Anterior cruciate ligament rupture is a common knee injury in young people. It is the commonest cause of an acute haemarthrosis following trauma. Acute management involves aspiration, the restoration of full movement, followed by muscle rehabilitation. The long-term natural history of non-operative management is usually a failure to return to high level sports and in most, symptomatic instability with secondary meniscal and chondral injury. The late outcome is that of premature degenerative arthritis. Reconstructive techniques are now advanced and minimally invasive. However, considerable technical skill and experience is required to avoid complications. Physiotherapy guided rehabilitation over 4–6 months is vital prior to a return to sport. The stabilised knee should reduce secondary injury and progressive degenerative disease. In the future an increased number of reconstructions, tissue engineered grafts and accelerated healing will probably be seen.

**Key words**: knee; ligament; cruciate; anterior

**Introduction**

‘A torn anterior cruciate ligament is the beginning of the end’ (Allan, 1974)

‘No knee is so bad that it cannot be made worse with surgery’ (Hughston, 1985)

Anterior cruciate ligament (ACL) rupture is a common serious knee injury, often occurring in young athletic people. Its true incidence is unknown as it is not uncommon for the injury to be overlooked. The annual incidence has been estimated at 1 in 3000 in the general population, but is undoubtedly higher in the young and physically active (Miyasaka et al., 1991).

In the last three decades the secondary sequelae of ACL rupture, chronic instability and accelerated joint degeneration, have become more apparent. This situation was eloquently summarised above by Allan in 1974, as ‘the beginning of the end’. As a consequence of a more demanding population and concern to prevent the secondary sequelae, many reconstructive procedures have been developed and advanced. The number of reconstructive procedures has rapidly increased in frequency to approximately 100 000 per year in the USA alone. This increase probably represents both a true rise in incidence matching increases in sports participation and also greater awareness among the medical profession.

Although a common injury that is reasonably easy to diagnose, the management of ACL rupture is full of controversies ranging from whether or not to operate to the methods of assessing outcome. Reconstruction surgery has a long learning curve and as Hughston (1985) stated ‘No knee is so bad that it cannot be made worse with surgery’.

This review article addresses many of the controversies and attempts to outline current practice across the world.

**Anatomy**

The anterior cruciate ligament is an intra-articular, extra-synovial structure, which is enveloped in a synovial mesentery (Figure 1). This thin vascularised
layer is supplied by the middle geniculate artery, which provides the nutrition for the whole ligament. It differs from the thick vascular soft tissue coverings of the collateral ligaments, which alters its capacity to heal.

On average it is 30–35 mm in length. It runs from the anteromedial aspect of the tibial plateau, just medial to the anterior horn of the lateral meniscus, to 5 mm in front of the posterior edge of the intercondylar notch on the lateral femoral condyle. In extension the ACL runs parallel with the roof of the notch. At its entrance the average width of the notch is 20 mm. A narrow notch, which is more common in females, may predispose to rupture.

The overall diameter of the ligament is about 10 mm. There are two main bundles; a smaller anteromedial and a larger posterolateral, which describes their positions in the extended knee. The two bundles appear to twist or rotate 90° externally about themselves with flexion as a result of varying tension.

On a microscopic level the ligament consists of non parallel Type I collagen bundles (200 nm) that are grouped together firstly as fibrils, then fasciculae. The fasciculae are grouped and surrounded by paratenon to form the two discrete bundles. At the insertion points there is a gradual four-stage transition through fibrocartilage to bone. The ligament has a dense neural supply of largely mechanoreceptors involved in proprioception.

**Biomechanics**

The ultimate tensile strength of the ACL exceeds 2000 N and the stiffness in the bone–ligament–bone complex is 250 N/m. Normal walking activities lead to forces of 500 N, but cutting, pivoting and acceleration/deceleration raises forces up to 1700 N (Fu et al., 1999; Woo et al., 1994).

