonly seen fractures in PLC injuries are the fibular head avulsion fracture, known as the arcuate sign, and an avulsion of Gerdy's tubercle. The arcuate sign is caused by popliteofibular and fabellofibula ligament avulsions and produce a small fragment (1–8 mm) which is different from a fibular head fracture or an LCL avulsion which have a larger fragment (15–25 mm).

The laterally based capsular avulsion 'Segond' fracture is pathognomic for an ACL rupture which in the presence of a PCL and or PLC injury should increase suspicions for a spontaneously reduced knee dislocation.

In chronic injury, weight-bearing X-rays may demonstrate degenerative or post-traumatic arthritis, especially in the medial and patellofemoral compartments. Finally, standing alignment films may be needed to rule out varus malalignment that can threaten future reconstructions. Varus is defined as the mechanical axis of the leg falling medial to the medial tibial spine on a weight-bearing alignment film.

A magnetic resonance imaging (MRI) scan is essential in all cases to confirm diagnosis and rule out associated intra-articular pathology such as meniscal or chondral injury.

Signs of a complete PCL tear include complete non-visualization of the PCL, diffuse amorphous high signal on T-2 weighted imaged throughout the PCL and visualization of PCL fibres but with full thickness fibre disruption. If there is high signal change within the PCL or disrupted fibres but not to the level of these three criteria then a partial tear is diagnosed.

It has been reported that the most important criterion among the sonographic findings is an AP diameter of the PCL increased from the normal 6 mm to >7 mm. This is clearly visible on the MRI scans [55, 56].

In chronic PCL injuries, continuity is regained in three quarters of observed cases. Therefore, the only sign on an MRI of a chronic injury may be a lax ligament. This may change with the more widespread use of 3 T MRI scanners.

As with ACL grafts, the revascularization that occurs in the first 2 years can lead to ongoing intra-graft high signal during that time period.

The standard MRI sequences will enable evaluation of LCL, popliteus, biceps, gastrocnemius and iliotibial band (ITB). Coronal, oblique thin slices of fibula head and styloid make evaluation of the PFL, arcuate and FFL easier. Using oblique MRIs, the PFL is seen in 53–68 % of cases [57–59], the arcuate ligament in 46 % and the FFL in 48 %. This compares to 8 %, 10 % & 34 % respectively using standard coronal imaging [58].

While identifying all the components of the PLC is not always possible, if there is a bone contusion to the anteromedial femoral condyle, a PLC injury should be looked for with great care. A ruptured LCL will have a serpiginous contour and have lost continuity. The popliteus complex may demonstrate muscle oedema and heamorrhage on T-2 weighted and PD images. The tendon itself can be ruptured in severe injuries. An arcuate ligament injury may be suggested by oedema posterior to the popliteus tendon on sagittal or axial images. There may just be disproportionate oedema in the expected anatomical course of the other PLC structures. There may also be a lack of a joint effusion due to the disruption of the posterolateral capsule [60].

Ultrasonography can produce real time evaluation of the components of the posterolateral corner. However, this requires significant expertise on the part of the operator [61].

9.3 Treatments

9.3.1 Isolated PCL

9.3.1.1 Non-operative

The need for surgery is dependent on the severity of the injury and the associated lesions that mandate surgical intervention. The PCL has an intrinsic ability to heal after injury although this often occurs in a lax or attenuated position [62–64].

Therefore isolated partial, grade I or grade II PCL injuries are usually managed non-operatively [62, 65, 66]. Grade III PCL injuries need to be examined with a high index of suspicion for an associated PLC or multiligament injury and need surgical management.

The evidence for outcomes after non-operative management of PCL injuries varies between isolated and combined PCL tears.

Torg et al. published in 1989 that patients with isolated PCL tears that were treated non-operatively had favourable outcomes with a follow up of 5.7 years. However, if the pattern of injury included associated ligament tears, there was a higher incidence of fair or poor outcomes and osteoarthritic progression [67]. Some studies that have focused on isolated PCL injuries report good subjective functional scores and a healed appearance of the PCL on MRI at short term follow up (1.7–2.6 years) but less than satisfactory objective scores [34, 64–66, 68]. The conclusion was that the PCL healed in an attenuated fashion.

There is increased radiographic progression of osteoarthritis and decreased functional outcomes as the time from injury increases if treated non-operatively [66, 68]. Radiographic evidence of arthritic changes were reported in 23 % at 7 years and 41 % at 14-year follow up. However, at 14 years, only a minority had moderate or severe osteoarthritis (11 %) and the majority had good strength and subjective outcome scores [66].

Jacobi et al. reported that, treating isolated acute PCL with a dynamic brace for 4 months reduced the posterior sag significantly (7.1 mm), which improved at 12 months (2.3 mm) and was maintained at 24 months (3.2 mm). Ninety five percent had MRI PCL continuity restored at 6 months. There was no clinically significant decrease in Lysholm scores at 12 & 24 months [62].

Non-operative treatment uses an extension brace with a pad behind the upper tibia for a period of 6 weeks. Most patients with isolated PCL injuries do well with non-operative treatment with 80 % returning to their normal level of sport within 4 months. The key to the rehabilitation is a quadriceps-based programme to create a favourable quadriceps to hamstrings ratio. Most patients do not complain of subjective instability.

There is a relative indication for surgery in patients with a grade III, isolated PCL injury, who have not responded well to rehabilitation or in those with associated meniscal or major chondral injuries that require treatment. In patients with associated ligamentous injury then, early reconstruction is advised. When assessing the outcomes of isolated PCL injuries it is critical to ensure that poor outcomes were not due to missed, associated PLC injuries.

9.3.1.2 Operative

Prior to any surgery for PCL injury, it is vital to assess for associated ligamentous injury, especially of the PLC. An assessment of any varus malalignment is also mandatory. Along with incorrectly placed tunnels, failure to address these two factors are the most common causes for a failure of PCL reconstruction [31, 69, 70].

The indications in acute injuries are a PCL tear in conjunction with a dislocated knee or a grade III injury as assessed clinically or on stress radiographs or if there is a grade II injury with an associated repairable meniscal tear. For chronic PCL injuries, indications can include functional limitation including deceleration, difficulty descending stairs and hills while clearly assessing for post-traumatic arthritis.

Surgery is best performed within the first year or two from injury to prevent the development of fixed deformities. An osteotomy should be considered in the presence of a varus malalignment or medial joint disease (see Chap. 14). Reconstruction can then be carried out at the same time or staged should secondary instability persist.

The ruptured PCL may appear normal at arthroscopy in both acute and chronic cases. This is because many tears are found in the lower third obscured by the ACL, fat and synovial tissue. It is important to make the diagnosis clinically and from MRI imaging rather than use arthroscopy as a diagnostic tool.

There are multiple surgical techniques for PCL injury including bony re-attachment, local repair, microfracture, synthetic augmentation, single tunnel, double tunnel and tibial inlay techniques. These can be performed open or arthroscopically.

There is a lack of consensus on many surgical decisions in PCL surgery, including whether open or arthroscopic procedures should be used, the degree of laxity at which the surgery should be performed, the type of fixation and the rehabilitation protocol. This demonstrates that there is no good, reproducible method for reconstructing the PCL as there is with the ACL.

The principles of PCL reconstruction are to identify and treat all pathology, place tunnels accurately to produce anatomic graft insertion sites, use strong graft material, mechanical graft tensioning, secure graft fixation and a targeted post-operative rehabilitation programme.

Tunnel Placement

Tunnel placement has changed over time. Even though the PCL is not an isometric ligament, the aim used to be to use isometric points but these led to over-constraint and increased laxity over time [71–73]. More recent studies have focused on placing the tunnels using arthroscopic and radiographic reference points [1, 74]. It has been established that it is the position of the femoral tunnel, not the tibial tunnel that determines graft tibiofemoral separation distance with knee flexion and extension [75].

The placement of the tibial tunnel is uniformly agreed upon. However, it is difficult to visualize arthroscopically so intra-operative fluoroscopy is recommended. The radiographic landmarks have been quantified by Johannsen et al. as being 5.5 mm proximal to the champagne glass drop-off on a lateral radiograph and the landmark of the centre of the PCL attachment on an AP radiograph was 1.6 mm distal to the proximal tibial joint line [74].

The argument over the femoral tunnel mostly centres around a single-bundle or a double-bundle technique. Most agree that in a single-bundle technique, the tunnel should be placed in the anterior portion of the femoral footprint, recreating the larger AL bundle [1, 76–79]. This means putting it as superiorly as possible with the knee flexed to 90°.

Single Versus Double-Bundle

A review of ten studies of isolated PCL reconstruction of the AL bundle with 2 years' follow up showed improved Lysholm scores, normal or nearly normal subjective function on IKDC and improved posterior laxity. However, normal knee stability was not returned in any study [80].

Hermans et al. reported on long-term follow up of isolated single-bundle PCL reconstruction – IKDC, Lysholm, visual analog scale (VAS) and Tegner improved at mean 9-year follow up. AP translation on stress radiographs and KT-1000 arthrometer were significantly increased compared to non-operated knee (4.7 mm vs. 2.1 mm). Radiographic evaluation demonstrated 60 % of knees had evidence of osteoarthritis [76].

Multiple studies have reported similar results in multiligament injuries with transtibial PCL reconstructions and concurrent ACL or PLC reconstructions. They showed decreased antero-posterior (AP) translation compared to preoperatively but residual laxity compared to the non-injured knee [77, 81, 82].

There has been a technique described of single bundle transtibial PCL reconstruction preserving the PCL remnants to augment the reconstructed graft providing soft tissues for vascular ingrowth [82–85]. Kim et al. reported on this technique showing that their postoperative Tegner activity scores, rates of near-return to activity, subjective international knee documentation committee (IKDC) scores were significantly improved compared to a conventional reconstruction. However, there was no difference in Lysholm scores, return to activity, objective IKDC and side-to-side differences in posterior tibial translation [86].

Markholf et al. studied single-bundle versus double-bundle reconstructions in a biomechanical cadaveric study. They found that single-bundle best reproduced normal PCL force profiles [87]. Whiddon et al. also compared the two in a cadaveric study looking at open tibial inlay technique. They tested them intact and then after sequential sectioning of the PCL and PLC. In those cadavers that only had a PCL reconstruction, the double-bundle PCL reconstruction had better rotational stability. If the PLC was also reconstructed, there was no difference between single- and double-bundle techniques [88].

Harner et al. and Race et al. have shown that the double-bundle technique is likely to restore the posterior laxity levels to a more normal situation than the single-bundle [9, 72]. A clinical review by Kohen and Sekiya compared single-bundle to double-bundle and could not be certain of the superiority of one technique over the other [89].

Li et al. prospectively randomised 50 patients with half having single and half having double-bundle tibialis anterior allograft PCL reconstructions with a minimum of two-year follow up [90]. They found no difference in Lysholm & Tegner scores or posterior tibial translation between the two groups. The double-bundle group did have a better grade distribution and statistically higher grade of IKDC.

Yoon et al. compared 25 single and 28 double-bundle PCL reconstructions using Achilles tendon allograft with a minimum of 2-year follow up [91]. They found a statistically significant difference in posterior tibial translation of 1.4 mm. However, this is a small difference and when combined with the finding of no differences in the subjective scores, is unlikely to be clinically significant.

Shon et al. retrospectively assessed single-bundle vs. double-bundle finding no significant difference in Lysholm or side-to-side posterior translation (3.0 vs. 2.6 mm) between two tibial inlay groups [92]. In a prospective comparative clinical study, Wang et al. prospectively looked at 19 patients with a single-bundle and 16 with a double-bundle reconstruction using hamstring autograft. They found no significant difference in functional outcomes, ligamentous laxity or radiological scores at 2 years [93]. Fanelli et al. reported on 90 consecutive PCL reconstructions where the first 45 were single-bundle technique and the next 45 double-bundle technique. Each used a transtibial approach with fresh frozen allograft. At follow up of between 24 and 72 months, they were unable to find any significant differences between the two groups in their Tegner-Lysholm knee scoring scale or HSS functional knee scores [94].

Tibial Inlay Technique

The tibial inlay technique was devised to bypass the 'killer curve' of the graft passing over the tibial ridge as it exits the tibial tunnel [95, 96]. Biomechanical studies have shown that a Patellar tendon graft undergoes abrasion, attenuation and increased failure during a cyclic loading protocol [69, 95, 97]. However, it is not known if these changes occur in vivo when graft remodelling occurs or in grafts other than patella [83]. This technique requires careful patient positioning and incisions both anteriorly and posteriorly. There is no evidence that it has any functional advantages for the patient: McAllister et al. compared transtibial tunnel and tibial inlay techniques in a cadaveric study taking the reconstructions through cyclic loading to failure. They found no significant advantage to either technique over the other [98].

In the case of bony avulsions, acute fixation is generally warranted if there is more than 5 mm displacement. Care should be taken in high-energy injuries where the ligament may have been attenuated prior to the avulsion increasing the risk of post-fixation laxity.

Graft Selection

Autograft options include bone-patellar tendon-bone, quadruple strand hamstrings, and quadriceps tendon-patellar bone (BTB). There is a theoretical concern with weakening the extensor mechanism as it acts as a dynamic restraint to posterior tibial translation. Good results have been reported with quadriceps tendon as well as hamstring and BTB with no difference found in direct comparisons.

Allograft options include tendoachilles (TA), double stranded anterior and posterior tibial tendons as well as hamstrings, quadriceps tendon and patellar tendon. As with the ACL (Chap. 8), allograft reduces donor site morbidity but does have the risk of disease transmission and immune mediated tissue rejection.

A porcine biomechanical study has shown quadruple hamstrings to have the significantly highest load to failure compared to BTB or allograft TA but the BTB graft resisted elongation significantly more than the quadrupled hamstrings [99]. Wang et al. compared autografts and allografts and found the only difference to be the donor-site morbidity of the autograft group [100]. Hudgens et al. carried out a review comparing allograft and autograft in PCL reconstruction and found no significant differences with both performing to a satisfactory level clinically and functionally [101].

For the tibial inlay technique, most studies describe the use of the patellar tendon but Kim et al. have described using an allograft Achilles tendon [96]. In the double-bundle technique, many different combinations of autograft and allograft have been used. The standard grafts for the anterolateral bundle using a transtibial technique are a BTB autograft or a TA allograft. The posteromedial bundle is reconstructed with semitendinosus autograft or allograft, tibialis anterior or tibialis posterior allograft. There is a double-bundle tibial inlay technique, which uses a split TA, quadriceps tendon or BTB allografts.

Complications

The most common complication is residual posterior laxity which is defined as greater than

4 mm of posterior translation on PCL stress radiographs. Range of motion exercises are critical as loss of flexion range is a problem due to the use of extension bracing [102, 103]. The very serious complication of popliteal artery damage during tibial tunnel drilling can be avoided using the techniques described above. Posterior meniscal root avulsion is a potential problem if the tibial guide pin is placed too proximally [104]. Specifically in the case of an inlay procedure, saphenous nerve damage & non-union can occur.

9.3.1.3 Operative Descriptions

Fixation of a Bony Avulsion

Position the patient prone, applying a tourniquet so as to allow access to the popliteal fossa. Use a standard posterior approach, taking care of short saphenous vein and posterior cutaneous nerve of calf. Identify and bluntly dissect the interval between semimembranosus and medial head of gastrocnemius. Retract the medial head of gastrocnemius laterally with the neurovascular bundle and identify and ligate the middle geniculate artery as needed. When incising over the capsule in an acute injury, haematoma will be released. Identify the site of the avulsion and then debride the bed. Flex the knee and reduce the fragment, temporarily fixing with a k-wire. Pass two 4 mm partially threaded screws or one large screw across the fragment into the tibia. Postoperatively, check X-ray. Passive range exercises after 48 h. A protective brace is recommended until 6 weeks when the patient should be able to flex to 90°.

The arthroscopic fixation of an avulsion fragment with a retrograde screw or a trans-osseous suture lasso has been described but there are no data published comparing it to the open technique.

Single Bundle: Left Knee

Position the patient supine with a tourniquet applied, the knee at 90° and access for an image intensifier.

Prepare the grafts to a diameter of 10–11 mm. Place the lateral portal slightly higher than medial while applying and an anterior drawer to the knee. Assess for intra-articular pathology remembering that the ACL may be lax due to posterior translation. Debride remnants of the PCL. Mark the most superior and anterior area of the femoral PCL footprint for tunnel drilling.

The femoral tunnel can be drilled using an all-inside technique similar to an ACL reconstruction, or an outside to in technique. To go from outside to in, use a medial incision and dissect under VMO to place the guide on the medial femoral cortex, proximal to the articular cartilage by more than 5 cm to avoid fracture or avascular necrosis. Place the tip of femoral tunnel guide at 11 o'clock in the notch with the knee at 90° flexion and pass the guide wire and incrementally increasing drill sizes (to avoid fracture) from outside in.

Tibial tunnel

Make a longitudinal incision over the proximal tibia and pass the guide wire at the level of the tibial tubercle from anterolateral to posterocentral. Avoid going from anteromedial, even if hamstrings have been harvested, as it makes the killer curve even worse. The angle of the tibial tunnel is a compromise between too shallow creating a killer angle for the graft to pass around, or too steep, potentially exiting the posterior cortex too early and compromising the posterior neurovascular bundle.

There is a real risk of the guide wire becoming stuck in the drill and advancing with it, damaging the neurovascular bundle. This can be avoided by repetitive screening of the guide wire tip as you drill, placing the guide wire only one third across the tibia and over-drilling to that point before removing the guide wire and drilling under II or making a posteromedial incision 1 cm posterosuperior to the PM joint line and placing a spoon onto the posterior tibia to feel for the guide wire as you drill. All drilling is undertaken at 90° to protect the posterior neurovascular structures.

The exit of the tibial tunnel is prepared and smoothed using rasps and a shaver through the lateral portal or a posteromedial portal allowing the scope to be placed further posteriorly in the joint for a better view.

Pass the graft's lead sutures through the tibial tunnel using a suture passer. Capture these sutures with a grasper through the medial portal and pull the graft into the tibial tunnel. Use the graspers to pull these sutures and the graft up into the femoral tunnel.

Once the graft is seated within the tibial tunnel, place the knee at 90° and fix it on the tibial side with an interference screw and accessory fixation if necessary. Check for impingement taking the knee through a full range of motion. Fix the femoral tunnel with the tibia brought anteriorly to recreate the step-off, using a femoral interference screw 1–2 mm larger than the tunnel used.

If there is a PLC injury, the PLC is addressed just before final fixation of the PCL.

Double Bundle

This technique uses the same set-up. The main differences are in the grafts used, femoral tunnel position and fixation. Allograft is preferred due to size of graft needed. If using semi-tendinosus grafts, usually it is necessary to use one for the posteromedial and two for the anterolateral bundles.

The AL bundle typically requires an 8 mm tunnel so is centred 6 mm from the articular surface and the PL requires 6 mm and is situated more posteriorly. The tunnels should diverge by a few millimetres. The tibial tunnel is prepared in the same way as with the single-bundle technique.

After tibial fixation the PM bundle is fixed in 30° of flexion with as much tension as possible on the graft and an anterior force on the tibia. The AL bundle is fixed at 90° with an anterior force and as much tension as possible on the graft. Bioabsorbable screws are used in both femoral tunnels sized to 1 mm bigger than the graft size.

Inlay Technique

This combined arthroscopic and open technique was popularized by Berg [95]. The femoral tunnel is placed under arthroscopic guidance as per the single-bundle technique. The tibial attachment is an open bone trough created in the posterior tibia. This reduces the risks to the popliteal neurovascular structures.

The described graft is a 10 mm wide, central third patella bone-tendon-bone autograft. The tibial tubercle bone block is drilled and tapped to accept a 6.5 mm cancellous screw and spiked washer.

Positioned in decubitus with operative leg up. After drilling the femoral tunnel, the knee is extended and the table tilted towards a prone position. The hip is abducted and externally rotated 45° with the knee flexed 90° to allow a posterior approach in the plane between medial head of gastrocnemius and the semimembranosus tendon. The medial head of gastrocnemius is incised near its insertion and retracted laterally. The inferior medial geniculate artery and vein are identified and ligated. A vertical incision is made through the posterior capsule. The insertion of the PCL is visualized and the posterior tibial plateau is exposed subperiosteally. The tendon graft traction sutures are advanced retrograde through the femoral tunnel using a suture passer. The graft is fixed in the femoral tunnel using a 7 or 9 mm interference screw. The bone portion of the graft should not be recessed to avoid tendon-tunnel wall abrasion.

Position the knee in full extension (no recurvatum) reducing the posterior tibial subluxation. Place the patellar graft under slight manual tension to determine the site of tibial fixation. Create a unicortical window with an osteotome in the posterior tibia equal in size to the bony portion of the patella graft. The graft is inlaid and secured with a 6.5 mm titanium screw and spiked washer to the cancellous tibial bone.

9.3.2 Isolated Posterolateral Corner (PLC)

9.3.2.1 Non-operative

Historically, PLC injuries have progressed to chronic laxity through missed diagnosis or strategies of watchful neglect, especially as part of a multiligament knee injury. Chronic PLC instability can lead to quadriceps wasting and associated gait abnormalities including knee hyperextension and varus thrust through stance phase [38].

The data for PLC treatment suggests that Grade I injuries can be successfully treated non-operatively. As part of their cohort of lateral knee injuries, Krukhaug et al. found that six of their seven patients with grade I injuries who were treated with early immobilization had good results by the IKDC scale (follow up = 0.5 to 13 years). One patient needed cast immobilization for residual 1+ laxity [105].

Kannus et al. had good results treating grade II PLC injured patients non-surgically. They followed 23 patients with grade II and III PLC injuries and at an average of 8 years of follow up, of the 11 patients with grade II injuries, all had excellent or good scores on standardized knee scoring scales, 9 were asymptomatic and all demonstrated residual laxity. The 12 patients with grade III injuries averaged only fair or poor scores. Eight had subsequent cruciate ligament injury. There was radiographic evidence of post-traumatic arthritis in half of the grade III patients and none of the grade II patients [106].

From limited data, it would appear that while isolated grade I PLC injuries can be treated non-operatively and grade III injuries should be treated surgically, grade II injuries need to be treated on merit. While low demand patients may accept long-term instability, active patients with a grade II PLC may well require surgery. However, low grade isolated PLC injury is uncommon. PLC injuries are most commonly associated with PCL, ACL and also multiligament injuries. Surgery is more strongly indicated to address all the injuries in these knees with combined instability. Surgery is therefore indicated in Fanelli grade A, B in high demand patients, B with concomitant cruciate injury and C. Patients with bony varus malalignment may require prior high tibial valgus osteotomy.

9.3.2.2 Operative

The goals of reconstruction are to restore knee stability and kinematics, return to pre-injury activity levels without pain or instability and reduce the likelihood or severity of post-traumatic arthritis.

Operative management for isolated PLC injuries includes an examination under anaesthetic to confirm the grade of the injury and assess for associated injuries. An arthroscopy is performed to diagnose and treat associated chondral and meniscal injuries. It can also be useful to confirm diagnosis of a severe PLC injury looking for a drive-through sign and whether there is a meniscofemoral or meniscotibial injury [107].

Grade III injuries with varus alignment need an HTO first. A medial opening wedge has the advantage of not leaving any lateral scar tissue for the planned second stage PLC reconstruction.

Timing

Acute repair tends to have better results than late reconstruction due in part to restoration of native anatomy and normal biomechanics [32, 33, 35, 105, 108, 109]. However, certain injury patterns are more amenable to successful repair. Avulsion injuries are treated with rigid internal or suspensory fixation and augmenting any questionable tissue with autograft or allograft. If the LCL is injured mid-substance then it should be reconstructed. As part of any acute PLC surgery, any concomitant injuries should be addressed at the same sitting and the common peroneal nerve may need to be released.

Stannard et al. followed 57 tears in 56 patients. There was a failure rate of 37 % (13/35) for those who underwent acute repair and 9 % (2/22) for those who were reconstructed with a modified two-tailed procedure with allograft. The decision to repair or reconstruct was based on the location of the injury to the ligament and the quality of the tissue. If not suitable for a repair, they were reconstructed. Of note, 44 of the patients had multiligament injuries with only 13 having isolated PLC tears. It is noteworthy that the majority of those with multiligament injuries had a staged reconstruction for their cruciate ligament injuries with early ROM starting as early as 10 days. All repairs in the multiligament injured knees were rehabilitated with a level of cruciate dysfunction possibly stressing a healing repair more than a reconstruction [110].

The injury becomes chronic beyond 4–6 weeks and is associated with capsular stretching, extensive rotatory instability patterns, persistent subluxation and arthrofibrosis [105, 106, 108]. From a surgical viewpoint, the pericapsular scarring makes identification and isolation of discrete anatomical structures too difficult to carry out a repair.

Type of Reconstruction

The next decision is whether to perform an anatomic or non-anatomic reconstruction. The earliest reconstructions were non-anatomic and involved non-isometric advancement procedures. These included arcuate complex or proximal bone block advancements, biceps, tenodesis and an ITB sling, amongst others. Noyes and Westin performed an advancement located proximal to LCL and PLC with definitive but lax posterolateral structures. They found that 64 % (14/21 knees) of PLCs were completely stable at a mean follow up of 42 months [111].

Fibula-based techniques were then developed to use a single femoral tunnel and a fibula sling reconstructing LCL and popliteus. Muller was an early advocate for separate LCL and popliteus bundles [112]. Larson also described a fibular-based LCL and PFL [113] (Fig. 9.4).

This evolved into 2 femoral tunnels with a fibula sling to reconstruct the PFL and attempt to control external rotation. The more recent tibia-based or combined tibia-fibula approaches attempt to completely reconstruct the PLC [114–116].

The fibula based reconstructions are less technically demanding and have good outcomes [117].

Noyes and Barber-Westin described a combined tibia-fibula reconstruction of LCL, popliteus with plication of the posterior capsule to reconstruct PFL [118]. With a mean follow up of 4.7 years 93 % of their 14 patients scored normal or near-normal on IKDC.

