10 Intraoperative Considerations Crucial for a Successful Outcome

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10.1 Introduction

This chapter discusses the indications and contraindications for anterior cruciate ligament (ACL) reconstruction, graft options, preoperative planning, anatomic graft placement issues, and treatment of additional injuries that may occur to the menisci and other knee ligaments. Acute complete ACL ruptures are treated first with rehabilitation until pain and swelling subside and joint motion and muscle function are restored (see Chap. 8). Reconstruction is then performed if the appropriate indications are met. However, even with surgery, patients are informed that an ACL rupture is a serious injury, and it is unlikely that they will ever have a truly normal knee joint. The injury may also involve a bone bruise and chondral damage, with sequelae for future joint symptoms. The treatment of partial ACL ruptures has been discussed elsewhere [1].

Upon the initial patient presentation, a comprehensive physical examination requires assessment of knee flexion and extension, patellofemoral indices, tibiofemoral crepitus, tibiofemoral joint line pain, muscle strength, and gait abnormalities. The medial posterior tibiofemoral step-off on the posterior drawer test is done at 90° of flexion. The integrity of the ACL is determined with KT-2000 arthrometer testing (134 N force) and the pivot shift test that is recorded on a scale of 0 to III, with a grade of 0 indicating no pivot shift; grade I, a slip or glide; grade II, a jerk with gross subluxation or clunk; and grade III, gross subluxation with impingement of the posterior aspect of the lateral side of the tibial plateau against the femoral condyle. Radiographs include standing anteroposterior (AP) at 0°, lateral at 30° of knee flexion, weight-bearing posteroanterior (PA) at 45° of knee flexion, and patellofemoral axial views. Double-stance full-standing radiographs of both lower extremities are obtained in knees in which varus or valgus lower extremity alignment is detected on clinical examination. Magnetic resonance imaging (MRI) is performed to provide further details of the condition of the articular cartilage and menisci and includes fast-spin-echo techniques and 3-Telsa articular cartilage T-2 mapping when necessary to obtain superior-quality articular cartilage images [2, 3].

10.1.1 Indications for ACL Reconstruction

Patients who are highly motivated to return to sport (RTS) or who are involved with strenuous occupations are considered for reconstruction [4]. In patients with a concomitant displaced bucket-

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handle meniscus tear, surgery within 7–10 days is required to reduce the meniscus to a normal location and repair the tear. The ACL reconstruction may be performed at the same setting; however, knees with excessive swelling and pain undergo a staged meniscus repair first. After an appropriate period of rehabilitation, ACL reconstruction is then performed.

Repairable meniscus tears almost always indicate a concurrent ACL reconstruction. Otherwise, the success of the meniscus repair may be compromised [5–7]. A grade III pivot shift and grossly positive Lachman (increased ≥10-mm anterior tibial translation) indicate involvement of the secondary ligamentous restraints and, in our experience, an increased risk of giving-way reinjuries with recreational activities, and reconstruction is frequently recommended.

Systematic reviews have demonstrated that ACL reconstruction reduces the incidence of subsequent meniscus injuries, reduces the need for further operations, and results in greater improvements in activity levels [8]. In patients who undergo reconstruction and in whom the menisci are retained, there is a lower incidence of knee osteoarthritis [9, 10]. Mather and associates [11] reported that, in the short term, ACL reconstruction was less costly (cost reduction of $4503) and more effective compared with rehabilitation. In the long term, the mean lifetime cost to society for a patient undergoing ACL reconstruction was calculated to be $38,121 compared with $88,538 for nonoperative treatment with rehabilitation.

10.1.2 Contraindications for ACL Reconstruction

Patients involved in low-impact activities or who are willing to avoid strenuous athletic and occupational activities that place the knee at increased risk for reinjury may not require ACL reconstruction. These patients undergo rehabilitation to regain muscle strength and neuromuscular function and are counseled on the risk of future giving-way reinjuries and potential damage to the joint. Patients who are unable to participate or be compliant with postoperative rehabilitation are not surgical candidates.

The presence of symptomatic patellofemoral or tibiofemoral arthritis is a general contraindication to ACL surgery, because pain symptoms remain postoperatively. Weight-bearing 45° PA views determine the millimeters of remaining medial or lateral tibiofemoral joint space. In knees with absent or nearly absent joint space, conservative measures are instituted until such time that partial or total joint replacement is warranted.

Patients with symptomatic medial tibiofemoral arthritis and varus malalignment require high tibial osteotomy. These patients often do not require subsequent ACL surgery due to limitations in activities from the joint damage. Patients with lower extremity muscle atrophy require rehabilitation until adequate muscle function has been restored. These patients have an increased risk for postoperative complications including quadriceps muscle shutdown, patella infera, and arthrofibrosis. Complex regional pain syndrome is a contraindication to surgery.

Patients with a body mass index of 30 or greater are usually not surgical candidates. A history of prior infection with subsequent joint arthritis often contraindicates ACL surgery. There may be associated medical conditions contraindicating surgery. The use of nicotine products is strongly discouraged and absolutely contraindicated if osteotomy alignment procedures are required.

10.1.3 Preoperative Planning

All abnormalities or potential problems are addressed preoperatively, including patient expectation issues, muscular weakness, painful neuromas, residual pain syndromes, and anterior knee pain due to patellofemoral cartilage damage. Considerable counseling and patient education are required on the expected results and outcomes from the reconstruction. This is especially important in knees with preexisting arthritis or loss of meniscal function or those that require additional major operative procedures. A surgeon-rehabilitation team is required to provide instruction on rehabilitation to ensure that the postoperative exercise program will be successfully followed by the patient. The patient and family consult with the physical therapy team before surgery to ensure that the postoperative rehabilitation requirements are thoroughly understood. Disclosure is required that approximately 50% of patients in whom a bone-patellar tendon-bone (B-PT-B) autograft is used will have a small area of numbness just lateral to the patellar tendon.

Knees with grossly positive clinical laxity tests have involvement of the secondary ligament restraints, primarily the lateral structures. Associated medial or lateral ligament laxity is an indication for medial or lateral ligament reconstruction. A summary of the essential aspects of ACL reconstruction is shown in Table 10.1.

It is important to determine the ACL graft length well before surgery to ensure a mismatch does not occur between intra-articular length of the tunnels and the length of the graft. The length of the patellar tendon is determined on lateral radiographs. The normal patellar length based on the Linclau technique [13] is a 1:1 ratio with the patellar tendon in the 35-mm range. The intra-articular ACL length is measured on the lateral MRI, and this length is matched with the graft.

10.1.4 ACL Graft Selection

The two most common autograft tissue sources for ACL reconstruction are B-PT-B and semitendinosus-gracilis (STG) tendons. A quadriceps tendon-patellar bone (QT-PB) autograft is also an excellent graft to substitute for STG tendons in small females and in other situations such as ACL revision reconstructions. We prefer B-PT-B autogenous grafts over allografts in athletes, a recommendation supported by multiple long-term studies [14–18]. In addition, several investigations have documented a higher rate of ACL reconstruction failure in allografts compared with autografts, especially in younger active patients [15, 19–26]. Although allografts offer technical ease and reduced donor site pain, there are additional risks of disease transmission, a biomechanically inferior graft, and biological reaction to irradiation and chemical sterilization processing [27].

A B-PT-B autograft is not recommended if there is associated patellofemoral arthritis, anterior knee pain, or history of patellar subluxation or dislocation. A B-PT-B autograft is not performed when patient issues suggest a decreased ability to manage the initial postoperative graft harvest-related pain. In recreational athletes

Table 10.1 Summary of essential aspects of ACL reconstruction

1. Autografts are recommended over allografts based on the superior healing, graft incorporation, overall higher success rates, and avoidance of transmission of disease (even though of rare incidence). Allografts are reserved for multioperated revision knees with concurrent instability where suitable graft sources are not available or special clinical cases in which a graft harvest is to be avoided
2. ACL grafts should be placed in an anatomic position within the femoral and tibial footprint. The central portion of the femoral and tibial attachment site is recommended. The native ACL femoral attachment is located entirely on the lateral wall; no fiber attachments extend to the intercondylar roof
3. The ACL graft is placed in a femoral tunnel that is located in the proximal two-thirds of the ACL footprint. A distal placement in the femoral attachment shortens the length and increases the failure rate. A tibial tunnel located in the posterior one-third of the ACL footprint results in an ineffective graft orientation. A central tibial footprint location should be achieved in the anteromedial bundle portion
4. A limited notchplasty is usually required to prevent roof impingement in extension and to have an adequate graft space between the lateral notch and the posterior cruciate ligament
5. Associated ligament injuries overload ACL grafts and require correction to prevent failure of the ACL reconstruction
6. Abnormal knee hyperextension of 12–15° may overload an ACL graft and requires operative correction. The recommended posterolateral graft reconstructive procedures for a severe hyperextension varus recurvatum deformity have been described elsewhere [12]. Certain ACL revision knees with stretching or injury to the secondary ligament restraints and a grade III pivot shift require a lateral extra-articular procedure
7. A comprehensive rehabilitation program is essential for success and return of lower extremity function. Rehabilitation principles and protocols are addressed in Chaps. 11 and 14

and more sedentary patients, a four-strand or six-strand STG autograft or QT-PB autograft is recommended. Modern soft tissue graft fixation methods have increased success rates.

10.1.4.1 Critical Points

Indications
- Complete ACL rupture
- Patient desires to return to high-risk activities (pivoting, cutting, twisting, turning)
- Acute ACL rupture and concomitant displaced bucket-handle meniscus tear

Contraindications
- Sedentary patient, no symptoms, little exposure high-risk activities
- Patient unable to participate in postoperative rehabilitation program
- Preexisting severe loss of patellofemoral or tibiofemoral compartment joint space
- Marked muscle atrophy, complex regional pain syndrome, obesity
- Prior joint infection

Preoperative planning
- Address patient expectation and goals of surgery
- Determine need for concomitant procedures, extra-articular procedures, other ligament reconstructions to correct all instabilities
- Determine ACL graft length

Graft Selection
- Prefer B-PT-B autograft in athletes, STG or QT-PB in recreational, more sedentary patients or those with patellofemoral problems.
- Allografts are rarely used and are reserved for multiligament procedures or special cases where graft harvest is to be avoided.

10.2 Intraoperative Evaluation

After the induction of anesthesia, all knee ligament subluxation tests are performed in both the injured and contralateral limbs. The amounts of increased anterior tibial translation, posterior tibial translation, lateral and medial joint opening, and external tibial rotation are documented. A thorough arthroscopic examination is conducted, noting articular cartilage surface abnormalities and the condition of the menisci. Appropriate debridement and meniscus repair (to be described) or partial excision are performed as necessary.

The lateral and medial gap tests are done during the arthroscopic examination [28]. The knee is flexed to 25–30° and a varus load of approximately 89 N applied. A calibrated nerve hook is used to measure the amount of tibiofemoral compartment opening. Knees that have 12 mm or more of joint opening at the periphery or 10 mm at the midpoint of the tibiofemoral compartment require a posterolateral or medial ligament reconstructive procedure. Studies have shown that uncorrected deficiency of other knee ligaments increases the risk of failure of ACL reconstruction [29, 30].

10.3 Graft Harvest

10.3.1 B-PT-B Autograft

A summary of the steps for the harvest of the B-PT-B autograft is shown in Table 10.2 [1]. A 3- to 4-cm vertical medial incision is made just adjacent to the medial border of the patella tendon, avoiding the tibial tubercle (Fig. 10.1). A cosmetic approach is used where the plane beneath the subcutaneous tissues is dissected to allow for a limited skin incision. The retinaculum in the middle of the patellar tendon is incised and the dissection limited only to the midportion of the patellar tendon. The retinaculum is protected to allow for closure over the bone-grafted patellar defect. A similar procedure is used at the tibial tuberosity.

The patellar tendon is incised in the midportion to 9–10 mm. The patella is displaced distally into the wound using a forked retractor placed at the superior patellar margin. A powered handheld saw with a thin-width blade is marked with a Steri-Strip 9–10 mm from the tip. A trapezoidal

Table 10.2 Summary of steps to harvest a bone-patellar tendon-bone autograft [1]

• Inflate tourniquet 275-mm pressure
• 3–4-cm incision adjacent medial border patellar tendon, medial to inferior pole of patella, mobilize skin flaps for cosmetic approach
• Retinaculum middle patellar tendon incised, limited dissection only for width of graft to be removed
• Use precut 10-mm and 22-mm paper ruler to define graft dimensions
• Patellar tendon incised in midportion
• Trapezoidal bone block graft from patella removed with fine saw cuts, osteotome, similar procedure for tibial bone block
• Sutures placed each bone block, prepared for passage
• Graft wrapped in blood-soaked sponge
• Diameter of tunnels 1 mm larger than diameter of bone block
• End of procedure, loosely approximate tendon graft harvest site with sutures
• Meticulous bone graft from core reamer patella, tibia defects. Place 2 horizontal mattress sutures inferior pole patella, superior tibial tendon attachment to hold bone grafts in defects, close anterior tissues

bone block graft from the patella is removed by angling the fine saw 15° at each side of the cut. The bone cut extends to the inferior pole, and care is taken to protect the insertion site of the patellar tendon. A 4-mm osteotome gently removes the patellar bone block. A similar procedure is followed in the harvest of the tibial bone block. The tourniquet is deflated, and a cotton sponge is placed in the wound. The graft is later wrapped in the blood-soaked sponge, which provides for protection of the graft, maintains a moist blood environment, and may allow cells to survive in the graft-remodeling process.

