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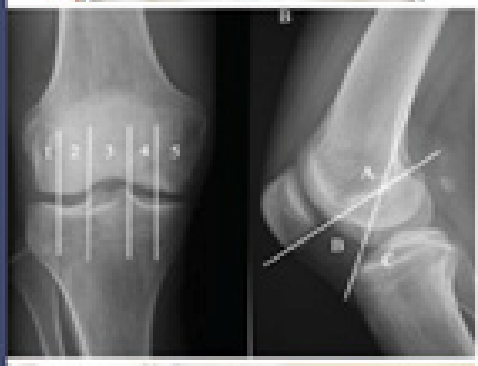

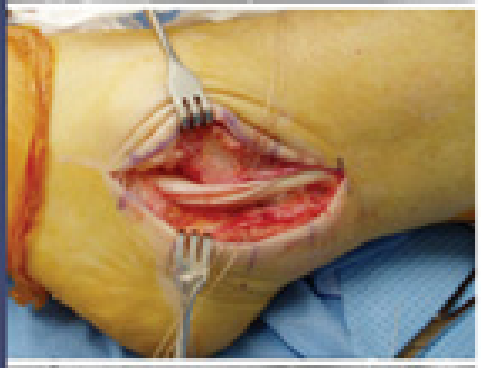

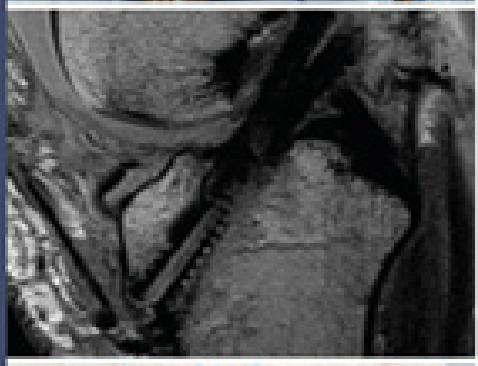

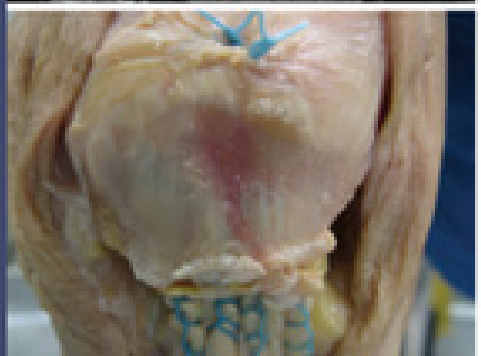

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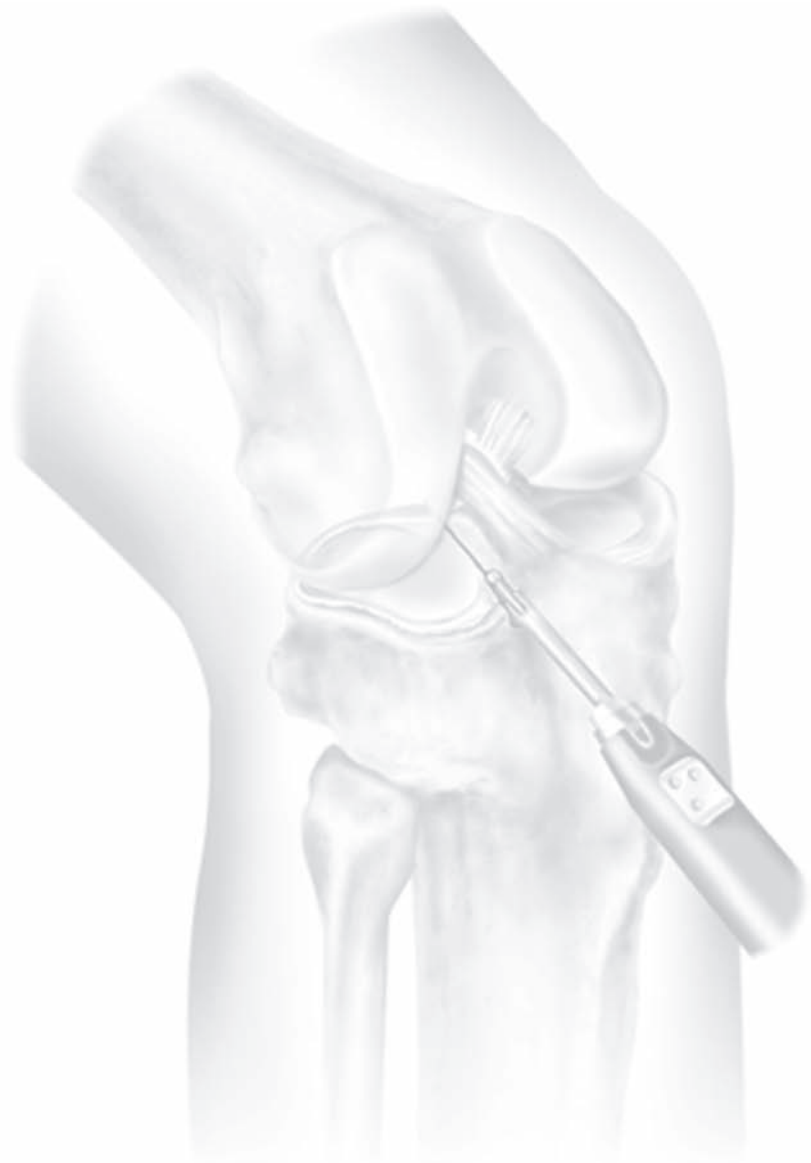