The ACL is the primary constraint to anterior tibial translation. It prevents excessive mobility between the two bones. The secondary constraints, medial meniscus, collaterals and capsule, play a relatively minor role in the intact knee, but assume major importance when ACL-deficient. This increases the risk of injury to these structures. The cruciates are often thought of as a four-bar linkage system in which the ligaments are isometric (no change in length or tension during movement). However, neither bundle in the ACL is isometric and there is variable tension depending on the knee position. The anteromedial bundle is most taut in flexion and the posterolateral in extension.

Recent studies (Sakane et al., 1997) have shown that the in-situ force (force carried in its natural environment) in the whole ACL and that in the posterolateral bundle in response to anterior tibial load, is highest at 30° of flexion. The in situ force in the anteromedial bundle is different and remains similar throughout the range of movement. This means that a single bundle replacement as in current reconstructions, is probably best inserted to replace the posterolateral bundle.

**Mechanism of rupture**

ACL rupture may be isolated or part of a multiple ligamento-capsular disruption, the extreme example being a knee dislocation. Most isolated ruptures are deceleration injuries often not involving direct contact. There is usually a rotational component with a fixed foot. Direct contact resulting in a valgus and external rotation or hyperextension of the knee may result in a rupture associated with additional injuries, for example to the medial collateral ligament. Varus forces less
commonly lead to ACL disruption unless as part of a major complex ligament injury.

There is usually a clear injury event that the patient can recite leading to acute knee symptoms. Sports involving rapid deceleration and cutting manoeuvres, particularly netball and soccer, are classically associated with ACL ruptures (Figure 2).

Falls and accidents may also result in a rupture, which is often not initially recognised as it is masked by other injuries.

Pathology/biology of rupture

Site
In the adult the usual site of rupture is a mid substance tear where the ultimate tensile resistance to failure of the ligament is less than that of its bony insertions. In the immature skeleton it is the reverse and bony avulsions, particularly at the tibial end that are more common. Failure at the insertion in adults, although uncommon, tends to occur at the femoral end rather than the tibial end.

Partial/complete tears
Complete tears most commonly result in disruption of all the fibres and synovial coverings (Figure 3), leading to a haemarthrosis. The disruption of the synovial envelope is important since this is the crucial difference with respect to healing or repair ability compared with other ligaments. Localised haematoma, the first stage of repair, is therefore unable to form at the rupture site.

Partial tears are uncommon and are difficult to truly diagnose. There is usually complete microscopic or functional disruption, but with only apparent partial macroscopic rupture. With partial tears the synovial envelope may not be disrupted, leading to a contained haematoma without a haemarthrosis. It is possible that some repair may occur.

Clinical presentation

History

Acute ruptures
In most cases there is a clear traumatic event or mechanism as described before. Occasionally a ‘snap’ is heard or felt and the knee collapses. In sport the patient is usually unable to play on. A tense swelling occurs within 3–4 hours, which is very painful and often results in an Accident and Emergency department
attendance. Aspiration, which should be undertaken with aseptic techniques, removes blood in most cases. Approximately 75% of traumatic haemarthroses of the knee are caused by ACL ruptures and should be considered so until proven otherwise.

**Chronic ruptures**

Some cases of rupture do not present or are not recognised acutely for various reasons. The patient generally describes a degree of instability (giving way when changing direction) or the sequelae of secondary injury such as a meniscal tear. Actual descriptions are numerous: ‘feels like one bone is sliding off the other’, ‘not joined’, ‘collapses or gives out’, ‘not secure’. All these become more significant if associated with changing of direction, pivoting or cutting actions.

**Examination**

A general limb and knee examination is undertaken before specifically looking for an ACL rupture. In particular, awareness of the neurovascular status of the limb is essential. Drainage of a haemarthrosis relieves pain, gains the patient’s confidence and improves the examination results.

Two examination tests have become synonymous for the ACL assessment, the Lachmann test and the pivot shift test.