LaPrade et al. describe two separate femoral tunnels and two separate grafts designed to recreate the anatomical femoral footprints of the LCL and the popliteus tendon [116] (Fig. 9.5). They found that the stability of a grade III reconstructed PLC was comparable to an intact knee in all position except 30° of flexion with a total difference in varus translation of 2.8 mm. They found no evidence for over constraint. Sekiya and Kurtz [119] describe a method using a bifid Achilles tendon graft in a double femoral tunnel technique similar to LaPrade et al. This has the advantages of only using a single allograft and approximating the anatomy of the PFL more closely with the location of the split in the graft.

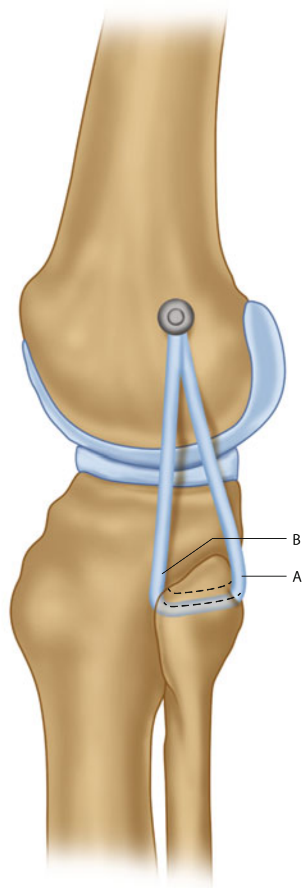

Fig. 9.4 Diagrammatic illustration of the Larson procedure (*A*) PFL (*B*) LCL [2]

In 2006, Yoon et al. [120] reported on the results of their 46 patients using an anatomic reconstruction with a split Achilles allograft in 21 comparing them to a posterolateral corner sling in 25 patients. The reconstruction resulted in less varus laxity and tibial external rotation than did the PLC sling procedures.

In a retrospective case–control study in 2016, Yoon et al. studied patients who had an anatomic PLC reconstruction for a combined varus and rotational instability with a 2-year follow-up [121]. Ten patients who had a tibiofibular-based reconstruction (LaPrade type) were compared to 10 who had a femorofibula-based

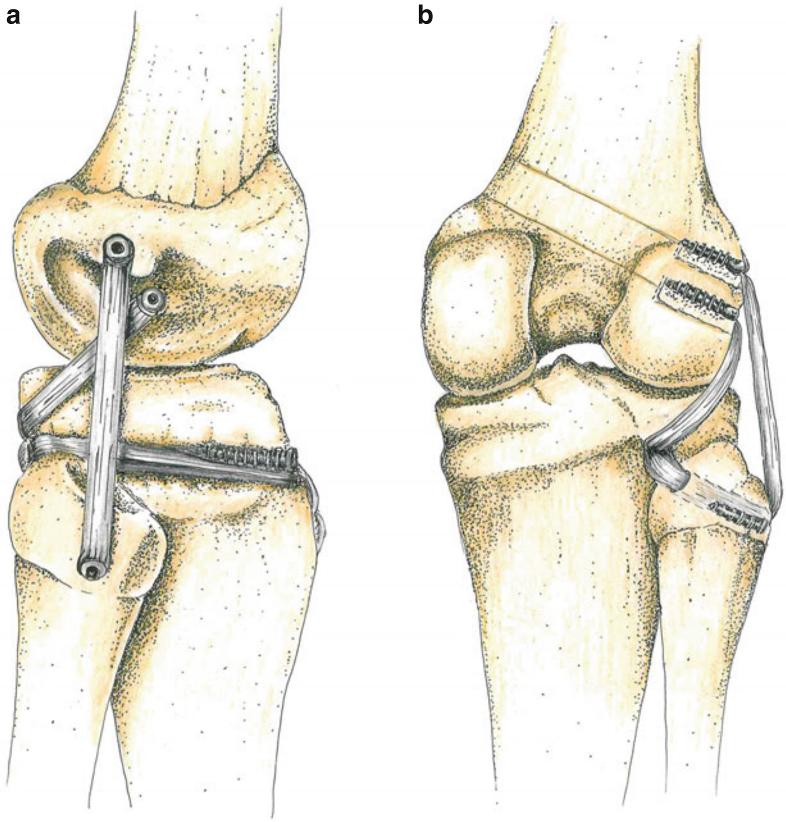

Fig. 9.5 Drawing of the (**a**) lateral and (**b**) posterior knee demonstrating an anatomic reconstruction – LaPrade anatomic reconstruction technique

reconstruction (Yoon type) as a matched control group. All patients in both groups had other ligamentous injuries including concurrent PCL rupture in all cases which was reconstructed in the majority of cases. There was no significant difference in Lysholm, Tegner, IKDC or side-to-side varus laxity. The tibiofibular reconstruction group did have less external rotation at final follow up ($p = 0.044$). This suggested a greater degree of rotational control with a tibial-based construct but the evidence level is weak.

As the reconstructions become more technical, over-constraint is a concern. In cadaveric studies, Nau et al. and Markolf et al. reported over-constraint of internal rotation and varus rotation if the LCL, PFL and popliteus were reconstructed compared to just the static restraints of the LCL and the PFL [122, 123].

The following is an algorithm for operative treatment based on Fanelli's classification [124].

Type A
: The critical point is anatomical reconstruction of popliteus complex with a popliteofibular reconstruction to control rotation. Requires a fibula tunnel and a tunnel at the femoral insertion point of popliteus.

Type B
: Use a figure of eight technique which mimics PFL and LCL. Drill 1 fibula tunnel and 2 femoral tunnels for LCL and popliteus insertions.

Type C
: Use a figure of eight technique with a tibial sling graft. This reconstructs PFL, LCL and popliteus. Needs a tunnel in the tibia as well.

Despite the numerous techniques described in the literature, there are limited data on the long-term outcomes for PLC reconstruction. This is because of the heterogeneity of the clinical population with a high frequency of associated injuries and a mixed number of acute and chronic cases not to mention the lack of consistent outcome measures in the treatment of these injuries.

Operative Technique for an anatomic reconstruction

Position the patient supine with the knee flexed to 80°. A tourniquet is used only when necessary. Mark the landmarks of fibular head, lateral femoral condyle, lateral aspect of trochlea and Gerdy's tubercle. The typical skin incision sits halfway between fibular head and Gerdy's curving upwards towards the lateral femoral condyle.

Dissect the subcutaneous tissues and expose biceps femoris and ITB. Identify the common peroneal nerve at the fibular neck behind the biceps femoris and follow it distally into the anterolateral compartment to ensure no band is compressing it. Retract the biceps and gastrocnemius posteriorly and expose the popliteus and posterolateral capsule.

The standard choice of graft is for two semitendinosus allografts. A guide wire is passed into Gerdy's tubercle, along the posterolateral tibia, just medial to the fibular head, exiting at the musculotendinous junction of popliteus, approximately 1–2 cm distal to the tibial articular surface. Use an image intensifier to check position.

Incise the ITB longitudinally to access distal femur. Drill the tunnel for the popliteus insertion just behind lateral femoral epicondyle.

If the LCL needs reconstructing, drill an oblique tunnel from anterior to posterior proximal fibula and a femoral tunnel immediately anterior to the lateral femoral epicondyle.

Tension with the knee flexed to 30° and internally rotated and fix with an interference screw.

9.4 Rehabilitation

The key is to protect the grafts from posterior and varus forces while the grafts incorporate within the bony tunnels in the first 6–12 weeks and continue to mature after. The aim is to maintain motion and quadriceps strength while minimizing posterior loads on the grafts. This is done with an extension brace and a posterior pad to apply an anterior force to the proximal tibia for 24 weeks [125]. Pierce et al. described a five phase, progressive, goal-orientated rehabilitation programme improved stabilization of the posterior tibial translation, varus and external rotation stresses.

Patients are kept non-weight bearing for 6–8 weeks with passive range starting at 2 weeks but there is no hamstring activation for 3 months. Patellar mobilizations are begun immediately and active quadriceps exercises at 2 weeks in an arc from 0° to 30° up to a maximum of 90° at 6 weeks. It has been shown that the PCL is subjected to considerable force beyond 60° of flexion.

Strength work does not begin for 3 months and return to sport takes 9–12 months.

9.5 Multiligament Injuries

This chapter touches on combined injuries, especially to the PCL and PLC. Multiligament injuries that by definition include both cruciates with combinations of other ligamentous injuries are a separate specialized topic on their own.

Conclusions

Posterior cruciate and posterolateral corner injuries are less common than injuries to the anterior cruciate ligament, often occur alongside other injuries and are frequently missed. A sound knowledge of the mechanism of injury, careful clinical examination, and the use of appropriate imaging techniques prevents under-diagnosis, which may have serious consequences for the patient. If there is doubt as to the extent of the injury, examination under anaesthetic is a helpful diagnostic tool. Timely management, whether conservative or surgical, has the potential to provide restoration of function and improvement in subjective and objective measures of laxity, although longer-term results, in terms of progression to osteoarthritis, are less convincing. The majority of isolated PCL injuries and low-grade isolated PLC injuries may be managed non-operatively; however, surgeons should have a high index of suspicion for associated injuries which necessitate surgical management in a substantial proportion of patients. Several techniques of surgical management have been documented, and are described above, but there is little evidence to decisively choose one technique over another.

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10 Synovitis: Hemophilia and Pigmented Villonodular Synovitis

E. Carlos Rodríguez-Merchán

Abstract

In this chapter, the treatment of chronic hemophilic synovitis and pigmented villonodular synovitis (PVNS) is analyzed. Radiosynovectomy (RS) is the advised first option for the management of chronic hemophilic synovitis; the procedure is highly cost effective in comparison to arthroscopic synovectomy (AS). The second-line recommended therapy is AS. Regarding pigmented villonodular synovitis (PVNS), there are two forms of the disease: diffuse PVNS (DPVNS) and localized PVNS (LPVNS). For both, the surgical options are AS and open synovectomy (OS). In general, the rate of recurrence of DPVNS ranges from 8 to 70 %, and the rate of recurrence of LPVNS ranges between 0 and 8 %. For LPVNS, the two most-reported options are OS and AS. Between these two techniques, no difference has been found in terms of local recurrence (8.7 % for OS and 6.9 % for AS) and postoperative complications (<1 % for OS and 0 % for AS). For DPVNS, the two most-reported options are OS and AS. Between these two courses of treatment, no difference has been encountered in terms of local recurrence (22.6 % for OS and 16.1 % for AS). A lower rate of reported complications between OS (19.3 %) and AS (0 %) has also been found. Internal irradiation or external beam radiation as an adjuvant treatment to surgical synovectomy seems to diminish the rate of local recurrence in DPVNS.

Keywords

Synovitis • Hemophilic synovitis • Pigmented villonodular synovitis Treatment • Radiosynovectomy • Arthroscopic synovectomy • Open synovectomy

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10.1 Introduction

In hemophilia, repeated episodes of joint bleeding due to the lack of one of the coagulation factors (Factor VIII in hemophilia A, Factor IX in hemophilia B) lead to an inflammatory and proliferative synovitis that results in osteochondral damage and joint degeneration (hemophilic arthropathy) [1, 2]. In some cases, aggressive factor replacement therapy combined with physical medicine and rehabilitation is ineffective in halting the bleeding and there is progressive joint destruction leading to musculoskeletal morbidity and poor health related quality of life [3–6]. Removal of the synovium by surgical, chemical or radioactive techniques may be useful to change the natural history of hemophilic synovitis, especially before the damage is irreversible [7].

Pigmented villonodular synovitis (PVNS) is a proliferative synovial disorder of uncertain etiology that may lead to joint destruction and activity limitation. PVNS may have local recurrences and as such can lead to erosive destruction of the involved joint. Open synovectomy (OS) and arthroscopic synovectomy (AS) have been used for the treatment of PVNS of the knee, but it is unknown which technique is most advisable [8–32]. In this chapter, the author has revised current treatment of hemophilic synovitis and PVNS.

10.2 Hemophilic Synovitis

Hemophilic synovitis can be treated by radiosynovectomy (RS), chemical synovectomy (CS) or AS. Ablation of the synovium by RS, CS or AS may be useful to change the natural history of hemophilic synovitis, especially before the damage is irreversible (Fig. 10.1) [33–59].

There is a large body of evidence supporting RS in hemophilia (Table 10.1). The largest such study, performed by Rodriguez-Merchan et al. over a 40-year period, comprises more than 500 cases of RS (knee, elbow and ankle) either with yttrium-90 (Y-90) or rhenium-186 (Rh-186). Between one and three injections were performed with a 6-month interval between them [59]. RS was performed under factor coverage to avoid the risk of re-bleeding during the procedure. For the knee, they used Y-90 at a dose of 185 megabecquerels (MBq) – 1.48 mSv. Rh-186 was used for elbows and ankles. Yttium-90 (Y-90) or Rheinum-186 (Rh-186) emit beta radiation, and have a therapeutic penetration power (TPP) of 1 mm (Rh-186) and 2.8 mm (Y-90). The authors performed joint scintigraphy using a small amount of Tc99 (Technetium-99) after the procedure to check the correct distribution of the radioactive material into the joint. After RS, bleeding frequency declined by 65 %. The size of the synovium (on clinical examination and imaging) declined by 30 % and clinical scores improved by 20 %. However, radiological scores did not improve. The rate of complications of RS was 1 %. The most serious complication was septic arthritis which occurred in 1 patient. Other complications included cutaneous burns if the radioactive material was injected out of the joint, and transient inflammatory reactions following injection which are successfully treated with rest and non-steroidal anti-inflammatory drugs. RS was considered an effective option for the treatment of chronic hemophilic synovitis (Fig. 10.2) [33–70].

Regarding the potential genotoxic effect of RS, no increase in the risk of cancer has been reported in the literature. In 1977, Ahlberg et al. reported chromosome changes in the circulating lymphocytes of patients undergoing Gold-198 (Au-198) RS [47]. However, in 1985 Rivard et al. did not find an increase of chromosome aberrations after ^{32}P RS, reporting <4 % extra-articular escape of radiation compared to intra-articular counts [58]. Several authors have reported chromosomal changes in patients after RS. In 2000, Falcón de Vargas and Fernandez-Palazzi reported reversible premalignant or nonspecific changes in chromosomal structure in the lymphocytes of hemophilia patients after using Au-198, Rh-186, Y-90; such changes persisted in a low proportion of metaphases up to 2 years after injection when ^{198}Au was used [51]. In 2001, Fernandez-Palazzi and Caviglia reported that chromosomal changes could be observed in equal numbers and frequency in patients after RS as in non-irradiated patients.

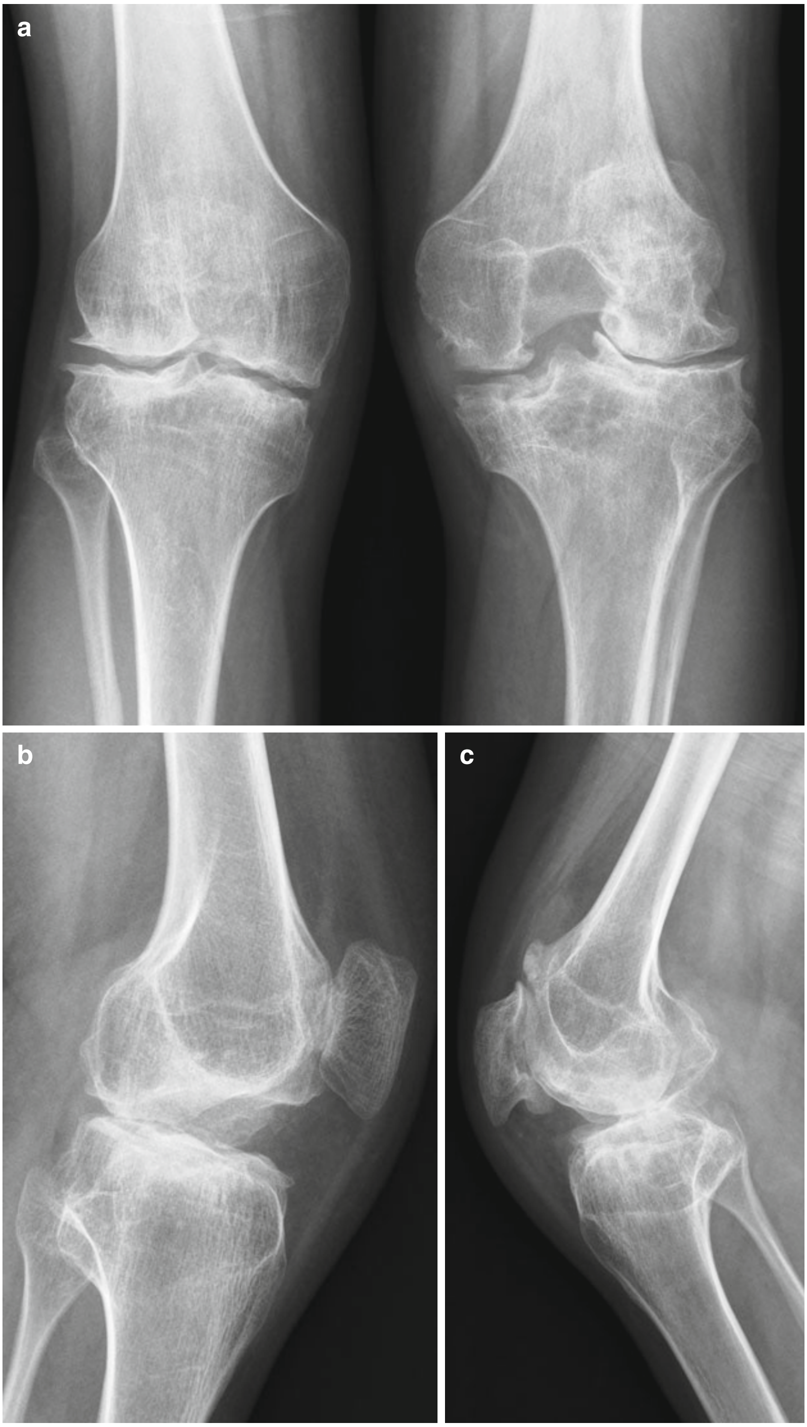

Fig. 10.1 Advanced bilateral hemophilic arthropathy of the knee: (**a**) Anteroposterior view; (**b**) lateral radiograph of the right knee; (**c**) lateral view of the left knee. As chronic hemophilic synovitis was not controlled, it led to severe joint degeneration (hemophilic arthropathy) eventually

Table 10.1 Main data from the review of the literature on radiosynovectomy (RS) in chronic hemophilic synovitis

Author [Ref]	Year	Age (years)	Number of joints (patients)	Isotope used	Inhibitor (yes/no)	Effect on bleeding	Effect on joint
Ahlberg [68]	1977	NA	NA	Au-198	No	Replacement therapy was reduced to less than 1/4 and the effect persisted over at least 3 years	Synovitis was cured in 50 % of cases and given a notable improvement in about another 40 %
Ahlberg and Petterson [47]	1979	NA	NA (27)	Au-198	No	RS decreased the bleeding frequency	RS stopped the progress of the arthropathy if applied at an early stage when the arthropathy was still reversible. If RS was begun at a later stage, the arthropathy seemed to progress independently of the effect on the bleeding frequency
Rivard [58]	1985	12–28	22 (14)	P-32	4 patients yes, 10 patient no	Frequency and importance of bleeding decreased in all patients	Effect on ROM was best in knees; six of the seven treated improved and one was unchanged. In elbows, flexion-extension was improved in four cases, unchanged in five and decreased in one; pronation-supination was decreased in four cases. ROM was not affected in shoulders and ankles except for internal-external rotation which was improved in two of three shoulders treated
Lofqvist [55]	1992	<15	13 (5)	Au-198	All patients yes	9/13 with 0 joint bleeding for 6 months and 6/9 for 1 year	NA

Author [Ref]	Year	Age (years)	Number of joints (patients)	Isotope used	Inhibitor (yes/no)	Effect on bleeding	Effect on joint
Lofqvist [69]	1997	3–40	19 (9)	Au-198	All patients yes (<10 BU)	11 joints 0 bleeding for 6 months and 6 joints 0 bleeds for 1 year	5 joints good, 1 fair and 11 poor after 18–182 months
Siegel [33]	2001	NA	125 (81)	P-32	No	54 % resulted in complete cessation of bleeding into the treated joint after the procedure. Of patients 18 years old and younger, 79 % had a greater than 75 % reduction in bleeding incidence, and of patients older than 40 years, only 56 % had a similar reduction	73 % of patients reported improved ROM of the treated joint
Fernandez-Palazzi and Caviglia [34]	2001	6–40	104 (97)	Au-198 and Rhe-186	No	80 % of excellent results with no further bleeding	NA
Heim [52]	2001	11–15	163 (115)	Y-90	No	Over 80 % of the patients with hemophilia reported a decrease in the number of hemarthroses and 15 % stopped bleeding altogether in the treated articulation	NA
Mortazavi [56]	2007	6–28 (15.9 on average)	66 (53)	P-32	No	In latest follow-up, 77 % of patients reported at least a 50 % decrease in bleeding frequency after treatment. The need for antihemophilic factor consumption dropped by about 74 % post-RS	In most of the injected joints, ROM remained stable or improved

(continued)

Table 10.1 (continued)

Author [Ref]	Year	Age (years)	Number of joints (patients)	Isotope used	Inhibitor (yes/no)	Effect on bleeding	Effect on joint
Calegaro et al. [40]	2009	8–34 (20.6 on average)	NA (31)	Sm-153-HA	No	The reduction in hemarthrosis and use of the coagulation factor was respectively 78 % and 80 % for elbows, 82 % and 85 % for ankles and 30 % and 35 % for knees	NA
Cho et al. [41]	2010	13.8 on average	58 (33)	Holmium-166-chitosan complex	No	The average frequency of bleeding of the elbow joint has decreased from 3.76 to 0.47 times per month, the knee joint from 5.87 to 1.12 times per month, and the ankle joint from 3.62 to 0.73 times per month, respectively	There was no significant improvement of ROM in affected joints
Rodriguez-Merchan et al. [59]	2014	6–53 (23.7 on average)	443 (345) and 57 repeat RS procedures	Y-90 and Rhe-186	Some patients yes	On average, the number of hemarthroses decreased by 64.1 %	The degree of synovitis showed a reduction of 31.3 %
Turkmen et al. [45]	2014	5–39 (16.8 on average)	82 (67)	Y-90	Some patients yes	Joint bleeding was reduced	NA

ROM range of motion
Hemophilic synovitis (*P-32* Phosphorus.32, *Y-90* Yttrium-90, *Rh-186* Rhenium-186, *Au-198* Gold-198, *NA* not available)

Fig. 10.2 Radiosynovectomy (RS) of the knee with Yttrium-90 (Y-90) in a case of chronic hemophilic synovitis

Furthermore, the changes due to the radiation disappeared with time, never reaching more than 2 %, the threshold considered to be dangerous [35].

The report by Dunn in 2002 alerted the community to the occurrence of two cases of acute lymphocytic leukemia (ALL) in children with hemophilia after P-32 RS [64]. The children, ages 9 and 14 years, developed ALL within 1 year of RS. Although a causal relationship could not be established, the authors recommended the use of RS only in patients with clearly defined risk/benefit situations, e.g. the treatment of synovitis in patients with inhibitory antibodies or in extremely non-compliant patients whose bleeding is not manageable with factor replacement alone.

Following this report, two publications by Turkmen et al. showed that RS with Rh-186 and : Y-90 in hemophilic children did not induce genotoxic effects [37, 38]. The effects of specific isotope doses and the number of RS treatments were analyzed by Infante-Rivard et al. [66]. These authors found no increase in the risk of cancer and there was no dose–response relationship with the amount of radioisotope administered or number of RS treatments. This study provided some reassurance of the safety of the procedure but groups of younger hemophilia patients receiving RS may still need further study. To highlight this position, Silva et al. stated that unresolved questions regarding the safety of radiation exposure argues against the use of RS in children with hemophilia [67].

The dose of radiation after RS in patients with hemophilic synovitis is minimal and does not approach dangerous levels. The dose of radiation incurred during a single session of RS is less than that received due to natural sources (approximately 2 mSv –millisieverts per year). It is estimated that the lifetime cancer risk increases about 0.5 % with exposures of at least 100 mSv per year. Knee RS in children provides an approximate radiation dose of 0.74 mSv (90 megabecquerels-MBq) [46]. Although two cases of ALL in children with hemophilia treated with RS have been reported, no causal relationship could be established and no further cases have been reported.

The data suggest that the risk of cancer after RS is not increased. The author recommends that clinicians consider RS in children with hemophilic synovitis when the potential benefits are clearly defined, such as in children with inhibitors or in pediatric patients whose recurrent joint bleeding is unmanageable with factor replacement alone. Importantly, in countries where the availability of factor replacement is limited, RS should be considered early in the patient's clinical course before osteochondral changes are evident. The authors also recommend that clinicians avoid unnecessary radiation exposure whenever possible [59].

In our practice, AS is indicated after the failure of three episodes of RS with 6-month intervals. In our series, only 28 (6.3 %) joints eventually had to be subjected to AS or total knee arthroplasty (TKA) [59]. We have never used CS because it requires multiple painful weekly injections. Global results of treatment with CS in the literature have been less favorable than with RS [71].

RS is our first option for treatment of hemophilic synovitis; the procedure is highly cost effective in comparison to AS (€3,000 per injection). Our second-line therapy is AS (€ 60,000 per procedure) [59].