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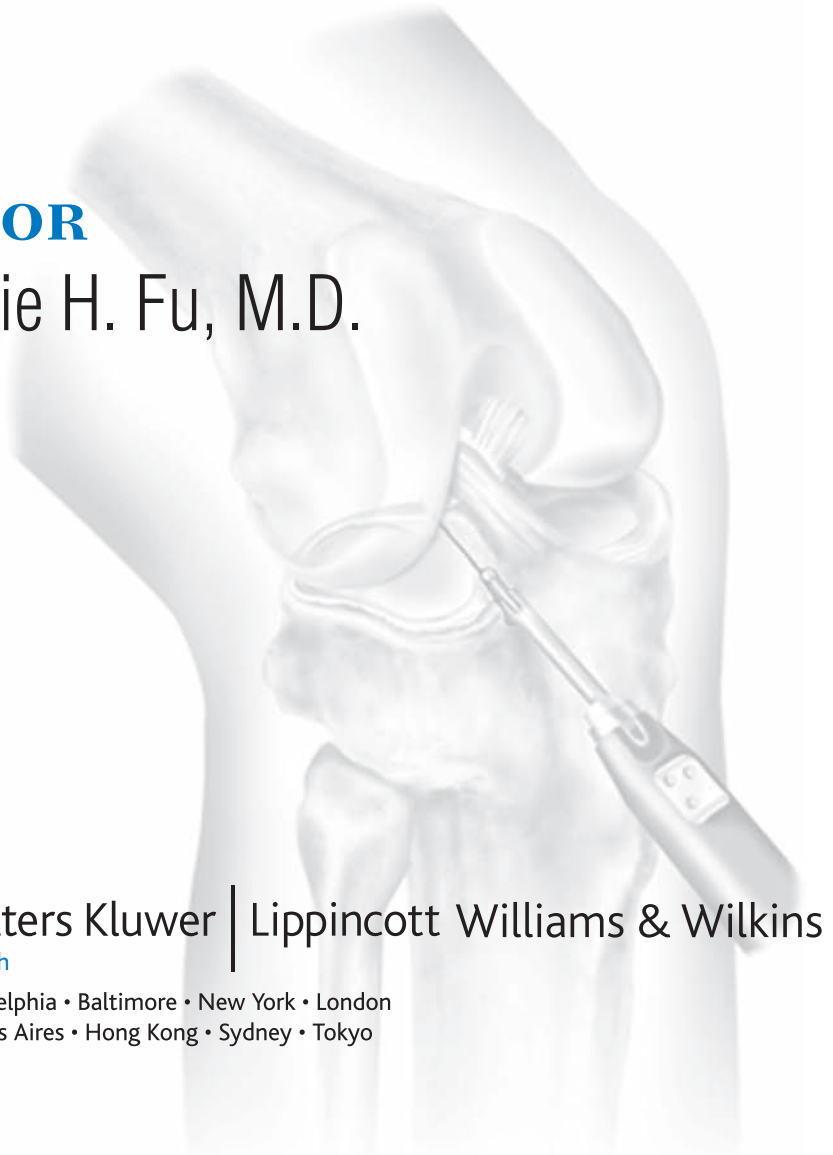

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Series Preface

Since its inception in 1994, the *Master Techniques in Orthopaedic Surgery* series has become the gold standard for both physicians in training and experienced surgeons. Its exceptional success may be traced to the leadership of the original series editor, Roby Thompson, whose clarity of thought and focused vision sought "to provide direct, detailed access to techniques preferred by orthopaedic surgeons who are recognized by their colleagues as 'masters' in their specialty," as he stated in his series preface. It is personally very rewarding to hear testimonials from both residents and practicing orthopaedic surgeons on the value of these volumes to their training and practice.

A key element of the success of the series is its format. The effectiveness of the format is reflected by the fact that it is now being replicated by others. An essential feature is the standardized presentation of information replete with tips and pearls shared by experts with years of experience.

Abundant color photographs and drawings guide the reader through the procedures step-by-step.

The second key to the success of the *Master Techniques* series rests in the reputation and experience of our volume editors. The editors are truly dedicated "masters" with a commitment to share their rich experience through these texts. We feel a great debt of gratitude to them and a real responsibility to maintain and enhance the reputation of the *Master Techniques* series that has developed over the years. We are proud of the progress made in formulating the third edition volumes and are particularly pleased with the expanded content of this series. Six new volumes will soon be available covering topics that are exciting and relevant to a broad cross-section of our profession. While we are in the process of carefully expanding *Master Techniques* topics and editors, we are committed to the now-classic format.

The first of the new volumes is *Relevant Surgical Exposures,* which I have had the honor of editing. The second new volume is *Essential Procedures in Pediatrics*. Subsequent new topics to be introduced are *Soft Tissue Reconstruction, Management of Peripheral Nerve Dysfunction, Advanced Reconstructive Techniques in the Joint*, and finally *Essential Procedures in Sports Medicine*. The full library thus will consist of 16 useful and relevant titles.

I am pleased to have accepted the position of series editor, feeling so strongly about the value of this series to educate the orthopaedic surgeon in the full array of expert surgical procedures. The true worth of this endeavor will continue to be measured by the ever-increasing success and critical acceptance of the series. I remain indebted to Dr. Thompson for his inaugural vision and leadership, as well as to the *Master Techniques* volume editors and numerous contributors who have been true to the series style and vision. As I indicated in the preface to the second edition of *The Hip* volume, the words of William Mayo are especially relevant to characterize the ultimate goal of this endeavor: "The best interest of the patient is the only interest to be considered." We are confident that the information in the expanded *Master Techniques* offers the surgeon an opportunity to realize the patient-centric view of our surgical practice.

Bernard F. Morrey, M.D.

Preface

This is the first of the *Master Techniques in Orthopaedic Surgery* series dedicated to sports medicine and provides the orthopaedic surgeon with a comprehensive overview of current pathology and treatment in field of sports medicine including new advances and novel approaches in the areas of shoulder, hip, knee, and foot.