**Lachmann test**

The anterior drawer or antero-posterior (a-p) laxity in 20° flexion is called the Lachmann test. Figure 4 shows a diagramatic picture of the Lachmann test. The leg is rolled out slightly and the knee slightly flexed at 20–30°. The leg is grasped above the knee with the thumb on top and below the knee with the other hand again with the thumb on top. Relaxed quadriceps and hamstrings, which the proximal hand assists, are essential. The tibia is then firmly translated forward with respect to the femur. The approximate translation distance and the quality of the endpoint are assessed. Each side is compared and the degree of laxity measured and recorded 1 + (<5 mm), 2 + (5–10 mm), 3 + (>10 mm). There is a spectrum of physiological laxity between individuals, but both sides are usually similar. The endpoint is normally solid and clear, but when ruptured is soft or absent.

This is the most specific and sensitive test in both acute and chronic cases. It may be the only test possible in the acute setting.

**The pivot shift test**

The pivot shift test simulates the patient’s usual complaint of instability. There are various methods. The classic MacIntosh pivot shift test (Galway et al., 1972) is undertaken with the relaxed patient lying supine. The examiner stands on the same side and the hand closest to the foot picks up the foot by the heel and internally rotates the extended leg. The other palm is placed against the posterior aspect of the proximal fibula applying an anterior and valgus force. This subluxes the tibia forward in an ACL-deficient limb. The knee is slowly flexed. In the ACL-deficient limb, initially the tibia may sublux further forward before relocating at about 30°. The relocation may occur with a considerable clunk and is often uncomfortable to the patient. Some patients may anticipate this movement and tense up, preventing the test, particularly in the acute group.

There are several variations that are possibly less uncomfortable, such as the Flexion-rotation drawer (Noyes et al., 1978). The limb is better supported and the relocation is more controlled and subtle. Although this method is more difficult and requires practice, it can be more sensitive (Bowditch and Edwards, unpublished data, 1999). A positive Lachmann a-p laxity test, but negative pivot shift may represent a partial tear or a late complete rupture in which the stump has adhered to the posterior cruciate ligament.
The anterior drawer at 90° flexion is not so useful. It is difficult to undertake in the acute knee as it rarely flexes this far. In the chronic knee, it may indicate laxity or stretching of the secondary constraints.

Examination of the rest of the knee is clearly important to determine the extent of associated injuries such as the collateral ligaments, menisci and capsule. In the acute knee, additional injuries are important to recognise as they will affect management plans. Of particular note is the postero-lateral corner structures, which have only recently been recognised as a significant albeit uncommon additional injury that may lead to poor outcome from ACL surgery alone.

Significant valgus or varus opening in extension usually means that there has been a complex ligamentous injury including both a collateral and the ACL.

In the chronic knee, progressive effects of knee instability may be present and laxity of the secondary constraints may be evident. Concurrent meniscal or chondral damage should be considered.

**Investigations**

Plain radiographs may have been taken in the accident department to exclude fractures in the acutely swollen knee. An avulsion of either end, but usually the tibial end, may occur in adolescents. ‘Minor’ capsular avulsions may in fact be the only evidence of a major disruption to the knee. The classic is the lateral capsular avulsion known as the 'Segond' fracture, which raises high suspicion of an ACL rupture (Figure 5).

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*Figure 5* Segond fracture. Lateral capsular avulsion often associated with ACL rupture

*Figure 6* MRI of the knee. (a) intact ACL, (b) ruptured ACL
Magnetic resonance imaging (MRI) has a high specificity and sensitivity for ACL rupture (93% accuracy) and associated injuries, particularly the menisci (90% accuracy) (Mackenzie et al., 1996). In the straightforward isolated ACL rupture (Figure 6a,b) it is not necessary to confirm clear clinical findings of a rupture. Where there is less certainty, such as an equivocal examination in the acute scenario, or suggestion of a complex injury, MRI may be very useful.

Associated injuries

Depending on the mechanism and degree of trauma, other structures may have been injured at the time of the ACL rupture or secondarily as a consequence of ACL deficiency.

Acute

Probably the most extreme injury is knee dislocation, which usually involves multiple ligament, capsular and meniscal disruption and in about 50% of cases neurovascular injury. More commonly, meniscal tears, medial collateral ligament (MCL) strains and chondral damage are found in approximately 50%, 10% and 20% of cases, respectively (Daniel and Fithian, 1994).