10.3 Pigmented Villonodular Synovitis (PVNS)

Pigmented villonodular synovitis (PVNS) is a rare proliferative process of the synovium which most commonly affects the knee (Fig. 10.3) and

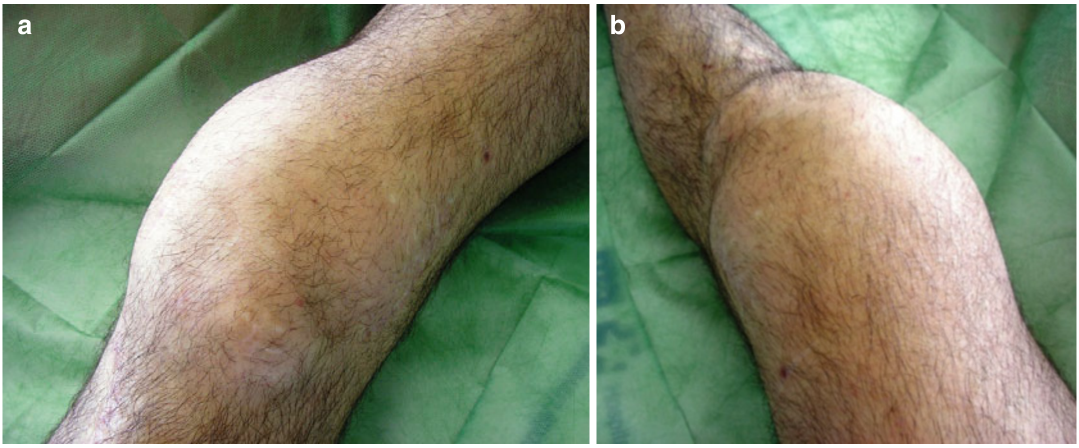

Fig. 10.3 Clinical view of the knee of a patient with pigmented villonodular synovitis (PVNS): (**a**) lateral view; (**b**) superior view

occurs in either a localized (LPVNS) or a diffuse form (DPVNS). The effect of different methods of surgical synovectomy (either AS or open synovectomy, OS) and adjuvant radiotherapy on the rate of recurrence is unclear [8–32]. While there are several studies of synovectomy in PVNS, most are small series. Table 10.2 summarizes main data in patients with PVNS of the knee according to the literature.

10.3.1 Arthroscopic Synovectomy

The evidence for the use of AS in PVNS generally consists of small series. In the series of Baroni et al., nine patients, aged between 2 and 15 years and with a mean follow-up of 8.5 years were treated [8]. They performed OS in five patients and AS in four. There were no cases of recurrence following synovectomy and no complications were found.

Rhee et al. [9] performed AS in 11 patients, with a mean follow-up of 112 months. They had two cases in which lesions recurred. In two cases the patient developed secondary osteoarthritis requiring surgical intervention. A total of 13, with an average age of 28 years, were treated by Kubat et al. [10] with AS. The mean follow-up was 7 years. There was only one recurrence. No relevant complications were found. Thirty patients were treated by AS by Loriaut et al. [12]. The average follow-up was 75 months. The median age of the patients was 46 years. No postoperative complications occurred. De Carvalho et al. [14] treated eight patients with AS and an additional posterior incision for extra-articular lesions, followed by local adjuvant radiotherapy. Patients were followed up for a mean of 8.6 years. In no case was radiographic osteoarthritis progression detected. Three patients had late minor complications (peripatellar pain, articular effusion, and persistent quadricipital muscle atrophy). Only one patient (12.5 %) presented with recurrence of the disease.

The largest series is that of Colman et al. [18], who reported 48 patients treated by all-arthroscopic, open posterior with arthroscopic anterior, or open anterior and open posterior synovectomy. Mean follow-up was 40 months. Recurrence rates were lower in the open/arthroscopic group compared with the arthroscopic or open/open groups: 9 % versus 62 % versus 64 %, respectively. Progression of arthritis occurred in 17 % of the study group. They found no difference between groups with regard to progression. The most common complication was hemarthrosis, which they had to drain in three patients (6 % of the total study group), but there were no differences between groups. Open posterior with arthroscopic anterior synovectomy

Table 10.2 Main data in patients with pigmented villonodular synovitis (PVNS) of the knee according to literature on the topic

Author [Ref]	Year	Surgical technique	*N*	Mean age (years)	Mean follow-up (years)	Mean recurrence rate (%)	Mean complication rate (%)	Mean development of OA rate
Baroni [8]	2010	AS	9	2–15	8.5	0	22	NA
Rhee [9]	2010	AS	11	NA	NA	18.1	0	18.1
Kubat [10]	2010	AS	13	28	7	0	0	NA
Akinci [11]	2011	OS	19	42.2	6.8	26.3	15.7	NA
Loriaut [12]	2012	AS	30	46	6.2	0	0	NA
Nakahara [13]	2012	OS	17	33.2	8	11.7	11.7	23.5
De Carvalho [14]	2012	AS	8	NA	8.6	12.5	37.5	0
Chen [15]	2012	OS	19	NA	3.5	10.6	0	0
Park [16]	2012	OS and PR	23	NA	9	17.4	0	NA
Liu [17]	2012	OS, AS and PR	97	33	5	8.2	5.1	NA
Colman [18]	2013	OS and AS	48	NA	3.3	9	6	17
Ma [19]	2013	OS	75	46	NA	14.7	0	NA
Jain [20]	2013	AS	40	NA	7	32.5	0	NA
Auregan [21]	2013	AS	23	41	7	0	0	NA
Gu [22]	2014	AS and OS	NA	NA	1	12	0	NA
Mollon [23]	2014	AS and OS	18	39	6.7	13	20	NA
Jabalameli [24]	2014	OS	26	28	4	7.7	0	NA
Lalam [25]	2015	RTA	3	NA	NA	33.3	0	NA
Li [26]	2015	AS and PR	28	NA	4.5	0	0	NA
Xie [65]	2015	AS and OS	233	36	NA	20	0	NA
Yang [66]	2015	AS, OS and PR	47	NA	1.3	17	0	NA
Isart [67]	2015	AS	24	NA	5	61.5	0	NA

N number of patients, *AS* arthroscopic synovectomy, *OA* osteoarthritis, *OS* open synovectomy, *PR* postoperative radiotherapy, *RTA* radiofrequency thermoablation, *NA* not available

provided both low recurrence rates and a low postoperative complication rate.

Jain et al. [20] performed AS in 40 patients. Mean follow-up was 7 years. Twelve (32.5%) patients developed recurrences between 3 months and 2 years. No recurrence was noted after 2 years.

10.3.2 Open Synovectomy (OS)

Akinci et al. [11] performed OS in 15 patients (mean age: 42.8 years). The patients were followed for an average of 6.6 years. Radiotherapy was performed as an adjuvant treatment in one patient with recurrence. Recurrence occurred in five patients. A second OS was performed in four patients. Radiotherapy was used for the remaining one patient. Two patients were operated upon three times. Three patients had a postoperative flexion deformity of 10–25°.

Seventeen patients underwent OS in the report of Nakahara et al. [13]. Their average age was 33.2 years. The mean postoperative follow-up was 5.4 years. Two of 17 patients had recurrence. Two knees had a slightly reduced range of motion and four knees progressed to osteoarthritic changes. Ma et al. [19] performed OS in 75 patients (81 joints). The average age of patients was 46 years. Twelve patients had recurrent lesions; four patients had more than two recurrences.

Table 10.3 Rates of recurrence and complications of localized pigmented villonodular sinovitis (PVNS) and diffuse PVNS in relation to the type of surgery [31]

	Open synovectomy (OS)		Arthroscopic synovectomy (AS)	
Type of disease	Rate of recurrence	Rate of complications	Rate of recurrence	Rate of complications
Localized PVNS	8.7 %	<1 %	6.9 %	0 %
Diffuse PVNS	22.6 %	19.3 %	16.1 %	0 %

10.3.3 Recent Reviews and Meta-analyses

Rodriguez-Merchan compared OS with AS for PVNS of the knee in terms of rates of recurrence, complication and osteoarthritis [30]. Ten studies specifically on this topic were analyzed; all were retrospective case series, and thus level of evidence was low. Respectively after OS and AS, the overall recurrence rates were 26.7 and 24.6 %, the overall complication rates were 5.7 and 3.2 %, and the overall osteoarthritis rates were 20 and 17.1 %. AS and OS did not differ significantly in terms of rates of recurrence, complication, and osteoarthritis. The author concluded that prospective randomized studies were needed to confirm the findings.

A systematic review by Auregan et al. [31] included studies that reported the results of treatment for any type of PVNS between 1950 and 2013. Sixty studies (1,019 patients) met the inclusion criteria. Thirty-five presented data on the treatment of localized PVNS (LPVNS), 40 on diffuse PVNS (DPVNS), one on extra-articular LPVNS and seven on DPVNS with extra-articular involvement. Many therapeutic options were reported. Depending on these options, DPVNS recurred in 8–70 % of the patients and LPVNS recurred in 0–8 %. For LPVNS, the two most often reported options were OS and AS. Between these two courses of treatment, no difference was found in terms of local recurrence (8.7 % for OS and 6.9 % for AS) and postoperative complications (<1 % for OS and 0 % for AS). For DPVNS, no difference was found in terms of local recurrence (22.6 % for OS and 16.1 % for AS). However, Auregan et al. found a lower rate of reported complications in AS (with no cases having complications) compared to OS (19.3 %). Internal irradiation or external beam radiation as an adjuvant treatment to surgical synovectomy seemed to decrease the rate of local recurrence in DPVNS cases which had a high risk of recurrence. Finally, the authors reported great heterogeneity in the way the functional results were reported, and they suggested that no valid conclusions could be made based on the data they extracted. They found no difference in local recurrence rates after OS or AS for either LPVNS or DPVNS. However, a lower rate of postoperative complications was reported after AS for DPVNS (Table 10.3).

Mollon et al. [32] reported a systematic review on the use of surgical synovectomy to treat PVNS of the knee. A meta-analysis included 630 patients, 137 (21.8 %) of whom had a recurrence after synovectomy. For patients with DPVNS, there was low-quality evidence that the rate of recurrence was reduced by both OS and combined OS and AS compared with AS. There was only very low-quality evidence that the rate of recurrence of DPVNS was reduced by perioperative radiotherapy, or that the rate of recurrence of LPVNS was the same regardless of surgical approach. This meta-analysis suggested that OS or AS combined with perioperative radiotherapy for DPVNS was associated with a reduced rate of recurrence. The authors stated that large long-term prospective multicenter observational studies, with a focus on both rate of recurrence and function, were required to confirm their findings.

Conclusions

Radiosynovectomy (RS) is the recommended first option for the treatment of chronic hemophilic synovitis; the procedure is highly cost effective in comparison to arthroscopic synovectomy (AS) (€3,000 per injection). The second-line recommended therapy is AS (€60,000 per procedure). Regarding PVNS, many therapeutic options have been reported. Depending on these options, DPVNS recurs between 8 and 70 % of cases and LPVNS recurs much more rarely (0–8 % of cases). For LPVNS, the two most-reported options were OS and AS. Between these two courses of treatment, no difference was found in terms of local recurrence (8.7 % for OS and 6.9 % for AS) and postoperative complications (<1 % for OS and 0 % for AS). For DPVNS, between the same two courses of treatment, no difference was found in terms of local recurrence (22.6 % for OS and 16.1 % for AS), but AS was associated with a lower rate of complications (0 %, compared to 19.3 % for OS). Internal irradiation or external beam radiation as an adjuvant treatment to surgical synovectomy appears to decrease the rate of local recurrence in DPVNS cases with a high risk of recurrence.

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Cartilage Injuries of the Knee

11

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Abstract

Cartilage injuries of the knee are common and can be managed in a variety of ways. Choice of management must take into account the demands and expectations of the patient as well as the size, depth and location of the defect, how chronic it is and any concomitant intra-articular, extra-articular or general conditions. Previous treatments and injuries should be addressed before starting the treatment. Defect size is one of the most important parameters to take into account for pre-operative planning. All symptomatic cartilage defects of type III or IV using the International Cartilage Repair Society grading system should be managed surgically. No more than three localized cartilage defects can be treated successfully at the same time. Cartilage lesions can be managed with a wide spectrum of different techniques that can be used isolated or in combination according to surgeon's choice. These techniques can be classified into five main groups: (1) cartilage reparative techniques (microfracture, drilling, cartilage shaving), (2) cartilage restoration techniques (fresh allograft transplantation or autograft transplantation – mosaicplasty), (3) autologous chondrocyte implantation (ACI) or matrix-induced autologous chondrocyte implantation (MACI), (4) other biologic approaches, including repair with gene-activated matrices (GAMs), scaffolds, mesenchymal stem cell (MSCs), platelet-rich plasma (PRP), growing factors (GRs), magnetically labelled synovium-derived cells (M-SDCs), bone morphogenetic proteins (BMPs) and elastic-like polypeptide gels, and (5) other therapies such as osteotomies, stem cell-coated titanium implants and chondroprotection with pulsed electromagnetic fields (PEMFs).

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Knee • Cartilage • Injuries • Treatment

11.1 Introduction, Etiology and Epidemiology

Cartilage injuries of the knee are common. Newer imaging techniques have determined that cartilage lesions are more frequent than previously thought, as the cartilage can be damaged even if the lesion is not seen at arthroscopy [1]. Although trauma and instability are the most frequent causes, many etiologies can cause cartilage injuries (Table 11.1). They affect about 900,000 patients per year in the USA, resulting in more than 200,000 surgical procedures [2].

Cartilage injuries in sportsmen are thought to be caused by mechanical injury in the context of a blunt trauma or ligament disruption (i.e. anterior cruciate ligament - ACL). Blunt injury can also cause bone oedema [3]. The key point on cartilage injuries is the degree of cell death and matrix disruption. Chondrocytes die as a direct consequence of trauma. Matrix disruption derives from the inability of the remaining chondrocytes to maintain the matrix. In the acute setting, just 2 % of traumas lead to a chondral defect, but on medial to long term, it could be developed on 20 % of cases.

Table 11.1 Etiology of knee cartilage lesions

Trauma (blunt impacts, fractures, traumatic patellar dislocation, polytraumatic injuries)
Axial malalignment of the knee
Partial or total meniscectomy
Instability (ACL, PCL, etc.)
Osteochondritis dissecans
Osteoarthritis
Rheumatoid arthritis, lupus, gout, psoriasis, etc.
Genetic factors
Obesity
Cartilage tumours
Microtrauma
Iatrogenic (surgery, infiltration, medicaments, etc.)

ACL anterior cruciate ligament, *PCL* posterior cruciate ligament

The natural history of these lesions is not well-known. As we do not know which lesions become symptomatic and what governs the evolution of symptoms, it is difficult to determine the effect of interventions on that natural history [4]. This is particularly important in smaller lesions. In larger lesions, the tendency appears to be for the lesion to enlarge over time, becoming more symptomatic as it becomes bigger.

The most common locations for chondral lesions are the patella (36 % of total) and medial femoral condyle (34 %). They rarely occur in isolation; 37 % of cases have a medial meniscal tear and 36 % occur alongside an anterior cruciate ligament injury [5–7].

Most studies and most surgeons use the Outerbridge classification to categorize these lesions [8], but other options have been proposed (Table 11.2) including that of the International Cartilage Repair Society (ICRS) which we will use in this chapter. In the past, the great majority of lesions were treated non-surgically, but many options now exist for the management of osteochondral lesions, from non-invasive treatments to the most recent biological strategies (Tables 11.3 and 11.4). The main objectives of the treatment are pain relief and improvement of function.

Choice of management strategy must take into consideration the demands and expectations of the patient as well as the size, depth and location of the defect, the degree of chronicity and any concomitant intra-articular, extra-articular or general conditions. Previous treatments and injuries should be addressed before starting the treatment [9].

As the population ages, and sporting injuries become more common, the prevalence of symptoms related to cartilage injuries are increasing. The challenge we face as orthopaedic surgeons is that the potential of cartilage to regenerate is virtually non-existent, in contrast to other tissues we encounter such as bone [10]. As a result, a number of approaches have been proposed to

Table 11.2 Classifications of cartilage lesions

Grade	Modified Outerbridge	ICRS (International Cartilage Repair Society)	ICRS
0	Normal cartilage	Intact cartilage	Intact cartilage
I	Softening and swelling	Chondral softening or blistering with intact surface	Superficial affection (soft indentation, fissures, cracks)
II	Fragmentation and fissures in area less than 0.5 in. in diameter	Superficial ulceration, fibrillation or fissuring less than 50 % of depth of cartilage	Lesion less than half the thickness of articular cartilage
III	Fragmentation and fissures in area larger than 0.5 in. in diameter	Deep ulceration, fibrillation, fissuring or chondral flap more than 50 % of cartilage without exposed bone	Lesion more than half the thickness of articular cartilage
IV	Exposed subchondral bone	Exposed subchondral bone	Exposed subchondral bone

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Table 11.3 Operative interventions capable of covering a knee cartilage defect completely

Refixation of detached cartilage fragments
With reabsorbable pins
With screws
With fibrin glue
With osteochondral plugs
Cartilage reparative strategies
Aggressive debridement (spongialisation): removal of the subchondral plate to expose cancellous bone
Bone marrow stimulation techniques: drilling, microfractures, abrasion arthroplasty (gentle superficial burring of the subchondral plate)
Cartilage restorative techniques
Transplantation of fresh osteochondral allografts
Transplantation of osteochondral autografts (plugs-mosaicplasty)
Autologous chondrocyte implantation (ACI) and matrix-induced autologous chondrocyte implantation (MACI)

address chondral injuries. Despite this, there is limited evidence that any surgical procedure significantly alters the natural history of these lesions. While bone marrow techniques such as microfracture continue to play a role, recent techniques such as osteochondral auto- or allograft, techniques based on the stimulation or growth of chondrocytes such as ACI (autologous chondrocyte implantation) or MACI (matrix-induced ACI) and even genetic techniques are becoming more available for clinical use and it is likely that the indications for these techniques will expand in the coming years [11].

The purpose of this chapter is to determine how to diagnose and manage an osteochondral injury and to summarise the different options which are available in clinical use today [12, 13].

11.2 Physiology of Articular Cartilage

Hyaline articular cartilage is a hypocellular and viscoelastic tissue. It covers bone in synovial joints, providing a low-friction surface, with a coefficient of friction even lower than that of ice on ice [14]. Hyaline cartilage is a specialized tissue, with specific architecture to provide an excellent vehicle for transmission of forces with little friction while being resistant to injury. The key of the tissue architecture is in the cartilage matrix, formed by chondrocytes.

The cartilage can be divided in four zones: superficial, middle, deep and tidemark layer. Superficial layer is mainly composed of collagen with minimal proteoglycans, oriented parallel to the joint surface, and contains a high concentration of water concentration, which decreases the friction. The chondrocytes in this layer are flat or disc-shaped.

The middle layer has oblique collagen fibers, with increased proteoglycan content and a lower concentration of water. This matrix is produced by round chondrocytes. No progenitors exist in this layer.

The vertical disposition of collagen type II in the deep layer confers special resistance to

Table 11.4 Indications for the different knee cartilage repair/restorative techniques

Technique	Advantages	Disadvantages	Indications
Bone marrow stimulation	No donor site morbidity Arthroscopic procedure	Fibrocartilage	Lesion size <4 cm^2; age <40 years; focal contained lesions in the femoral condyles
Transplantation of fresh osteochondral allograft	No size limitation Hyaline cartilage	Arthrotomy Graft availability High cost Prolonged return to sports	Large uncontained lesions and lesions with bone and cartilage loss
Transplantation of osteochondral autograft (plugs-mosaicplasty)	Mature hyaline cartilage Primary bone healing Fast recovery	Technically difficult Donor site morbidity	Femoral lesions <2.5 cm^2
Autologous chondrocyte implantation (ACI) and matrix-induced autologous chondrocyte implantation (MACI)	No size limitation Hyaline-like cartilage	Arthrotomy High reoperation rate High cost Prolonged rehabilitation	Chondral lesions >2 cm^2

compression forces. These fibers are attached to the calcified layer known as the tidemark, which is a barrier to nutrient diffusion [15].

Proteoglycans give a negative charged environment within articular cartilage and incorporate water in non-weight-bearing situations. On weight-bearing, water leaves the matrix. When the cartilage is damaged, loss of proteoglycans and water alter the normal mechanical properties and joint function.

In general, articular cartilage is unable to heal. The absence of an intrinsic source of new chondrocytes and the fact of being an avascular tissue are the main reasons. The density of chondrocytes and their ability to divide decrease with ageing. Despite this, lesions in which subchondral bone is affected tend to heal, at least clinically. This repair of the chondral surface is determined by the mobilization of cells of subchondral bone marrow, including multipotential cells and chondroblasts [16].

11.3 Clinical Presentation and Physical Examination

There are no pathognomonic symptoms of knee cartilage defects. Consequently, it is necessary to conduct a thorough assessment including symptoms, examination and imaging studies to identify a cartilage lesion as the cause of symptoms [17].

Any type of impact leading to increased force transmission through the articular surface can cause alterations in the ultrastructure of the cartilage. Accumulation of microtrauma or high-energy trauma can lead to macroscopic cartilage damage [18].

Many cartilage lesions can be asymptomatic [19], especially those which are small or away from weight-bearing areas in the knee joint. As lesions become larger, they tend to become more symptomatic. Symptoms are more frequent in those lesions affecting the patellofemoral joint and weight-bearing surfaces of tibiofemoral compartments.

Hyaline cartilage has no sensory innervation, in contrast with the rich innervation of the subchondral bone. When a cartilage defect is full-thickness, contact with the subchondral plate leads to pain. Overload on the defect can lead to enlargement of the injury and increasing symptoms. Breakdown products of the defect produce synovitis, with effusion, liberation of enzymes, pain and increased degradation of the cartilage. If cartilage repair occurs, new tissue is produced to fill the defect, with relief of symptoms and delay of development of osteoarthritis.

Most of patients with osteochondral lesions suffer repetitive episodes of swelling and pain with loading. Pain is typically associated with weight bearing and is located in the area where the defect is. In tibiofemoral defects, pain is usually located at the joint line and it is associated with weight bearing. Posterior defects are more symptomatic in knee flexion. Trochlear defects are associated with crepitus and large effusions while these symptoms are not so frequent in condylar defects. This sign can be useful to differentiate trochlear defects of patellofemoral pain syndrome, where swelling usually is not present. Unless there is a concomitant meniscal tear, mechanical symptoms are not a common feature of chondral defects [17]. Other symptoms can be present as catching, locking and popping, especially if there are loose bodies in the joint.

Physical examination should be focused to identify where the painful lesion is (femoral condyle, patellofemoral joint, etc.), to confirm if the symptoms are related to the presence of the lesion, and to rule out concomitant pathologies which may affect results of chondral surgery or require treatment in themselves [20].

Most symptomatic lesions are painful with palpation, weight-bearing or overload manoeuvres. Standing analysis (and full-length radiographs of the lower limb) should be performed to rule out any malalignment, including rotational deformity. Gait, muscle power, flexibility and contractures should also be evaluated.

Ligament injuries have to be ruled out, as instability has been demonstrated to lead to inferior results in cartilage restoration techniques [21]. Anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), collateral ligaments and both posterolateral and posteromedial corners should be examined (see Chaps. 1, 8 and 9). Attention should be paid to the medial patellofemoral ligament (MPFL) in patellofemoral defects, as it can be insufficient as a consequence of a traumatic patellar dislocation. Some specific manoeuvres as Wilson's test can be performed if an osteochondral defect or osteochondritis dissecans of the medial femoral condyle is suspected [22].

11.4 Imaging Diagnosis

11.4.1 Radiography and CT

A standard study of knee cartilage lesions should include an AP (anteroposterior) radiograph in full extension (to evaluate femorotibial compartments), AP in 45° of flexion or Rosenberg view (to assess the joint space in flexion), lateral view, and sunrise or Mercer-Merchant view (for the patellofemoral compartment). All AP and lateral views should be performed standing. A standard full-leg radiograph should be obtained to study the mechanical and anatomic axis [18], as normal alignment is necessary for success in cartilage restoration techniques. An osteotomy may be performed in presence of abnormal axis.

Radiographs (Fig. 11.1) provide good information about cartilage surfaces but they are more useful in more advanced stages of cartilage lesions or osteoarthritis [17]. Computed tomography (CT) provides good information about the bony characteristics of the joint. Another potential advantage of using CT is that it provides imaging at different flexion angles or muscle contraction states, which can be helpful in assessing patellofemoral mechanics. CT arthrogram may be helpful and is more accurate than arthroscopy to determine the presence of subchondral bone cysts [14].

11.4.2 Magnetic Resonance Imaging (MRI)

MRI studies are the most accurate test for assessing cartilage in the knee (Fig. 11.2). It is indicated when an intra-articular pathology (i.e. pain, swelling or mechanical symptoms) is present, despite relatively normal weight-bearing radiographs.

Gradient-echo sequences are able to differentiate articular cartilage from the articular fluid. T2-weighted sequences are better to discriminate subchondral bone oedema from the cartilage surface. Newer MRI techniques, such as T1rho mapping, T2-mapping, sodium imaging and delayed gadolinium-enhanced MRI of cartilage are becoming more and more frequent in the clinical setting and provide useful information about cartilage ultrastructure, morphology, biology and metabolism [18].