The bone blocks are prepared. The diameter of the tunnels will be configured 1 mm larger than the diameter of the bone block. One 2-mm drill hole is placed one-third of the way from the end of each bone block for sutures. The end sutures allow the graft to be passed into the tunnel. The bone block tip is fashioned into a bullet tip configuration for tibial tunnel passage. At the conclusion of the ACL reconstruction, closure of the patellar tendon graft harvest site is performed with loosely approximated 2-0 absorbable sutures. A coring reamer used for the tibial tunnel provides a large dowel of cancellous bone to completely fill the patella and tibia defects.

10.3.2 Graft Harvest: STG Autograft

The STG graft harvest procedure is summarized in Table 10.3. A 3- to 4-cm oblique incision is made over the pes tendons (Fig. 10.2). An anteromedial incision over a popliteal-based incision is preferred to gain maximum length of the tendons at the tibial confluent attachment. The sartorius fascia is incised directly proximal to the semitendinosus and gracilis tendons to provide an opening to protect the superficial medial collateral ligament (SMCL). Each tendon is identified, incised through the confluent distal tendon region, and then grasped at a 90° angle and rolled two to three times around a straight hemostat, which allows tension to be placed on the tendon without producing damage.

The proximal fascia about each tendon is bluntly dissected, and the semitendinosus tendon attachment to the medial gastrocnemius fascia is incised. The tendons will freely displace 10 cm. The closed-end graft harvester is passed along the trajectory of each tendon, and each tendon is transected at 20 cm for a four-strand graft or 24 cm for a six-strand graft described later.

In the four-strand graft, each tendon is looped about a 3-mm tape and the tendon end sutured to itself with a No. 2 nonabsorbable suture. A third suture (FiberLoop, Arthrex) is added at both graft tendon ends. A running 0-nonabsorbable suture is used to produce a tubed structure running from proximal to distal and then back to the proximal starting point. The graft is marked 25 mm from each end, wrapped in a blood-soaked sponge, and placed in a secure place on the back table. A six-strand graft is used in women and patients of small stature in which the STG tendon diameter is decreased and to provide added tendon substance for a 9- to 10-mm graft diameter. This avoids a 6–7-

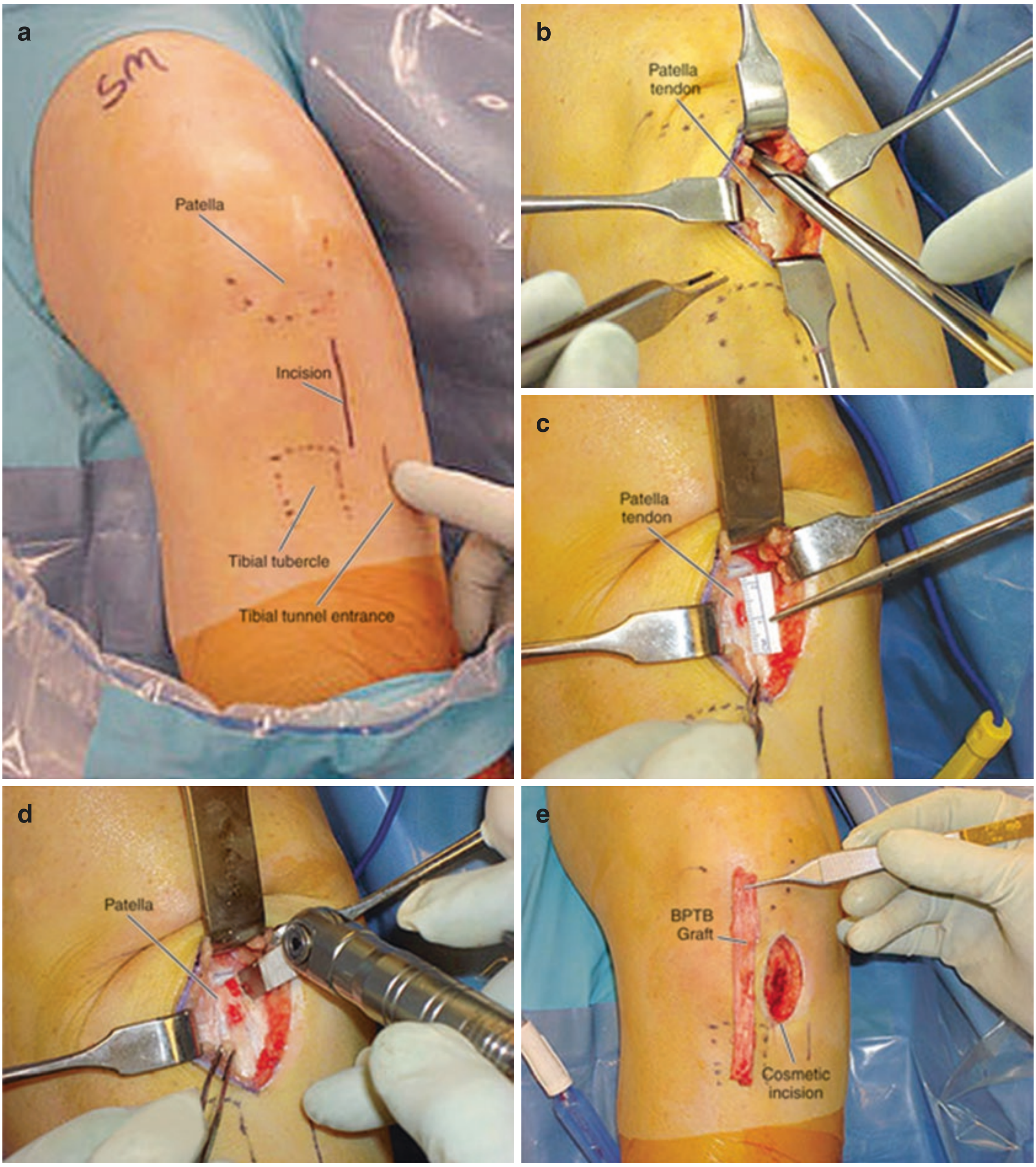

Fig. 10.1 The recommended technique for harvest of a bone-patellar tendon-bone (B-PT-B) autograft is shown. (**a**) A 3- to 4-cm skin incision, just medial to the patellar tendon, is made to avoid the bony prominence of the patella and tibial tubercle. The index finger points to the planned tibial tunnel, which can be reached through this cosmetic incision. (**b**) Mobilization of subcutaneous tissues to allow the cosmetically placed incision to be moved in a proximal-distal and medial fashion. Infrapatellar nerves when present are protected. (**c**) A ruler measures the length of the patellar tendon and a 10-mm wide patellar tendon graft is marked by two or three ink dots. (**d**) The patella is displaced distally and the patellar bone block removed. Note the saw has a tape marking a 9-mm depth to prevent from cutting too deep into the patella. The saw is angled 10–15° to produce a trapezoidal bone block. The saw carefully cuts the medial and lateral borders, making sure the bone beneath the tendon insertion has been cut to prevent a fracture of the graft. A similar technique is used for the tibial tubercle. (**e**) Appearance of the graft after harvest. (**f**) Preparation of the graft is shown. Two nonabsorbable No. 2 sutures are placed in a distal drill hole in each bone plug. The bone tendon junction is marked. The graft is wrapped in a blood-soaked sponge with the goal of maintaining viability of some tendon cells. (**g**) The skin incision is displaced distally to reach the desired position for the coronal tibial tunnel, as described in the text. (**h**) The core reamer is placed in the tibial tunnel for the graft harvest. (**i**) The bone plug removed by the core reamer (Reprinted from Noyes and Barber-Westin [1])

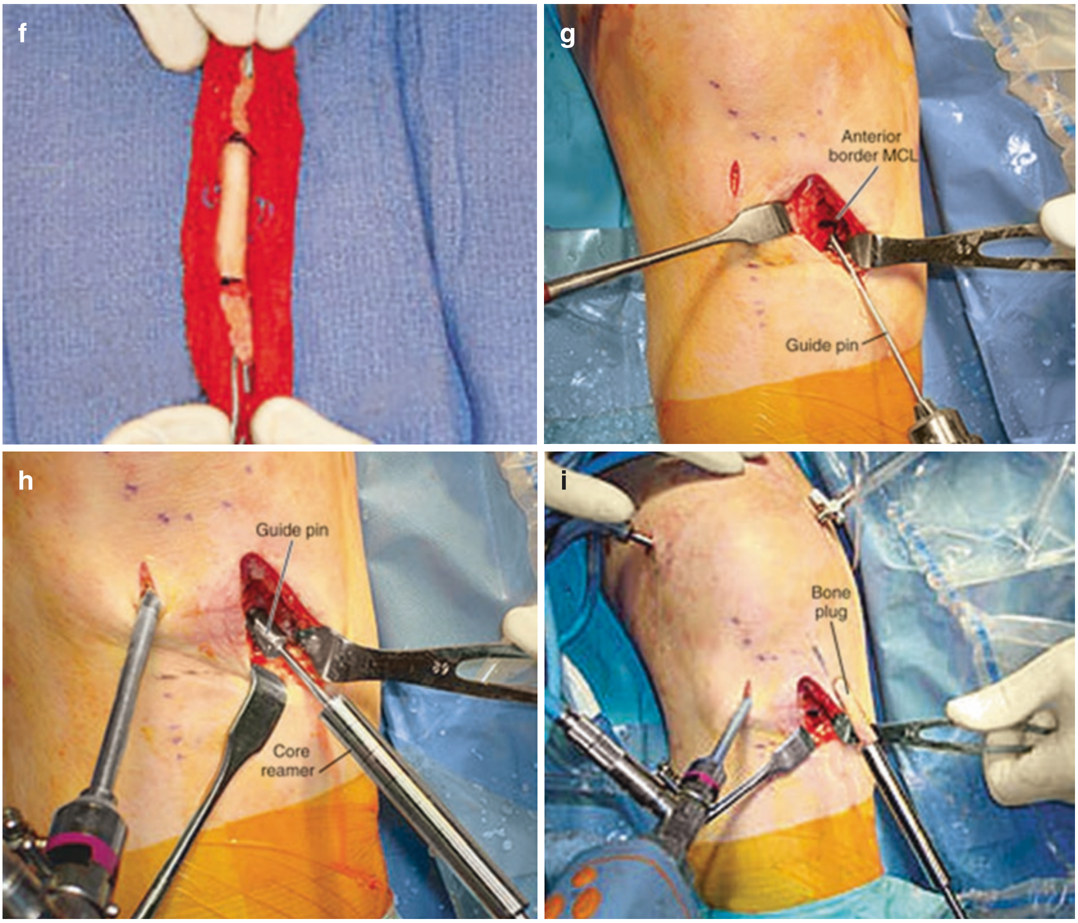

Fig. 10.1 (continued)

Table 10.3 Summary of steps to harvest a four-strand semitendinosus-gracilis autograft [1]

• 3–4-cm oblique cosmetic incision over pes tendons
• Sartorius fascia incised, provides opening to protect superficial medial collateral ligament
• Identify, palpate semitendinosus and gracilis tendons
• Turn down confluent tibial attachment
• Grasp each tendon 90° angle distal end, roll 2–3 times about straight hemostat
• Superficial tissues removed, overlying sartorius fascia protected
• Proximal fascia bluntly dissected, semitendinosus tendon attachment medial gastrocnemius fascia incised, avoid saphenous nerve
• Displace each tendon 10 cm in push-pull maneuver
• Pass graft harvester, transect each tendon 20 cm for a 4-strand graft or 24 cm for a 6-strand graft
• Prepare, wrap in blood-soaked sponge
• Six-strand graft used in women and patients of small stature

mm graft which has a known increased failure rate. The six-strand graft technique has been described in detail elsewhere [1].