A crush tear of the lateral meniscus is the most frequently associated injury, but often does not require any intervention, whereas medial meniscal tears (Figure 7) often require resection or repair. The classic injury combination is known as O’Donoghue’s Triad, describing ruptures of the ACL and MCL with a peripheral medial meniscal separation. Fortunately this severe injury is infrequent.

Chronic

A chronically unstable knee may lead to progressive damage first to the menisci and later the articular cartilage. A medial meniscus tear is a common sequelae and presents with pain, clunking and occasionally locking. The medial joint line is tender to direct pressure.

All associated injuries influence management and should be identified.

Natural history

Following ACL rupture, the acute inflammatory process settles within two to three weeks and provided there is no significant associated injuries preventing it, full movement returns. Considerable muscle wasting of the quadriceps and hamstrings often develops, leaving a weak knee. This may be reversed with specific muscle rehabilitation (see later) over about 12 weeks.

Return to sport

At least 50% of patients experience symptoms of chronic instability (Andersson et al., 1989; Daniel et al., 1994). This becomes greater when more physical demands are put on the knee. Only about 20% of sportspersons are able to return to pre-injury level of activity (Andersson and Gilliquist, 1992; Johnson et al., 1992). Patients frequently avoid activities that lead to symptoms of instability and reduce their activity levels to produce an acceptable level of symptoms (Harter et al., 1988; Andersson et al., 1989; Shirakura et al., 1995).

A traditional rough rule of thumb is one-third of patients are able to return to their previous level of sports, one-third of patients are unable to play sports or only manage a lower level and one-third of patients have instability interfering with everyday activities (Nogalski and Bach, 1994). In fact today considerably less than 1/3 successfully return to sport and very few top-level athletes are able to continue without surgical reconstruction.

Figure 7  Arthroscopic appearance of medial meniscal tear associated with 25–50% of ACL ruptures

Trauma 2001; 3: 249–261
Prognosis
Secondary injury is common in the unstable knee where the menisci and articular cartilage are at severe risk. The literature suggests as many as 40% of patients will sustain a meniscal tear and 65% will develop degenerative changes within eight years (Thompson and Fu, 1993; Casteleyn and Handelberg, 1996). These figures rise in high-risk sports. There is irrefutable evidence showing that meniscectomy leads to progressive degenerative change (Fairbank, 1948).

The association of meniscal injury with ACL-deficiency implies significant risk of progressive degenerative change.

Initial management
In the acute case the immediate treatment aim is similar to any other soft tissue injury in that it attempts to reduce the pain and swelling of the acute inflammatory process, followed by early restoration of a full range of joint movement. Draining a tense haemarthrosis as highlighted earlier may be extremely useful in pain relief and restoring some movement.

RICE (‘Rest Ice Compression Elevation’) anti-inflammatories and early physiotherapy for movement are the first-line treatments. The acute phase usually settles and movement is restored within 2–3 weeks of injury.

The quicker swelling is reduced and full movement restored, the faster the definitive management, whether operative or non-operative, can progress.

Some surgeons advocate early arthroscopy to wash out the haemarthrosis and assess the knee for associated injuries. This policy depends somewhat on the patient, resources and opinions with respect to definitive management.

Definitive management
The first real controversy is to decide whether to operate or not. There are essentially two areas to consider; return to pre-injury activities, and long-term prognosis of the knee.

Firstly, although there is general acceptance that the natural history of the condition is poor, there are some patients (‘copers’) who will do well with non-operative management and make a full return to pre-injury activities. Unfortunately, there are no ways of identifying this patient at the outset. Elite level sports players and those in sports such as football, netball and hockey rarely return to prior levels with an ACL-deficient knee. The downside of the ‘wait and see’ approach is the risk of secondary injury in the ‘non-copers’ and the resulting double length of rehabilitation.

Secondly, some patients prefer to modify their activities sufficiently to avoid symptomatic problems. Each patient has to be carefully counselled to help them make the most appropriate decision for their individual circumstances. General agreement on the high risks of progressive secondary injury and degenerative change is slightly confounded by the fact that not all are symptomatic later and/or are able to modify their activities sufficiently.