While there are many sequences described for cartilage, the most important detail is to be able to discriminate between healthy and

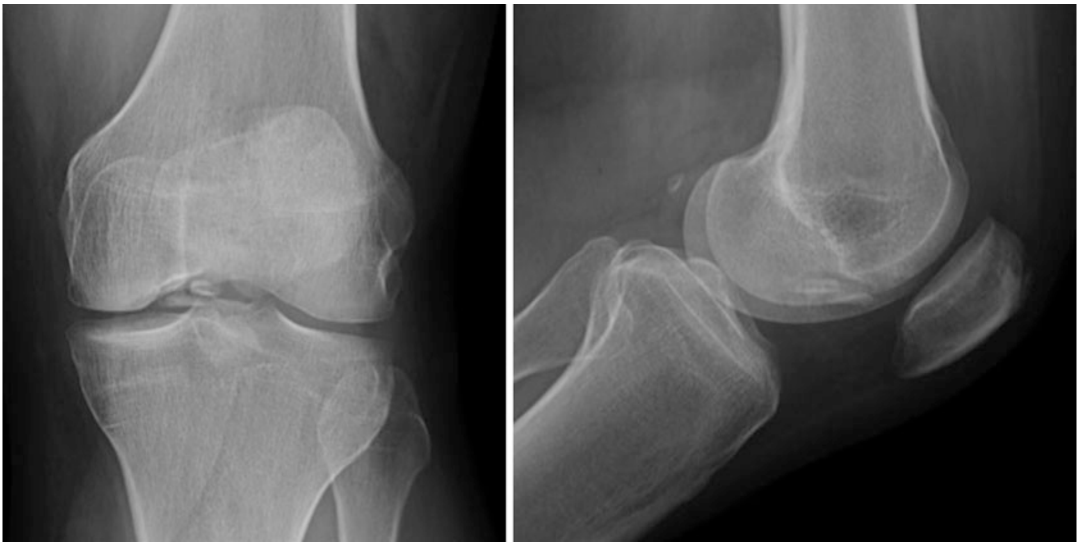

Fig. 11.1 Anteroposterior (*left*) and lateral (*right*) radiographs of an osteochondral lesion with loose bodies in the medial femoral condyle of the knee

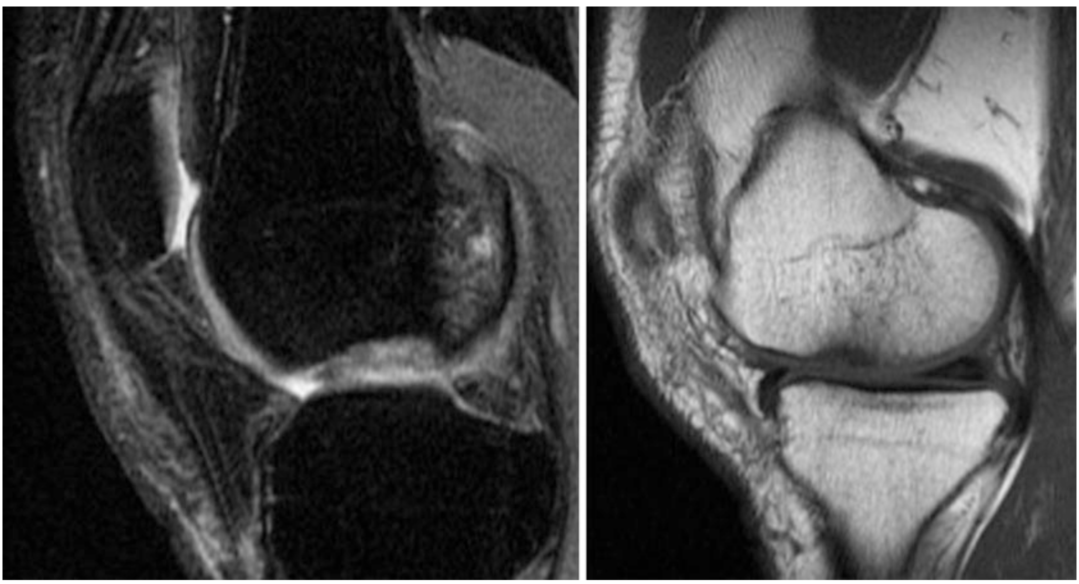

Fig. 11.2 Two lateral images of an MRI of a knee with a chondral lesion

affected cartilage. It is important to review all sequences and all slices (axial, sagittal and coronal). Bone oedema is a sign of mechanical overload and its extension is usually correlated with pain and symptoms [23]. It is also important to know the state of the ligaments and extra-articular soft tissues.

11.5 Non-operative Treatment

Conservative treatment is the first line of treatment for all chondral defects. Despite this, the presence of symptomatic loose bodies is an indication for surgical treatment to retrieve them, even if the defect is not being treated [17].

Table 11.5 Conditions influencing prognosis and post-operative results

Muscular imbalance/Quadriceps weakness
Genetic predisposition
Malalignment (Varus/valgus; patella infera/lateral)
Activity loading, torsional load, impact
High BMI, obesity
Instability (ACL, PCL, multiligamentary)
Meniscus tears
Subchondral bone oedema
Size of defect
Location of defect
Age
Duration of symptoms
Previous surgeries
Smoking status

ACL anterior cruciate ligament, *PCL* posterior cruciate ligament, *BMI* body mass index

Physical measures such as weight loss, exercise and bracing can be helpful in the initial stages of the treatment. Obesity is an independent risk factor for symptomatic arthritis of the knee and isolated weight loss decreases symptoms [24]. Muscle imbalance, especially quadriceps weakness, is a contributing factor to symptomatic osteoarthritis, and strengthening can be helpful to partially relieve symptoms. However, high-level activities and those including impact and torsion are not recommended, because they can increase symptoms [25]. Bracing can be helpful in cases of a ligament deficit or to offload unicompartmental lesions [26].

Pharmacologic treatment includes painkillers, non-steroidal anti-inflammatory drugs (NSAIDs), chondroitin and glucosamine. Steroids and viscosupplementation can be useful for the management of the pain in mid-term, but they have no effect on the natural history of the defect.

11.6 Predictors of Outcome Following Cartilage Injury and Treatment

Prior to surgery, a full evaluation of the state of the ligaments and menisci, bone oedema and any extra-articular pathology has to be performed. Several factors may adversely affect the natural course of the injury and the results of surgery (Table 11.5).

11.6.1 Ligament Status

Chondral lesions are often the result of ligamentous injuries [27, 28]. ACL, PCL and multiligament injuries are related to an increased presence of cartilage damage as ligament-deficient knees load differently from normal knees. Cartilage restoration techniques have poor results in ACL deficient knees. Careful examination of the ACL, including anteroposterior and rotational stability, should be done. If anteroposterior or rotational instability exists, concomitant ACL reconstruction is recommended with cartilage restoration techniques.

PCL and multiligament injuries should be ruled out. Inferior results have been reported for ligament reconstructions when cartilage injuries are present [28].

11.6.2 Meniscus Status

The meniscus has several functions in the normal knee. It acts on synovial fluid circulation, stability (as AP stability is provided by the posterior horn of medial meniscus in ACL deficient knees) and has an essential role in transmission of forces between femur and tibia.

In full extension, about 50 % of forces are transmitted by the meniscus, but in full flexion, it is about 90 % [29]. Tears of the meniscus (and meniscectomy) reduce the load-sharing ability of the meniscus and increase the forces transmitted through the cartilage. This increases the incidence of chondral lesions, and cartilage restoration techniques should only be performed in the presence of an intact meniscus. Procedures such as meniscal repair or transplant may be necessary to preserve the restored chondral surface [30].

Meniscus repair or transplantation can be done at the same time as cartilage restoration or in a staged procedure.

11.6.3 Body Mass Index (BMI)

Obesity and increased body mass index (>30) has been related to poorer results following microfracture and ACI [31, 32]. No effect of

BMI has been demonstrated in the context of fresh osteochondral transplantation, as there are mature living chondrocytes and a complete chondral matrix.

11.6.4 Bone Oedema

Subchondral bone and hyaline cartilage have been identified to work as a functional unit, the osteochondral unit [33]. Several changes, such as thickening and stiffening of the subchondral plate and thinning of cartilage, are developed in chronic lesions. In these conditions, a thin cartilage layer can be more susceptible to suffer injury as a result of the application of shear forces. When bone oedema is present, complete substitution of the affected bone is recommended. This can be done in auto- or allograft transplantation or the sandwich technique for ACI (which will be covered in more detail later in the chapter).

11.6.5 Malalignment

If malalignment is identified on pre-operative long-leg standing radiographs, correction of the axis should be carried out at the same time or before a cartilage technique is performed. Classically, slight overcorrection is recommended, aiming to move the mechanical axis to transect the healthy tibiofemoral compartment. In the setting of a patellofemoral lesion, several osteotomies have been proposed. Antermomedial or anterior transfer of the tibial tubercle can be useful to offload the patellar cartilage surface. If a trochlear lesion is present, there is no osteotomy which has been shown to offload the trochlear surface [18].

11.6.6 Size of the Defect of Cartilage and Location

Defect size is one of the most important parameters to take into account during pre-operative planning. It has been seen that defects >1 cm become more and more symptomatic as the defect grows [34]. Despite the correlation between symptoms and defect size, the most important parameter is not only the absolute size of the defect, but its size in relation to the total cartilage surface. The surface affected determines the best technique to choose (Table 11.4).

In terms of location, it is clear that a lesion will not have the same clinical relevance if it is located in a non-weight-bearing area. Location can also help determine which procedure to employ for the treatment of the lesion.

Femoral condyle injuries may be treated with techniques such as ACI, microfracture or allograft/autograft transplantation. Cartilage in this zone is thick and bone marrow oedema is frequent.

Tibial plateau lesions are not frequent. Cartilage is thinner and bone oedema is again common. The treatment of these defects is not easy to perform and it is especially important to address and treat all the conditions that can lead to mechanical overload (i.e. meniscal tears, malalignment) in order to avoid the necessity to treat the cartilage or to improve the results of whatever treatment is necessary. Allograft transplantation, retrograde drilling and microfracture have been proposed.

Large patellofemoral lesions remain a major challenge. Even given that microfracture is not the best technique for large defects, allografts are not such a reliable option for trochlear or patellar defects, in comparison with femoral condyle defects. One reason is that it is extremely difficult to have an allograft with the exact size and shape of the complex anatomy of the patellofemoral surfaces. Despite this situation, good outcomes have been reported as for allograft as a salvage procedure [35].

11.6.7 Other Factors

Overall it appears that patients younger than 30 years have the best results due to the lack of secondary osteoarthritis [36], but in recent studies, age does not seem to be a determinant factor in a proven isolated chondral defect [37], because older patients can achieve good functional results with restorative techniques. Duration of symptoms, previous surgery, smoking status and gender can influence in the result of cartilage treatment.

11.7 Indications for Surgical Management

All symptomatic cartilage defects of ICRS type III or IV should be managed surgically. No more than three localized cartilage defects can be treated successfully at the same time [4]. As a large proportion of chondral lesions are asymptomatic, the surgeon must determine what degree of symptomatology to attribute to the lesion and how much is caused by concomitant conditions such as meniscal tears or instability. In the next section, different techniques for treating cartilage injuries will be described.

11.8 Clinical Repair of the Cartilage

When cartilage repair is achieved, there are many different repair tissues, depending on the technique used and intrinsic and local factors. Fibrous tissue, transitional tissue, fibrocartilage, hyaline cartilage, articular cartilage, bone or a mixture of these tissues can be obtained.

11.9 Treatment of Focal Cartilage Lesions

11.9.1 Classification of Techniques

Cartilage lesions can be managed with a wide spectrum of different techniques. These techniques can be used isolated or in association according to surgeon criteria.

These techniques can be classified into five main groups: (1) cartilage reparative techniques, including aggressive debridement or bone marrow stimulation (e.g. microfractures, drilling, cartilage shaving), (2) cartilage restoration techniques, where the objective is to restore the articular surface with autograft or allograft (fresh allograft transplantation or autograft transplantation (mosaicplasty) are included in this group), (3) autologous chondrocyte implantation (ACI) or matrix-induced autologous chondrocyte implantation (MACI), (4) other biologic approaches such as gene-activated matrices (GAMs), scaffolds, mesenchymal stem cell (MSCs), platelet-rich plasma (PRP), growth factors (GRs), magnetically labelled synovium-derived cells (M-SDCs), bone morphogenetic proteins (BMPs) and elastic-like polypeptide gels, and (5) non-biological approaches such as osteotomies, stem cell-coated titanium implants, and chondroprotection with pulsed electromagnetic fields (PEMFs). We will cover the first three of these groups, which are the techniques in widespread use clinically.

11.9.2 Cartilage Reparative Strategies

This group includes all techniques that aim to achieve coverage of subchondral bone with repair (scar) tissue, using the natural ability of the bone to heal in response to injury. The objective is to achieve a blood clot with growth factors of several progenitor cell lines, which will form repair tissue to cover the defect. In most cases, the tissue obtained is fibrocartilage, mostly formed by collagen type 1 fibers, which are less resistant to shear forces than collagen type 2 (which is present in true hyaline cartilage) [15].

In the classic study of Neher et al. [38], analysing tissue formed following drilling, microfracture and cartilage abrasion, clinical failure was reported in defects >3 cm^2 at a mean of 2.5 years of follow-up; it was concluded that these techniques are useful only for the treatment of small defects.

Arthroscopic debridement and microfracture are the first line of treatment for articular cartilage defects. That is because they are low cost and not technically demanding. Given that no special equipment is required, they have the advantage of being able to treat lesions incidentally encountered during an arthroscopy for other reasons.

Cartilage debridement or chondroplasty is indicated for the treatment of incidental lesions encountered during arthroscopy or in low-demand patients. It can be a good option for the initial treatment of a large lesion not suitable for microfracture or osteochondral graft transfer. Debridement can be performed with a shaver, burr or radiofrequency probe. Good results have been reported with debridement in terms of functional scores at 5 years in over 50 % of patients [39]. It seems to not negatively influence future treatments such as ACI, in contrast to microfracture [40].

Microfracture of subchondral bone is the most widely used technique (Fig. 11.3). It was introduced by Steadman [41], being a modification of the classical technique of drilling described by Pridie [42]. It is important to curette the damaged cartilage to stable vertical walls while removing the calcified layer of the tidemark. After that, individual microfractures are performed, penetrating through the subchondral bone. The objective is to obtain a clot composed of marrow derived cells, which will develop repair tissue. Continuous passive motion is thought to help cartilage nutrition and differentiation, but no clinical evidence of efficacy exists. It takes about 3 months to develop a complete repair tissue in the defect site, so it seems reasonable to limit weight bearing during this time.

Indications for microfracture have recently been refined. It is especially indicated in young patients (<35–40 years) with small defects (<3 cm^2).

Up to two thirds of patients have a real and continuous improvement. Worse results and early deterioration were seen in larger defects and patellofemoral location [43]. Microfracture is as cost-effective as osteochondral transplantation at 10 years follow-up [37] for the treatment of isolated femoral cartilage defects. Despite this, no differences between ACI, microfractures, and osteochondral transplantation were seen in a recent systematic review [4]. Microfractures for small lesions in patients with low post-operative demands provide good clinical outcomes at short-term follow-up, but after 5 years, failure can be expected, regardless of lesion size [44]. In contrast, patients are least likely to return to sports after microfracture compared with those who received ACI or osteochondral autograft/allograft. The prognosis is

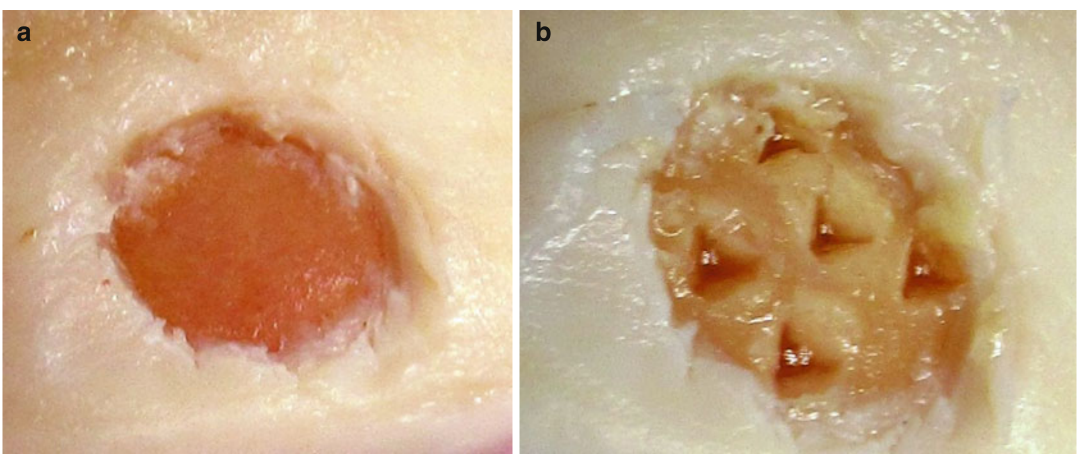

Fig. 11.3 Microfractures in a cartilage injury of the knee: (**a**) chondral lesion after arthroscopic debridement: (**b**) same lesion after microfractures

better if the patient is young, has had a short preoperative duration of symptoms, has not undergone previous surgical interventions, complies with a rigorous rehabilitation protocol and the cartilage defect is small [45].

11.9.3 Cartilage Restorative Strategies

Osteochondral autograft transfer (OATs) or mosaicplasty is useful for the management of small (<2 cm^2) defects in the femoral condyles and trochlea [46]. However, it is not useful for patellar defects.

The most utilized technique is the use of trephine to harvest plugs of bone and mature cartilage from non-weight-bearing parts of the knee, and it can be performed open or arthroscopically. Usually, plugs are harvested from the intercondylar notch or the lateral or medial trochlear ridges.

The main advantages of this technique is that it allows a rapid return to sport (between 4 and 8 months); the resultant tissue is mature autologous hyaline cartilage and increased function in comparison with pre-operative status is seen [47].

The main limitation of this technique is the limited autograft available and the donor site morbidity. This is encountered specially in small knees, where a small lesion can represent a big proportion of the total surface of the cartilage. A specific complication of the technique is the necrosis of central plugs surrounded by other plugs, as they do not have contact with healthy surrounding bone. It is not well known what happens in terms of the donor site in mid to long-term follow-up.

It is usually indicated as first option for young patients with small defects (1–1.5 cm^2), when microfracture is not indicated or is not accepted by a high-demand patient. Good long-term results have been reported, with limited diminution of activity level in sportsmen [45, 48]. It is also at least as cost-effective as microfractures [49].

In a recent systematic review of Level I and II studies by Lynch et al. [50], it was reported that OATs/mosaicplasty improves clinical outcomes in comparison with the pre-operative state, and that patients can return to sports as early as 6 months after the procedure. They conclude that mosaicplasty (Fig. 11.4) is well indicated in lesions smaller than 2 cm^2, but that there is a risk of failure about 2–4 years after the procedure. Nevertheless, more studies are needed to accurately refine the indications of this technique. In another systematic review, no significant differences between cartilage reparative techniques, ACI and mosaicplasty were reported in terms of function and pain at mid-term follow-up [51], and no sufficient evidence of long-term results is present [52].

Osteochondral allograft transplantation is the last main restorative cartilage technique. Its main limitation is limited avaibility of grafts of a suitable match. Transplantation of fresh tissue is also associated with problems in tissue recovery, storage and delivery for the treatment. Another limitation is that the allograft is size-matched, but not shape-matched, so it is not usually useful for the patellofemoral compartment.

These concerns aside, it is useful for the treatment of large lesions. Osteochondral allograft is an immunoprivileged tissue and presence of viable chondral progenitors has been demonstrated [53]. Another advantage is that there is no limit on the size of the graft. It is indicated in osteochondritis dissecans, osteonecrosis and postraumatic defects [14]. It is of special interest on the treatment of postraumatic defects on tibial plateau or as salvage procedure when other reparative or restorative techniques have failed.

There remain concerns in terms of graft survival at long-term follow-up, specially in young patients [54]. Allograft should be protected for a prolonged period, until total incorporation is achieved; bone incorporation is the key to avoid failure. As the immunogenic part of the allograft is in the bone, the bone layer must be thin but sufficient to sustain a stable fixation (usually <8 mm) [17].

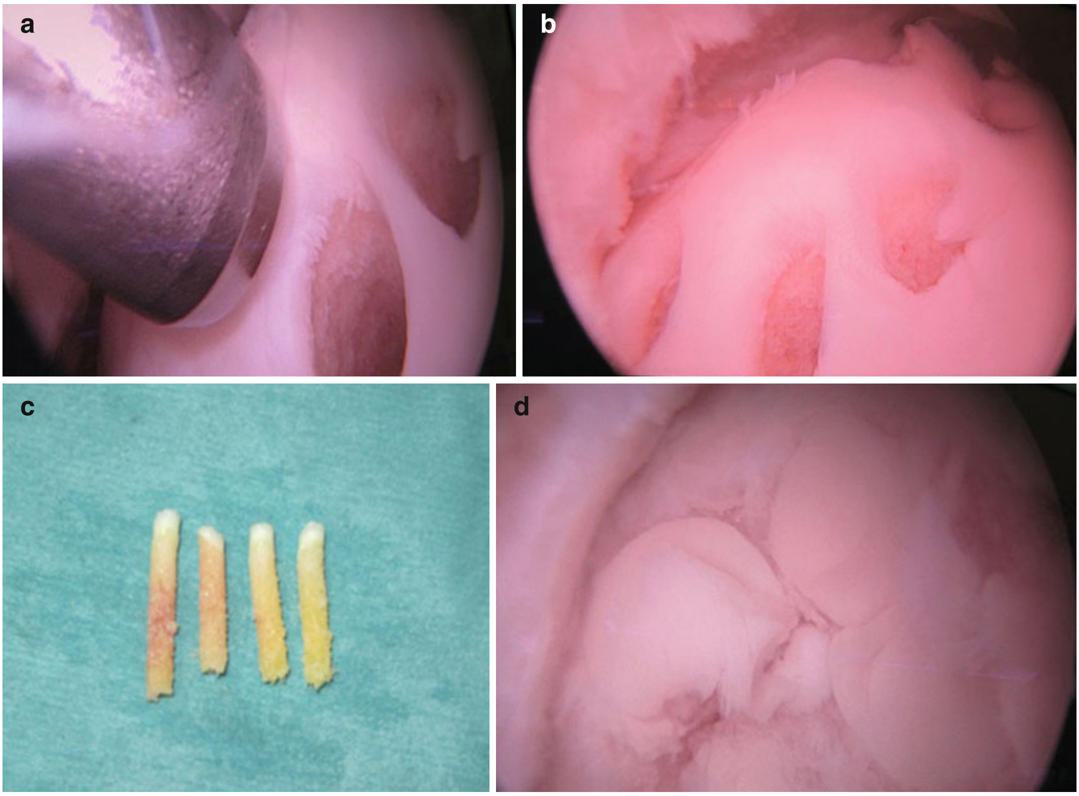

Fig. 11.4 Mosaicplasty in a cartilage injury of the knee: (**a**) cylinder extraction; (**b**) donor site after extraction of cylinders; (**c**) view of the cylinders obtained; (**d**) cartilage defect filled with the cylinders

11.9.4 ACI and MACI

Autologous chondrocyte implantation (ACI) was first performed by Lars Peterson et al. [55]. ACI was usually includes a two-stage procedure. In the first surgery, an arthroscopy is performed, to assess the lesion, to address concomitant injuries (i.e. ACL or meniscal tear) and to harvest cartilage cells (using a 200–300 mg biopsy of all layers of articular cartilage from a minor load bearing site, usually the intercondylar notch or the superior medial margin of the trochlea). In the second surgery, an arthrotomy is performed to implant the cultured cells. This "new" cartilage can be implanted with a periosteal cover [55] or a collagen membrane, avoiding the hipertrophy and perioperative morbidity of the first option [20, 56]. Matrix-induced ACI (MACI) is a scaffold preseeded with chondrocytes that can be implanted arthroscopically and secured with fibrin glue.

The main advantage of ACI is that the chondrocytes form a repair tissue containing type II collagen, which can simulate hyaline cartilage. It is not exactly the same as the native articular cartilage, because there is no true zonal differentiation. Another advantage is that no limit on size exists and the results are more or less reliable for small to big defects. The patient's age is not a limitation for these tecniques, as several studies have demonstrated good results in patients over 40 years old [57, 58].

The main disadvantages of these techniques are the high costs, prolonged rehabilitation period and a substantial reoperation rate for graft failure, debridement of hypertrophic grafts and arthrofibrosis.

The indications for ACI are a symptomatic full-thickness weight-bearing chondral injury of the femoral or patellofermoral articular surface in a physiologically young patient who is able to comply with the rehabilitation protocol. Initially, results on patellofemoral surfaces were not so consistent as in femoral surface, but with correction of maltracking, the results have improved [59]. It can be also indicated in large chronic focal deffects in early osteoarthritis as well as in osteochondritis dissecans with good results [60, 61].

Conclusions

Arthroscopic debridement (cartilage debridement or chondroplasty) and microfracture are the first line of treatments for articular cartilage defects. Bone microfracture is the most widely used technique. Microfracture is especially indicated in young patients (<35–40 years) with small defects (<3 cm^2). Osteochondral autograft transplantation (OATs)/mosaicplasty is useful for the management of small (<2 cm^2) defects in the femoral condyles and trochlea. However, it is not useful for patellar defects. Autologous chondrocyte implantation (ACI/MACI) usually necessitates a two-stage procedure but has the advantage that the chondrocytes form a repair tissue containing type II collagen, which can simulate hyaline cartilage. Multiple experimental techniques exist and it is likely that there will be major new therapies for chondral injury in coming years.

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Septic Arthritis of the Knee

12

Simon D.S. Newman and Charles E.R. Gibbons

Abstract

The knee is the commonest joint in the body to be affected by septic arthritis. Septic arthritis of the knee is usually caused by *Staphylococcus aureus*, but there is a wide spectrum of causative organisms, and Gram-negative organisms are implicated in 10–20 % of cases. The gold standard for diagnosis is joint fluid culture, but microscopy and Gram staining can be negative in up to 50 % of cases, and newer assays such as α-defensin and blood tests such as procalcitonin have potential to improve the diagnostic yield in the acute situation. Septic arthritis is serious with a mortality of over 10 % and permanent joint damage in 40 %. Recognition of symptoms, proper interpretation of investigations and prompt treatment are mandatory to achieve a good outcome.

Keywords

Knee • Septic arthritis • Diagnosis • Treatment

12.1 Introduction

The hot, swollen knee is a common presentation to healthcare professionals in primary and secondary care. Whilst there is a wide differential diagnosis (Table 12.1), arguably the most serious is septic arthritis. The incidence of septic arthritis is 4–10 per 100,000 per year in Western Europe with the incidence rising to 30–100 per 100,000 in those with rheumatoid arthritis [1–3]. The knee, with its extensive synovial lining facilitating microbial ingress, is the commonest joint in the adult body to be affected with in excess of 50 % of confirmed cases and in children, it is affected second only to the hip joint [4].