10.3.3 Graft Harvest: QT-PB Autograft

A 5- to 6-cm longitudinal incision is made from the superior pole of the patella that extends proximally (Table 10.4). The prepatellar retinaculum is reflected and protected for later closure over the grafted patellar defect. The quadriceps tendon and its junction with the vastus medialis obliquus and vastus lateralis obliquus (VLO) are identified. The proximal portion of the quadriceps tendon is identified, and the graft harvest is carried 10 mm distal to the rectus femoris muscle-

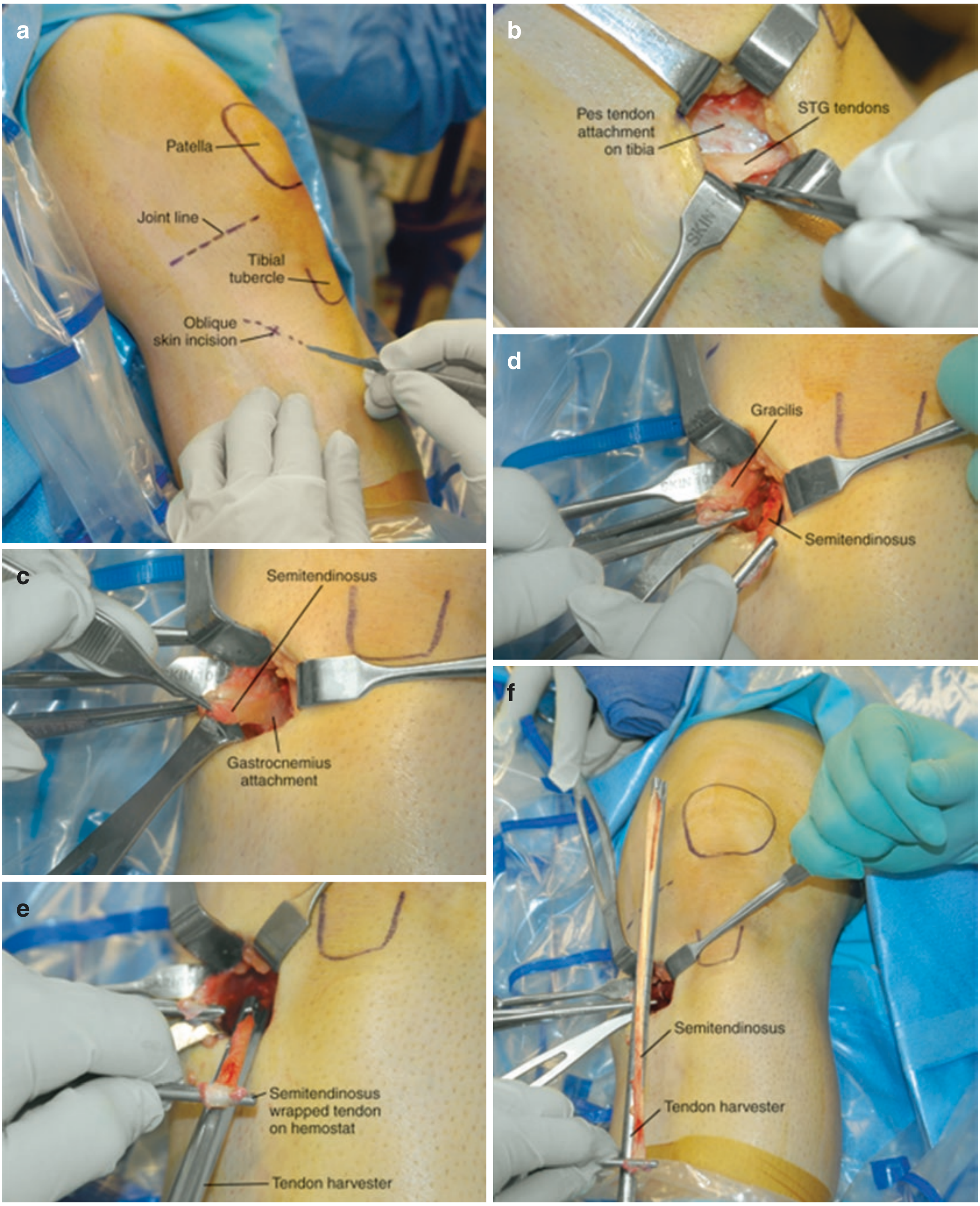

Fig. 10.2 The recommended technique for harvest of a semitendinosus-gracilis (STG) autograft is shown. (**a**) A 2-cm longitudinal or oblique incision at the AM tibia region. (**b**) An L-shaped incision at the pes tendon tibial attachment is performed, and the tendon flap is reflected to identify the STG tendons. (**c**) Dissection of soft tissue to identify STG and remove the gastrocnemius secondary attachment. (**d**) "Push-pull" test to confirm that the STG tendons are free of attachments. (**e**) Harvest of STG using closed-end harvester to prevent premature transection of STG. (**f**) Appearance of long semitendinosus tendon obtained at harvest. (**g**) Graft preparation with graft board. Nonabsorbable 3-mm tape at the proximal end and three 2-0 FiberWire fixation at the distal end. (Alternative is tight-rope fixation device.) Running suture is used on each side of the STG graft (Reprinted from Noyes and Barber-Westin [1])

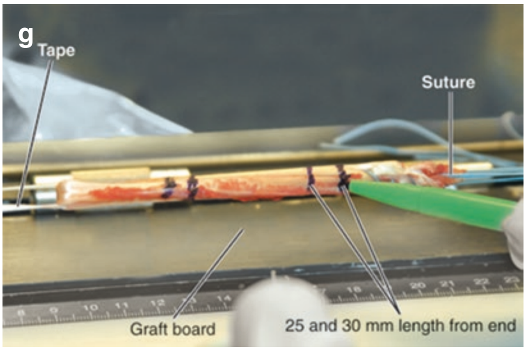

Fig. 10.2 (continued)

Table 10.4 Summary of steps to harvest a quadriceps tendon-patellar bone autograft [1]

• 5–6-cm longitudinal incision from superior pole patella, extending proximally
• Graft harvest: 10-mm wide through all 3 layers, length 60–70 cm
• Patellar bone graft: Length 22–24 mm length, diameter 9–10 mm
• Close quadriceps tendon defect with sutures
• Meticulous bone grafting patellar defect, closure soft tissues

tendon attachment in order not to weaken this site. A 10-mm wide tendon graft, through all three layers, is removed to a length of 60–70 cm (Fig. 10.3). A power saw with the cutting blade marked with paper tape to a depth of 10 mm is used to cut the anterior cortex. It is necessary to place the thin saw blade at the superior pole immediately posterior to the quadriceps tendon patella attachment to saw through the patellar bone at this location. The goal is to produce a patellar bone graft 22–24 mm long by 9–10-mm wide. The bone graft is sized to 9–10 mm in diameter. The quadriceps tendon defect is closed with interrupted 0-Ethibond suture (Ethicon, Sumerville, NJ). Two sutures of 0-nonabsorbable material are placed just proximal to the proximal patellar bone defect to create a pocket for the bone graft obtained from the coring tibia reamer. The core bone graft completely obliterates the patellar defect, and a meticulous closure of anterior tissues over the graft is performed, as already described.

10.4 ACL Anatomic Reconstruction

10.4.1 ACL Anatomy and Function Issues

Studies disagree on the division of the ACL into two distinct fiber bundles. Some authors have provided evidence of both an anatomic and functional division, whereas others doubt this division exists and argue that ACL fiber function is too complex to be artificially divided into two bundles. In some studies [31, 32], the anteromedial (AM) bundle is identified functionally at its femoral location as the proximal half of the attachment (knee in extension) that tightens with knee flexion. The posterolateral (PL) bundle is identified as the distal half of the ACL femoral attachment that tightens with knee extension. The PL bundle is described to relax with knee flexion, as the ACL femoral attachment changes from a vertical to a horizontal structure. The problem is that this description of a reciprocal tightening and relaxation of the bundles occurs only under low anterior loading conditions. With substantial anterior tibial loading, and particularly with the coupled motion of anterior translation and internal tibial rotation, the majority of the ACL fibers are brought into a load-sharing configuration to a differing percentage.

We believe the characterization of the ACL into two fiber bundles represents a gross oversimplification not supported by biomechanical studies [33, 34]. The length-tension behavior of ACL fibers is primarily controlled by the femoral attachment in reference to the center of femoral rotation, the coupled motions applied, the resting length of ACL fibers, and tibial attachment locations. Under loading conditions, fibers in both the AM and PL divisions contribute to resist tibial displacements. The function of the ACL fibers is determined by the anterior-to-posterior direction (knee at extension) as well as the proximal-to-distal femoral attachment. Placement of a graft in an anterior or posterior position may produce deleterious lengthening and graft failure.

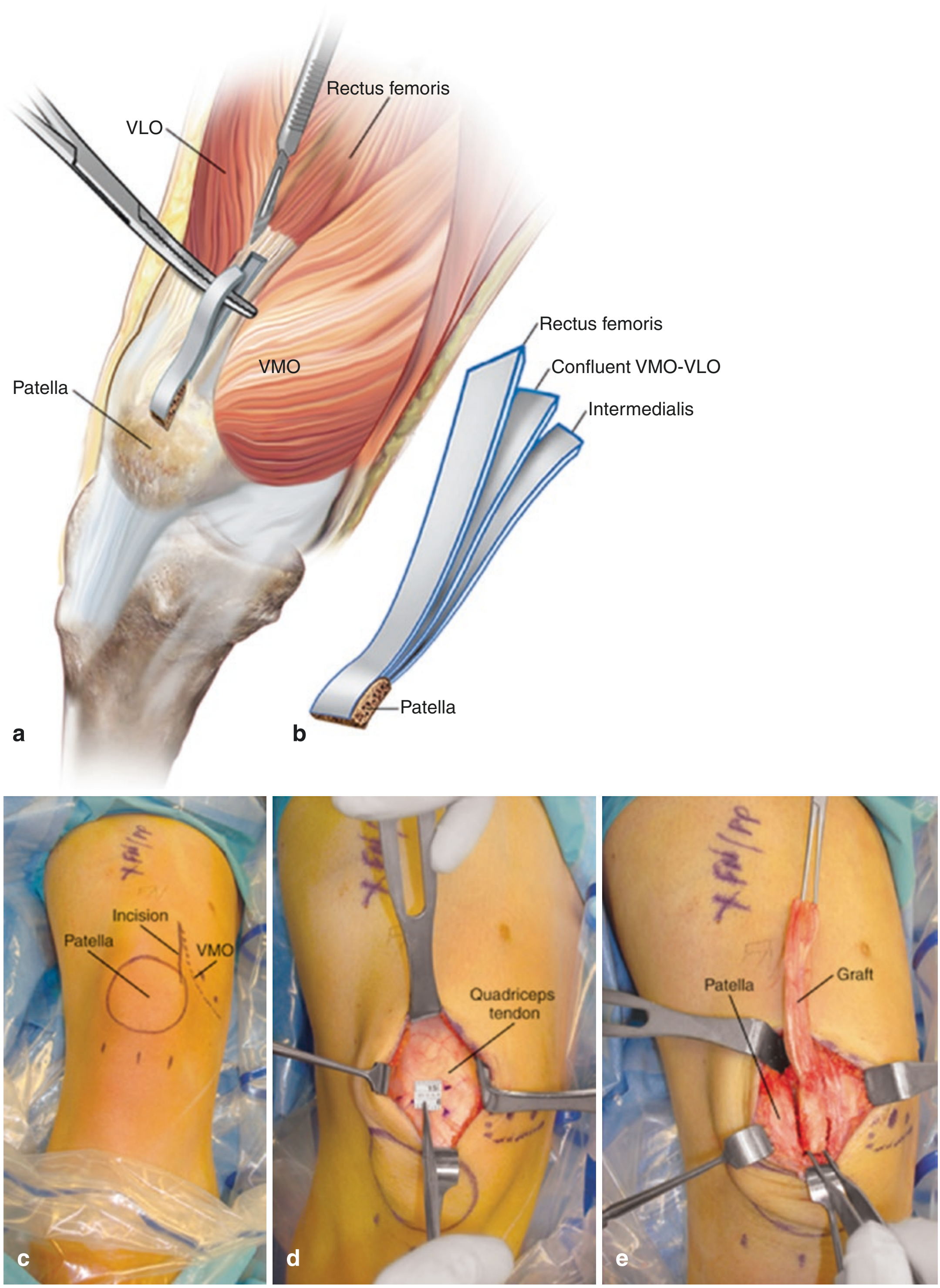

Fig. 10.3 (**a**) A quadriceps tendon graft 9- to 10-mm wide and 60–70 cm in length is removed. (**b**) Usually, all three layers are sutured together at the end of the graft (2-0 nonabsorbable suture) with a running suture on both sides of the graft. (**c**) Surgical case, initial skin incision. (**d**) Measurement of graft width. (**e**) Final harvest (Reprinted from Noyes and Barber-Westin [1])

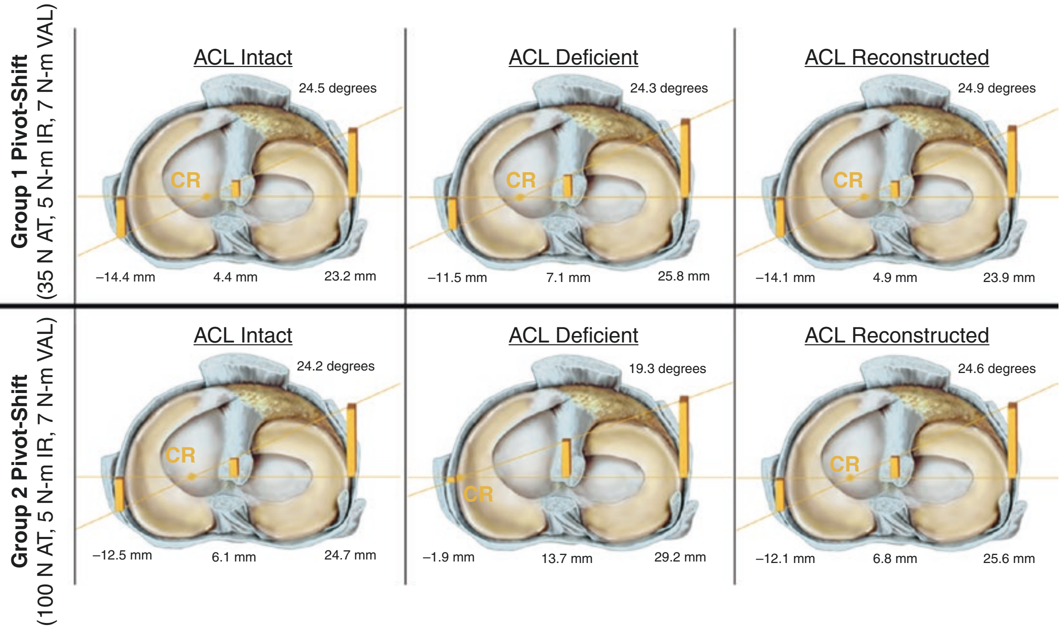

Fig. 10.4 Compartment maps of a representative specimen under two pivot-shift loading profiles for ACL-intact, ACL-deficient, and ACL-reconstructed conditions. The specimen is a right knee with the medial compartment on the left and lateral compartment on the right (*AT* anterior load, *CR* center of rotation, *IR* internal rotation, *VAL* valgus) (Reprinted from Harms et al. [38])

We conducted a series of robotic cadaveric in vitro studies on the kinematic function of the AM and PL bundles of the ACL [35–37]. The results showed both ACL bundles functioned synergistically to resist medial and lateral compartment subluxations during the simulated Lachman and pivot shift tests. In addition, a single ACL graft placed into the anatomic center of the femoral and tibial attachment sites restores normal tibiofemoral compartment translations and rotations (Fig. 10.4). The results of these studies support the recommendations in this chapter to use a single ACL graft instead of a double-bundle ACL graft construct.