Non-operative treatment

Physiotherapy
A three-month physiotherapy rehabilitation programme is instituted. This concentrates on improving range of movement, strengthening of quadriceps and hamstring, agility, and proprioceptive and sport-specific training.

Knee braces
Bracing remains controversial with little definitive evidence to support their ability to prevent anterior translation or rotational movements. However, some patients find their knee feels more stable using a brace than not. Braces may have more of a proprioceptive role than mechanical. Most are used in those wishing to avoid surgery or only have mild-moderate instability during certain sports activities. They are used occasionally in post-operative regimes, particularly with allografts in order to help reduce inappropriate rehabilitation.

Operative

Primary suture repair
Acute repair was described in 1938, but has a high failure rate (>50%) (Grontvedt et al., 1996). Acute reattachment of bony avulsions has good results. This is most frequently achievable in the immature skeleton.

Primary suture repair with augmentation
Augmentation may be extra- or intra-articular (Ligament Augmentation Device, LAD). Autograft and prosthetic materials such as Dacron™ or carbon fibre have been used. Synthetic grafts have significant problems as described below, without any significant
improvement in outcome compared with suture repair alone (Grontvedt et al., 1996).

**Extra-articular substitution**

Several extra-articular lateral tenodesis procedures have been described (MacIntosh and Darby, 1976; Ellison, 1979). These were designed to abolish instability as seen in the pivot shift. Although it fails to restore the true knee mechanics, the procedure works well initially and indirectly eliminates the symptom with which most patients present. However, the tenodesis stretches in most cases, leading to mid- or long-term failure (Amirault et al., 1988; Reid et al., 1992).

**Prosthetic replacement**

Prosthetic ligaments (Polyester, Gore-tex™, Dacron™, carbon fibre) are not currently recommended. They have high failure rates (40–80%) at 5–15 years (Frank and Jackson, 1997; Maletius and Gillquist, 1997). Perhaps of more concern is the fact that they produce significant intra-articular wear debris, which can lead to marked osteolysis, and there are reports suggesting accelerated degenerative change (Maletius and Gillquist, 1997).

**Reconstruction**

This refers to intra-articular substitution of the ruptured ACL with a graft material.

**Hospital stay**

Most ACL reconstructions involve one overnight stay in hospital to allow pain control and start rehabilitation.

**Anaesthesia and length of procedure**

Combinations of regional blocks and light general anaesthesia are the most common. Reconstructions take approximately one hour and are conducted under tourniquet following limb exsanguination.

**Graft material**

The present choices for intra-articular reconstruction are autograft and allograft biological tissue grafts. Graft options include patella tendon, medial hamstrings, quadriceps tendon and achilles tendon.

**Autografts**

Autografts have the advantage of low risk adverse inflammatory reactions, no risk of disease transmission, and faster incorporation and remodelling.

**Patella tendon graft**

The bone-patella tendon-bone (B-PT-B) graft (Figure 8a) has probably been the gold standard for several years. It has a high ultimate tensile strength (2300 N) and stiffness (620 N/mm), similar to the ACL (Fu et al., 1999). The middle third of the patella tendon is harvested from the same knee with adjacent tibial and patellar bone blocks. The graft and plugs are approximately 10 mm wide (~40% width of the

Figure 8 Graft types. (a) Bone–patella tendon–bone, (b) hamstring

*Trauma* 2001; 3: 249–261
The bone blocks allow bone to bone fixation and early healing at either end. Occasionally the medial third is used and some take the contralateral patella tendon. The latter is said to speed up rehabilitation, but interferes with a ‘normal knee’.

**Hamstring grafts**

Hamstring grafts (Figure 8b) have become increasingly popular on the basis of lower donor morbidity. The four-strand semitendinosus/gracilis graft is currently the most popular. Both tendons are harvested from the same knee through a small incision on the medial side of the proximal tibia using a tendon stripper. The two tendons are folded in half to make four strands, which are sutured together at either end. Overall, the graft is approximately 8–10 mm in diameter and has an ultimate tensile strength of 4000 N (Fu et al., 1999). The drawbacks concern the tendon to bone fixation and healing in the tunnels at either end.