Septic arthritis is the invasion of a joint by a microorganism that generates a purulent response. In the majority of cases the responsible organism is a bacterium and acute bacterial septic arthritis will form the focus of this chapter, however other pathogens including viruses and fungi may also directly infect joints. Reactive arthritis

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Table 12.1 Differential diagnosis for the acute swollen knee

Crystal arthritides	*Trauma*
Gout	Soft tissue injury
Pseudogout	Spontaneous haemarthrosis
	Fracture
Inflammatory arthritides	
Rheumatoid arthritis	*Infection*
Psoriatic arthritis	Acute bacterial septic arthritis
Reactive arthritis including Reiter's disease	Viral septic arthritis
Ankylosing spondylitis	Fungal septic arthritis
Enteropathic associated arthropathies	Mycobacterial septic arthritis
Lupus	Lyme disease
Familial mediterranean fever	Acute rheumatic fever
Other	*Tumour/Metaplasia*
Osteoarthritis	Pigmented villous nodular synovitis
Avascular necrosis	Synovial chondromatosis
Ochronosis	Sarcoma
	Hypertrophic pulmonary osteoarthropathy

is a separate condition whereby infection elsewhere in the body, commonly the upper respiratory tract, genitourinary system or bowel, leads to joint inflammation.

12.2 Risk Factors

Numerous risk factors exist for septic arthritis (Table 12.2), with skin infection being the most significant. Following arthroscopic surgery, septic arthritis is relatively uncommon with a reported incidence of 0.14 % [5], though infection following anterior cruciate ligament reconstruction is more common with 0.14–2.6 % of procedures affected [6]. The risk of joint infection following intra-articular corticosteroid injection is low with a reported incidence of 0.04 % [2]. Systemic conditions that are associated with the condition include diabetes mellitus, chronic renal failure, malignancy and alcohol abuse. Diabetic patients are at increased risk of septic arthritis due to immune system suppression, propensity to skin infections and ulceration, and the potential requirement for haemodialysis [7]. In a study from the Netherlands, increased age, particularly over 80 years, was associated with an increased risk of septic arthritis [5]. Conditions that lead to joint injury, in particular rheumatoid arthritis and to a lesser extent osteoarthritis, also confer an increased risk of joint infection [2]. The use of anti-tumour necrosis factor alpha (TNFα) therapies is reported to double the risk of septic arthritis in patients with rheumatoid disease [8]. Intravenous drug abusers are at greater risk than the general population of developing polymicrobial septic arthritis, potentially with atypical pathogens including fungi.

Table 12.2 Risk factors for septic arthritis

Extremes of age
Low socioeconomic status
Diabetes mellitus
Chronic renal failure
Malignancy
Rheumatoid arthritis
Osteoarthritis
Alcohol abuse
Intravenous drug abuse
Knee surgery/intra-articular injection
Cutaneous ulcers/skin infection
Immunodeficiency

12.3 Causative Agents

The aetiological agents for septic arthritis vary with age (Table 12.3), but in all age and risk groups, the principal causative organism is *Staphylococcus aureus* followed by other Gram-positive organisms, particularly streptococci [2]. *S. aureus* has a strong predilection for joints due to the presence of multiple microbial surface components that facilitate binding to joint extracellular matrix. Some strains of *S. aureus* (the Panton-Valentine Leukocidin complex) are producers of cytotoxins and can survive within neutrophils; these can be responsible for severe joint infections in otherwise healthy individuals [9]. The finding of

Table 12.3 Agents responsible for septic arthritis

Patient group	Aetiological agent	Source
Neonates	Group B streptococci	Maternal-foetal transmission
	Escherichia coli	
	Staphylococcus aureus	
Children (<3 years old)	*Streptococcus pyogenes*	Bacteraemia
	Streptococcus pneumoniae	
	Staphylococcus aureus	
	Kingella kingae	
	Haemophilus influenzae	
Adolescents	*Neisseria gonorrhoea*	
	Pseudomonas aeruginosa	
	Kingella kingae	
	Staphylococcus aureus	
Adults	Gonococci	Genitourinary tract or pharyngeal infection
	Staphylococcus aureus	Bacteraemia
	Streptococci	
	Haemophilus influenzae	
	Pseudomonas aeruginosa	
	Kingella kingae	
	Moraxella osloensis	
	Arcanobacterium haemolyticum	
	Mycoplasma hominis	
	Mycobacterium marinum	
	Shigella sp	
	Salmonella sp	
	Ureaplasma urealyticum	
Bite wounds		
Human	*Eikenella corrodens*	
	Staphylococcus aureus	
	Group B streptococci	
	Oral anaerobes	
Rat	*Staphylococcus aureus*	
	Streptobacillus moniliformis	
	Spirillum minus	
	Streptococci	
Cat/dog	*Staphylococcus aureus*	
	Pasteurella multocida	
	Pseudomonas sp	
	Moraxella sp	
	Haemophilus sp	
Elderly	Streptococci	
Concomitant diseases	*Enterobacter*	
	Pseudomonas aeruginosa	
	Serratia marcescens	
	Salmonella sp	
Immunocompromised	*Mycobacterium tuberculosis*	
Intra-articular injections	*Mycobacterium kansasii*	

(continued)

Table 12.3 (continued)

Patient group	Aetiological agent	Source
Arthroscopy	*Mycobacterium marinum*	
HIV associated	*Mycobacterium avium-intracellulare complex*	
	Mycobacterium fortuitum	
	Mycobacterium haemophilum	
	Mycobacterium terrae	
	Mycobacterium chelonae	
	Nocardia asteroides	
Viruses	Parvovirus B19	
	Hepatitis B or C	
	Rubella	
	Togavirus	
	Chikungunya virus	
	Varicella	
	Mumps virus	
	Adenovirus	
	Coxsackie A9, B2, B3, B4	
	Retroviruses – HIV	
	Epstein-Barr virus	
	O'nyong nyong	
	Ross River	
	Barmah forest virus	
	Ockelbo agent	
Fungi	*Spirothrix schenckii*	
	Coccidioides immitis	
	Blastomyces dermatitidis	
	Paracoccidioides brasiliensis	
	Candida albicans	
	Pseudallescheria boydii	

Adapted from Mathew and Ravindran [3]

methicillin resistant strains of *S. aureus* (MRSA) causing septic arthritis has been a particularly worrying trend over the past decade [2].

Neisseria gonorhoeae has traditionally been considered the principal cause of septic arthritis in the United States, particularly amongst young sexually active individuals [3]. In the 1970s, approximately two thirds of cases of septic arthritis in the United States were gonococcal in origin [10]. As a consequence of effective control programmes, the rate of disseminated gonococcal infection and septic arthritis has significantly decreased. The rate of gonococcal arthritis remains high in developing countries [10].

Gram-negative bacillus infections (*E. coli, Proteus mirabilis, Klebsiella and Enterobacter*) account for 10–20 % of septic arthritis cases and occur in immunocompromised patients, intravenous drug users and proportionately more frequently in older patients due to higher rates of urinary tract infections. Anaerobic bacteria are an infrequent cause of septic arthritis, but can be found in diabetic patients and those who have sustained penetrating trauma to the joint [10].

Common causative agents in children include *S. aureus*, *S. pneumonia* and *Kingella kingae. Haemophilus influenzae B* was a significant cause of septic arthritis in the young paediatric population, but the introduction of a vaccine has led to a marked reduction in infections by this bacterium [11].

12.4 Pathophysiology

Septic arthritis occurs when an infectious agent penetrates the synovium of the joint and initiates a purulent host response. This may occur in the knee via haematogenous spread or direct inoculation of a pathogen into the joint. The synovium is a highly vascular structure with no basement membrane to obstruct the passage of bacteria from the blood stream [1]. Within the joint space, the low fluid shear environment facilitates bacterial attachment and proliferation. Enhanced production of matrix proteins by the host further encourages bacterial adhesion [10]. The bacteria replicate rapidly in the synovial fluid prompting phagocytosis of the microbes by neutrophils, macrophages and synoviocytes. A series of inflammatory mediators are released, with mouse knock-out studies suggesting the particular importance of interleukin (IL) 1β, IL-10 and TNFα in the host defence against *S. aureus* infection [2]. In the immunocompetent individual, this response should be sufficient to clear the pathogen from the joint. However, in the immunocompromised individual, the effects of inflammatory mediators lead directly to joint destruction, and indirectly via synovial hypertrophy and joint effusion that raise the intra-articular pressure which causes synovial and cartilaginous ischaemia [10].

12.5 Clinical Presentation

Septic arthritis of the knee tends to present with a relatively acute history (<48 h) of malaise, swelling, erythema, tenderness and a decreased range of motion of the joint, though these symptoms and signs are not always present and low virulence organisms may produce a more insidious onset [2, 12]. Systemic features of infection such as fever, sweats and rigours are less frequent than may be expected. Fever (>37.5°) is only present in 60 % of patients and a temperature above 39° in only 30–40 % of patients [2, 10]. Poly-articular septic arthritis occurs in 10–20 % of patients and tends to be more common in individuals with significant co-morbidities [10].

The diagnosis of septic arthritis in neonates and small infants can be challenging and may be missed. Swelling, tenderness and restriction of joint movement are the most sensitive signs of septic arthritis in children under 3 months [13]. Though it should be borne in mind that the initial presentation may be vague and the condition should be considered in infants with failure to thrive, irritability, anaemia and tachycardia [10].

12.6 Diagnostic Tests

A variety of investigations are available to help the clinician make the diagnosis of septic arthritis. However, no one test is sufficiently specific and sensitive to reliably diagnose all cases. As a consequence, test results need to be considered in conjunction with the clinical picture.

12.6.1 Synovial Fluid

The gold standard for the diagnosis of septic arthritis requires the isolation of a microorganism from the joint either directly from microscopy of synovial fluid or following culture [3]. The aspiration of synovial fluid from any potentially infected knee joint is crucial and should be performed before the administration of antibiotics. Care should be taken to avoid aspiration of the knee joint through regions of superficial infection, including cellulitis, which may inadvertently inoculate bacteria into an uninfected joint. Meticulous aseptic technique should be used for all joint aspirations.

Infected synovial fluid is usually turbid, but may not be frank pus. The fluid should be sent for immediate Gram stain and microscopy, though this returns positive results in under 50 % of cases [1]. Polarised light microscopy should also be requested to exclude crystal arthropathies. Culture of synovial fluid for aerobic, anaerobic, mycobacteria and fungi should be performed. A multi-disciplinary approach with the involvement of local microbiology services is important. Synovial fluid culture is reported as being positive in two thirds of cases of non-gonococcal septic arthritis [1], though higher rates may be achieved in experienced units. There is a debate over whether synovial fluid should be injected into blood culture bottles to improve the diagnostic yield; this is currently unresolved and local microbiological guidance should be sought [2, 10].

Synovial fluid white blood cell (WBC) analysis is a potentially useful test with the probability of septic arthritis rising from a pre-test value of 27–64 % with a WBC count of 50,000–100,000 mm^3 and 83 % with a count over 100,000 mm^3 [3]. Inflammatory and crystalline arthritis also increases the WBC count, with lower counts (15,000–50,000 mm^3) more frequently associated with these conditions rather than septic arthritis. There is considerable overlap between the ranges for septic arthritis and inflammatory conditions so WBC counts alone are not diagnostic [10].

Synovial fluid glucose levels decrease in septic arthritis and protein levels, including lactate dehydrogenase (LDH), increase. However, measurement of these parameters is of limited clinical use due to the relatively low specificity of these tests [3]. Cytokine assays for TNF α, IL-1β and IL-6 have been used, but again suffer from low specificity limiting their use in clinical practice.

A number of synovial fluid biomarkers for periprosthetic joint infections have been investigated including α defensin, neutrophil elastase 2, bactericidal/permeability increasing protein, neutrophil gelatinase-associated lipocalin and lactoferrin [14]. An α defensin assay is now available for clinical use for diagnosing peri-prosthetic joint infections, but it is not validated for use in native joint septic arthritis and the manufacturer has stated it is not sufficiently accurate for this purpose [15].

Polymerase chain reaction (PCR) based tests are useful for the detection of bacterial DNA. However, there are issues with contaminants providing false positive results and the tests will detect dead as well as living bacteria. The use of PCR has not been shown to be any more useful than cultures in streptococcal or staphylococcal infection, though it is useful for the identification of *Kingella kingae*, anaerobic bacteria and mycobacteria [10].

12.6.2 Blood

Blood cultures should be obtained prior to the commencement of antibiotics and are positive in 50–70 % of cases of septic arthritis [1]. Blood tests usually show a leucocytosis, increased erythrocyte sedimentation rate and C-reactive protein. However, these tests are non-specific and the absence of elevated acute phase reactants does not necessarily exclude septic arthritis [10]. Whilst these tests are not diagnostic, their measurement is useful in assessing response to treatment.

Procalcitonin is a potential serum biomarker for the differentiation of septic arthritis and inflammatory arthritis. It was found to have a sensitivity of 59.3 %, specificity of 86 % and an accuracy of 75.3 % in one study [16]. CD64, a neutrophil marker, has also shown promise in diagnosing septic arthritis in patients with rheumatoid arthritis, with a sensitivity of 76 % and specificity of 94.4 % [17].

12.6.3 Imaging

Imaging modalities are of limited use in septic arthritis of the knee. Plain radiographs may indicate underlying conditions such as rheumatoid arthritis that predispose to septic arthritis. The initial appearance of plain radiographs of the knee in septic arthritis may be essentially normal aside from evidence of an effusion. As the condition progresses, osteopenia develops in the surrounding bone and eventually joint space narrowing occurs [10]. The superficial nature of the knee means there is little need for additional imaging techniques, such as magnetic resonance imaging (MRI), Computed tomography (CT), ultrasound or nuclear medicine modalities in the diagnosis of adult septic arthritis of this joint. However, in neonates and infants, ultrasound may be beneficial in confirming the presence of an effusion and facilitate guided aspiration of the knee; we find eutectic mixture of local anaesthetics (EMLA) cream for anaesthetising the skin helpful in these circumstances. MRI may also be useful in children when making the diagnosis of osteomyelitis of the proximal tibia or distal femur.

12.7 Treatment

Septic arthritis is an emergency that necessitates prompt treatment. The purpose of surgery is to decompress the joint and remove microorganisms and enzymatically active material from the joint cavity [18]. Little evidence exists for the optimum method of removing purulent material from the joint. Rheumatology texts frequently cite repeated needle aspiration of the joint as a preferred option [2, 10, 19]. In our opinion this approach is not ideally suited to large joints such as the knee for which aspiration to dryness may be challenging [20].

Surgical intervention in the form of arthroscopy is preferable as it permits direct inspection of the articular surfaces, lavage of the joint cavity and debridement of necrotic tissue. Synovectomy, either total or subtotal, is not usually required in the initial surgical procedure for acute septic arthritis, though may be considered in cases of delayed presentation or in patients who require more than one surgical procedure due to persistent infection [21, 22]. The optimum volume of lavage required for treatment of septic arthritis of the knee is unknown and is likely to vary according to the size of the joint, though 10 l of saline has been suggested [23]. If using suction devices or arthroscopic shavers as an outflow, care needs to be taken to avoid the so called “highway effect” whereby the flow of saline circumvents large portions of the joint by travelling directly between inflow and outflow cannulae [23].

Arthroscopic procedures have gradually replaced open arthrotomy for septic arthritis of the knee due to the argument that less arthrofibrosis develops and faster rehabilitation is achievable [18]. Staging of joint infections, such as the Gächter system (Table 12.4), has been used by some surgeons to guide surgical management. Arthroscopic intervention is advocated in Gächter stages I-III, with repeat arthroscopies performed if sepsis persists. Open arthrotomy has been advised for stage IV or for persistent sepsis despite multiple arthroscopies, this occurs in 0–10 % of patients [24].

The number of arthroscopic procedures required varies according to the infecting microorganism and the timing of surgery after the onset of infection [24]. A single procedure is frequently all that is required. Dave et al. reported successful treatment of knee septic arthritis with a single arthroscopic procedure in 75 % of 79 patients [18]. The use of irrigation and drainage systems post arthroscopy has been suggested to reduce reoperation rates. Using such a system, Yanmis et al. achieved 95 % clearance with a single procedure in 20 patients and in a further retrospective study of 39 patients, the use of an irrigation and drainage system was associated with a shorter hospital stay than with arthroscopy alone [25, 26]. In our practice, we prefer to avoid external drainage but instead plan for a further arthroscopic washout of the joint within 48 h of the initial surgery.

Table 12.4 Gächter staging of joint infection

Stage	Description
I	Opacity of fluid, redness of the synovial membrane, possible petechial bleeding, no radiological abnormalities
II	Severe inflammation, fibrinous deposition, pus, no radiologic abnormalities
III	Thickening of the synovial membrane, compartment formation (“sponge-like” arthroscopic view, especially in the suprapatellar pouch), no radiologic abnormalities
IV	Aggressive pannus with infiltration of the cartilage, possibly undermining the cartilage, radiological signs of subchondral osteolysis, possible osseous erosions and cysts

Adapted from Ateschrang et al. [23]

Antibiotic treatment is an essential component of the treatment of bacterial septic arthritis. In the majority of cases, the initiation of antibiotic therapy should be delayed until after blood and synovial fluid samples have been sent for microscopy and culture. No randomised controlled trials have directly compared antimicrobial regimes for septic arthritis nor determined the optimal duration of treatment. A large systematic review and meta-analysis found no difference in the outcomes between antimicrobial regimens, so initial therapy should include broad spectrum antibiotics with consideration given to potential organisms on the basis of patient co-morbidities and the outcome of any Gram stain

[27, 28]. Subsequent antimicrobial treatment should be directed by the results of cultures and local prescribing guidelines.

With respect to duration of antibiotic therapy, this will be determined by the microorganism and response to treatment. Gonococcal arthritis usually requires 7–14 days of intravenous ceftriaxone with 7 days of additional doxycycline or azithromycin to cover concomitant *Chlamydia trachomatis* infection. In non-gonococcal septic arthritis, the recommended duration of intravenous therapy is 2–4 weeks [27]. In the UK, a common regime is 2 weeks of parenteral antibiotics followed by 4 weeks of oral therapy [29]. The injection of antibiotics directly into the joint is not required as adequate concentrations are generated in synovial fluid with systemic administration [23]. Intravenous corticosteroids as an adjunct to the use of antibiotics in the treatment of septic arthritis in children have been shown to reduce morbidity and duration of antibiotic therapy [30, 31]. However, a recent systematic review concluded there is insufficient information to recommend the use of corticosteroids in the treatment of adult septic arthritis [32].

Prolonged joint immobilisation is not necessary following septic arthritis and animal studies have suggested it may accelerate cartilage damage [33]. Passive range of motion exercises should be encouraged, and as the synovitis settles, more aggressive physiotherapy may be required to restore function.

12.8 Prognosis

The mortality rate of monoarticular septic arthritis has been reported as around 11 %, rising to 30 % in patients with polyarticular, non-gonococcal disease [34, 35]. Permanent impairment of joint function may occur in up to 40 % of patients [36]. Paediatric patients with knee septic arthritis are at risk of the early development of osteoarthritis. Adults are at risk of chondral damage, joint stiffness and secondary osteoarthritis. Poorer prognosis is associated with elderly patients with impaired immune responses and in those with pre-existing joint disease. Delay to treatment is also associated with a worse prognosis, with Balabaud et al. reporting inferior outcomes in patients with a longer duration of symptoms before treatment [37]. Wirtz et al. reported superior outcomes in patients in whom treatment was started in the first 5 days compared to 5–10 days after the onset of symptoms [38].

Successful primary Total knee replacement (TKR) following septic arthritis is achievable, but is associated with a higher risk of subsequent infection even if the surgery is performed many years after the joint sepsis has clinically resolved [39]. In cases where infection is believed to have resolved, the subsequent infection rate has been reported as up to 9.7 % [40]. Though not our preferred practice, some authors have suggested that in cases of ongoing infection, a two-stage procedure may be performed with initial joint preparation, insertion of an antibiotic impregnated cement spacer and a period of culture guided antibiotic therapy before a second stage prosthesis implantation [41, 42].

Conclusions

The knee is the commonest site for septic arthritis in the adult population and second commonest in the paediatric age group. It is a serious condition associated with significant morbidity and mortality without prompt treatment. Diagnosis may be difficult, though the development of new biomarkers for clinical use could assist with this in the future. Arthroscopic treatment has become the predominant initial method of management, though further studies are required to determine the optimum duration of antibiotic therapy.

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Bone Tumors Around the Knee

13

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Abstract

Bone tumors are commonly located around the knee, in the distal femur and proximal tibia and less frequently in the proximal fibula and patella. Treatment of bone tumors depends on the histological grade, the size and location of the tumor and the characteristics of the patient. Generally, benign bone tumors are adequately treated by either an intralesional or a marginal resection. To reduce the risk of recurrence, the intralesional resection may be extended with mechanical, chemical, and thermal adjuncts. Primary bone sarcomas and some aggressive benign tumors require a wide resection. Limb salvage principles are largely employed if neurovascular structures can be preserved and a level of function maintained. After tumor resection with a wide margin, the defect left poses a reconstructive challenge. In this chapter, we will refer to bone tumors that most frequently arise around the knee and may affect adult population. First, we consider the basic characteristics of these tumors and then the surgical treatment, focusing in those techniques that preserve the joint.

Keywords

Knee • Bone tumors • Diagnosis • Treatment

13.1 Introduction

Primary tumors of bone are relatively uncommon, but a significant proportion of cases arise around the knee. It is likely that the distal femur and proximal tibia and fibula are common sites of bone tumor location because they are highly vascularized areas, with very active physes. The patella, however, is only rarely affected. Bone tumors around the knee occur in those ages when

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the skeleton is in growth phase and especially in a range between 5 and 20 years, with the exception of the giant cell tumor and chondrosarcoma which most commonly affect adults.

Any benign or malignant bone tumor can arise in the knee region. Among benign bone tumors, between 30 and 35 % of chondroblastomas, 50 % of osteochondromas and 60 % of giant cell tumors affect this region. Of malignant primary bone tumors, 50 % of osteosarcomas arise here but only 12–15 % of chondrosarcomas. A high percentage of nonossifying fibroma are located at the distal end of the femur, up to 90 % in some series. Aneurysmal bone cysts have a predilection for the proximal tibia [1–4].

Clinical manifestations are pain, but occasionally a mass and swelling can be felt at the tumor site. Some benign tumors and inactive or indolent lesions (such as enchondroma and non ossifying fibroma), have no symptoms or are discovered in a radiological examination for other reasons. Occasionally, tumors present with a pathological fracture. The tumor may cause an irritative effect on the neighboring joint, which can lead to an effusion; this situation is more common in the epiphyseal lesions, as with chondroblastoma.

Plain radiography, computed tomography, bone scan and magnetic resonance imaging, are the mainstays of diagnostic imaging for patients with bone tumors. The biopsy of a suspected bone tumor must be performed with great care and skill, because inappropriate biopsy can compromise the patient's functional prognosis and sometimes their chances of survival. Biopsy can be done percutaneously under radiological control. If a malignancy is suspected, the biopsy must also be performed in the line of the intended approach for definitive resection (the biopsy tract should be excised when definitive surgery is performed) and before starting specific treatment. The biopsy tract must avoid the joint, the popliteal neurovascular bundle and the extensor apparatus.

In this chapter we will refer to bone tumors that most frequently arise around the knee and may affect adult population. First, we consider the basic characteristics of these tumors and then the surgical treatment, focusing in those techniques that preserve the joint.

13.2 Benign Bone Tumors

13.2.1 Chondroblastoma

Chondroblastoma is a benign bone tumor of cartilaginous origin. It is rare, accounting for less than 1 % of all bone tumors and occurs most commonly among people aged 10–20 years and in males. It has predilection for the epiphyses and apophyses, occurring frequently in the long bones; proximal and distal femur, proximal tibia and proximal humerus. An unusual site is the patella [1–4].

Clinically, chondroblastoma presents with joint pain and swelling, eventually joint effusion, stiffness and limitation appears. Radiographs demonstrate a geographic pattern, an osteolytic lesion with a sclerotic margin, 1–5 cm in diameter. Metaphyseal extension and calcification in the matrix may be seen in 30–50 % of cases. MRI can help diagnostically by showing characteristic changes [5]. The tumor may have behavior not normally associated with benign tumors including pulmonary metastases as well as local invasion of bone and soft tissue [6].

Treatment consists of intralesional resection and bone graft. Percutaneous radiofrequency ablation (Fig. 13.1) is an alternative to surgery for treatment of selected chondroblastomas [7].

13.2.2 Osteochondroma

Osteochondroma, or osteocartilaginous exostosis, is the most common skeletal neoplasm. The cartilage-capped subperiosteal bone projection accounts for 35 % of benign and 8 % of all bone tumors, which is probably an underestimate as the majority are asymptomatic and not clinically apparent. Osteochondroma is a benign tumor of young people, 10–30 years of age, with no known sex predilection. Osteochondromas appear in a juxta-epiphyseal location, frequently around the knee. Approximately 15 % of patients have

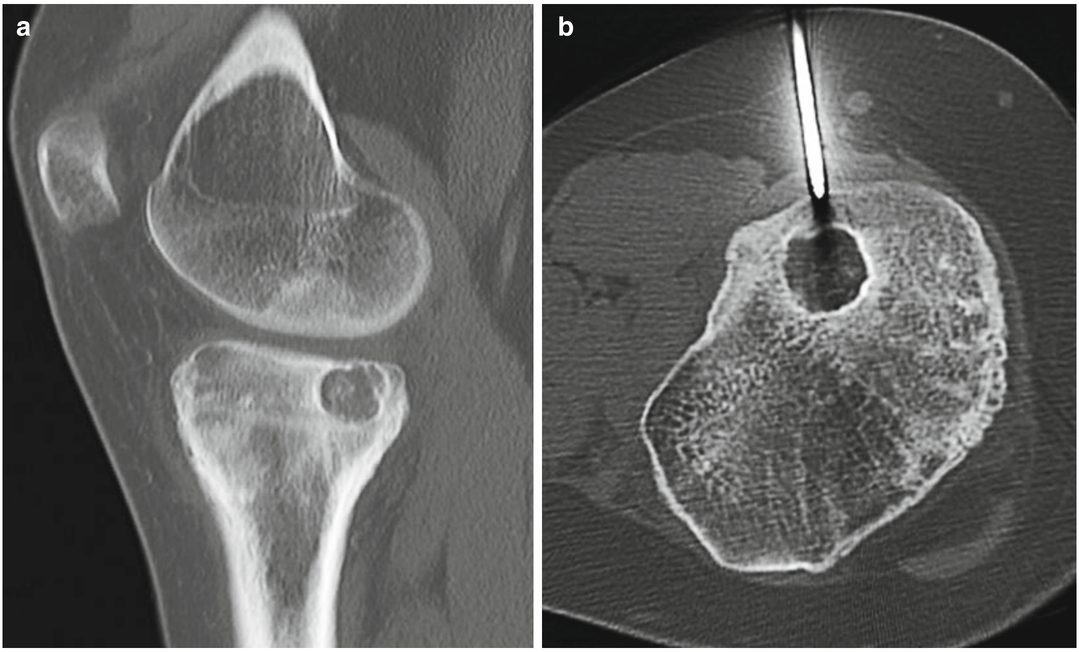

Fig. 13.1 CT scan of a chondroblastoma of the proximal tibial epiphysis. (**a**) It was treated by means of percutaneous radiofrequency ablation. (**b**) Electrode in place

multiple lesions. Hereditary multiple osteochondromatosis is an autosomal dominant condition that can lead to both sessile and pedunculated lesions [1–4].