10.4.2 Recommended Location and Placement of Tibial Tunnel

It is important during surgery to outline the individual size and shape of the ACL attachment for each patient. The important landmarks for the ACL tibial attachments are the medial tibial spine, posterior interspinous ridge (RER) of the proximal PCL fossa, and the attachment of the lateral meniscus. The recommended ACL tibial attachment location for a single graft is directly adjacent and anterior to the posterior edge of the lateral meniscus anterior horn attachment (Fig. 10.5). In some knees, the anterior extent of the ACL attachment may be obscured by soft tissues, and in these cases, the RER or posterior interspinous ridge of the PCL fossa is an important landmark. The center of the ACL will be 16–20 mm anterior to the RER or posterior interspinous ridge.

The guide pin is placed eccentric and 2–3 mm anterior and medial to the true ACL center, because the ACL graft displaces to the posterior and lateral aspect of the tibial tunnel [39]. The tunnel places the majority of the graft within the central tibial attachment and avoids the posterior attachment location. It is important that graft impingement against the anterior intercondylar notch does not occur because the circular graft may occupy a portion of the native flattened ACL tibial attachment. An anterior notchplasty is required, particularly in knees with an A-shaped

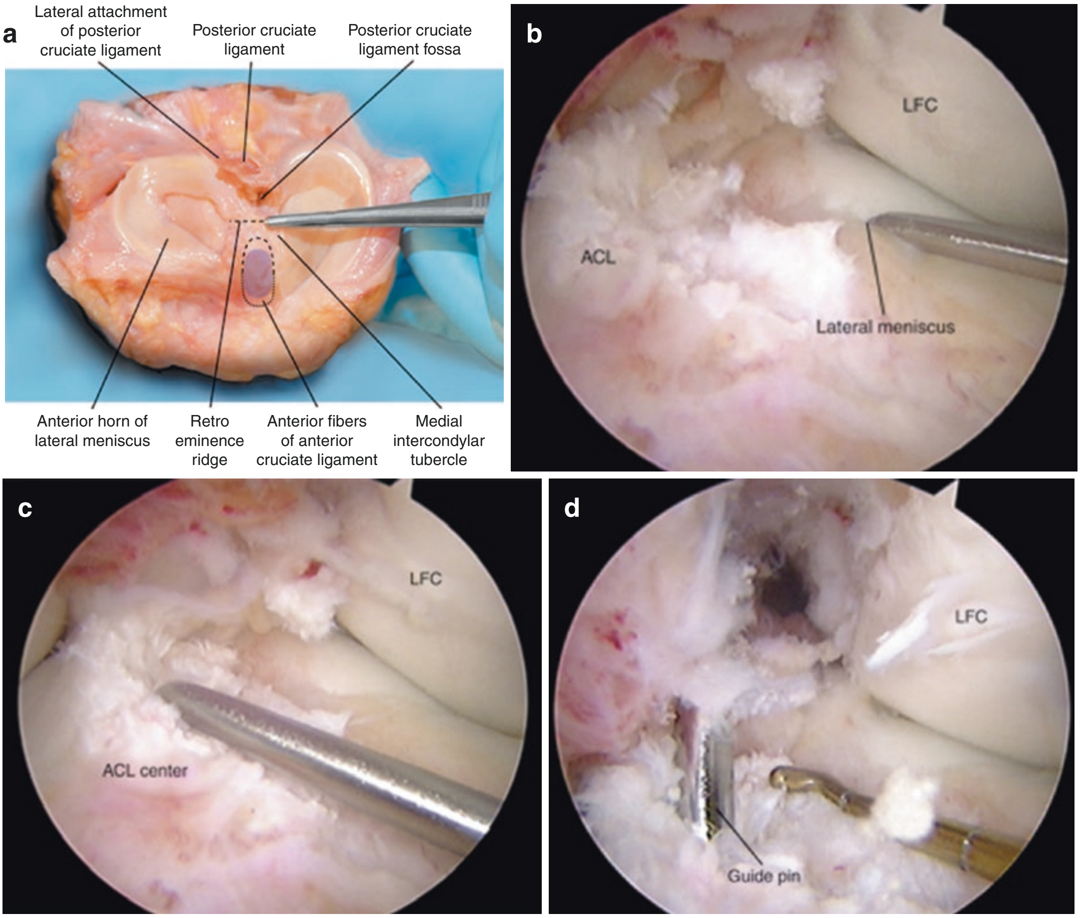

Fig. 10.5 (**a**) ACL tibial attachment is outlined along with the shaded region, indicating a central placement of an ACL graft and tibial tunnel. (**b**) Arthroscopic ACL attachment anterior to the posterior edge of the lateral meniscus. (**c**) Center of ACL attachment is marked and is anterior to the lateral meniscus posterior edge. (**d**) Placement of central guide pin for single tunnel ACL reconstruction. *FC* femoral condyle (Reprinted from Noyes and Barber-Westin [1])

notch. In order to avoid a vertical graft orientation, it is important that the tibial drill does not inadvertently penetrate into or beyond the posterior one-third ACL attachment and adjacent posterior interspinous ridge.

The tibial tunnel is placed in a coronal manner, at a 55–60° angle, allowing a tunnel length of 35–40 mm. The tunnel is begun just anterior and adjacent to the SMCL and is usually 15 mm medial to the tibial tubercle medial border and 10 mm distal to the most proximal point of the patellar tendon tibial tubercle insertion. A core reamer is placed over the guide pin to remove a tibial bone plug when a B-PT-B autograft is used to obtain a core of bone to fill the bone defects. The tunnel is drilled to the desired graft diameter, and the joint tunnel edges are chamfered to prevent graft abrasion.

10.4.3 Recommended Location and Placement of Femoral Tunnel

Important landmarks for the femoral attachment are the posterior articular cartilage, Blumensaat's line, and identification of the ACL attachment on the lateral femoral wall of the notch (Fig. 10.6). The goal is to locate the tunnel in the central to

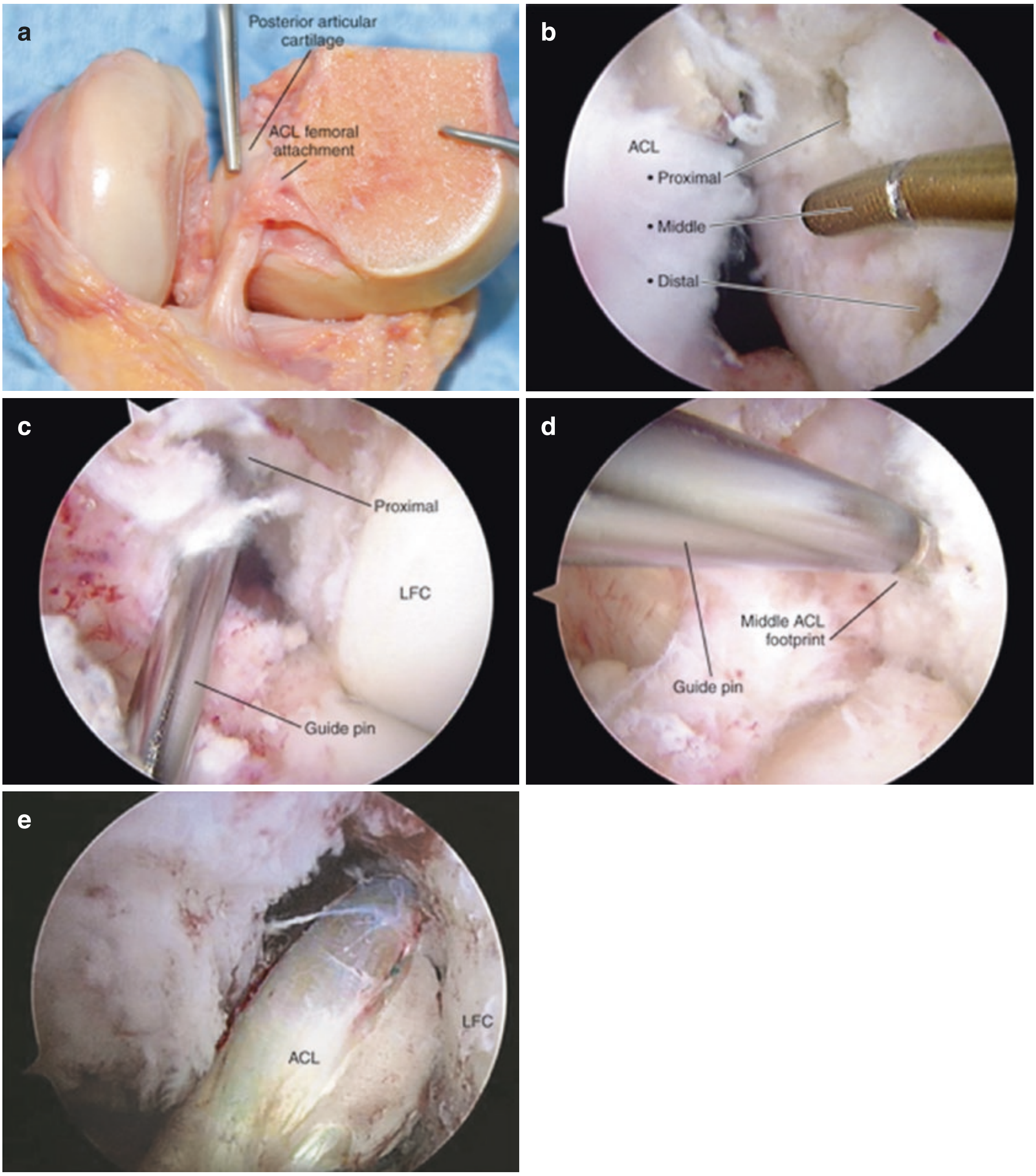

Fig. 10.6 (**a**) ACL femoral attachment at 30° knee flexion shows the entire attachment on lateral wall of notch. (**b**) Three points identified in proximal, middle, and distal portions of ACL attachment. (**c**) Transtibial guide pin placement reaches only proximal one-third of ACL attachment with a portion of the femoral tunnel extending onto the notch roof when a central ACL tibial tunnel is used. (**d**) ACL central point reached with knee hyperflexion and AM portal or with two-incision rear-entry technique. (**e**) Final graft appearance on lateral wall (Reprinted from Noyes and Barber-Westin [1])

proximal thirds to maintain ACL graft length, and within the central direct ACL native insertion that occurs through fibrocartilage and not within the posterior indirect insertion of fibers adjacent to the femoral articular cartilage edge. Piefer and colleagues [40] in a systematic review of 20 ACL femoral footprint publications arrived at recommended arthroscopic osseous landmarks on the lateral wall of the intercondylar notch which are very useful. These include, when possible, identification of the native ACL attachment, the resident's ridge or intercondylar ridge, the bifurcate ridge, the notch roof where no ACL fibers attach, and the articular cartilage junction of the lateral femoral condyle.

We recommend a central anatomic ACL placement with the femoral guide pin 2–3 mm above the midpoint of the proximal-to-distal length of the ACL attachment (30° of knee flexion) and 8 mm from the posterior articular cartilage edge (Fig. 10.5). This will produce a 10-mm tunnel in the proximal two-thirds of the ACL attachment, leaving a 3-mm thick posterior tunnel wall. The ACL attachment is defined at 20–30° of flexion with the arthroscope in the AM portal. After the femoral site is marked, the knee can be placed in 120° of flexion if an AM portal arthroscopic drilling technique is selected. A very acceptable alternative option is use of a flexible drill with the knee at 90° of flexion. A flip-cutter is also a viable technique. A 9- to 10-mm diameter tunnel occupies the proximal two-thirds of the ACL attachment. It is important that the ACL femoral tunnel not be placed too far posteriorly because this produces excessive graft tension with knee extension. In addition, the graft should not be too distal at its femoral attachment because this shortens the intra-articular graft tibiofemoral length.

A two-incision technique retrograde-drilling procedure is used if the B-PT-B graft is >90 mm and (Fig. 10.7) involves a lateral incision of 2–3 cm in length at the distal lateral femoral condyle. The posterior one-third of the ITB is incised for 4–6 cm to allow exposure. The interval posterior to the vastus lateralis is entered and the muscle protected. An S retractor is placed beneath the VLO to gently lift the muscle anteriorly, avoiding entering the proximal joint capsule. The proximal edge of the lateral femoral condyle is bluntly palpated with an instrument (over-the-top location), with the goal of locating the tunnel entrance just anterior to this point. A 15-mm periosteal incision is made and an elevator used to remove soft tissues from the site for the tunnel proximal entrance. The two-incision technique allows adjustment of graft length if required by proximal advancement in the femoral tunnel and is ideal when there is graft mismatch due to an excessively long patellar tendon. Alternatively, with a B-PT-B graft length of 80–85 mm, a FlipCutter procedure may be selected to create a femoral socket rather than a tunnel.