**Quadriiceps graft**

Quadriiceps grafts have generally been less popular in view of the additional donor site incision and slower rehabilitation. It has a similar tensile strength to the patella tendon but only one bone block.

**Allografts**

All of the above grafts and, in addition, the Achilles tendon are available as allografts. Allografts avoid donor site morbidity and decrease surgical time. Certain preservation and sterilization techniques such as ‘freeze thaw’, ethylene oxide and irradiation alter the graft mechanical and structural properties and incorporation rates. Sterile harvesting, deep freezing and low dose (3-Mrad) irradiation limit these effects.

Allografts have an important role in revision or multiple ligament reconstructions.

**Surgical approach**

Intra-articular reconstructions may be termed open, arthroscopically assisted or arthroscopic only. As with other branches of surgery, there has been a tendency towards less invasive techniques. There are short-term advantages with respect to post-operative pain relief, rehabilitation and cosmesis, but no long-term differences. Whatever the approach, it should not compromise graft tunnel placement. Most require a short incision to harvest the graft and it is then inserted arthroscopically. Single incision techniques refer to incision/s on the tibial side only (in addition to arthroscopy portals) rather than on both the tibia and the femur, which is described as a two-incision process.

Some surgeons augment an intra-articular reconstruction with an open extra-articular lateral tenodesis.

**Bone tunnel placement**

The aim of tunnel positioning is to allow anatomical graft placement in order to best reproduce ACL function. Failure to do so may lead to stretching, impingement, or overconstraint, all of which may result in graft failure or limited motion.

The tibial tunnel is drilled from the proximal tibia just medial to the tuberosity to exit through the ACL footprint in the knee. The ideal position is at the central or posterior part of the anatomical ACL foot. The tunnel is angled at 45–55° to the tibia and drilled in most cases using a specific jig.

The femoral tunnel or graft insertion site should start immediately anterior to the back of the intercondylar notch ('over-the-top' position) on the respective side. This is at about 10 or 11 o’clock for the right knee and 1 or 2 o’clock for the left knee (Figure 9). The tunnel should angle anteriorly and laterally with respect to the femur. There should be a thin (1–2 mm) posterior wall, although a small ‘blow-out’ is acceptable. Some earlier techniques pass the graft out the back (over the top) and through to the lateral femur.

**Notchplasty**

This refers to removing part of the lateral and superior walls of the intercondylar notch. It improves the view

![Figure 9 Arthroscopic appearance of new reconstruction graft in place in the knee](image-url)
of the posterior notch, helping femoral tunnel placement and may reduce graft impingement in full extension.

**Graft fixation**
Fixation at either end may be achieved by a large variety of direct and indirect techniques; interference screws, staples, sutures and tapes, suture-posts, cross-pins, washers, buttons, bone wedge, and combinations of these.

Interference screws are probably the most commonly used, particularly for B-PT-B grafts. These screws are tapered and are smooth to wedge the bone block in the tunnel without damaging the tendon. Metal and bioabsorbable versions are available. As with the normal ACL, fixation of the graft should be as close to the joint line as possible. With most techniques this is not possible in both femur and tibia.

The new graft should be adequately tensioned before the second fixation (usually the tibia) to prevent either a lax or over-tight reconstruction. The precise amount of tension and knee position for tensioning is unknown.

**Management of associated injuries**
Meniscal injuries should be addressed at an early stage as they compromise rehabilitation. Stable splits or tears (less than 10 mm in the outer two-thirds) may be left as they usually heal if the knee is stabilised. Larger horizontal tears in the outer two-thirds may be repairable with sutures or fixation devices (arrows, darts). Complex irregular flap tears are usually irreparable and are resected.

Chondral damage should be noted for future reference and debrided.

All grades of medial collateral ligament strains have been shown to heal well by non-operative measures (braces) that limit varus-valgus movement. Some severe grade III avulsions from the femur may benefit from operative reattachment.