Many, if not most lesions, are asymptomatic and found incidentally. In symptomatic cases, the most common presentation is that of a hard mass of long-standing duration. Some cases present with symptoms related to secondary complications such as mechanical obstruction, nerve impingement, bursa forming over the osteochondroma, pseudoaneurysm of an overlying vessel, infarction of the osteochondroma or fracture of the stalk of the lesion [4]. After closure of the growth plate in late adolescence, there is normally no further growth of the osteochondroma, so an enlarging tumor in an adult should raise concern of malignant transformation. This occurs in less than 1 % of patients with solitary and approximately 1–3 % of patients with hereditary multiple osteochondromatosis [8].

Plain radiographs are normally enough to diagnose an osteochondroma. It is a metaphyseal lesion, appearing as a sessile or pedunculated osseous mass, typically growing away from the adjacent joint. This lesion is in continuity with the medullary cavity and cortex of the bone and is covered by a cap of hyaline cartilage. Computed tomography (CT) is helpful in determining if the marrow and cortices of the lesion are continuous with the bone. Magnetic resonance imaging (MRI) can delineate the relationship of the lesion to other structures and can allow measurement of the thickness of the cartilage cap, which assists in predicting the risk of malignant transformation [8].

Osteochondromas do not always need surgery; only if the symptoms are significant, marginal resection is indicated. Patients with multiple osteochondromatosis should have regular screening exams and radiographs to detect malignant transformation early.

13.2.3 Enchondroma

Enchondroma is a benign hyaline cartilage neoplasm of medullary bone. Most tumors are solitary; however, they occasionally involve more than one bone or more than one site in a single bone. Enchondromas are relatively common, accounting for 10–25 % of all benign bone tumors. Again, the true incidence is much higher since many tumors are detected incidentally and never biopsied. The peak incidence is in the third decade and is equal between men and women. Enchondroma occurs most commonly in the hands and feet; the long bones, especially proximal humerus and proximal and distal femur, are next in frequency [1–4].

Most patients have no symptoms and many cases are detected incidentally in radiographs, MRI or bone scans taken for other reasons. The presence of pain is suspicious for malignant transformation to chondrosarcoma or for the presence of pathological fracture. Multiple enchondromatosis is a non-heritable condition also known as Ollier's disease; multiple enchondromas and soft tissue hemangiomas constitute a condition known as Maffucci's Syndrome. Change in symptoms and extension beyond the bony cortex into the adjacent soft tissue herald the development of chondrosarcoma. Malignant transformation occurs by 40 years of age in approximately 25–30 % of cases of multiple enchondromatosis [4, 9].

Radiographically, enchondromas form well marginated tumors that vary from radiolucent to heavily mineralized. Calcifications throughout the lesion can range from punctate to rings. In larger lesions, the lucent defect has endosteal scalloping and the cortex is expanded and thinned; in long bones, this is considered suspicious for low grade chondrosarcoma. More extensive endosteal erosion, cortical destruction and soft tissue invasion should never be seen in enchondromas. Long bone tumors are usually centrally located within the metaphysis which may extend to the diaphyseal or subarticular region of the bone. CT, MRI and bone scan allow differentiation between an enchondroma and a low grade chondrosarcoma [10].

A solitary painless enchondroma may be observed. Painful or worrisome lesions suspicious for low grade chondrosarcoma should be treated.

13.2.4 Chondromixoid Fibroma

Chondromyxoid fibroma is a benign cartilage tumor that also has myxoid and fibrous elements. It is extremely rare and accounts for less that 1 % of all bone tumors [1]. It presents in the second to third decade and has a male to female ratio of 2:1. It is most frequent in the long bones, most often the proximal tibia (the most common site) and the distal femur. The clinical presentation is usually chronic pain, swelling and possibly a palpable soft tissue mass or restriction of movement, but it can be an incidental finding [2, 3].

The appearance on imaging studies is of a lytic lesion with well defined usually sclerotic margins, eccentrically placed and located near the end of long bones. Most lesions are entirely lucent; approximately 10 % may show focal calcified matrix, more often detectable with CT scans [5]. Treatment is intralesional resection and bone grafting.

13.2.5 Osteoid Osteoma

Osteoid osteoma is a small and disproportionately painful benign bone-forming tumor. This lesion accounts for approximately 10 % of benign bone tumors, and usually affects children and adolescents. It is more common in males. It can occur anywhere in the body but is most commonly located in the diaphysis and occasionally in metaphysis of femur or tibia [1–4].

Patients will have pain during the day but also pain that wakes them at night. In many cases, they will have discovered that use of aspirin or ibuprofen provides rapid but temporary relief of the symptoms. When lesions are located at the very end of a long bone, patients may present with swelling and effusion of the nearest joint. Generally, the diagnosis is clear enough from imaging studies that biopsy is not required. On plain films, the lesion is characterized by dense cortical sclerosis surrounding a radiolucent nidus. The best imaging study to demonstrate osteoid osteoma is a CT scan.

Most osteoid osteomas are treated by an interventional musculoskeletal radiologists using percutaneous radiofrequency ablation. Less often, osteoid osteomas are surgically curetted or excised [7, 11].

13.2.6 Giant Cell Tumor

Giant cell tumor (GCT) is a benign, locally aggressive neoplasm which is composed of sheets of neoplastic ovoid mononuclear cells interspersed with uniformly distributed large, osteoclast-like giant cells. GCT represents around 4–5 % of all primary bone tumors, and approximately 20 % of benign primary bone tumors. The peak incidence is between the ages of 20 and 45. GCTs have a predilection for the epiphysis and adjacent metaphysis; frequently, there is extension up to the subchondral plate, sometimes with joint involvement. GCT occurs around the knee in 50–65 % of cases [1–4].

Clinical presentation includes pain, swelling, and limitation of motion. Pathological fracture occurs in up to 10 % of cases. These tumors are considered locally aggressive. They tend to continue to enlarge, destroy bone, and may eventually erode the rest of the bone and extend into the soft tissues. These tumors are notorious for their tendency to recur. Radiographs demonstrate a subarticular and metaphyseal lytic lesion. The lesion is typically eccentric and elongated, and it may appear multiloculated and expansile. CT and MRI allow evaluation of the extraosseous and intraosseous extent of tumor. In very rare instances, this lesion has the potential for metastasis to the lungs, and in these cases, the lung lesions may behave in an indolent fashion and even require no treatment [12].

Treatment of giant cell tumors is surgical. Extended intralesional resection is the treatment of choice, because curettage alone is thought to lead to high rate of local recurrence. Multiply recurrent GCTs, those with extensive bone destruction or pathological fracture are also treated with wide resection [13]. In recent years, clinical results using denosumab, a highly effective and specific antagonist of RANKL, have shown that it reduces bony destruction and therefore may offer an option for unresectable tumors or in cases with severe surgical morbidity. The role of denosumab in curative treatment is the subject of ongoing studies [14].

13.3 Tumor-Like Lesions of Bone

13.3.1 Nonossifying Fibroma

Nonossifying fibroma is a well circumscribed, solitary fibrous proliferation. A very small nonossifying fibroma is called a fibrous cortical defect. These lesions are developmental defects in which parts of bone that normally ossify are instead filled with fibrous tissue. They commonly affect the metaphyses, and the most commonly affected sites are, in order, the distal femur, distal tibia, and proximal tibia. Nonossifying fibromas are common among children. The lesion is found in males more commonly than in females. Most lesions eventually ossify and undergo remodeling, often resulting in dense, sclerotic areas in adults [1–3].

Small nonossifying fibromas are asymptomatic, they are generally first noted incidentally on imaging studies. However, lesions that involve nearly 50 % of the bone diameter tend to cause pain and increase the risk of pathologic fracture. Plain film radiography demonstrates a well-circumscribed, eccentric, multiloculated osteolytic lesion, arising from the metaphyseal cortex. Serial X-rays will show the lesion migrating away from the epiphyseal plate with time.

For most patients, lesions will heal as they reach their 20s and thus they are typically simply observed. In the rare cases where the lesion is large enough to weaken the bone and threaten fracture, surgery can be performed to remove the tumor and fill the bone defect with bone graft alongside internal fixation of the fracture if necessary. The only definite indication to treat nonossifying fibromas is a pathologic fracture.

13.3.2 Aneurismal Bone Cyst

Aneurysmal bone cyst is a benign lesion that contains blood-filled cavities and is seen in young people, 10–30 years of age. It is not a neoplastic lesion that should be considered in the differential diagnosis of lytic neoplasms around the knee joint. Aneurismal bone cyst may arise de novo as a primary lesion, or secondarily complicate other benign and malignant bone tumors that have undergone haemorrhagic cystic change. It occurs in the metaphysis of the long bones, including the tibia and the femur [1–4].

The most common signs and symptoms are pain and swelling, which are rarely secondary to fracture. Radiographically it presents as a lytic, eccentric, expansile mass with well defined margins. Most tumors contain a thin shell of subperiosteal reactive bone. CT and MRI studies show internal septa and characteristic fluid-fluid levels created by the different densities of the cyst fluid caused by the settling of red blood cells. In secondary lesions, CT and MRI may show evidence of an underlying primary lesion. A careful search for radiological signs of the precursor lesion, if any, is recommended. Some of these precursor lesions may have a flocculent chondroid matrix that may be a clue to their pathogenesis [5].

Aneurismal bone cyst is a benign, potentially locally recurrent lesion. Extended intralesional resection is normally used. Large lesions may require other treatments, such as embolization. The cyst can be packed with bone chips or polymethylmethacrylate cement [15].

13.4 Malignant Bone Tumors

13.4.1 Osteosarcoma

Osteosarcoma is a primary malignant mesenchymal tumor in which the neoplastic cells produce osteoid, even if only in small amounts. There are many types of osteosarcomas. The most common type, conventional osteosarcoma, which is intramedullary and high grade, represents approximately 75 % of all osteosarcomas. Osteosarcoma is the most common, nonhaematopoietic, primary malignant tumor of bone, with an estimated incidence of 4–5 per million population.

It most frequently occurs in the second decade and 60 % of patients are under the age of 25. Although 30 % of osteosarcomas occur in patients over 40 years of age, the possibility of a secondary osteosarcoma should always be considered in older patients. Secondary osteosarcomas are bone forming sarcomas occurring in bones that are affected by preexisting abnormalities, the most common being Paget disease and following radiotherapy. Osteosarcoma is slightly more common in males than females possibly due to longer period of male skeletal growth. The most common sites are the distal femur and proximal tibia. Most (90 %) arise from the metaphysis of the bone, thus in most instances, the tumor arises next to the knee joint [1–4].

Symptoms generally develop over a period of weeks to a few months. The most common presentation is pain and a mass, which occurs near a joint. Pain gradually becomes more severe and is accompanied by swelling and limitation of motion. On radiographs, conventional osteosarcoma occurs predominantly in the metaphysis, and appears as a mixed sclerotic and lytic lesion, that may permeate the bone and the nearby cortex, causing a soft tissue mass and a periosteal reaction. Bone formation within the tumor is characteristic of osteosarcoma and is usually visible on the X-rays [5].

Although rare, parosteal osteosarcoma is the most common type of osteosarcoma of the surface of bone. Patients in their 20s and 30s are most commonly affected. About 70 % involve the surface of the distal posterior femur [2, 4]. Patients generally complain of a painless swelling; inability to flex the knee may be the initial symptom. Some patients complain of a painful swelling. Radiographs show a heavily mineralised mass attached to the cortex with a broad base. Other variants of osteosarcoma are commonly located around the knee.

High grade osteosarcoma is treated with neoadjuvant chemotherapy, surgical resection with a wide margin and adjuvant chemotherapy. The vast majority of patients do not require amputation but rather can be treated with limb salvage surgery.

13.4.2 Chondrosarcoma

Chondrosarcoma is a malignant mesenchymal tumor that produces cartilage matrix. There are several subtypes of chondrosarcoma, which vary in terms of location, appearance, treatment, and prognosis. Primary chondrosarcoma accounts for approximately 20 % of malignant bone tumors in one large series. It is the third most common primary malignancy of bone after multiple myeloma and osteosarcoma. In the total group of chondrosarcomas, more than 90 % are primary (conventional) type. Chondrosarcoma most commonly occurs in adults aged 30–70 years. The most common skeletal site is the pelvis; approximately 25 % occur in the femur but rarely in the distal part [1–4].

Clinically, chondrosarcoma presents with pain, a soft tissue mass, warmth, and erythema, and may present with pathological fracture. Chondrosarcoma is classified as central or peripheral, with the peripheral form arising from a preexisting osteochondroma. It is difficult to prove malignant transformation in enchondromas. Patients with Ollier's disease or Maffucci's syndrome are at much higher risk (25–30 %) of developing chondrosarcoma than the normal population and often present in the third and fourth decade [4, 9]. Local swelling and pain, alone or in combination, are significant presenting symptoms. The symptoms are usually of long duration.

In the long bones, primary chondrosarcomas occur in the metaphysis or diaphysis where they produce fusiform expansion with cortical thickening of the bone. They present as an area of radiolucency with variably distributed punctate or ring-like opacities (mineralization). Cortical erosion or destruction is usually present. The cortex is often thickened but periosteal reaction is scant or absent. MRI can be helpful in delineating the extent of the tumor and establishing the presence of soft tissue extension. CT scans aid in demonstrating matrix calcification [5].

Treatment of chondrosarcoma is wide surgical excision. In most cases, surgery is the only treatment. The role for chemotherapy or radiation is currently unknown. However, for high grade dedifferentiated and mesenchymal chondrosarcoma, chemotherapy is indicated. Extended intralesional resection is safe and effective in the treatment in low grade chondrosarcomas of the appendicular skeleton [16].

13.4.3 Ewing Sarcoma

Ewing sarcoma is a primary osseous neoplasm composed of uniform, monotonous, small round blue cells without any matrix production.

It is the fourth most common primary malignancy of bone and the second most common sarcoma in bone and soft tissue in children. Nearly 80 % of patients are younger than 20 years. Ewing sarcoma tends to arise in the diaphysis or metaphyseal-diaphyseal portion of long bones, but its location around the knee is rare [1–4].

Pain and a mass in the involved area are the most common clinical symptoms. Fever (low grade, about 38 °C), anemia, leukocytosis and increase in sedimentation rate are often seen. Radiographically, an ill defined osteolytic lesion involving the diaphysis of a long bone or flat bone is the most common feature. Permeative or moth-eaten bone destruction is characteristic, often associated with "onion-skin" multilayered periosteal reaction. The cortex overlying the tumor is irregularly thinned or thickened. A large, ill defined soft tissue mass is a frequent association in Ewing tumor. Expansile bone destruction with soap-bubble appearance might be seen. CT is helpful in defining bone destruction. MRI is essential to elucidate the soft tissue involvement [5].

Treatment for Ewing sarcoma includes neoadjuvant chemotherapy, surgery with wide margins and adjuvant chemotherapy. Radiotherapy also has a role.

13.4.4 Undifferentiated/Unclassified Sarcoma of Bone

Undifferentiated sarcoma of bone is a malignant neoplasm composed of fibroblasts and pleomorphic cells with a prominent storiform pattern. It represents less than 2 % of all primary malignant bone lesions. It can occur in patients ranging from 10 to 60 years, with a higher incidence in adults over 40 years of age. The knee is a common location, with concurrent involvement of the distal femur and proximal tibia. Undifferentiated sarcoma of bone can arise as a primary bone tumor or may develop secondary to preexisting bone conditions such as Paget disease or bone infarct, or at the site of bone which has been irradiated [4].

Clinically, most patients complain of pain. Radiographically, there are osteolytic lesions, but sclerotic areas may be present. The margins are usually ill-defined and a moth-eaten or permeative pattern of bone destruction can be observed.

Treatment is the same as conventional osteosarcoma, including chemotherapy and wide surgical resection.

13.4.5 Bone Metastases

Skeletal metastases are the most common malignant tumors of bone, typically seen in patients over 40 years of age. Cancers that most frequently spread to bone include; breast, lung, thyroid, kidney, and prostate. Metastases are most commonly seen in the axial skeleton and proximal femur and humerus, with rare occurrence about the knee. Pain is the most common presenting symptom, pathological fracture typically occurs after a few weeks or months of pain. Radiographically, metastases may appear purely lytic, blastic, or with a mixed pattern depending on the primary tumor.

Metastatic tumors are treated according to the prognosis of the patient. When palliative surgery is performed, which is the most common situation, metastatic lesions are treated in case of impending or pathologic fracture by internal fixation and if necessary an intralesional resection (Fig. 13.2). If a curative procedure is performed, in the case of solitary breast metastasis, for example, the lesion is treated as if it was a primary bone sarcoma, with en bloc resection and endoprosthetic replacement.

13.5 Treatment

Treatment for bone tumors depends on the histological grade, the size and location of the tumor and the age of the patient. Both benign and malignant tumors of bone should be staged according to the Enneking staging system, adapted by the Musculoskeletal Tumor Society, prior to planning treatment [17]. The surgical treatment of tumors and tumor-like lesions of bone involves a multidisciplinary team approach. Work-up begins with a detailed history, physical exam, and imaging. Biopsy to obtain a histological diagnosis is an important step prior to treatment. The principle of full surgical resection with maintenance of adequate margins is important to obtain local control. Tumors around the knee represent a difficult reconstructive challenge given their juxta-articular nature.

There are four basic types of resection; each is based on the relationship of the dissection plane to the tumor and its pseudocapsule. Margins can be defined as intralesional, marginal, wide, and radical. An intralesional margin is created if the tumor is entered or cut into at any point during surgery. A marginal margin is created when the surgical dissection extends into the abnormal, reactive tissues that surround the tumor. A wide margin is created when the dissection is through entirely normal tissues, and a cuff of normal tissue is left on all sides of the tumor. A radical margin is created if the surgeon resects the entire bony or myofascial compartment or compartments containing the tumor.

Tumor grade and location dictate the type of excision required. In general, benign bone tumors are adequately treated by either an intralesional procedure or by marginal resection and mechanical, chemical, and thermal adjuncts can be employed to further reduce the risk of recurrence. Primary bone sarcomas and some aggressive benign tumors require a wide excision. It is important to emphasize that a wide margin may be accomplished by a limb salvage procedure or by amputation. Staging studies are used to assess local tumor extent and relevant local anatomy, and thereby determine how a desired surgical margin may be achieved. Various reconstruction options can be used to help restore function.

Tumors around the knee are a difficult reconstructive challenge; limb salvage principles are largely employed if neurovascular structures can be preserved and a level of function maintained. Ultimately the surgical treatment of bone tumors

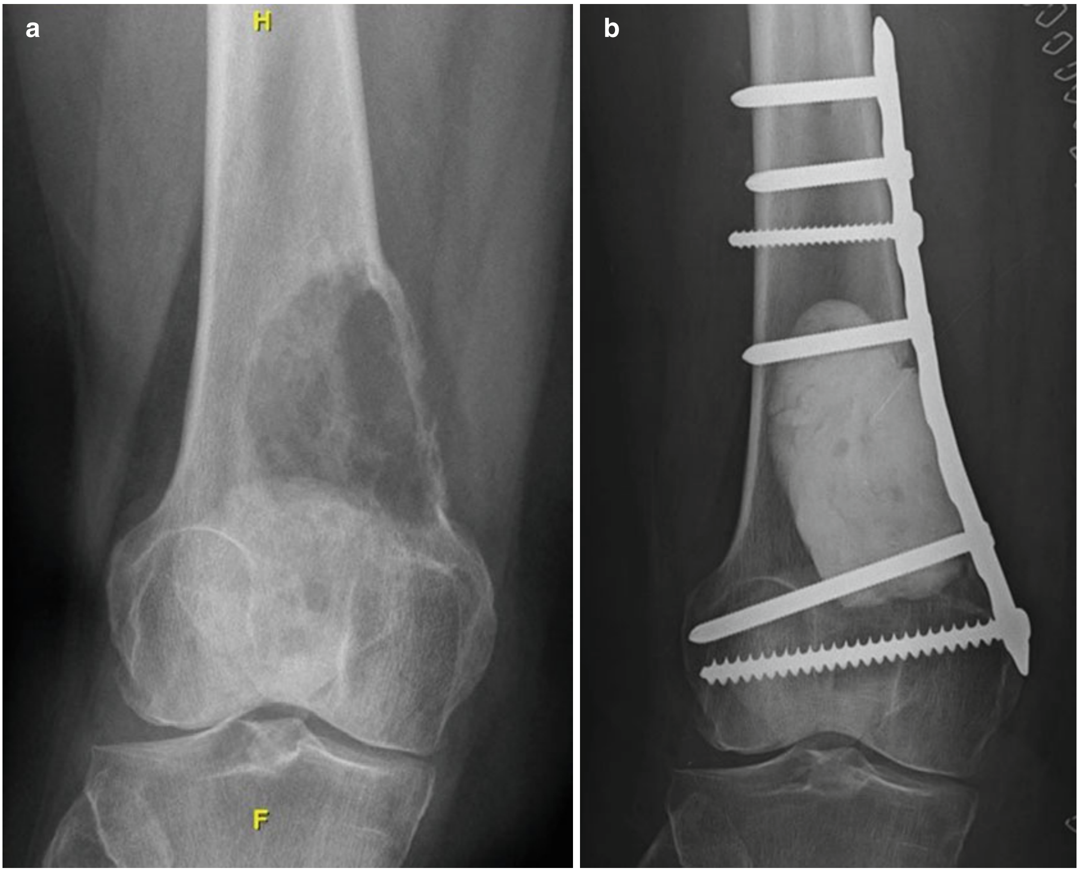

Fig. 13.2 A 64 years old woman with metastatic breast cancer, complaining of knee pain. Anteroposterior radiograph showing a lytic lesion in the metaphysis of the distal femur in risk of impending pathologic fracture. (**a**) Postoperative radiograph after prophylactic surgery (**b**)

provides unique challenges for surgeons, and advances in imaging, surgical techniques, prosthetic design, and adjuvant treatments have continued to assist surgeons in improving functional outcomes.

13.5.1 Benign Tumors

The indications for surgical treatment of benign bone tumors and tumor-like lesions depend on the biological activity, clinical symptoms and anatomic location of the lesion. The staging system for benign tumors is useful for determining which tumors are most likely to require treatment and which can be safely observed. Benign bone tumors are staged according to their radiographic appearance and apparent clinical behavior. Stage 1 lesions are static, latent lesions, which are typically self-healing. Stage 2 lesions are active but remain within the confines of the bone and are associated with bone destruction or remodeling. Stage 3 lesions are active and locally aggressive and tend to extend beyond the cortex into surrounding soft tissue.

As mentioned above, assessing the stage of a benign tumor is useful not only in establishing the diagnosis but also in planning appropriate treatment. Stage 1 lesions usually require no surgical intervention and can be followed periodically to confirm that the lesion is static. Stage 2 lesions may require intervention if they cause structural weakness or are markedly symptomatic. Stage 3 lesions usually require surgical treatment. In most cases, marginal resections or intralesional procedures are recommended, in cases where an intralesional resection may need to be augmented with adjuvant modes of therapy, it is often helpful to reconstruct with bone graft, cement or bone substitute to maintain structural integrity and functional stability of the bone and adjacent joint. Incomplete or inadequate treatment may make such lesions prone to local recurrence. The surgeon needs to strike a balance during treatment between reducing the incidence of local recurrence while preserving the joint and maximal function.

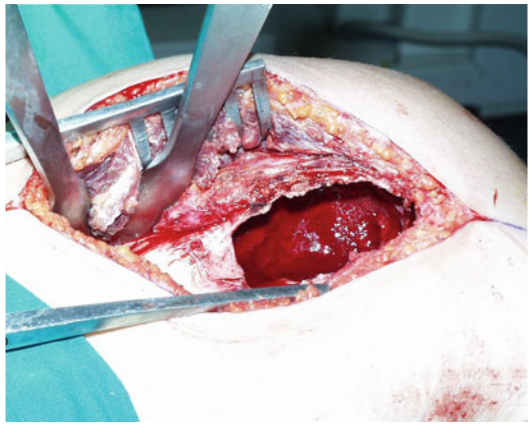

Fig. 13.3 Intraoperative image. Extended intralesional resection of a giant cell tumor of the distal femur. A large cortical window should be made, so that the entire cavity occupied by the tumor can be visualized to perform an adequate resection

13.5.2 Extended Intralesional Treatment

Depending on the tumor-specific risk of recurrence, adjuvant measures should be applied alongside simple curettage. Extended intralesional treatment used in active and aggressive benign tumors like giant cell tumor, chondroblastoma or aneurismal bone cyst, results in equivalent rates of local recurrence compared with wide resection but with improved function and lower rates of postoperative complications [13, 18, 19].