The ACL femoral attachment is mapped based on the bony landmarks already described. The location of the guide pin for an ACL central femoral tunnel is shown in Figs. 10.6 and 10.8. The guide pin is placed within the central ACL attachment, which is midway between the lateral notch roof and the distal articular cartilage edge, 8 mm from the posterior articular cartilage edge. With the central femoral tunnel, the posterior back wall is 3–4 mm thick and the graft occupies approximately two-thirds to three fourths of the ACL footprint. A guide pin placed 8 mm from the posterior articular cartilage at the central ACL attachment will have a 4-mm posterior back wall for an 8-mm graft and 3-mm wall for a 10-mm graft. The tunnel is drilled to the appropriate diameter, which is usually 1 mm greater than the bone portion that allows a snug graft fit in the tunnel. The edges of the tunnel are chamfered to prevent graft abrasion.

10.4.4 Graft Tunnel Passage, Conditioning, and Fixation

The graft is passed in a retrograde manner either with a Beath pin in the arthroscopic technique (placed through the accessory AM portal) or in the two-incision technique with a 20-gauge looped wire passed from the femur to the tibial tunnel. The graft is gently lifted up through the tibia and guided into the femoral tunnels with a nerve hook. The graft is marked at the bone-tendon junction to adjust its length in each tunnel. The graft is brought proximally until the bone is flush with the tibia. The femoral bone-graft plug is fixed with an interference screw of a metallic or absorbable type. Graft conditioning is performed by placing approximately 88 N tension on the distal graft sutures and flexing the knee from 0° to 135° for 30–40 flexion-extension cycles. The arthroscope is placed to verify that the graft position is ideal and there is no impingement against the lateral femoral condyle or notch with full hyperextension. Appropriate notchplasty is performed when necessary.

The knee is placed at 20° flexion, and the tension on the graft is reduced to approximately

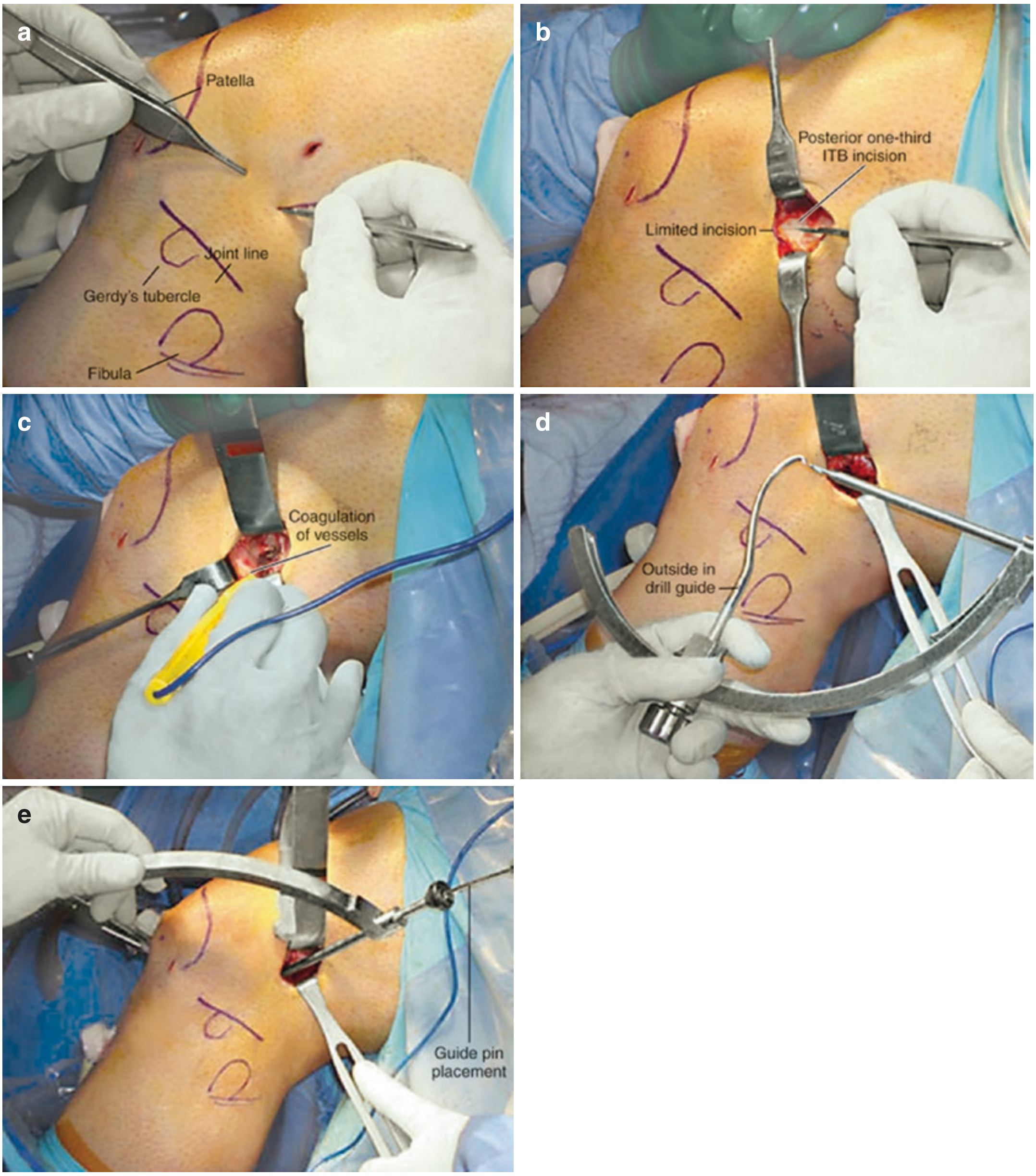

Fig. 10.7 The ACL procedure for a two-incision technique is shown. (**a**) The anatomic landmarks are shown. The joint line, tibial tubercle, and fibula are marked. (**b**) The 2-cm incision is made in the posterior one-third of the ITB, as described in the text. (**c**) Electrocoagulation of vessels. (**d**) Commercially available drill guide. (**e**) Placement of guide pin. Antegrade drilling is viewed arthroscopically (Reprinted from Noyes and Barber-Westin [1])

10–15 N in order to avoid overconstraining AP tibial translation. A finger is placed on the anterior tibia to maintain the posterior gravity position of the tibia. An interference screw is placed. In cases where the interference screw fixation is not ideal or the screw resistance on placement is not acceptable, the sutures are tied over a suture post. The arthroscope is placed into the joint and final graft inspection performed. A Lachman test is performed, and there should be total AP translation motion of 3 mm, indicating that the graft has not been over-tightened. If the graft

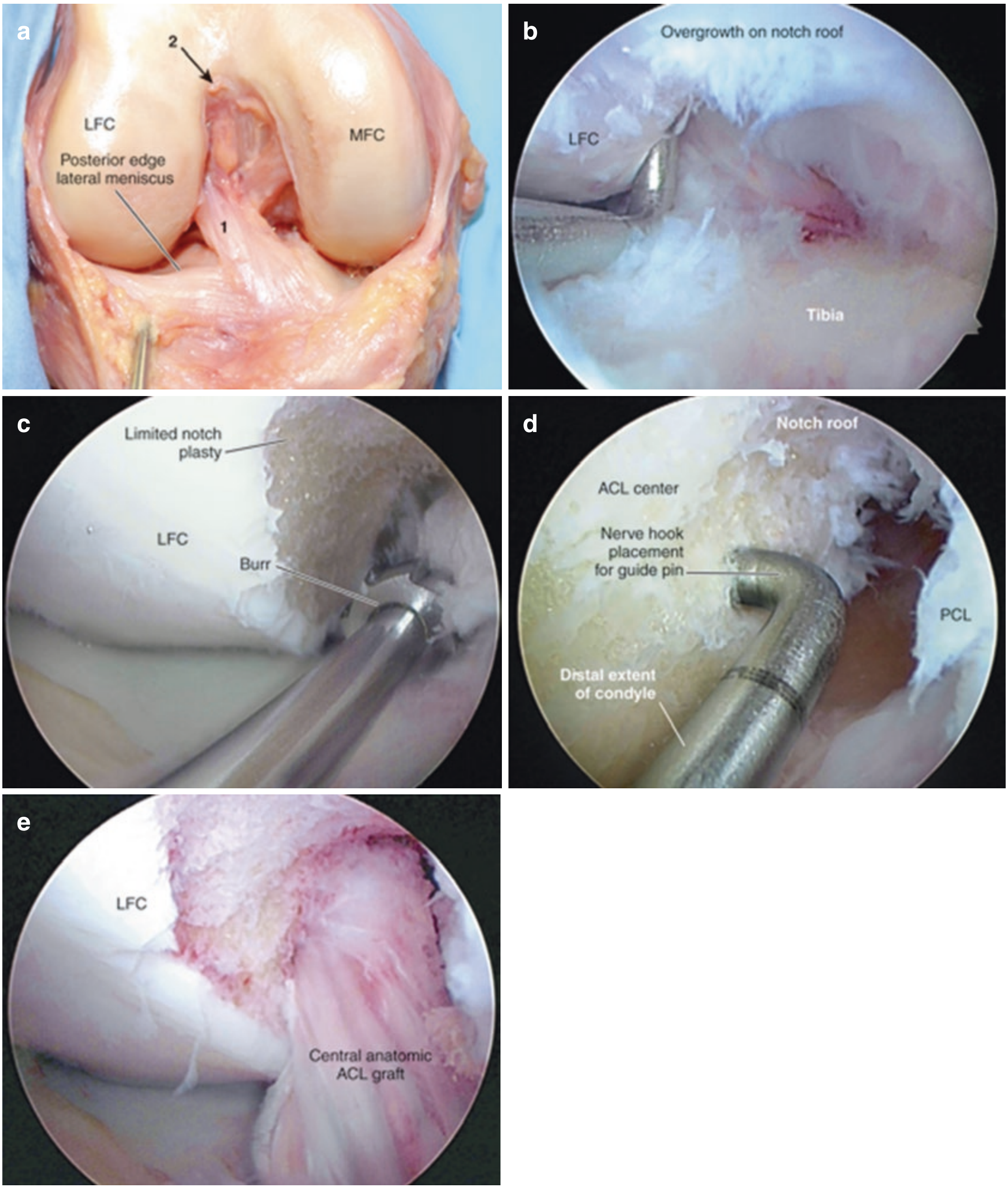

Fig. 10.8 (**a**) A normal femoral notch is shown, which is viewed at arthroscopy by using the AM portal. 1 shows the normal space between the medial femoral condyle and the PCL which is occupied by the ACL. 2 shows the normal anterior notch that should not impinge on the graft. (**b**) Revision ACL with failed ACL graft shows overgrowth of the lateral notch and notch roof, requiring a limited notchplasty. (**c**) The lateral notch wall is visualized entirely posteriorly to the articular cartilage of the femoral condyle. (**d**) The ACL femoral attachment is mapped out, and a central small hole is made for placement of the guide pin. The resident's ridge has been removed. The anterior notch region has not been disturbed. (**e**) Final placement of a single-bundle graft within a central anatomic tibial and femoral placement that occupies over 75% of the attachment site (Reprinted from Noyes and Barber-Westin [1])

has a "bowstring", tight appearance with little to no anterior tibial translation on testing, the distal tensioning and fixation procedure is repeated with less tension placed on the graft.