Postero-lateral corner and lateral collateral ligament injuries are uncommon and should probably be surgically addressed at the time of ACL reconstruction.

**Immature skeleton**
Although mid-substance rupture is uncommon, the open growth plate poses difficulties to the standard reconstructive techniques. Various techniques are used, ranging from nothing until mature through primary suture and extra-articular augmentation to full reconstruction. Each case requires individual assessment (Andrews et al., 1992).

**Rehabilitation**
Rehabilitation after reconstruction is as important as the surgery. A six-month programme, closely supervised by an appropriately trained physiotherapist, is essential. Accelerated or aggressive rehabilitation has been accepted, particularly for B-PT-B reconstructions. There are three stages.

Stage 1 (1–6 weeks) aims at limiting swelling, regaining a full range of movement, in particular extension and muscle control. In hospital a continuous passive movement machine may be applied for several hours per day to assist with regaining 0–90° movement. A normal gait pattern without crutches is encouraged. Whilst the graft is strong enough for normal daily activities, it is not able to withstand vigorous activity such as running, jumping or heavy lifting.

Stage 2 (6–12 weeks) involves gradual muscle strengthening and proprioception. A supervised gym programme may be started, with resisted closed-chain quadriceps and hamstrings at first. Hydrotherapy may be useful. This progresses to walking backwards, turning, and light running. No cutting or jumping is allowed.

Stage 3 (3–6 months) allows a full gym programme, running, pivoting, cutting, and sport-specific activities to be introduced.

At six months, muscle power, reaction and agility tests are undertaken and compared with the contralateral side. If 80% or more has been achieved then a graduated return to sports is allowed.

**Biology of graft healing**

**Insertion sites**
B-PT-B grafts allow rigid bone to bone fixation at both ends with bony union in approximately 16 weeks. Hamstring and other soft tissue tendon grafts heal much more slowly than bone to bone. The normal ligament–bone insertion site structure is not achieved in either for about six to nine months (Fu et al., 1999).
Graft body

The graft tissue undergoes inflammation and necrosis before gradual revascularisation over three months. The graft remodels over several years to form strong fibrous tissue, but never becomes structurally identical to the natural ACL.

Complications

Intra-articular reconstructions are technically exacting and there are many intra- and post-operative complications that may occur as a result of variance from the principles outlined above.

Early complications within the first few days include:

- Haemarthroses
- Extra-articular fluid extravasation leading to gross limb swelling and, occasionally, compartment syndrome
- Nerve palsy from positioning, tourniquet, or fluid pressure
- Infection

Subacute complications are varied and relate to donor site morbidity or failure to regain range of movement due to scar adhesions. Rarely, patella fracture (0.5%) or patella tendon rupture may occur. Donor site morbidity occurs with all autografts to a varying degree. It is avoided by using allografts. B-PT-B is associated with anterior knee pain in 4–40% of cases in the early stages (Fu et al., 2000). It usually improves or settles after six months, but about 10% of patients have chronic pain (Burwell et al., 1998). The specific cause is unknown, but patella infera (shortening of the patella tendon) is not thought to be the cause in most, although it can occur as a separate entity.

Immediate and aggressive rehabilitation, which lowers the incidence of anterior knee pain and stiffness, is felt to be more significant than surgical techniques. Hamstring grafts avoid interference in the extensor mechanism and although they have reduced the prevalence of anterior knee pain, they do not eliminate it. The hamstring donor site is sore for three months, but there appears to be little functional deficit resulting from removing two of the medial hamstrings.

Arthrofibrosis is a severe complication occurring in about 1–3% of cases where intra-articular fibrous adhesions develop, resulting in a painful stiff knee. The precise cause is unknown, but early ACL reconstruction in an inflamed knee (still swollen) that has a reduced range of movement is felt to be a significant risk.

Late complications such as graft impingement and rupture may be related to malpositioning of the grafts. An anterior tibial tunnel can lead to graft impingement on the arch of the notch. This may lead to the development of a fibrous nodule or ‘cylops lesion’, which restricts extension.