Over the past several years, there has been an international explosion in sports medicine research. Tremendous efforts have been made in improving outcomes in the treatment of musculoskeletal injuries with the use of minimally invasive arthroscopic techniques and advanced rehabilitation protocols.

Many well respected "masters" in the field of sports medicine have shared in an expanded collection of 54 chapters an overview of the current standard of care for musculoskeletal injuries.

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And finally, my thanks to Dr. Bernard F. Morrey who invited me to undertake the editorship of this volume and to the staff at Lippincott Williams and Wilkins for their determination and diligence in bringing this one-of-a-kind book to fruition.

Freddie H. Fu, M.D.

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PART ONE
ELBOW

1 Valgus Extension Overload

Chad J. Marion, Marc D. Dyrszka, and Christopher S. Ahmad

ETIOLOGY

Originally described by Bennet in 1959 (4), valgus extension overload develops in the overhead athlete from the distinctive forces created at the elbow during repetitive high-velocity throwing that results in tension on the medial aspect, compression in the lateral aspect, and shear in the posterior aspect. In 1969, King et al. (11) clinically described this same condition as "medial elbow–stress syndrome" consisting of a triad of medial soft tissue insufficiency, posteromedial compartment impingement, and lateral compartment chondrosis. Wilson et al. (20) in 1983 then postulated the mechanism of valgus extension overload as a wedging effect of the olecranon in the olecranon fossa during the acceleration phase of throwing. While the early descriptions gave insight to the condition, more recent research has further elucidated the etiology.

During overhand throwing, valgus torques are generated across the elbow that are resisted by articular, ligamentous, and muscular restraints. Extreme tensile forces generated from valgus torques are estimated to reach 64 N m during the late cocking and early acceleration phases of throwing and are resisted primarily by the anterior bundle of the medial ulnar collateral ligament (MUCL). Toward full elbow extension, the bony articulation has greater contribution to stability than the MUCL, and in the posterior compartment, shear forces are developed between the posteromedial olecranon and trochlea (12). The angular velocities extending the elbow are estimated to reach 5,000 degrees/s in the acceleration phase of throwing (15). The established arm momentum generated during the acceleration phase must then be decelerated in the follow-through phase. When deceleration is poorly controlled by the dynamic muscle forces, the olecranon traumatically abuts the posterior compartment toward full extension. Thus, the olecranon is subject to injury from both valgus and extension forces that has been described as valgus extension overload. Repetitive forceful shearing of the olecranon within its fossa causes posteromedial olecranon chondromalacia and osteophyte formation as shown in Figure 1.1. Posteromedial osteophytes are often observed in asymptomatic throwers, and it has been postulated that symptoms most commonly develop when the osteophyte fractures and goes onto nonunion (13).

The relationship of posteromedial impingement and valgus stability has been a focus of several biomechanical studies (1,9,10). Ahmad et al. (1) demonstrated in cadavers that existing MCL insufficiency causes contact

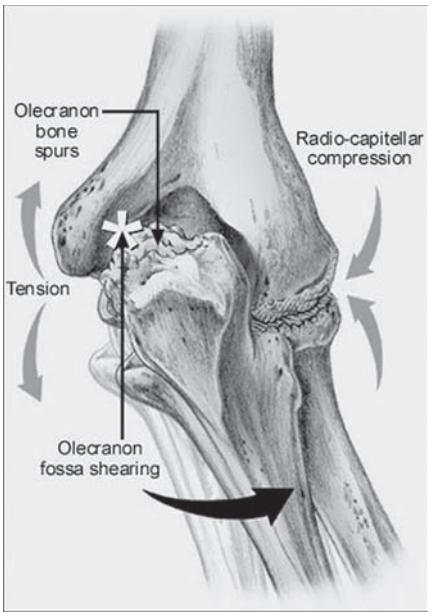

FIGURE 1.1

In the posterior compartment, the olecranon is subjected to medial shearing forces with valgus stress, which may be accentuated by increased valgus laxity, resulting in osteophyte formation and loose bodies. (Reprinted from Safran MR. Injury to the UCL: diagnosis and treatment. *Sports Med Arthrosc Rev.* 2003;11:15–24.)

alterations in the posteromedial compartment that may factor into the development of symptomatic chondrosis and osteophyte formation that manifests as valgus extension overload syndrome. This suggests that clinically, patients with symptomatic valgus extension overload with posteromedial impingement may have valgus instability although the instability may not be the presenting symptom.

HISTORY

For isolated posteromedial impingement, elbow pain is localized to the medial aspect of the olecranon and usually occurs just after ball release during the deceleration phase of throwing as the elbow approaches full extension. Pain during the acceleration phase should increase the suspicion for medial elbow instability that often occurs concomitantly (5). Patients may report limited extension from posterior impingement due to osteophytes or locking and catching from loose bodies. Other complaints may include difficulty warming up, fatigue, popping, and decreased performance such as loss of pitch, velocity, and accuracy. Ulnar neuritis may also occur concomitantly and history of numbness or parasthesias in the fourth and fifth digits should be ascertained.

PHYSICAL EXAMINATION

Osteophytes on the posteromedial olecranon observed on imaging studies do not always cause impingement pain. Therefore, it is critical to confirm the diagnosis of symptomatic valgus extension overload using history and especially physical examination. The extension impingement test is performed by the examiner by quickly snapping the patient's partially flexed elbow into terminal extension. Reproduction of posterior or posteromedial pain that is similar to the pain felt while throwing is considered a positive exam. Simultaneous valgus load during the maneuver will typically increase the pain while varus will diminish the pain. The arm bar test is performed with the patient's hand placed on the examiner's shoulder, and their shoulder in 90 degrees of forward elevation and full internal rotation. The examiner then pulls down on the olecranon, leveraging the elbow into extension. Pain is produced in the setting of posteromedial impingement. Physical examination may also demonstrate terminal extension motion loss and local tenderness over the posterior and medial olecranon.