10.4.5 Technique Using STG Graft

When a STG graft is selected, the same procedure is used with the following exception. In the two-incision technique, a femoral post is used with the sutures tied first at the femoral site about the post (35 mm, 4.0-mm cancellous self-cutting screw with washer). An absorbable interference screw is added. At the tibia, the interference screw is first placed, followed by the suture post fixation. Using the combined interference screw and suture post provides sufficient graft strength fixation for rehabilitation to proceed equal to the B-PT-B graft. An alternative technique for a four-strand STG graft using a FlipCutter (Fig. 10.9) and EndoButton

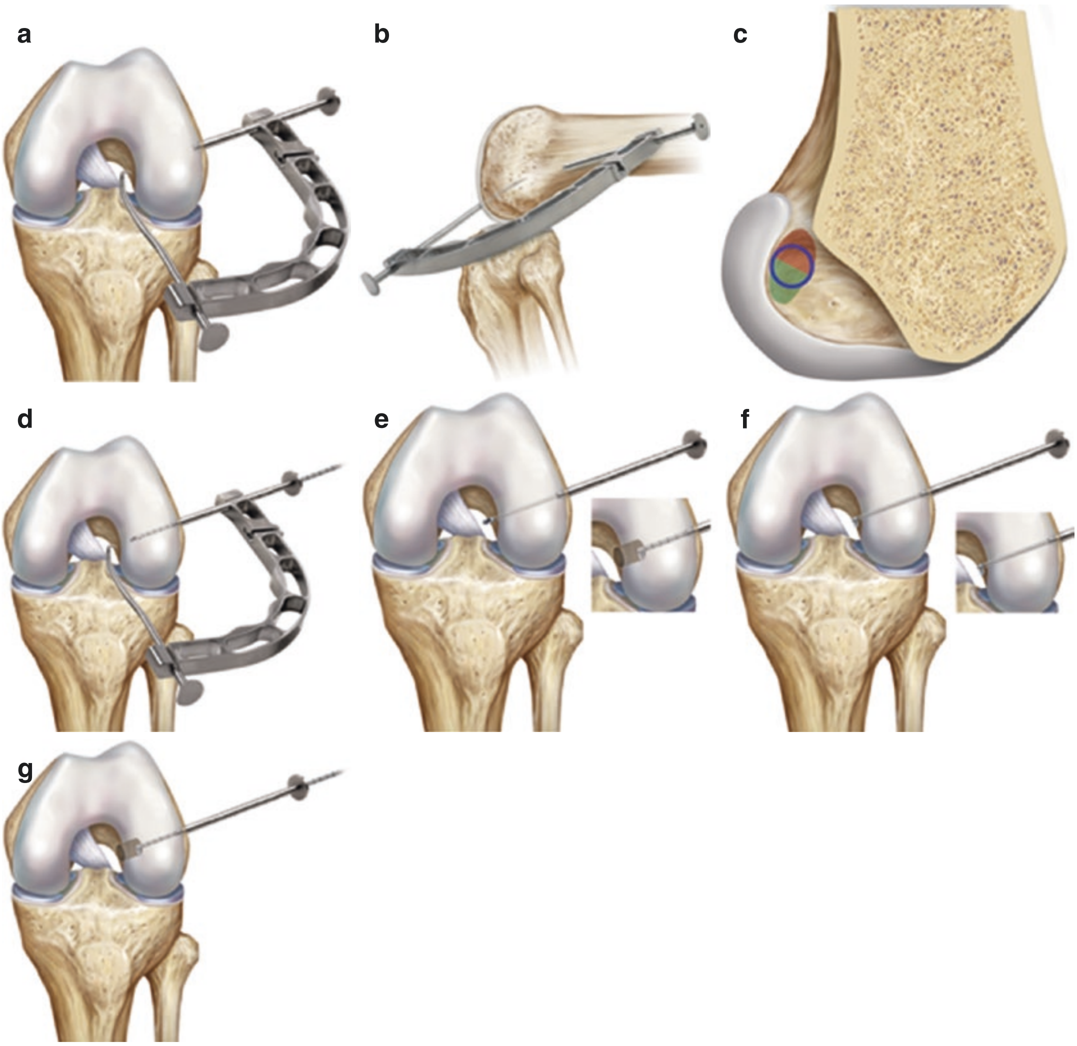

Fig. 10.9 Demonstration of FlipCutter technique for femoral socket or tunnel. (**a, b**) Placement and location of drill guide. (**c**) Central ACL anatomic tunnel placement. (**d**) Placement of the FlipCutter. (**e**) The FlipCutter is advanced at the femoral attachment. (**f**) The drill end is "flipped" at a right angle to the pin. (**g**) Creation of a femoral socket that can extend completely as a tunnel if desired. (This image provided courtesy of Arthrex, Inc., Naples, FL) (Reprinted from Noyes and Barber-Westin [1])

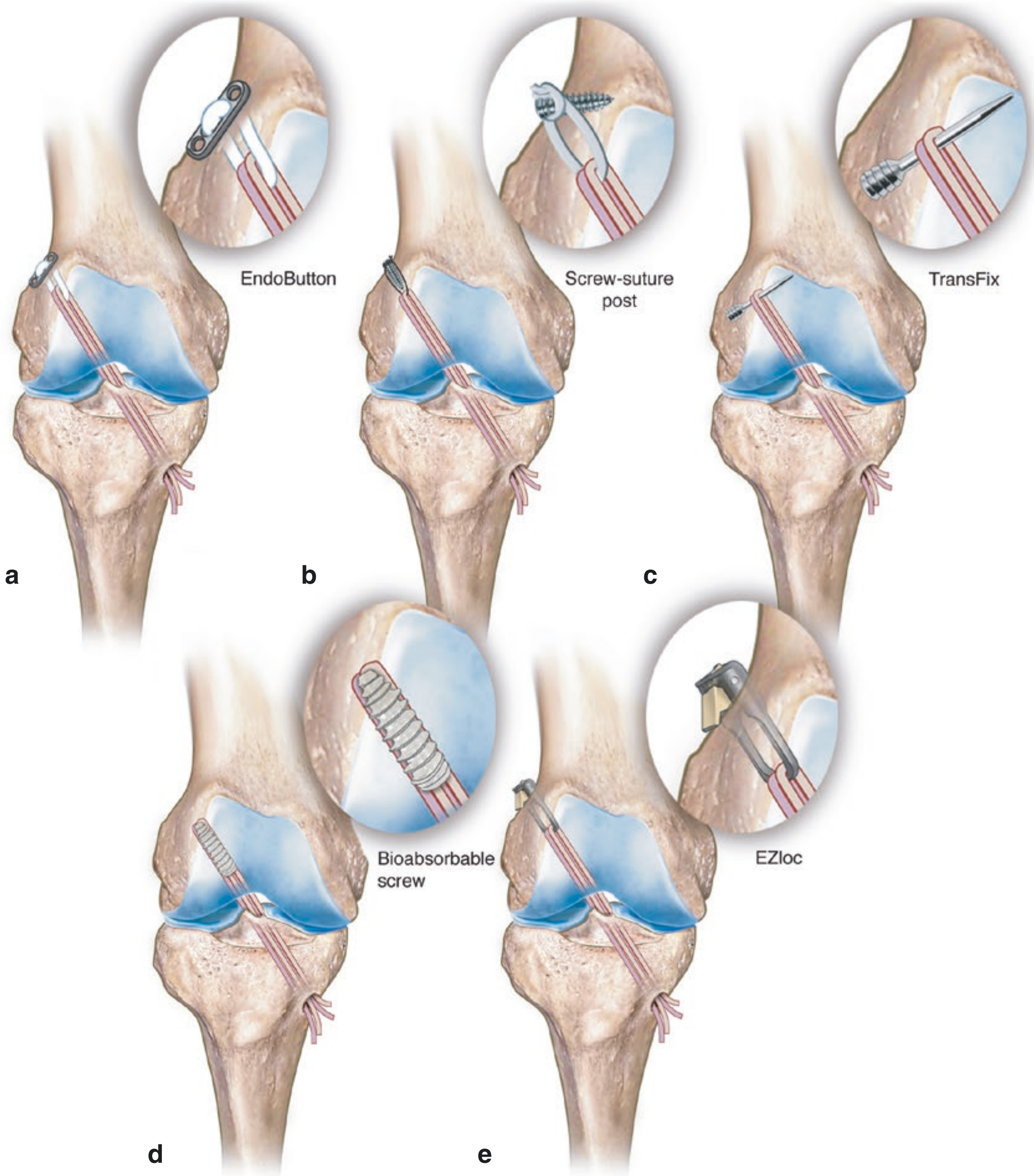

Fig. 10.10 (**a**–**e**)A variety of ACL femoral fixation techniques for STG grafts. The interference screw alone (**d**) is not recommended because it produces the lowest graft tensile strength to pull-out (Reprinted from Noyes and Barber-Westin [1])

or TightRope technique is described elsewhere [1]. A variety of techniques for femoral fixation (Fig. 10.10) and tibial fixation (Fig. 10.11) are available, based on the preference of the surgeon. Interference screw fixation alone is not recommended. A suture post is commonly required to achieve higher strength graft fixation.

Robust graft conditioning is required before final fixation to remove abnormal graft elongations in the postoperative period. Biomechanical studies in knee joints using robotic technology in our laboratory show that an 88-N tensile load applied from 0 to 120° for 40 cycles is necessary (Fig. 10.12). The graft board static conditioning alone does not provide adequate graft conditioning.

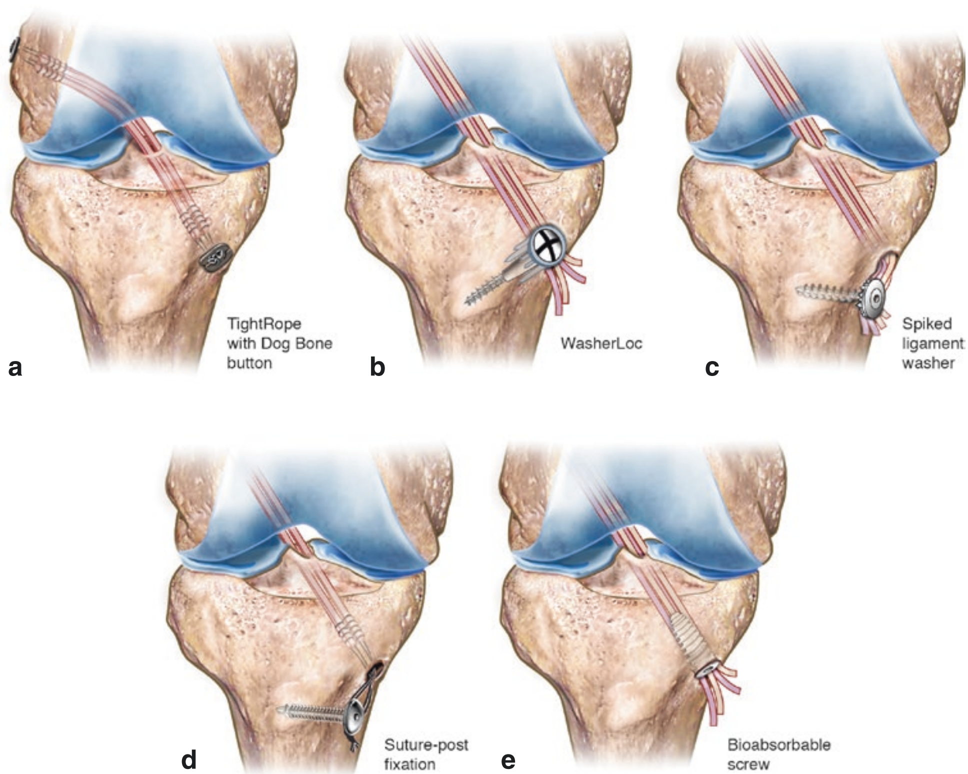

Fig. 10.11 (**a**–**e**) Various tibial fixation techniques for STG grafts. An interference screw alone (**d**) is not recommended (Reprinted from Noyes and Barber-Westin [1])

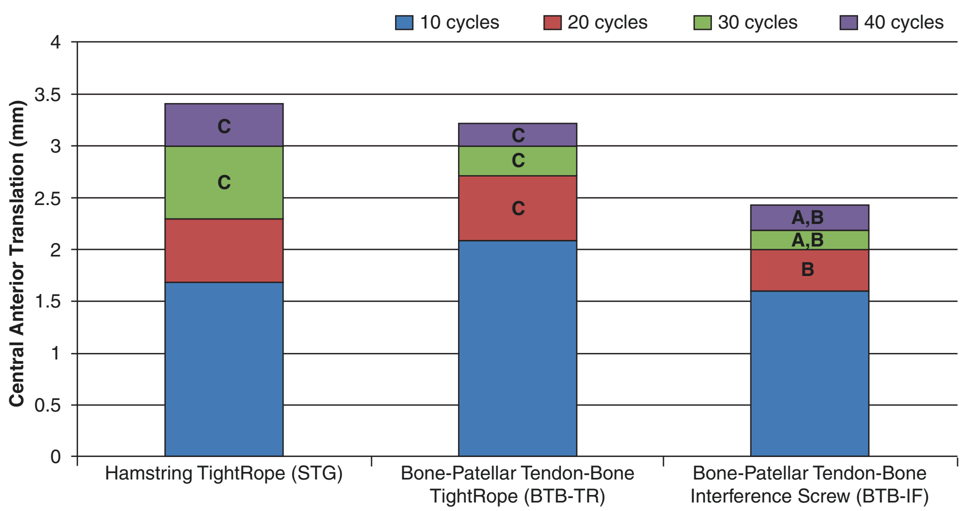

Fig. 10.12 Increase in knee anterior tibial translation with each ACL graft reconstruction during the flexion-extension conditioning cycles. The measurements were calculated at 25° knee flexion. This represents the graft elongation that occurs after graft-board pre-tensioning alone and indicates that this conditioning mechanism is ineffective in producing a steady-state graft. (**a**) Significantly different from hamstring TightRope (STG) graft (within the same cycle; $P < 0.05$). (**b**) Significantly different from bone-patellar tendon-bone TightRope (BPTB-TR) graft (within the same cycle; $P < 0.05$). (**c**) Significantly different from bone-patellar tendon-bone interference screw (BPTB-IF) graft (within the same cycle; $P < 0.05$)

10.4.5.1 Critical Points

ACL Anatomy

- Characterization of ACL into two fiber bundles represents a gross oversimplification not supported by biomechanical studies.
- A single ACL graft placed into the anatomic center of the femoral and tibial attachment sites restores normal tibiofemoral compartment translations and rotations.

Tibial Tunnel

- Recommended tibial attachment location is directly adjacent and anterior to the posterior edge of the lateral meniscus anterior horn attachment.
- Place guide pin eccentric and 2–3 anterior and medial to true ACL center.
- Place tibial tunnel in coronal manner, 55–60° angle, tunnel length 35–40 mm.
- Use core reamer to obtain good quality bone to fill bone defects.
- Drill tunnel, chamfer edges.

Femoral Tunnel

- Two-incision technique: drill tunnel retrograde through lateral incision 2–3 cm at distal lateral femoral condyle.
- Perform femoral notchplasty to avoid graft impingement.
- Identify ACL attachment with knee in 20–30° flexion, scope in anteromedial portal.
- Place guide pin within central ACL attachment. Preserve 3–4 mm of posterior back wall of the tunnel so that the graft is not placed too far posteriorly.
- Drill tunnel, chamfer edges.