The key to ensuring an adequate intralesional resection with complete removal of tumor is obtaining adequate exposure of the lesion. This is achieved by making a large cortical window to access the tumor (Fig. 13.3). In order to extend intralesional resection, a high-speed burr can be used to break the bony ridges in the tumor. The use of adjuvants aims to eradicate microscopic disease by thermal and chemical means; phenol, hydrogen peroxide, argon laser photocoagulation or cryotherapy using liquid nitrogen may additionally be applied. However, there is little evidence for the use of surgical adjuvants when meticulous tumor removal is performed [19, 20]. Meticulous surgical technique including high-speed burring is the most important step in reducing recurrence rates.

Reconstructing the defect after extended intralesional resection can be quite challenging. For larger defects the traditional methods of reconstruction have been cementation, bone graft or substitutes alone or with bone cement. Our preference is bone cement in adults; it functions as an adjuvant by thermal effect, facilitates detection of recurrences during follow-up, and gives an immediate mechanical support. In the younger population, bone graft is preferred. The advantage of allograft is that if it is successfully incorporated, the reconstruction is permanent, but its disadvantages include difficulty in detecting recurrence and the requirement of a bone bank. The combination of bone graft and cement allows reconstruction of the bone defect created after extensive curettage adjacent to subchondral bone (Fig. 13.4), bone graft in the subchondral region prevents articular degeneration from the thermal effect of the curing cement and supports the weakened subchondral area [21, 22]. If large enough, bone fixation with plates and screws or rods may be needed to avoid fracture.

In the case of expandable bones such as proximal fibula, wide resection may be performed with reinsertion of the biceps tendon and lateral ligament into the tibia using an interference screw with good functional results.

Some benign tumors, such as osteoid osteoma and selected cases of chondroblastoma, may be treated using minimally invasive techniques. CT-guided radiofrequency ablation uses long wave electromagnetic radiation to produce

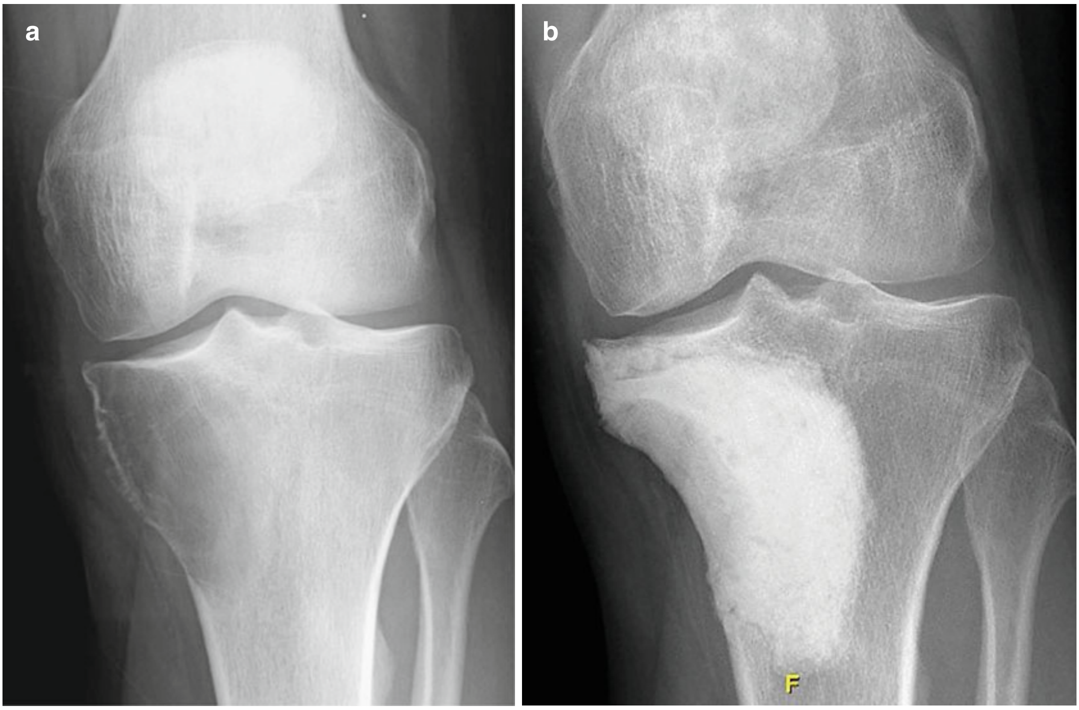

Fig. 13.4 Anteroposterior knee radiograph of a 43 years old man with a giant cell tumor in the proximal epimetaphysis of the tibia reaching the subchondral bone. (**a**) After extended intralesional resection of the tumor, a layer of autogenous bone graft is packed beneath the subchondral bone and the remaining cavity is filled with bone cement (**b**)

thermal coagulation. Results are equivalent to open techniques but without hospitalization, and with fewer complications and more rapid recovery [7–11]. Occasionally, when massive bone destruction or multiple recurrences occur, wide resection may be necessary.

13.5.3 Malignant Tumors

Before treatment can be planned, a complete oncological staging must be completed. This includes assessment of any potential for metastasis to the chest, to nearby bones or the rest of the extremity, or to other areas. Most patients have a CT of the chest, a whole body bone scan, and MRI of the extremity including the lesion. Enneking's staging system [17] is based on three factors: histological grade (G), site (T), and the presence or absence of metastases (M). The anatomical site (T) may be either intracompartmental (A) or extracompartmental (B). This information is obtained preoperatively on the basis of the data gained from the various imaging modalities. A tumor is assigned to stage III (M1) if a metastasis is present at a distant site.

The treatment of bone sarcomas has changed over the years. If the oncological treatment is not impaired (the tumor can be removed with an adequate margin) and the resulting limb is functional, limb salvage surgery is performed to avoid amputation whenever possible. The use of induction chemotherapy, coupled with advances in imaging and surgical techniques, now make it possible to perform limb salvage surgery in 90 % of patients with a primary bone sarcoma around the knee. The principal aim of limb salvage is to preserve function without compromising the patient's survival; the ultimate goal must always be to achieve adequate resection of the tumor.

Patients with primary bone malignancies must be treated by specialized multidisciplinary teams composed of pathologists, orthopedic oncologic surgeons, plastic and vascular surgeons, oncologists, radiologists and radiotherapists, all with experience in the diagnosis and treatment of these tumors. Successful limb sparing procedures consist of three surgical phases:

(a) Resection of tumor: Tumor resection strictly follows the principles of oncologic surgery. Achieving a surgical margin that will ensure a low rate of local recurrence is paramount. Avoiding local recurrence is the criterion of success and the main determinant of how much bone and soft tissue are to be removed.
(b) Skeletal reconstruction: The technique of reconstruction used is dependent on the size and location of the tumor, the histological grade, the age of the patient, surgeon preference and availability of graft material and implants. Options for reconstruction are diverse and it is of utmost importance that the most effective technique, with the lowest rate of complications, is used because a delay in resumption of chemotherapy is associated with a poorer prognosis [23].
(c) Soft tissue and muscle transfers: Muscle transfers are performed to cover and close the resection site and to restore motor power. Adequate skin and muscle coverage is mandatory to decrease infection risk. In proximal tibial resections and reconstructions, a medial gastrocnemius transposition flap is helpful to provide soft tissue coverage. Soft tissue loss in distal femoral replacement is less frequently encountered; occasionally it is necessary to perform a hamstring to rectus tendon transfer or less commonly a free flap.

The distal femur and proximal tibia are common sites of malignant neoplasms, and many options for limb salvage around the knee have been developed. The goals of treatment in malignant bone tumors around the knee are the complete eradication of the tumor with minimal complications while maintaining acceptable function, durability, and cosmesis of the limb.

In most cases, bone sarcomas around the knee joint are metaphyso-diaphyseal with frequent epiphyseal involvement. When the tumor extends into the epiphysis, an intra-articular resection which includes the articular surface is required. If the articulation is affected, an extra-articular resection must be performed. All or part of the joint is sacrificed. Under these circumstances, massive bone loss around the knee is managed with a megaprosthesis, an osteoarticular allograft or an allograft/prosthetic composite.

The focus of this chapter is the management of bone defects after tumor resection around knee, preserving the joint. This is possible if the size and location of the tumor allows the surgeon to preserve part of the epiphysis and therefore the joint.

13.5.4 Resections and Reconstructive Options Preserving the Knee

As a result of early diagnosis, more accurate imaging techniques, and advanced chemotherapy, tumors compromising the metadiaphyseal region of long bones can be treated with epiphyseal preserving surgery [24–29]. The improved accuracy of imaging techniques has encouraged preservation of the epiphyseal plate in both the distal femur and proximal tibia thus preserving the knee joint. Careful preoperative evaluations, particularly with magnetic resonance imaging, are crucial in order to obtain appropriate margins in all patients [30]. The procedure permits better limb function because of conservation of the joint, and obviates some complications associated with osteoarticular allografts or endoprostheses. Preserving the joint involves making a trans-epiphyseal osteotomy maintaining an adequate margin and leaving enough epiphyseal fragment for reconstruction.

The contraindications for this surgery are patients in whom preoperative imaging studies have demonstrated evidence of epiphyseal compromise of the tumor and tumor progression while on chemotherapy. Epiphyseal-preserving surgery is possible if at least 1 cm or more of disease-free epiphysis is present following resection with margins of 1–2 cm [26, 31]. Performing this procedure in selected patients, no recurrence at the retained epiphysis has been reported [27, 29].

The resulting segmental bone defect represents a challenging reconstructive problem, and multiple strategies exist to address it. The ideal reconstruction should have biological affinity, resistance to infection, sufficient biomechanical strength, and durability. Surgical options for reconstructing metadiaphyseal defects in adults include biologic reconstructions (i. e., not using megaprostheses); such as intercalary allograft, autogenous vascularized fibular grafts, a combination of intercalary allograft with vascularized fibular grafts, devitalized autograft and segmental bone transportation. With the improved survival for patients with malignant bone tumors, there is a trend to reconstruct defects using biologic techniques, especially in young and physically active patients. Non-biologic reconstructions, on the other hand, use intercalary endoprostheses.

With careful patient selection, the multiplanar osteotomy resection technique, instead of segmental resection, may be considered an option for treating patients with bone sarcomas, and when compared with traditional surgical techniques, these may lead to improved healing and function of the involved extremity. This technique is performed by making angled bone cuts around a tumor, achieving limited wide margins, rather than standard transverse osteotomies with the goal of preserving host bone, important soft tissue attachments to bone, and in some cases, a portion of the cortical circumference (Fig. 13.5). These osteotomies are technically demanding to plan and perform intraoperatively [32].

Low grade chondrosarcoma can be successfully managed with extended intralesional treatment [16].

13.5.5 Reconstructive Techniques

13.5.5.1 Intercalary Allograft

Fresh frozen allograft reconstruction has been used for a long time in oncologic orthopedic surgery with a high rate of success, usually resulting in a functional limb. After epiphyseal preservation, epidiaphyseal intercalary allograft (Fig. 13.6) provides an acceptable alternative in reconstructing tumor resections around the knee [24, 26, 27, 33].

Allografts have the advantage of being biologic reconstructions, which could be progressively incorporated by the host by creeping substitution. This gives them durability and good functional results (Fig. 13.7). Despite a greater number of complications in the short term compared to non-biologic techniques, after 5 years these stabilize with high rates of survival (range 70–85 %) after 10 years [27, 31, 33, 34].

Allografts may be expensive or unavailable, and complications of their use have included nonunion (17–50 %), fracture (9–19 %), and infection (10–15 %) [24, 34–36]. These complications influence graft survival negatively, especially in the case of infection and fracture. Aponte-Tinao et al. [27] analyzed 35 patients with osteosarcomas in distal femur and proximal tibia. Complications treated with additional surgical procedures were recorded for 19 patients (54 %), including three local recurrences, two infections, 11 fractures, and three nonunions. In 10 of these 19 patients, the allograft was removed. Five patients (14 %) lost the originally preserved epiphysis owing to complications.

Fracture and delayed or non-union can be avoided with rigid internal fixation and interfragmentary compression at the osteotomy union. Diaphyseal junctions have higher nonunion rates than metaphyseal junctions. Diaphyseal osteotomies are fixed with locking compression plates or with intramedullary nails. Intra-epiphyseal osteotomies are stabilized with plates and screws; if only a small part of the epiphysis and articular surface is saved, fixation is obtained with cancellous screws placed across the osteotomies. The

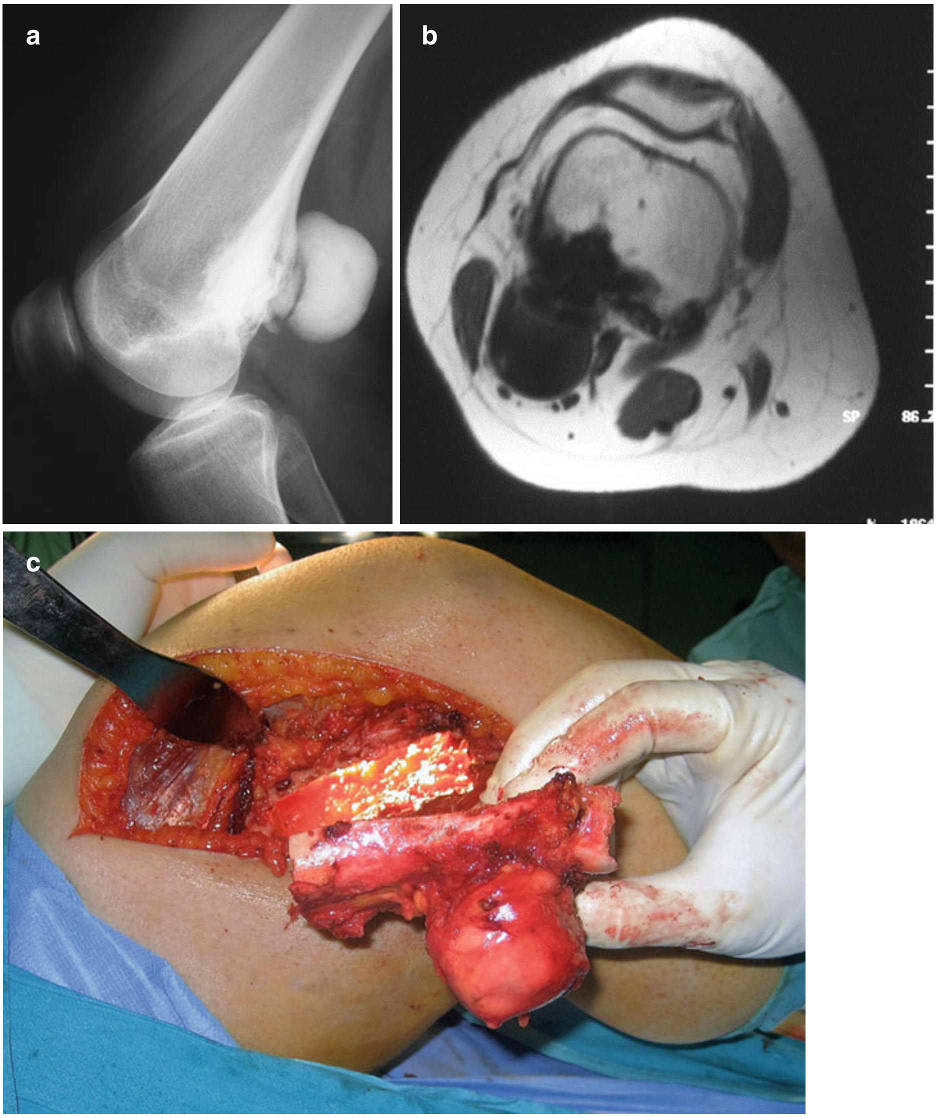

Fig. 13.5 A 29 years old woman with a parostal osteosarcoma of the distal femur. Lateral radiograph. (**a**) MRI images show the extent of the tumor to planning the osteotomy. (**b**) Intraoperative image of the tumor after a hemicortical resection (**c**)

internal fixation should span the entire allograft and reduce the number of screws on it, to avoid the risk of fracture [28, 31]. Fractured and ununited allografts can be repaired without removal, but infected grafts should be removed. Careful tissue matching and allograft processing helps to reduce complications that most likely are immunologically directed [35].

Reconstruction after intercalary resection of the tibia is demanding due to subcutaneous location, poor vascularity of the tibia, and high infection rate. In tibial allografts, the extensor mechanism is reconstructed by attachment of allograft patellar tendon to the corresponding host patella and a medial gastrocnemius transposition flap is performed to provide soft tissue coverage to the proximal tibial allograft. Despite the incidence of complications, an acceptable survivorship with excellent functional scores has been reported [37].

Fig. 13.6 A 16-year-old boy who had an osteosarcoma in the distal aspect of the femur. Anteroposterior radiograph of the distal aspect of the femur. (**a**) Coronal MRI image showing the tumor extension after preoperative chemotherapy. (**b**) Anteroposterior postoperative radiograph after an intraepiphyseal resection and reconstruction with an intercalary allograft (**c**)

13.5.5.2 Free Vascularized Fibular Graft

Autogenous vascularized fibular grafting is a biologic method with advantages, such as restoring bone stock and reported high survival rates, with good functional and durable results. The main advantage includes its capacity to reconstruct large defects and the improved biological properties due to its independent vascularity and short fusion time. The fibula is noted to incorporate and hypertrophy in response to mechanical stress. Furthermore, it has the ability to survive infection, radiotherapy and chemotherapy [38–41].

Problems have occurred when using an isolated free vascularized fibular graft for the reconstruction of defects in weight-bearing bones of the lower limb, especially the femur. The small diameter of the fibula in relation to the host bone can subject it to excessive stress, multiple fatigue fractures are common, and may require further

Fig. 13.7 Anteroposterior radiograph 6 years after intercalary allograft reconstruction of the proximal epimetaphysis of the tibia. Note that both osteotomies healed with mature callus

immobilization or fixation. This technique may require a lengthy period of restricted weight-bearing to allow for union and graft hypertrophy. Reports show a mean time of 1 year until full weight-bearing is achieved and a high incidence of complications that may affect 50 % of patients, including fractures, nonunions, infection and morbidity at the donor site. Hariri et al. [40] published a retrospective review of 38 cases of reconstruction following resection of the metaphysiodiaphysis of the lower limb for malignant bone tumors using free vascularized fibular grafts. The mean follow-up was for 7.6 years (0.4–18.4). Bony union was achieved in 89 % of the cases after one or more operations. The overall mean time to union was 1.7 years (0.2–10.3). Full weight-bearing was achieved at a mean time of 0.95 years (0.14–3.44). Stress fractures of the fibular graft occurred after four (13 %) femoral and four (50 %) tibial reconstructions. Seven reconstructions (18 %) were complicated by infection. Donor site morbidity developed in 14 patients (36 %). It can also be difficult to achieve solid bony fixation between the fibula and the small residual epiphyseal bone segment after an intercalary juxta-articular resection around the knee.

Although there is a sizable risk of complications, most of the problems can be resolved; revisions are rare and often preventable [39–42]. Nonunion is more frequent in femoral reconstructions due to mechanical causes and prevention can be achieved by a combination with an allograft. The use of bridging plate osteosynthesis is associated with a reduction in the risk of fracture and the need to restrict weight-bearing. Valgus deformity of the ankle in the donor site is prevented with a syndesmotic tibiofibular screw. In order to achieve initial strength in the early period, it is possible to combine the free fibula graft with an allograft, or to augment it as a double-barreled fibula [43]. Free vascularized fibular grafts are commonly used in low extremities as a salvage method in case of complications or failed allografts [44] (Fig. 13.8).

13.5.5.3 Allograft Combined With Free Vascularized Fibular Composite

Since it was first reported in 1993 [45], the combined use of a free vascularized fibular graft and allograft has gained popularity and several studies have reported good results with an excellent functional outcome, a high rate of union, and low rates of infection and fracture [39, 46, 47].

This technique decreases the problems encountered when using an isolated free vascularized fibular graft for the reconstruction of defects in weight-bearing bones of the lower

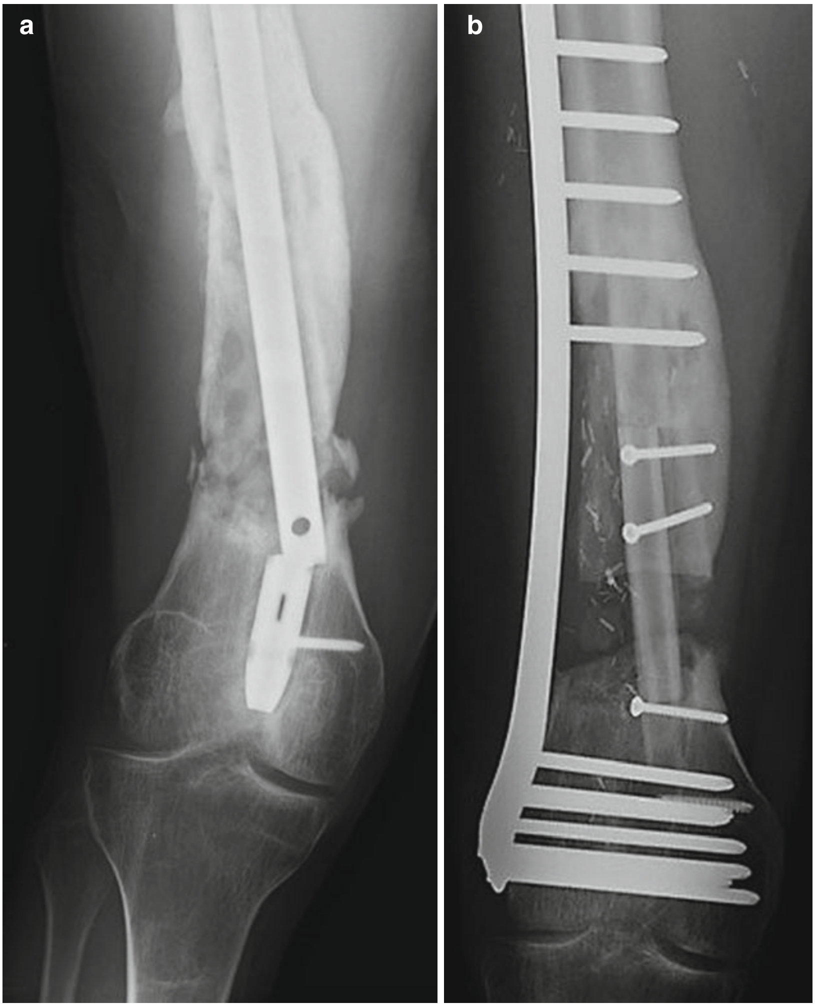

Fig. 13.8 A 26-year-old man presents 8 years after operation with an allograft fracture. (**a**) Surgical reconstruction with double-barreled free vascularized fibular graft and fixation with a locking plate and screws (**b**)

limb, especially around the knee. The combination provides mechanical strength and biological activity to the reconstruction with better primary stability and protection for the vascularized fibular graft from excessive mechanical stress. The vascularized fibular graft will undergo progressive hypertrophy and osseointegration with the allograft. This technique also facilitates the fixation with screws of a small epiphyseal bone fragment to the allograft.

Abed et al. [47] reviewed 25 patients who had undergone resection of a primary bone sarcoma which extended to within 5 cm of the knee with reconstruction by a combination of a free vascularized fibular graft and a massive allograft bone shell. They reported a survivorship of the reconstruction of 79 % at 5 years, with no change expected after these periods of time. Despite the high rate of local complications (48 %), treatment was successful in 75 % of patients.

The vascularized fibula can be assembled with the allograft using an intramedullary technique for femur and tibia reconstructions (Fig. 13.9), where the vascularized fibula is inserted through a trough opened up in the anterolateral cortex of the allograft [36]. It is

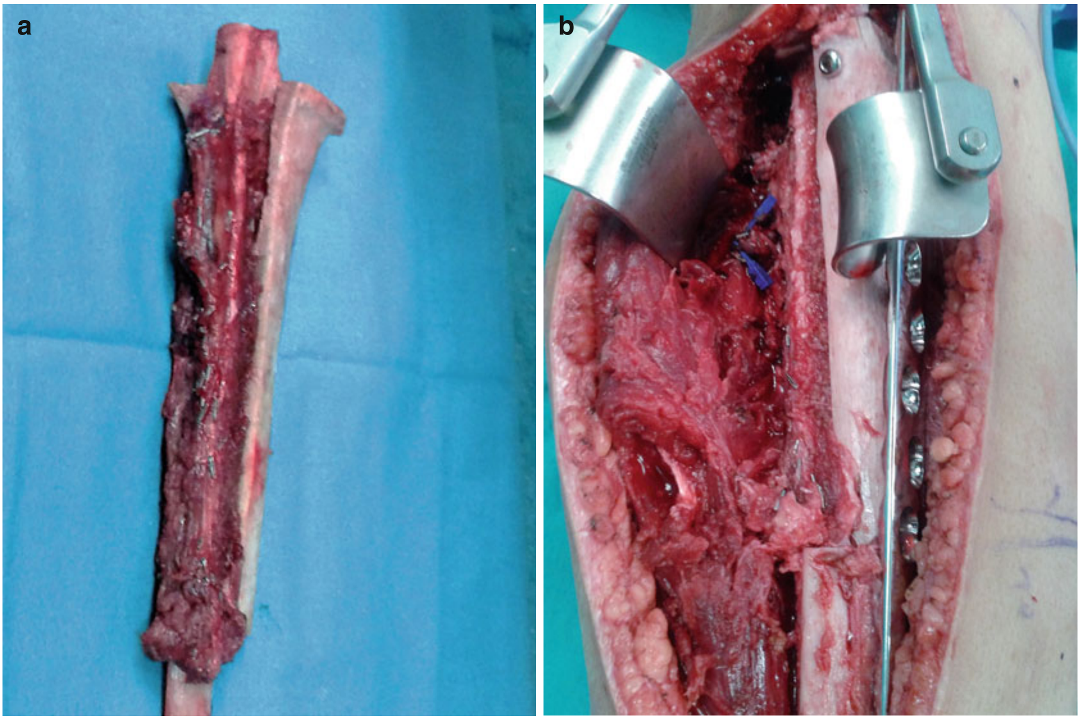

Fig. 13.9 Intraoperative image showing a combined graft (allograft plus vascularized fibula) asambled using an intramedullary technique. (**a**) The combined graft fixed with a plate to the host bone and ready to do the vascular anastomosis (**b**)

important to avoid damaging the flap pedicle while inserting it into the allograft.