The MUCL must be evaluated in all throwers presenting with medial elbow pain using direct palpation and the moving valgus stress test. Examination of the ulnar nerve involves assessing intrinsic muscle weakness or wasting, Tinel sign, and subluxation of the nerve.

IMAGING STUDIES

Anterior-posterior, lateral, oblique, and axillary views of the elbow may reveal posteromedial olecranon osteophytes and/or loose bodies (Fig. 1.2). Conway et al. also have described a posterior impingement view to assist in assessment of patients with suspected valgus extension syndrome (Conway AOSS Elbow Arthroscopy ICL 2009). The radiograph is a modified AP with the humerus in 40 degrees of external rotation and 140 degrees flexion. The best imaging study overall is a CT scan with two-dimensional sagittal (Fig. 1.3) and coronal reconstructions and three-dimensional surface renderings (Fig. 1.4) to demonstrate the overall morphologic

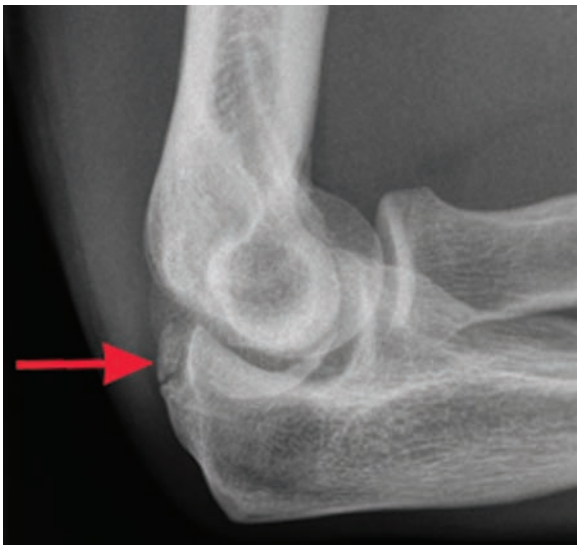

FIGURE 1.2
Lateral radiograph of the elbow demonstrating posteromedial osteophyte.

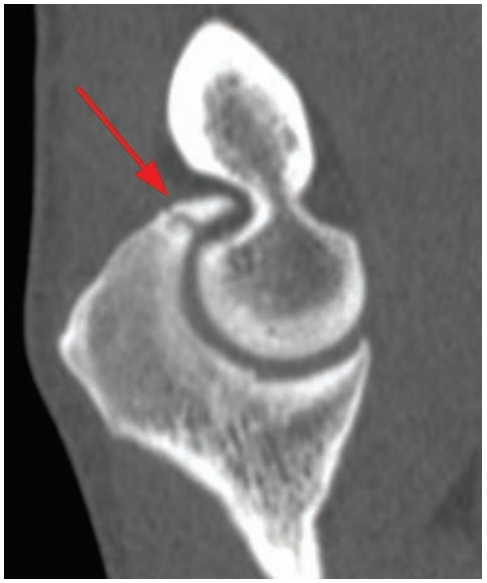

FIGURE 1.3
Sagittal CT scan clearly demarcating the posterior osteophyte in the olecranon.

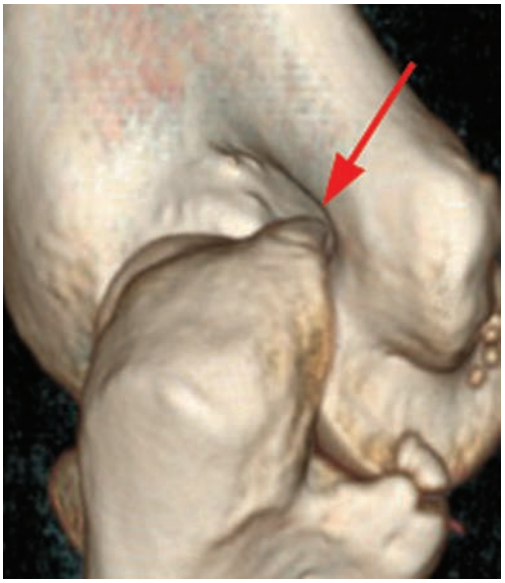

FIGURE 1.4
Three-dimensional reconstruction of the elbow showing morphology and precise location of the osteophyte.

changes, loose bodies, and osteophyte fragmentation. MRI is also informative, especially if MCL pathology is expected. MRI can also demonstrate osteochondral damage, synovial plicae, edema, and early stress fractures that can occur in the olecranon. Stress fractures can occur in the setting of a normal MRI, and if suspected, a bone scan can be useful.

INDICATIONS/CONTRAINDICATIONS

Valgus extension overload is a condition that affects throwing athletes primarily and is rare in nonthrowing athletes. An initial course of nonoperative treatment consists of activity modification with a period of rest from throwing, intra-articular cortisone injections, and non steroid anti inflammatory drugs (NSAIDs). Pitching mechanics should be evaluated and instruction should be instituted to correct flaws that may be contributing to the injury. After a period of rest, a progressive throwing program is instituted under the supervision of experienced therapists and trainers. Surgical treatment is indicated for those patients who maintain symptoms despite nonoperative management and wish to return to the same level of competition.

In a report of professional baseball players who underwent olecranon debridement, 25% developed valgus instability and eventually required MUCL reconstruction. Subsequent basic science studies have demonstrated that excessive olecranon resection increases the demands on the MCL during valgus stress and increases valgus instability (9,10). These studies, therefore, suggest that MCL insufficiency may develop following posteromedial decompression, and consequently, current recommendations are to limit olecranon resection to osteophytes only and avoid removal of normal olecranon. It has also been demonstrated that existing MCL insufficiency created in cadavers causes contact alterations in the posteromedial compartment that may be the cause of symptomatic chondrosis and osteophyte formation that eventually manifests as valgus extension overload syndrome (1). In addition, osteophyte formation may make the elbow clinically stable despite MUCL injury, and thus, treating the bony impingement with osteotomy may convert an asymptomatic MUCL into a painful MUCL. In summary, patients with posteromedial elbow pain should have a thorough evaluation of the MUCL, and overaggressive resection of posteromedial osteophytes should be avoided (1).