Graft Tunnel Passage, Conditioning, and Fixation

- Pass graft gently in retrograde arthroscopically assisted.
- Bring graft proximally until bone is flush with tibia.
- Femoral position of graft at or just proximal to inside femoral tunnel.
- Fix femoral bone graft plug with interference screw.
- Condition graft: 44 N tension, flex knee 0–135°, 40 cycles.
- Verify position arthroscopically, no impingement.
- Place knee in 20° flexion, reduce tension to 10–15 N.
- Place interference screw tibia. Use additional sutures tied over suture post if required.
- Perform Lachman test, ensure no overconstraint.
- For STG graft, femoral fixation: post with sutures and absorbable interference screw if necessary. Tibial fixation: interference screw plus suture post.
- Robust STG graft conditioning: 88 N tension, flex knee 0–120°, 40 cycles.

10.5 Authors' ACL Reconstruction Clinical Studies

We published a series of prospective clinical studies on ACL primary reconstruction in over 650 knees with acute, subacute, and chronic ruptures (Table 10.5) [28, 41–57] The data from these investigations provide information regarding the following variables on clinical outcome: (1) type of graft, (2) sterilization of allografts, (3) gender, (4) chronicity of injury, (5) concomitant operative procedures, (6) preexisting joint arthritis, (7) varus osseous malalignment, (8) the rehabilitation program, and (9) type of insurance (workers' compensation vs. private). A summary of the outcomes from our primary ACL reconstruction investigations is shown in Table 10.6.

10.6 Treatment of Meniscus Tears

Studies have shown that, regardless of the outcome of ACL reconstruction in terms of restoration of knee stability, meniscectomy accelerates degenerative joint changes [14, 58–64]. Nearly every long-term study has reported a statistically significant correlation between meniscectomy performed either concurrently or after the ACL reconstruction and moderate-to-severe radiographic evidence of osteoarthritis. We conducted a systematic review of the treatment of meniscus tears during ACL reconstruction of studies published from 2001 to 2011 [65]. Data on 11,711 meniscus tears (in 19,531 patients) from

Table 10.5 Summary of authors' primary ACL reconstruction clinical studies

Study citation	Demographic data, graft type, allograft sterilization	KT-2000 total AP displacement (I-N) at fu			Return to sports
		<3 mm (%)	3–5 mm (%)	>5 mm (%)	
Noyes [41]	*Acute ACL tears, 5–9 years fu*				47% preinjury level, 36% lower level, 13% no sports non-knee-related factors, 4% no sports knee-related problems
	Fascia lata allografts: fresh-frozen (*n* = 28)	77	20	3	
	Fascia lata allografts: freeze-dried (*n* = 40)	75	20	5	
Noyes, Barber-Westin [42]	*Chronic ACL tears, 2–4.5 years fu*				Compared with preoperative level: 66% increased level, 7% same level, 7% lower level, 16% playing with symptoms, 3% no sports non-knee-related factors, 13% no sports knee-related problems
	B-PT-B allografts: fresh-frozen (*n* = 54)	53	31	16	
	B-PT-B allografts: irradiated (*n* = 10)	60	10	30	
	B-PT-B allografts + ITB EA, fresh-frozen (*n* = 40)	74	23	3	
Noyes, Barber-Westin [43]	*Chronic ACL tears, 2–3.4 years fu* B-PT-B allografts + LAD, irradiated (*n* = 49)	53	30	17	Compared with preoperative level: 65% increased level, 10% same level, 4% lower level, 7% playing with symptoms, 7% no sports non-knee-related factors, 7% no sports knee-related problems
Noyes, Barber-Westin [44]	*Acute* vs. *chronic ACL tears, 2–3 years fu*				Acutes: 50% preinjury level, 3% increased level, 27% lower level, 3% playing with symptoms, 17% no sports non-knee-related factors Chronics compared with preoperative level: 54% increased level, 9% same level, 12% lower level, 11% playing with symptoms, 2% no sports non-knee-related factors, 12% no sports knee-related problems
	B-PT-B autografts chronic ACL tears (*n* = 57)	84	12	4	
	B-PT-B autografts acute ACL tears (*n* = 30)	92	4	4	
Barber-Westin [45]	*Male* vs. *female ACL reconstruction, 2–3 years fu*				Acutes: 45% preinjury level, 5% increased level, 33% lower level, 2% playing with symptoms, 15% no sports non-knee-related factors Chronics compared with preoperative level: 52% increased level, 11% same level, 15% lower level, 5% playing with symptoms, 11% no sports non-knee-related factors, 5% no sports knee-related problems
	B-PT-B autografts men (*n* = 47)	80	16	4	
	B-PT-B autografts women (*n* = 47)	87	8	5	
Noyes, Barber-Westin [46]	*Chronic ACL tears, 2–3.6 years fu* B-PT-B autografts (*n* = 53)	79	16	5	Compared with preoperative level: 66% increased level, 6% same level, 7% lower level, 6% no sports non-knee-related factors, 15% no sports knee-related problems

AP anteroposterior, *B-PT-B* bone-patellar tendon-bone, *EA* extra-articular, *fu* follow-up, *ITB* iliotibial band, *I-N* involved-noninvolved

159 studies showed that 65% were treated by meniscectomy; 26%, by repair; and 9%, by no treatment. This was concerning because many meniscus tears can be successfully treated by repair, thereby salvaging this important structure.

We have long advocated repair of meniscus tears instead of resection, assuming the appropriate indications are met [3, 57, 66–68]. Our indications for meniscus repair are shown below:

1. Meniscus tear with tibiofemoral joint line pain
2. Patient <50 years old, or physically active patient <60 years old
3. Concurrent knee ligament reconstruction or osteotomy
4. Meniscus tear reducible, good tissue integrity, will retain normal position in the joint once repaired

Table 10.6 Summary of conclusions from authors' primary ACL reconstruction clinical studies [1]

Factor	Conclusions
Type of graft	B-PT-B autografts preferred whenever possible, decreased failure rate in chronic knees, more rapid graft healing. Autografts provide higher success rate in subjective, objective, and functional parameters. Allografts reserved for multiligament surgery, knee dislocations, special situations
Augmentation procedures for allografts	ITB extra-articular procedure decreases allograft failure rate in chronic knees, recommended in grossly unstable knees (grade 3 pivot shift)
Secondary sterilization of allografts	Irradiation most likely deleterious, increase in failure rate, not recommended
Gender	No difference in outcomes between males and females. No scientific basis to use gender as selection criteria for reconstruction
Chronicity of injury	No difference between acute and chronic knee injuries in objective stability after B-PT-B autograft reconstruction Significantly poorer results in chronic knees for symptoms, limitations with sports and daily activities, and patient rating of knee condition owing to loss of meniscus tissue, preexisting joint damage Reconstruct ACL early after injury in active patients
Concomitant operative procedures	Meniscus repairs frequent, results may be improved by concomitant ACL reconstruction. High success rates, even in complex tears extending into central third region, regardless of patient age Posterolateral injuries frequently accompanied by ACL ruptures – reconstruct all ligamentous ruptures concurrently MCL injuries usually do not require surgical treatment unless gross instability exists
Preexisting joint arthrosis	Symptomatic unstable knees can be improved by ACL reconstruction. Advise return low-impact activities
Varus osseous malalignment	ACL reconstruction usually staged after osteotomy in symptomatic unstable knees. ACL reconstruction not required after osteotomy in knees that are asymptomatic, willing to modify activities
Rehabilitation program	Immediate motion and rehabilitation safe, not deleterious to healing graft, low incidence (<1%) of arthrofibrosis. Identify and immediately treat limitation of knee motion with overpressure program. Full motion regained within weeks of surgery (with exception of PCL reconstructions in which hyperflexion is delayed)
Insurance	No difference in outcome between workers' compensation and privately insured patients except days of lost employment. Reconstruct workers' compensation patients earlier after injury

B-PT-B bone-patellar tendon-bone, *ITB* iliotibial band, *MCL* medial collateral ligament, *PCL* posterior cruciate ligament

5. Peripheral single longitudinal tears: red–red, 1 plane, repairable in all cases, high success rates
6. Middle one-third tears: red-white (vascular supply present), often repairable with good success rates
7. Red-white single plane outer-third and middle-third tears (longitudinal, radial, horizontal): often repairable if good tissue quality
8. Outer-third and middle-third tears (complex, double longitudinal, triple longitudinal, flap): repair versus excision
9. Red-white, multiple planes: repair versus excision
10. Meniscus root tears: repair if not degenerative

Meniscus tears suitable for repair are located in either the periphery or at the junction of the middle and outer third regions where a blood supply is retained. Complex tears are evaluated on an individual basis for repair potential. The repair may require an accessory posteromedial (Fig. 10.13) or posterolateral (Fig. 10.14) approach for exposure to tie the sutures using an inside-out suture technique. A meticulous vertical divergent suture technique is favored in which multiple sutures are passed through both the superior and inferior surfaces of the meniscus (Fig. 10.15). All-inside suture-based meniscus repair devices are also available which are ideal for red/white longitudinal tears and root

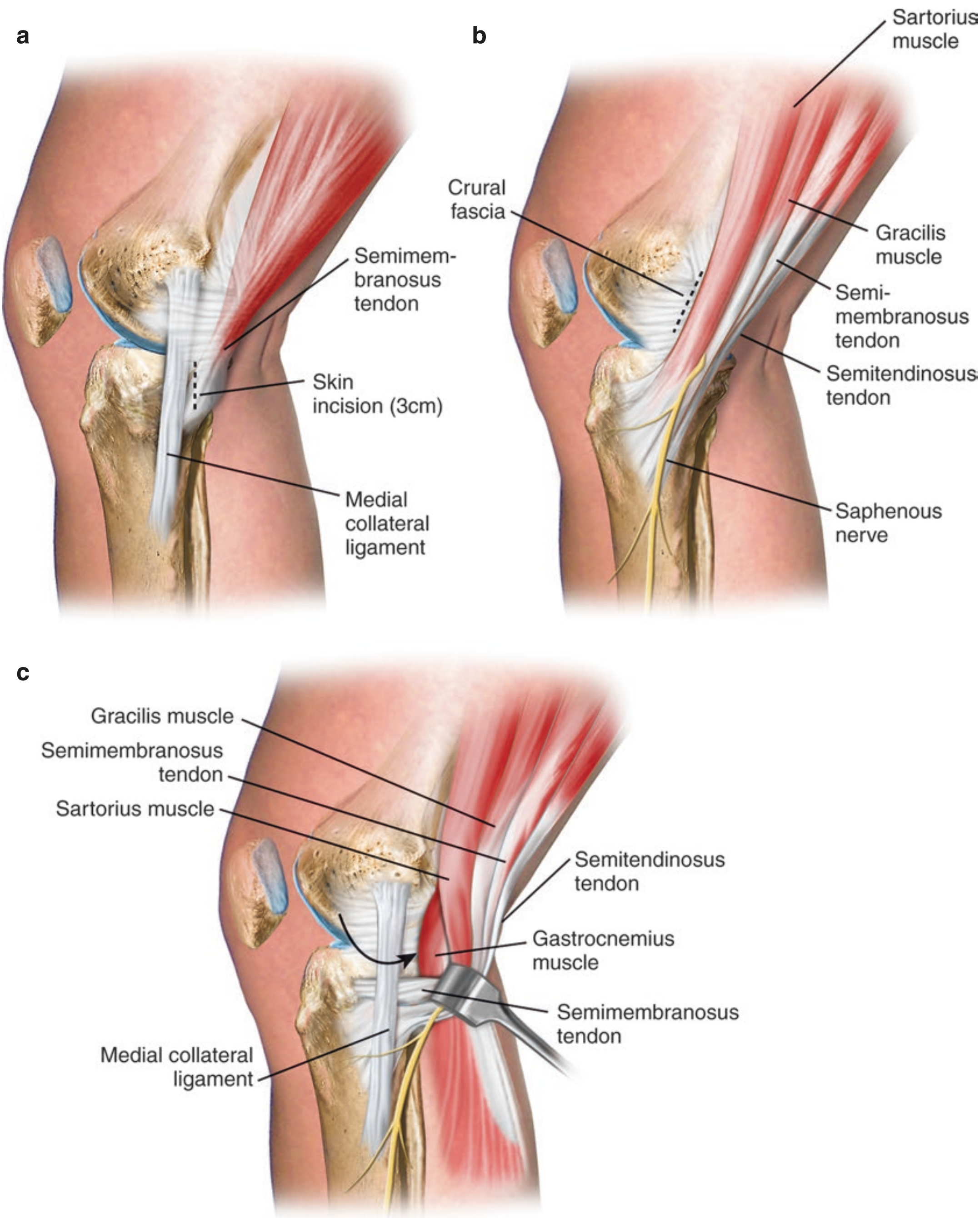

Fig. 10.13 The accessory posteromedial approach is shown for a medial meniscus repair. (**a**) Site of the posteromedial skin incision. (**b**) The incision is shown through the anterior portion of the sartorius fascia. (**c**) The interval is opened between the posteromedial capsule and the gastrocnemius tendon, just proximal to the semimembranosus tendon (*arrow*). The fascia over the semimembranosus tendon is excised to its tibial attachment to facilitate retrieval of the posterior meniscus sutures (Reprinted from Noyes and Barber-Westin [66])