13.5.5.4 Devitalized Autograft

In this technique, the bone is denuded of soft tissue and irradiated, autoclaved, frozen or pasteurized. The advantages of such autografts for large defects are ease of procurement, absence of problems associated with storage, obtaining grafts of suitable dimensions, ensuring stability, and elimination of the risk of infection and allogenic reactions. In developing countries, this technique provides a limb salvage option that is inexpensive and independent of external resources without sacrificing appropriate oncologic principles [48–52].

This technique has several disadvantages; it is impossible to perform histological analysis of the whole specimen to determine the effects of chemoradiotherapy and the adequacy of the surgical margins, it takes a long time for bone to be revascularized and incorporated into the surrounding bone, it cannot be performed if there is extensive destruction of host bone by the tumor and in addition, several investigators have reported high rates of infections, fractures, nonunions, and bone resorption associated with the procedure [36, 48–53]. Hayashi et al. [48] reported the clinical results of 74 patients, 54 of them with lower limb affected. Survival of the irradiated bone was 80 % at 10 years, infections occurred in 13 (18 %), fractures in 13 and nonunions in 12. The grafts were removed in eight patients (11 %) due to complications. Taken together, the risks and complications are comparable to other reports of intercalary reconstruction allografts [36].

Recent studies suggest that a devitalized autograft combined with a vascularized fibula graft is a promising biological alternative for intercalary reconstruction after wide resection of malignant bone tumors of the lower extremity [51].

13.5.5.5 Bone Transport

Limb salvage surgery and joint preservation, using distraction osteogenesis with bone transport with the aid of an external fixator, is a biologic reconstruction method with acceptable results [53, 54]. Gradual distraction starts 1–2 weeks after the operation at a rate of 1 mm per day and early weight-bearing is used. Frequent complications are pin tract infection, nonunion at the docking site and the disadvantage of a long period of external fixation. It is seldom used due to the high maintenance demands of the procedure combined with adjuvant oncological treatment, the success of distraction osteogenesis during concurrent chemotherapy is not well known.

13.5.5.6 Endoprosthetic Replacement

The majority of endoprosthetic replacements for tumors around the knee involve sacrifice of the joint. Epiphysis preserving surgery and reconstruction with custom-made prostheses, designed to achieve metaphysal fixation with the fragment, has the advantage of an effective curative effect, an easy operation, short operative time and quick recovery. However, further follow-up is required to assess the longevity of these prostheses [28, 55].

Nowadays, with improved survival in sarcoma patients, more durable reconstructions are needed. The advances in imaging techniques, chemotherapy, and surgical techniques allow us to improve our long-term functional results and facilitates greater individualization of the method of reconstruction used.

Conclusions

Primary bone tumors, especially bone sarcomas, are rare. The management of the patient with a malignant bone tumor or with an aggressive form of benign tumor is complex and with a high rate of potential complications, therefore it should only be carried out by specialized multidisciplinary teams with experience in the diagnosis and treatment of these tumors. A significant number of these tumors are located around the knee and although all or part of the joint is sacrificed in a high percentage of primary malignant tumors, most benign tumors, even those aggressive and some selected cases of sarcomas of bone, can be managed with techniques which preserve the knee joint. Nowadays, with improved survival in sarcoma patients, more durable reconstructions are needed. The advances in imaging techniques, chemotherapy and surgical techniques, allow us to improve our long-term functional results and facilitates individualization of the method of reconstruction used.

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Osteotomies About the Knee

14

Jonathan Palmer and Andrew J. Price

Abstract

Osteotomy surgery for the treatment of knee pathology is not a new concept. Historically, osteotomy was a valued surgical procedure for the management of unicompartmental osteoarthritis (OA) of the knee. However, since the successful introduction of arthroplasty surgery, the role of osteotomy has become less well defined. It is not routinely offered by many knee surgeons and often it is a procedure confined to specialist centres. Recent advances in pre-operative planning, surgical technique and fixation methods have brought osteotomy surgery into the modern age. Consequently, the indications for its use have become broader. This chapter will focus on osteotomy surgery for the management of unicompartmental osteoarthritis. It will describe indications for surgery and the outcomes that can be expected. It is hoped that this chapter will provide insight for anyone considering osteotomy as part of their surgical strategy for the management of patients with osteoarthritis of the knee.

Keywords

Knee • Osteoarthritis • Osteotomy • Indications • Results

14.1 Introduction

The basic principle of osteotomy surgery is to cut and re-shape bone in order to correct an underlying deformity. In the case of unicompartmental knee osteoarthritis (OA) the objective is to transfer load away from the compartment that is failing and shift it towards the compartment that has little or no pathology. Central to this is the concept that malalignment plays a pivotal role in

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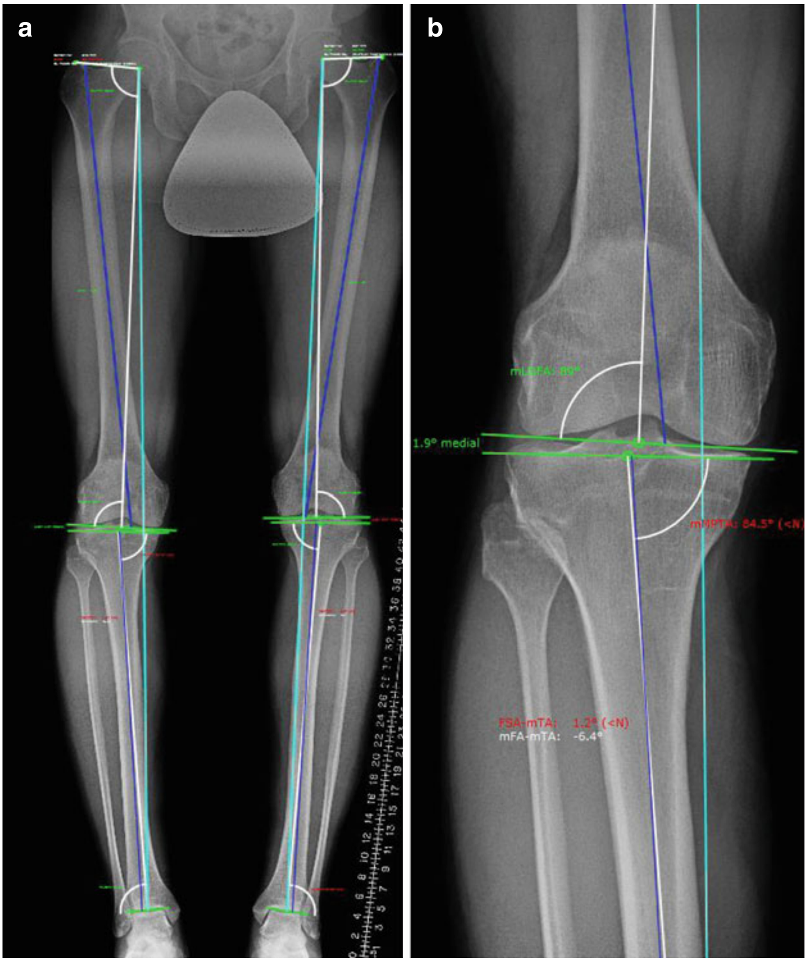

Fig. 14.1 (**a**) Physiological alignment measurements in the coronal plane from a long leg weight bearing radiograph measurement. (**b**) Enlarged image shows the weight-bearing axis in the medial compartment. Also shown are the medial proximal tibial angle (*MPTA*) and the mechanical lateral distal femoral angle (m*LDFA*) (All measurements taken using MediCAD© Classic Version 3.0.2.2)

both the incidence and progression of OA within the knee, with varus alignment leading to medial compartment OA and valgus alignment leading to lateral compartment OA [1]. Varus alignment is common amongst healthy individuals, affecting 32 % of men and 17 % of women [2]. This goes some way to explaining the higher proportion of medial compartment OA seen in the general population.

The weight-bearing axis (WBA) is represented by a line drawn, on a long leg radiograph, from the centre of the femoral head to the centre of the ankle (Fig. 14.1). In the varus knee, the WBA passes through the medial compartment and in the valgus knee the WBA passes through the lateral compartment. The mechanical effect of disproportionate load passing through one compartment over the other leads to progression of disease in the affected compartment. As disease progresses, the affected compartment narrows and a worsening of the malalignment is seen [3].

A high tibial osteotomy (HTO) is the most widely recognised and widely practiced osteotomy for the treatment of medial compartment OA in the varus knee. Broadly speaking, there are three methods that can be employed to achieve the desired correction. These include a closing

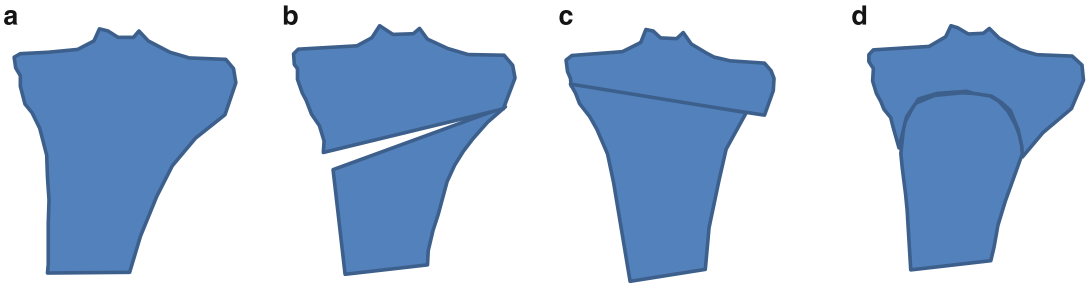

Fig. 14.2 Illustration of the three broad categories of high tibial ostetomy for medial compartment osteoarthritis associated with metaphyseal tibia vara (**a**). Opening wedge (**b**), closing wedge (**c**) and dome osteotomy (**d**)

wedge, an opening wedge and a dome osteotomy (Fig. 14.2). Traditionally, the objective of surgery is to push the patient into valgus alignment and transfer load into the disease-free lateral compartment. The objective is to reduce pain and slow the progression of disease.

The lateral closing-wedge HTO (CWHTO) was popularised by Coventry through his work at the Mayo clinic [4]. He took the original technique described by Gariepy and secured his closed wedge with a staple. He achieved good outcomes with 75 % survival rates reported at 10 years [5]. Subsequently, this has been the most widely reported and practiced surgical technique. More recently, a medial opening-wedge HTO (OWHTO) has gained in popularity. This is in part due to advances in plate technology that enable stable fixation and high rates of union [6]. The relative merits of these opposing techniques will be discussed later in this chapter.

Lateral compartment OA with valgus deformity is a less common phenotype and consequently there are fewer studies supporting the use of osteotomy in this patient group. A distal femoral varus osteotomy (DFVO) is typically achieved using a medial closing wedge technique [7]. Outcomes for this type of surgery will also be discussed later in the chapter.

The popularity of osteotomy surgery has certainly been in decline since the introduction of arthroplasty surgery. For many surgeons, the latter offers consistent outcomes and is their treatment of choice for patients with established osteoarthritis. However, there is evidence that arthroplasty surgery has less satisfactory outcomes in high demand, young patients. It is our belief that modern osteotomy surgery offers a viable alternative for these patients and others, offering good outcomes and low complication rates.

14.1.1 Patient Selection

As with any orthopaedic procedure, careful patient selection is key to a successful outcome. Patients should be made aware from the outset that osteotomy surgery is a major undertaking with significant risks and requires considerable application and commitment with post-operative rehabilitation. As a result, it should only be considered when all other conservative measures have been exhausted.

A thorough clinical history and examination is essential. Important considerations include the patient's age, body mass index (BMI), smoking status, medical co-morbidities and any history of prior trauma or surgery. In addition to current activity level, it is valuable to gain an understanding of the patient's expected activity level following osteotomy. Patients should be made aware that although a return to sport is expected they will typically not recover their pre-pathology level of activity [8]. Clinical examination should include an evaluation of alignment, soft tissue integrity, ligamentous stability and neurovascular status. In addition, the range of movement and the presence of any fixed flexion deformity should be documented. The presence of any active infection locally or systemically should preclude surgery.

Traditionally, osteotomy surgery was reserved for end-stage 'bone on bone' unicompartmental osteoarthritis. However, in line with developments in surgical technique, the indications for this procedure are evolving. An expert panel from ISAKOS defined the criteria for a patient undergoing HTO for medial compartment osteoarthritis [9] (Table 14.1 edited from Brinkman et al. [10]).

An important consideration is not only the underlying deformity but the cause of that deformity. Bonnin and Chambat reported superior clinical outcomes for patients undergoing osteotomy for medial OA for patients with a constitutional varus deformity of the proximal tibia [11]. They proposed using the Tibia Bone Varus Angle (TBVA) to differentiate those patients with a congenital varus deformity from those with an acquired varus deformity (Fig. 14.1). Osteotomy in patients with a TBVA >5° was described as a curative procedure compared to those with a TBVA <5° in whom such surgery was felt to be a palliative measure [11]. The anatomy of the distal femur may also play a part in outcome for HTO surgery. An overly varus distal femur has been associated with recurrence of varus deformity following surgery [12]. However, a recent study has challenged these findings determining that neither varus inclination of the proximal tibia or distal femur influenced long-term survival of HTO over 10 years [13] (Fig. 14.3).

Advances in the technical aspects of osteotomy are challenging the traditional concepts of an 'ideal' osteotomy patient. Favourable outcomes have been demonstrated in the young [14], the old [15], smokers [16] and those with a raised BMI [16]. As research progresses it is likely that the ideal osteotomy patient will continue to be re-defined. As such it is important for surgeons to keep an open mind when considering patients who might be suitable for such a procedure.

14.2 Pre-operative Planning

Careful pre-operative assessment should be undertaken for all patients undergoing osteotomy surgery. Radiological assessment is necessary to establish both the extent of disease and the presence of a correctable deformity.

14.2.1 Radiological Assessment

Pre-operative assessment should include antero-posterior, lateral and skyline radiographs to enable the pattern of disease to be

Table 14.1 Selection criteria for high tibial osteotomy as defined by ISAKOS, 2005 [9]

Ideal candidate	Possible but not ideal	Not suited
Isolated medial joint line pain	Flexion contracture <15°	Bi-compartmental (medial and lateral) OA
Age (40–60 year)	Previous infection	Fixed flexion contracture >15°
BMI <30	Age 60–70 year or <40 year	Obese patients
High-demand activity but no running or jumping	ACL, PCL or PLC insufficiency	Meniscectomy in the compartment to be loaded by the osteotomy
Malalignment <15°	Moderate patellofemoral OA	
Metaphyseal varus TBVA >5°	Wish to continue all sports	
Full range of movement		
Normal lateral and patellofemoral components		
Ahlback grade I to IV		
No cupula		
Normal ligament balance		
Non-smoker		
Some level of pain tolerance		

Table edited from previous publication by Brinkman et al. [10]

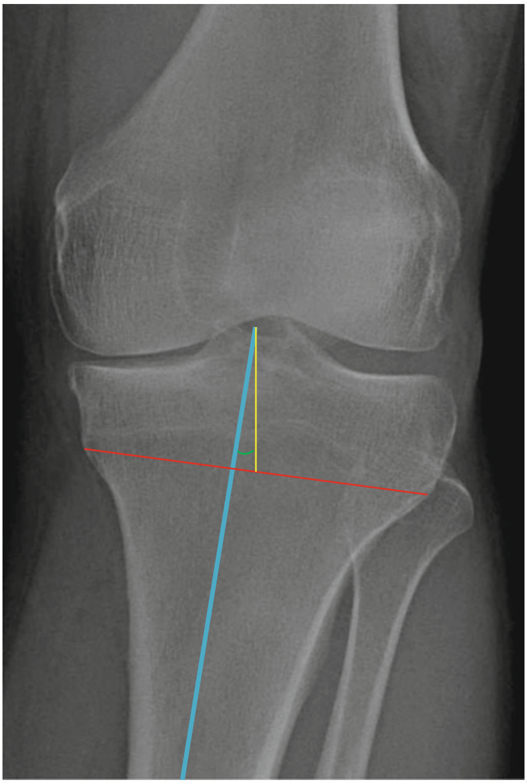

Fig. 14.3 Figure illustrating the tibia bone varus angle (*TBVA*). This angle is formed between a line that links the midpoint of the tibial spines and the midpoint of the physis and a line that represents the mechanical axis of the tibia. TBVA >5° was associated with improved outcomes for high tibial osteotomy surgery [11]

established. Weight-bearing views may assist with defining the severity of osteoarthritis and stress views can be used to identify the stability of the collateral ligaments. Where there is doubt about the underlying pathology or concerns that the disease process may not be confined to a single compartment, an MRI of the knee may be of use.

A weight-bearing radiograph of the lower limb is necessary to assess the site of the deformity and the correction required in the coronal plane. Institutions should make efforts to standardise the methods by which such radiographs are taken to ensure that the images obtained are both accurate and reproducible. The presence of malrotation or flexion deformity will significantly alter the perceived alignment [17].

Computed tomography (CT) may be required in cases associated with traumatic defects or where a significant torsional element to the deformity is suspected.

14.2.2 Coronal Alignment

The most frequent deformity associated with unicompartmental OA of the knee is varus or valgus malalignment. The long leg weight-bearing radiograph is considered by many to be the gold standard investigation for both the assessment of the underlying deformity and the planning of its correction.

Surgeons should familiarise themselves with the physiological axes of the lower limb (Fig. 14.1) and the principles of deformity correction described by Paley [18]. The differences between anatomical and mechanical definitions for lower limb alignment should be understood. The weight-bearing axis (WBA) of the lower limb describes a line from the centre of the femoral head to the centre of the ankle (Fig. 14.1). Broadly speaking if this line passes through the medial compartment then the limb is in varus alignment, conversely, if it passes through the lateral compartment then the limb is in valgus. The mechanical axis of the femur runs from the centre of the femoral head to the centre of the knee and a line from the centre of the knee to the centre of the ankle denotes the mechanical axis of the tibia. The anatomical axes of the lower limb relate to the centre of the medullary canal. Due to the inherent straightness of the tibia, in the coronal plane the anatomical and mechanical axes of the tibia are often coincident. In the femur, however, these measurements are different due to the lateral offset of the femoral shaft from the femoral head caused by the femoral neck.

Once the alignment of the lower limb has been established it is necessary to determine the site of any underlying deformity. Such deformity is identified by a significant deviation from the expected physiological axes and in order to be considered suitable for osteotomy around the knee will need to arise in the proximal tibia (Medial Proximal Tibial Angle; MPTA) or the distal femur (mechanical Lateral Distal Femoral Angle; mLDFA). If the site of the deformity is away from the knee joint then an osteotomy about the knee is inappropriate. The correction should be performed at the site where the deformity is observed.

14.2.3 Planning the Correction

Once the deformity has been established, it is necessary to determine the desired correction point. Traditionally, for medial compartment OA associated with varus deformity, patients have been deliberately placed into a valgus position. Biomechanical studies have suggested that in a neutrally aligned limb the majority of weight still passes through the medial compartment [19]. In the presence of an already failing compartment, it is understandable that surgeons would want to transfer a greater proportion of the weight into the disease-free lateral compartment by placing the patient into valgus. The so-called 'Fujisawa-point' has been widely adopted due to the superior results achieved when patients had a weight-bearing line positioned at approximately 62 % of the medial-lateral tibial plateau width [20]. Recently, a more individualised approach has been advocated [21]. This uses the weight-bearing line to determine the desired correction point and suggests a modest (more neutral) correction for patients with less advanced OA.

Once the desired correction has been determined it is possible to establish the size of the correction required using the pre-operative weight-bearing long leg radiograph. The two most commonly used techniques for planning the desired correction were popularised by Dugdale [22] and Miniaci [23]. Several planning software packages are available which incorporate these techniques into a user-friendly interface. Good inter- and intra-observer reliability has been demonstrated for many of these planning tools [24], however, they have a cost attached which may make them less desirable for the surgeon who only occasionally practices osteotomy.

14.3 Surgical Technique

The commonest osteotomy used about the knee is the HTO, either performed as a lateral closing-wedge or a medial opening-wedge. The most widely reported technique is the lateral closing-wedge HTO. Coventry popularised this technique using a staple to fix the osteotomy in position and reported very low complication rates [4]. Traditionally, a closing wedge osteotomy has been considered a more stable construct and the large surface area of cancellous bone contact means high rates of union can be expected. However, the procedure does have some inherent limitations. Once the wedge of bone has been resected the surgeon is committed to the osteotomy, whilst more bone could be resected it is not possible to lessen the osteotomy mid-procedure. The lateral approach to the knee joint leaves the common peroneal nerve vulnerable to injury and lateral ligament laxity may arise if the fibular head becomes elevated. A simultaneous fibular osteotomy or disruption of the proximal tibiofibular joint may be required to prevent this.

Opening wedge HTO has gained popularity more recently. The approach is on the medial side of the knee avoiding injury to the common peroneal nerve and loss of tension in the lateral collateral ligament. It is also possible to fine-tune the size of the correction once the osteotomy has been made. However, concerns have been raised over higher rates of non-union and morbidity associated with donor site pain if an iliac bone graft is required to fill the defect. Recent developments in surgical technique for opening wedge HTO have addressed many of these issues. In addition to a transverse osteotomy of the posterior tibia, a second osteotomy can be performed in the coronal plane underneath the tibial tuberosity [25]. This bi-planar osteotomy provides rotational stability to the osteotomy. Rigid fixation of the osteotomy allows for early mobilisation and high rates of union can be expected without the need for bone graft [25]. This technique also leads to minimal slope change in the sagittal plane.

Less commonly, a combined distal femoral and high tibial osteotomy can be performed for medial compartment OA associated with varus alignment. This technique enables a large correction to be achieved without compromising joint line obliquity [26].

Distal femoral osteotomy is less common. It is frequently indicated in isolated lateral compartment disease associated with valgus malalignment. A medial closing wedge osteotomy, fixed with a blade plate, is the most commonly reported technique, however, a lateral opening wedge osteotomy can also be performed to correct the underlying deformity [7].

Osteotomy can be considered in combination with other joint preserving surgery including cartilage repair and meniscal transplant. Some have suggested that such regenerative procedures should not be considered unless the affected compartment has been effectively unloaded [27].

14.4 Outcome

Osteotomy around the knee for the treatment of unicompartmental OA is a well-established and safe surgical procedure. It is, however, not without complications and understanding the benefits and risks of surgery is essential in order to enable patients to make an informed decision about whether or not to proceed.

The majority of the literature concerning outcomes from surgery involves closing wedge HTO. A systematic review of this procedure showed general complications including venous thrombi-embolism (3.1 %), infection (4.6 %), neuromuscular complications (9.8 %), intra-articular fracture (0–20 %), delayed union (6.6 %) and non-union (2.2 %) [28]. Similar complications are seen in opening wedge HTO and, historically, there has been little to distinguish the two procedures with regard to adverse events and clinical outcome. However, using new techniques with stable fixation methods very low complication rates have been recorded. In a series of 262 opening wedge HTO procedures using the Tomofix locking plate system (de Puy Synthes, Oberdorf, Switzerland), only two cases of delayed union and one case of deep infection were reported [29].

Survival of HTO is usually considered with regard to conversion to total knee replacement. A large registry based study including over 3000 patients from Finland revealed an overall survival of 89 % at 5 years and 73 % at 10 years [30]. This study revealed poorer outcomes in female subjects and in those aged over 50 years. Other studies have suggested that under-correction may lead to reduced survivorship of HTO [31].

The literature on distal femoral osteotomy is more limited. A review of distal femoral osteotomy (DFO) procedures estimated survival for a medial closing wedge DFO to be approximately 80 % at 40 months dropping to 45 % at 15 years [7]. Importantly, a recent study showed that neither age nor concomitant surgery (e.g. micro fracture) had a significant effect on patient reported outcome for DFO [32].

14.5 Future

Recent developments have brought osteotomy surgery into the modern era and progress in this area is continuing at a pace. The EOS imaging system (EOS Imaging, Paris, France) is a radiological development that may offer a viable alternative to the use of long-leg radiographs in the coronal plane. It simultaneously obtains frontal and lateral images without any stitching or vertical distortion. This enables a three-dimensional image of a weight-bearing lower limb to be obtained for surgical planning with only low-dose exposure to radiation [33].

Finite element modelling enables patient-specific models that can predict the stresses and strains within the knee joint during standing or walking. These models can be used to simulate a planned osteotomy and identify the 'safe-correction zone' that will off-load the diseased compartment without over-loading the disease-free compartment [34]. At present, such modelling is costly and labour-intensive; however, as the process develops and becomes more common it may well hold the key to improving individual outcomes from surgery.

Whilst it is important to predict the safe-correction zone, improvements in surgical accuracy are necessary in order to consistently achieve the planned correction. Personalised cutting blocks that incorporate three-dimensional planning with a patient-specific cutting jig have shown promising results with high surgical accuracy [35]. It is not clear at present whether or not this improved accuracy leads to enhanced clinical outcome.

There is currently significant innovation underway in osteotomy surgery. It is an exciting and expanding field of orthopaedics that will continue to make a significant impact on patients with symptomatic knee arthritis associated with malalignment. Whilst it is currently confined to a few specialist knee centres, as innovations lead to more clearly defined patient criteria and more consistent outcomes, it is destined to become more commonplace.

Conclusions

Whilst osteotomy surgery became less popular following the widespread adoption of arthroplasty, it has become clear that it has an important role in patients with single-compartment disease, particularly those who are young, have high demands, and have partial-thickness disease which may fare poorly with arthroplasty. Proper patient selection and pre-operative planning are important in providing a successful outcome following proximal tibial or distal femoral osteotomy. It is likely that as more sophisticated imaging techniques and patient-specific cutting guides become more widespread, outcomes of osteotomy will become more predictable.

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