SURGERY

There are several options for anesthesia including regional, general, or a combination. Regional anesthesia optimizes postoperative pain control, reduces postoperative nausea, and facilitates patient positioning. A disadvantage is the inability to perform a thorough postoperative neurological exam of the operative extremity. Advantages of general anesthesia include total muscle relaxation, more options for patient positioning including prone, and the ability to test nerve function at the end of the case. Disadvantages include higher risk of nausea, more postoperative pain, and longer postoperative unit stay.

Patients may be positioned in a supine, prone, or lateral decubitus position. We prefer the lateral decubitus position with a nonsterile tourniquet and an arm support. The lateral position places the shoulder in 90 degrees of abduction, with the elbow flexed 90 degrees while suspended over an arm holder (Fig. 1.5). The arm is draped free so that it can be manipulated during surgery to improve access during arthroscopy. A bean bag is used to pad the patient and hold him or her securely in place during the operation. An axillary role is also utilized to improve patient comfort.

The arm should be brought into a full 90 degrees of abduction as less abduction can cause impingement against the torso while working on the ulnar side of the elbow. Also, the arm holder should be placed close to the axilla to allow access to the anterior compartment. Advantages to the lateral position include the ability to easily manipulate the elbow, access to both anterior and posterior compartments, and no special equipment

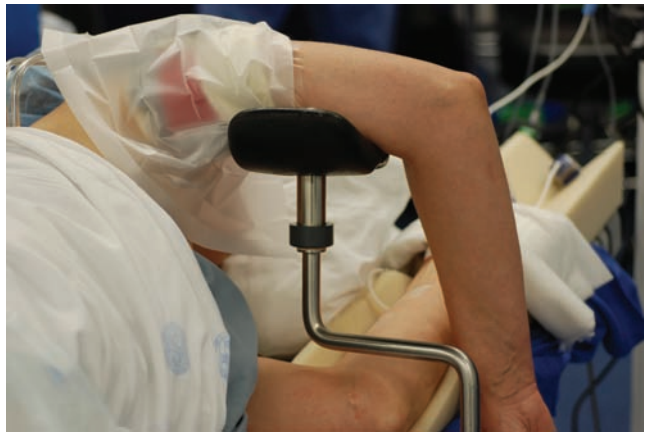

FIGURE 1.5

Lateral decubitus position. The shoulder is placed in 90 degrees of flexion and maintained over lateral arm support to allow ample room near the thorax for medial-sided work. The arm is free to allow flexion and extension.

necessary such as a hydraulic arm holder. Disadvantages include need to reposition if conversion to an open procedure is required, such as an MCL reconstruction or ulnar nerve transposition, and limited access if the patient is obese.

PORTALS

Arthroscopy begins with establishment of the *proximal anteromedial portal* for visualization. The anterior compartment is evaluated for chondral injuries, loose bodies, synovitis, and synovial plica. The portal is located 2 cm above the medial epicondyle and approximately 1 cm anterior to the intermuscular septum. The medial antebrachial cutaneous nerve is the structure most at risk as it is located on average 2.3 mm from the cannula. The ulnar nerve is on average 12 to 23 mm from the portal. Prior transposition of the nerve or subluxation requires exposure or identification of the nerve prior to placing the portal (Fig. 1.6).

The *proximal anterolateral portal* is used as a working portal. It is located 2 cm proximal to the lateral epicondyle and is placed directly on the anterior surface of the humerus (7,17). The posterior antebrachial cutaneous nerve is on average 6.1 mm away but lies in direct contact with the cannula 29% of the time (17). The radial nerve lies 4.9 mm away in extension and 9.9 mm away in flexion (Fig. 1.7).

The primary portals for managing posteromedial impingement from valgus extension overload are the superior posterolateral portal and the direct posterior portal. The *posterolateral portal* can be located anywhere from the tip of the olecranon to 3 cm proximal to it in the posterolateral gutter just off of the triceps tendon. For posteromedial debridement, we prefer to make it 1 cm proximal to the olecranon tip. The elbow is held in 30 degrees of flexion to relax the triceps while establishing the portal. It has one of the largest areas of safety. It provides excellent visualization of the entire posterior compartment and can be useful in debriding the olecranon fossa, tip of the olecranon, and latter gutter when necessary.

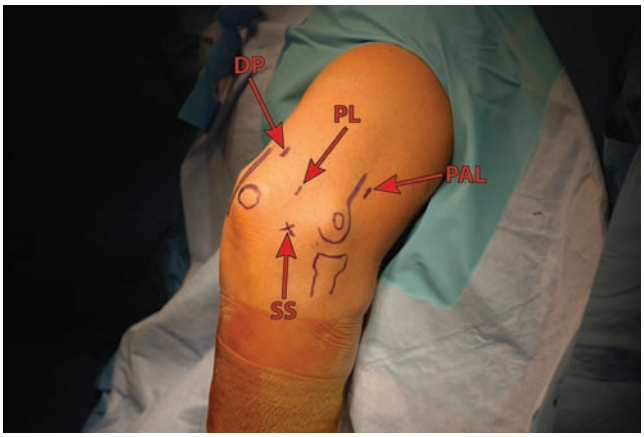

FIGURE 1.6
Lateral elbow anatomy and portal placement. DP, direct posterior; PAL, proximal anterolateral; PL, posterolateral; SS, soft-spot portal.