Outcomes

Outcome measures

Subjective outcome to the patient primarily concerns the removal of knee instability or the pivot shift phenomena and the regaining of confidence in the knee. Initially, most of the techniques described achieve this well. The controversies concern more objective outcome measures, which include short- and long-term antero-posterior laxity, return to and level of sport activities. Most papers comparing different techniques are generally required to report a minimum of five-year follow-up results.

Numerous functional scoring systems have been proposed and used. Most papers now use the International Knee Documentation Committee (IKDC) evaluation, Cincinnati, and Tegner and Lysholm assessments (Anderson, 1994). These incorporate symptoms, signs, instrumented laxity testing and return to activities.

Instrumented laxity testing uses devices such as the KT 1000 to measure pre- and post-operative anterior tibial translation and compare it with the non-injured side. Although required by most journals, the significance of this measurement is still controversial (Wojtys and Carpenter, 1994).

Outcome of different techniques

As stated previously, repair with or without augmentation, extra-articular substitution alone and the use of synthetic ligaments lead to poor long-term results and are not recommended.

Earlier reports suggested allografts had high complications and re-rupture rates but recent papers suggest similar outcomes at five to seven years when compared to autograft (Noyes and Barber, 1996). The risk of disease transmission still remains a concern. B-PT-B and hamstring grafts appear to have similar biomechanical and clinical results, with stability restored and pre-injury level return to sports in
80–90% of patients at five years (Bach et al., 1998; Feagin et al., 1997; Shelbourne and Gray, 1997).

Around the world intra-articular B-PT-B is still the most popular procedure and is the gold standard with which comparisons are made. Augmentation with a lateral tenodesis is advocated by some surgeons and has some support in the established literature (Dandy and Hobby, 1998). However, as cohorts with improved fixation techniques reach five years or beyond, intra-articular techniques alone are showing similar results (Bach et al., 1998).

**Prognosis**

The effect of ACL reconstruction on future knee arthrosis is still unknown. Several studies have shown increased, no difference and reduced prevalence at follow-up (Daniel and Fithian, 1994; Ferretti et al., 1991). The subject group undergoing ACL reconstruction is very varied with respect to associated and pre-existing injuries, which clearly affects the prognosis.

An inadequate reconstruction such as an over-constrained joint or complication such as arthrofibrosis will accelerate articular cartilage damage. However, from a theoretical view a stable joint following an appropriate reconstruction should reduce further articular injury and subsequent degeneration. Long-term studies of sub-divided population groups are currently being undertaken and should help resolve this question (Webb et al., 1998).

**Recommendations**

With the improvements in techniques and a more athletic population of all ages the indications for reconstruction are increasing all the time. Non-operative management may be appropriate for the non-athletic and older person, but age per se should not be a barrier to reconstruction.

The argument for earlier reconstructions is based on reducing secondary injury and is valid in those in whom the decision to reconstruct has been made. With the possible risk of arthrofibrosis, reconstruction should ideally take place after the immediate inflammatory response has settled and range of motion has been restored, perhaps after the first week. Minimally invasive arthroscopic techniques are preferred by all, if the surgeon is happy with the technique.

There is little in graft choice between B-PT-B and hamstring. Patient factors should be discussed. Those occupations involving a lot of kneeling are probably better with the lower anterior knee morbidity of hamstrings. B-PT-B is preferred in young high-level athletes because of its stiffness, quality of fixation and long term (>10 year) track record. High-level sprinters may also notice hamstring morbidity.

Allografts with the risk of disease are still largely reserved for revisions.

**Future developments**

Further refinements to the surgical techniques and rehabilitation protocols will continue. Current research is evaluating improvements in graft tensioning, tibial fixation and ‘in vivo’ assessment ligament strain during rehabilitation. Surgery assisted by computers, imaging and robotic technology may help reduce technical errors.

Molecular biology, tissue engineering and gene therapy are being targeted at accelerating ligament healing and cell insertions into graft scaffolds.

The aim is to restore the knee and patient as closely to their pre-injury state and function as possible and prevent the secondary sequelae.

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**References**


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