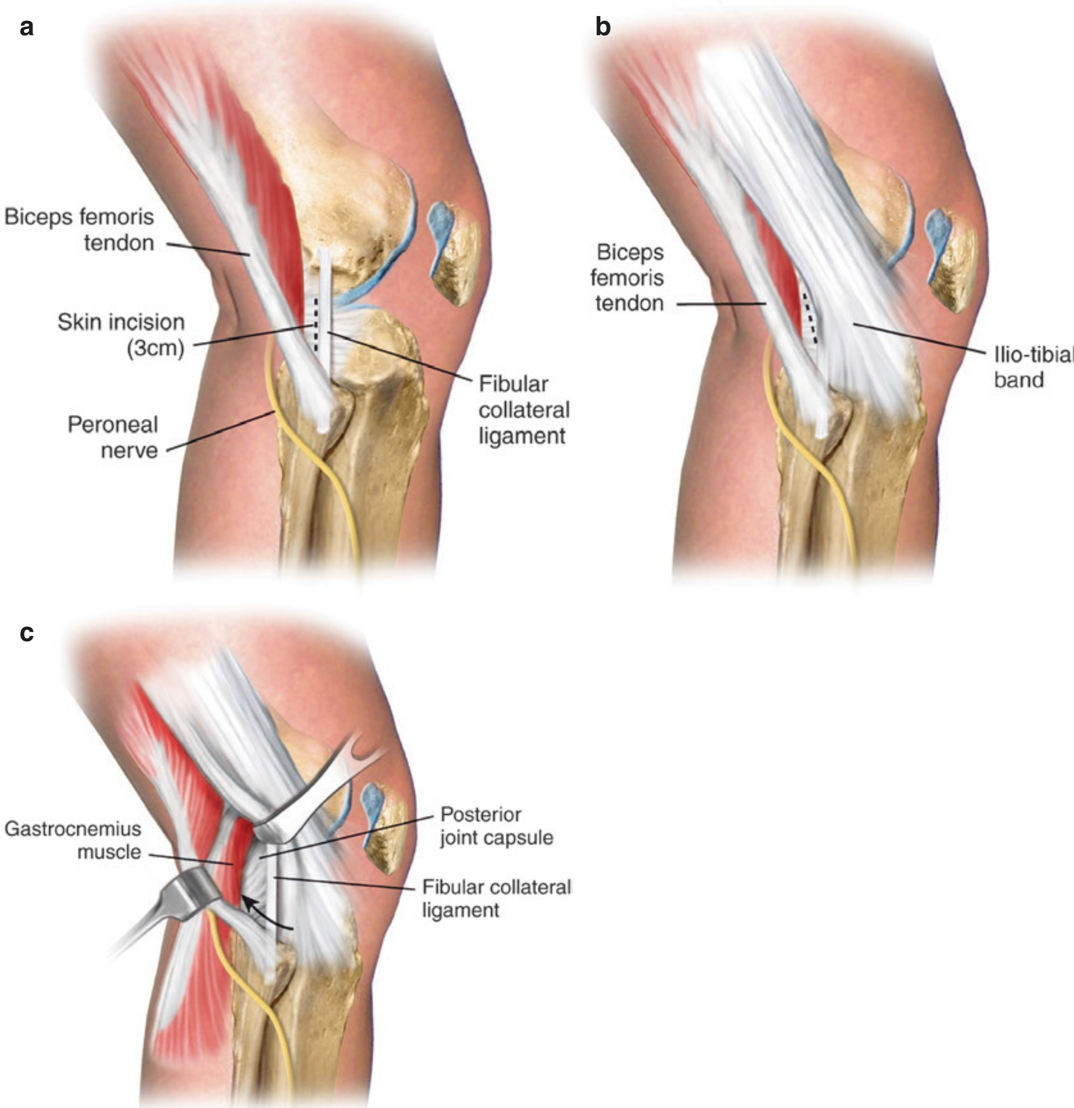

Fig. 10.14 (**a**) Site of the posterolateral incision for a lateral meniscus repair. (**b**) Incision site in the interval between the posterior edge of the iliotibial band and the anterior edge of the biceps tendon. (**c**) The interval between the lateral gastrocnemius and posterolateral capsule is opened bluntly, just proximal to the fibular head, avoiding entering the joint capsule (Reprinted from Noyes and Barber-Westin [66])

tears (Fig. 10.16). The postoperative rehabilitation programs allows immediate knee motion and early weight bearing but protects the repairs by not allowing squatting, kneeling, or running for 4–6 months [69].

We have conducted several clinical studies to determine the outcome of meniscus repairs [57, 67, 68, 70, 71]. In one study, 198 meniscus repairs in 177 patients were followed 2–9.6 years postoperatively [68]. All of the tears extended into the red-white zone or had a rim width ≥4 mm. At follow-up, 80% of the patients had not required additional surgery and had no tibiofemoral symptoms related to the repair. These results were verified more recently in a systematic review we conducted of 23 investigations in which menis-

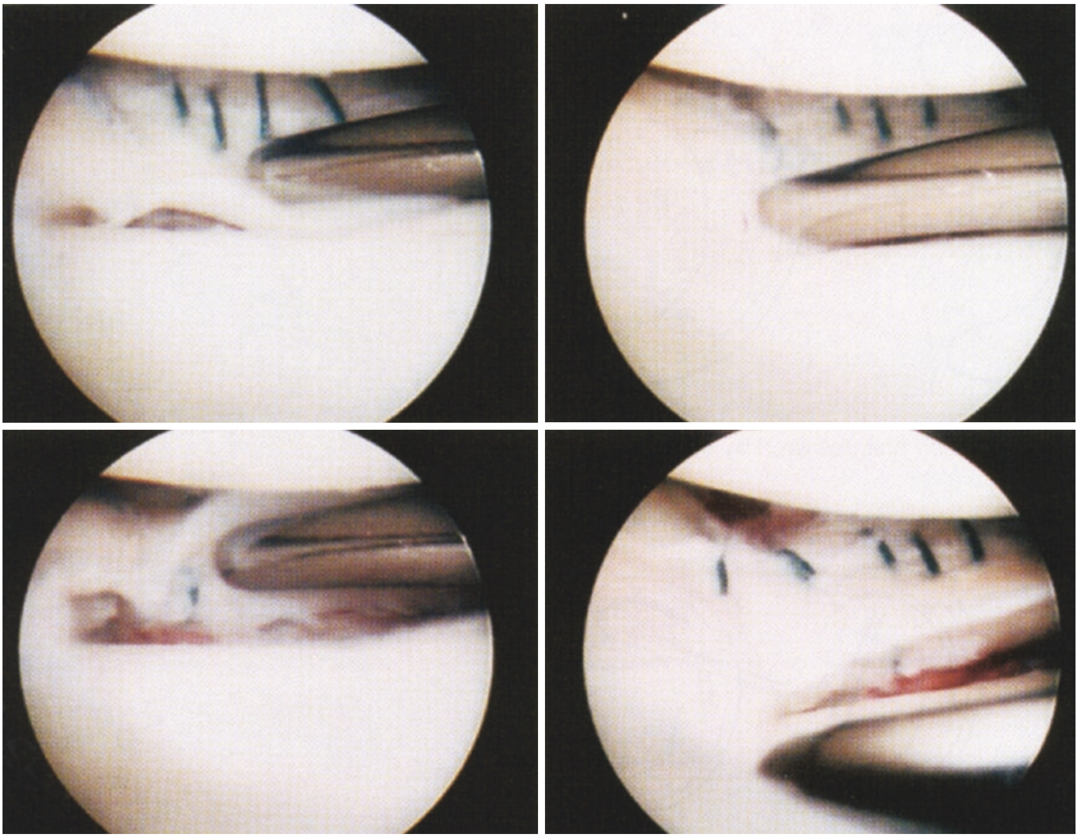

Fig. 10.15 Meniscus repair instead of meniscectomy to preserve knee joint function. A longitudinal meniscal tear site demonstrates some fragmentation inferiorly. This tear required multiple superior and inferior vertical divergent sutures to achieve anatomic reduction (Reprinted from Noyes and Barber-Westin [67])

cus repairs for tears in the red-white zone were performed [72]. There were 767 repairs, of which 78% were done with an ACL reconstruction. Overall, 83% of these repairs were considered clinically healed.

We conducted a long-term study (10–22 years) of single longitudinal meniscus repairs that extended into the central region in patients ≤20 years of age [3]. Twenty-nine repairs were evaluated; 18 by follow-up arthroscopy, 19 by clinical evaluation, 17 by MRI, and 22 by weight-bearing posteroanterior radiographs. A 3 Telsa MRI scanner with cartilage-sensitive pulse sequences was used and T2 mapping was performed. Eighteen (62%) of the meniscus repairs had normal or nearly normal characteristics. Six (21%) repairs required arthroscopic resection; two had loss of joint space on radiographs, and three that were asymptomatic failed according to MRI criteria. There was no significant difference in the mean T2 scores in the menisci that had not failed between the involved and contralateral tibiofemoral compartments. There were no significant differences between the initial and long-term evaluations for pain, swelling, jumping, patient knee condition rating, or the Cincinnati rating score. The majority of patients were participating in sports without problems, which did not affect the failure rate. The outcomes support the recommendation in younger active patients to spend as much time and attention to a meniscus repair as a concurrent ACL reconstruction, as the eventual function of the knee joint is equally dependent on the success of both structures (Fig. 10.17).

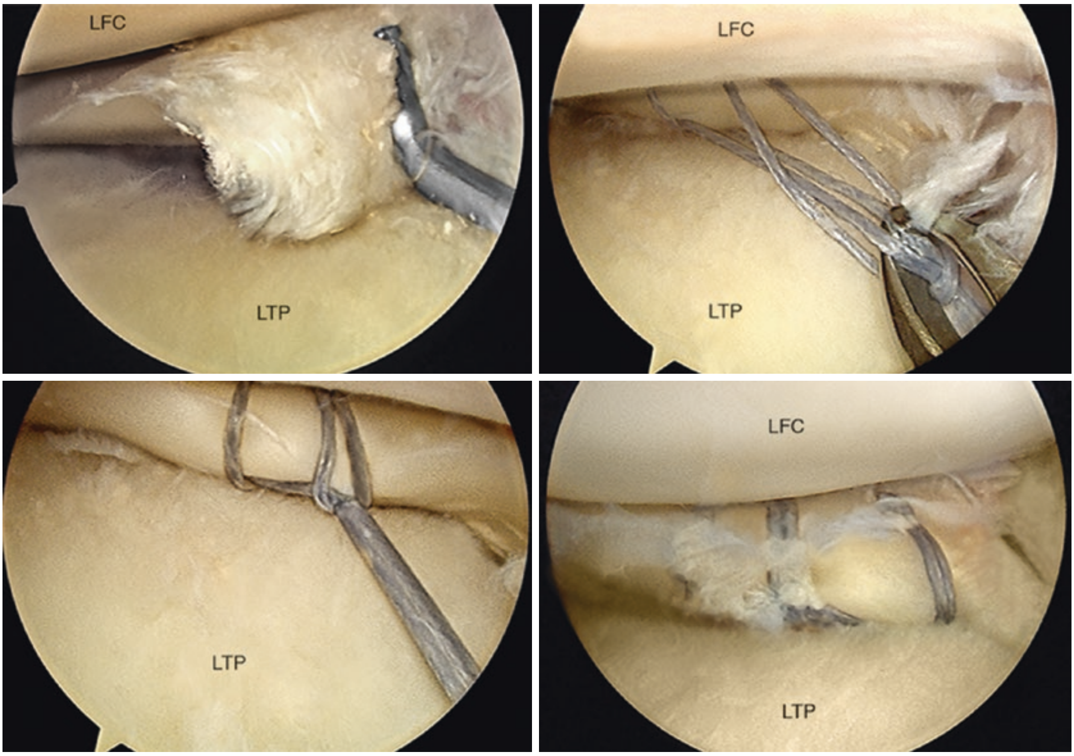

Fig. 10.16 Arthroscopic visualization of a lateral meniscus root tear (**a**). A double locking loop stitch (NovoStitch, Ceterix) is placed through the meniscus at the tear site (**b**). Three loop stitches were used to achieve a high strength fixation (**c**). Final configuration of the lateral meniscus repair with the meniscus pulled flush to the repair site (**d**) (Reprinted from Noyes and Barber-Westin [66])

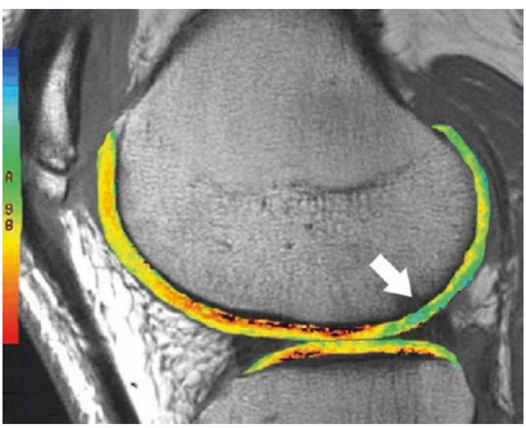

Fig. 10.17 T2 magnetic resonance imaging of a 37-year old male 17 years post-ACL reconstruction and lateral meniscus repair. The patient was asymptomatic with light sports activities. The lateral meniscus repair healed and the ACL reconstruction restored normal stability. Prolongation of T2 values is noted over the posterior margin with adjacent subchondral sclerosis (*arrow*) (Reprinted from Noyes et al. [3])

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