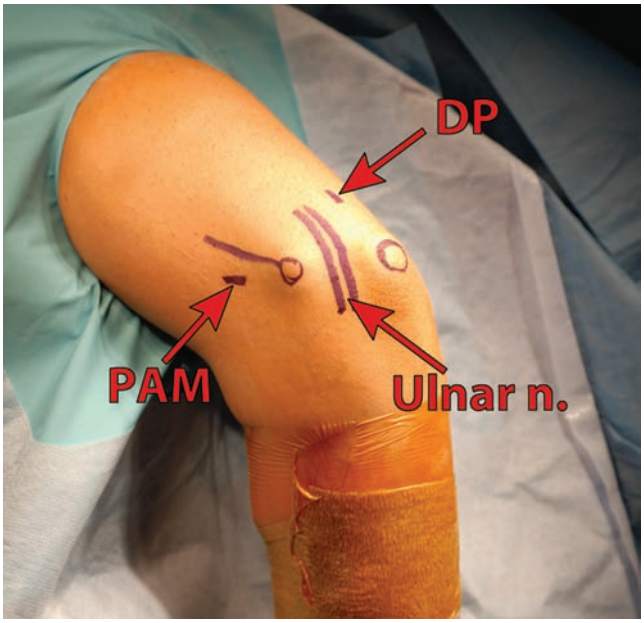

FIGURE 1.7
Medial elbow anatomy and portal placement.
DP, direct posterior; PAM, proximal anteromedial.

The *direct posterior portal* splits the triceps in its midline 3 cm proximal to the olecranon tip. It is the work-horse portal for valgus extension overload and is used for debriding posteromedial olecranon osteophytes, removing loose bodies, and addressing any posterior chondral lesions. The *soft-spot portal* is located in the center of the triangle formed by the lateral epicondyle, tip of the olecranon, and radial head. It is useful in insufflating the elbow joint and debriding posterolateral plica and osteochondritis dissecans (OCD) of the capitellum.

TECHNIQUE

After anesthesia is established, the patient is positioned, and prepping and draping, the anatomic landmarks are appropriately marked including the ulnar nerve. At this point, the elbow is distended using a 60 mL syringe attached to an 18-gauge needle introduced into the soft-spot lateral portal and distended (Fig. 1. 8). The joint distention facilitates the introduction of the trocar but more importantly shifts the neurovascular structures further away from the bone that decreases risk of nerve injury. We begin with anterior compartment arthroscopy with a superficial incision made through the skin at the proximal medial portal, and then, the soft tissues are spread with blunt clamp to prevent injury to the neurovascular structures. A blunt-tipped trocar is then introduced into the anterior compartment hugging the anterior humerus and directed toward the radiocapitellar joint.

Diagnostic arthroscopy is performed anteriorly to look for loose bodies and thoroughly examine the articular cartilage and synovium. The anterior radiocapitellar joint is evaluated for osteochondral lesions of the capitellum and the radial head. The coronoid tip and fossa are then examined for osteophytes followed by visualization of the trochlea and any cartilage lesions present. The anterior capsule is evaluated for thickening or contracture in the context of a loss of passive extension. Of note, the radial nerve lies in close proximity to the anterolateral capsule so any debridement in this area should utilize a retractor such as a switching stick introduced through an accessory portal and/or minimal suction with the hood of the shaver to the capsule to prevent iatrogenic injury. To test for MUCL insufficiency, an arthroscopic valgus stress test is performed. With the arthroscope in the proximal lateral portal visualizing the medial compartment, a valgus stress is applied manually to the elbow. A gap of 3 mm or more seen between the coronoid process and medial trochlea supports MUCL insufficiency (6).

After completion of the anterior arthroscopy, a posterolateral portal is then established with the elbow held in 30 degrees of flexion for viewing. A direct posterior portal is then established as a working portal. Diagnostic arthroscopy is then performed evaluating for osteophytes on the posteromedial aspect of the olecranon, loose bodies, and any evidence of chondromalacia. Synovial reflections and any other extra soft tissue may be removed using a cautery or a shaver. We prefer to use a 3.5-mm nonaggressive shaver for this purpose. The posterior radiocapitellar joint can also be inspected from the posterolateral portal.

The pathology of a fractured osteophyte on the posteromedial is identified with the camera in the posterolateral portal. The osteophyte may be encased in soft tissue and often requires probing and a debridement with a shaver introduced in the direct posterior portal before it can be fully appreciated. A small osteotome is inserted through the direct posterior portal to free the osteophytes, as shown in Figure 1.9. The olecranon can be further contoured with a burr and shaver. Often, osteophytes are also present in the olecranon fossa, which are debrided as well. Figure 1.10 illustrates proper placement of instruments and the desired olecranon resection. Once the osteophyte is removed, which may be performed using a tissue grasper (Fig. 1.11) or burr, the humeral chondral surface can be visualized more completely, and the kissing lesion of chondral abrasion opposite the osteophyte will be in direct view. If a chondral injury is present, standard principles apply. Loose chondral flaps should be debrided, and if necessary, microfracture can be performed. When

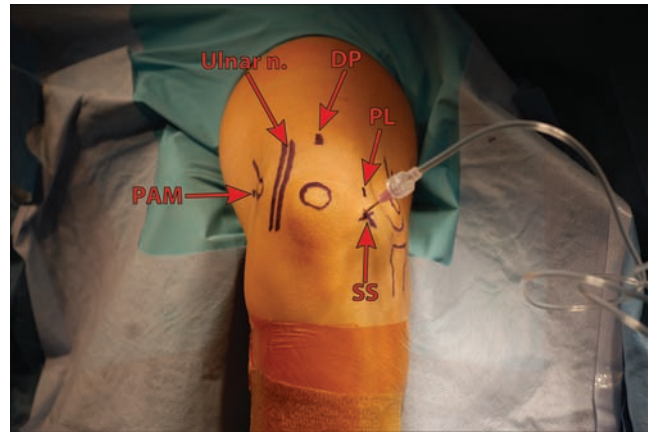

FIGURE 1.8

Joint insufflation is achieved by placing an 18-gauge needle into the soft spot that is connected via surgical tubing to a large syringe.

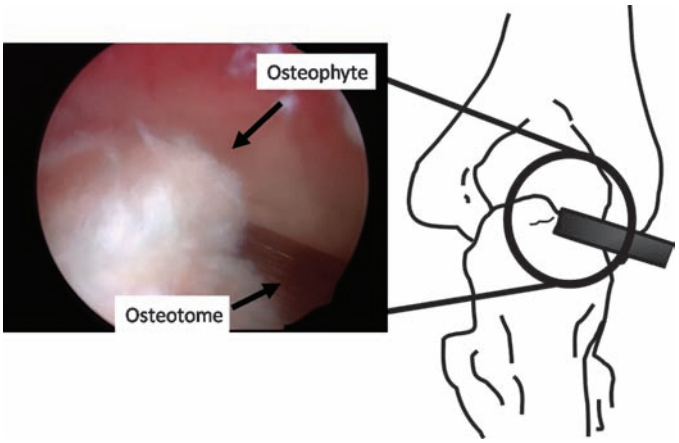

FIGURE 1.9

Osteophyte on olecranon tip with osteotome in position. (Reprinted from Ahmad. *Minimally Invasive Shoulder and Elbow Surgery*, Informa Healthcare, p. 344.)

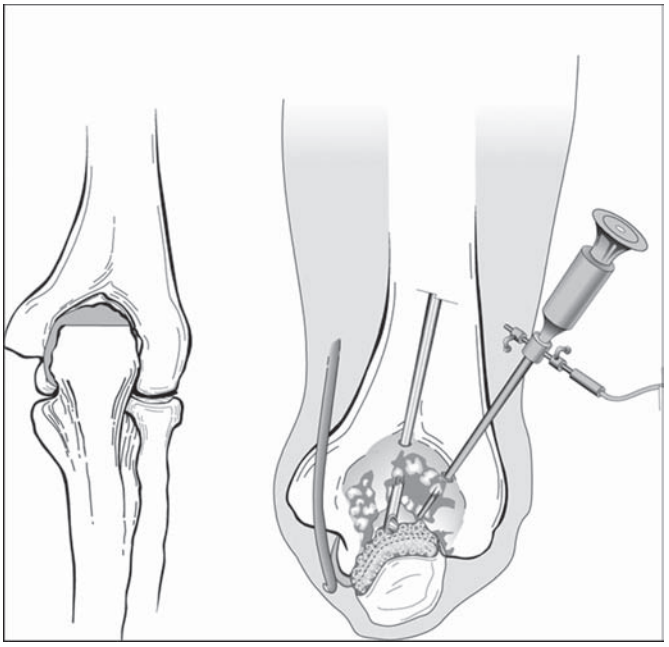

FIGURE 1.10

Illustration depicting instrument positioning and olecranon resection. (Reprinted from Ahmad *Minimally Invasive Shoulder and Elbow Surgery*, Informa Healthcare, p. 344.)

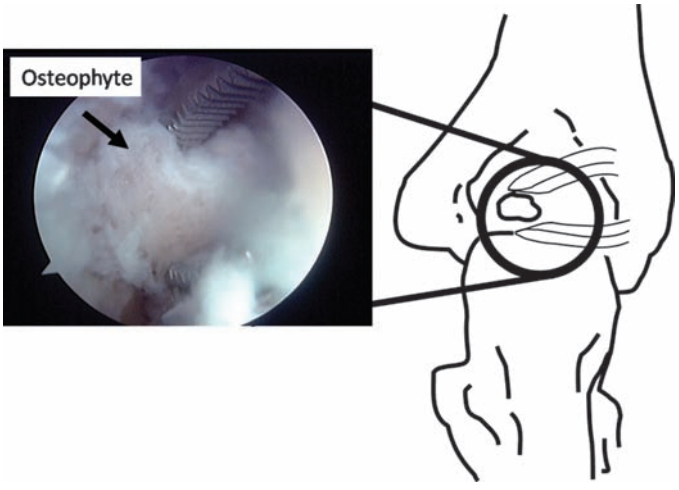

FIGURE 1.11

Removal of osteophyte. (Reprinted from Ahmad. *Minimally Invasive Shoulder and Elbow Surgery*, Informa Healthcare,p. 345.)

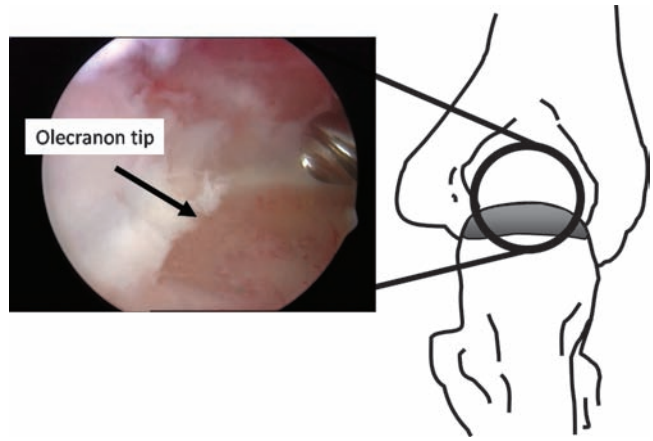

FIGURE 1.12
Olecranon tip, following contouring with a burr. (Reprinted from Ahmad. *Minimally Invasive Shoulder and Elbow Surgery*, Informa Healthcare p. 345.)

olecranon contouring is complete (Fig. 1.12), a lateral radiograph may be obtained intraoperatively to assess adequacy of bone removal. It is imperative to recognize the position of the ulnar nerve just superficial to the capsule in the posteromedial gutter. Avoid the use of cautery and suction when the shaver is near this area of the capsule.

We prefer to remove only the olecranon osteophytes present and not remove any of the normal bone (9). We preferentially remove more bone from the humeral side if there is doubt whether debridement is sufficient. This is intuitive as increased posteromedial olecranon resection increases the amount of elbow valgus and subsequently the strain placed on the MUCL.

Once the arthroscopy is completed, the fluid is evacuated from the posterior cannulas, and the portals are closed with simple interrupted 3.0 nylon. If MUCL reconstruction is needed, then the patient is placed in the supine position and re-prepped and draped. The technique is addressed in Chapter 2.

POSTOPERATIVE MANAGEMENT

The patient is placed in a compressive dressing and simple sling postoperatively. The dressing may be removed postoperative day number one and the patient may shower keeping the incisions dry. The sling is worn for comfort only and discontinued within 1 week. Active elbow flexion and extension exercises are initiated immediately. Emphasis is also placed on restoring flexor-pronator strength, as well maintaining rotator cuff and periscapular muscle strength to avoid shoulder injuries upon return to throwing. At 6 weeks, a progressive throwing program is begun and plyometric exercises and neuromuscular training are enhanced. Return to competition is typically allowed at 3 to 4 months postoperatively after the patient demonstrates full range of motion (ROM), no pain or tenderness to stress testing and palpation, and full strength of the involved extremity.

RESULTS

With the improvement in arthroscopy equipment and a clear understanding of portal placement and proximity to neurovascular structures, elbow arthroscopy has become a reliable, safe, and effective way to treat pathology in the thrower's elbow (2,6,14). Good results have been reported in treating multiple pathologic conditions in the throwing elbow including loose body removal, osteophyte debridement for valgus extension overload, and OCD.

Wilson et al. (20) reported the results for five pitchers treated with open osteophyte excision after failure of nonoperative treatment, and all returned to play for at least one season at 8 to 20 months of follow-up. One patient required repeat excision within two seasons. Andrews and Timmerman (3) reported on 72 professional baseball players undergoing either open or arthroscopic elbow surgery. Posteromedial osteophytes were identified in 65% of these cases. They reported a 41% reoperation rate in the group undergoing olecranon debridement and found that 25% developed valgus instability requiring MUCL reconstruction. They concluded that the incidence of MUCL insufficiency is underestimated and that treatment focused solely on the secondary effects of MUCL insufficiency without treating the underlying MUCL pathology that may lead to unsatisfactory results.

More recently, Reddy et al. (16) reported on the results of 187 elbow arthroscopies. The most common diagnoses were posterior impingement (51%), loose bodies (31%), and degenerative joint disease (22%). The average Figgie score improved from 27.7 points to 45.4 points, with the largest increases occurring in the pain score. An excellent result was achieved in 51%, a good result in 36%, a fair result in 11%, and poor result in 4% of the patients. Forty-seven of fifty-five baseball players (85%) were able to return to the same level of competition. The complication rate was 1.6%.

COMPLICATIONS

Elbow arthroscopy has evolved to be a safer procedure through a better understanding of the neurovascular structures about the elbow and avoiding them during portal placement and intra-articular work on or near the capsule. However, there still remains a real risk of serious nerve injury especially to the inexperienced elbow arthroscopist.

Nerve injury is the most devastating reported complication of elbow arthroscopy (2,8,14,18). Injury can be caused by direct laceration from a knife penetrated deep to the dermis, from the cannula trocar, or from overly aggressive debridement from a shaver, or getting wrapped in a burr. Other possible causes of nerve injury include fluid extravasation, direct infiltration with local anesthetic, and direct compression from cannulas or instruments (19). As noted previously, some portals described in the literature place the neurovascular structures at a higher relative risk than other portals. For this reason, to minimize the risk of neurovascular insult, we have chosen the portals as outlined above, incise only through the skin, spread the soft tissues with a straight hemostat, use blunt trocars to enter the elbow joint, and use retractors especially when working adjacent to the ulnar nerve.

It must also be mentioned that elbow arthroscopy inherently carries the risks of any arthroscopy or orthopaedic intervention about a joint. These include infection, articular cartilage injury, synovial fistula formation, instrument breakage, and tourniquet-related complications. Finally, the patient's compliance with postoperative physical therapy is crucial, and they are advised that should they not comply with the postoperative program they risk failure of the surgery or elbow stiffness.

Complications specific to olecranon debridement for valgus extension overload included missed MUCL injury and overaggressive olecranon resection. As previously mentioned, existing MUCL injury may become symptomatic after the recovery from the arthroscopic debridement. It is critical to remove only the osteophyte and not the normal olecranon. Removal of the normal olecranon can increase valgus angulation of the elbow and increase MUCL strain during valgus loading and contribute to MUCL pathology (9,10). We council all patients who elect arthroscopic posteromedial decompression of the possibility of developing MUCL injury and symptoms. In addition, care should be taken to avoid injury to the ulnar nerve that lies near this area in the cubital tunnel. The use of arthroscopic soft tissue retractors is extremely helpful when working in the medial gutter to protect the ulnar nerve.

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2 Medial Ulnar Collateral Ligament Reconstruction

Cory O. Nelson and Neal S. ElAttrache

The medial structures of the elbow are subjected to significantly high forces in the overhead athlete (21) and the anterior bundle of the ulnar collateral ligament (UCL) is the main restraint to these valgus forces in the flexed, throwing position (9,14). UCL insufficiency in overhead athletes was once considered to be a career-ending diagnosis. Since the first UCL reconstruction performed by Dr. Frank W. Jobe in 1974, surgical reconstruction has afforded these athletes the opportunity to return to their preinjury level of play with predictable outcomes.

In the original description of the surgical technique, the common flexor-pronator tendon was detached from its origin on the medial epicondyle and the ulnar nerve was transposed submuscularly (13). A long-term follow-up study at our institution using this technique showed good to excellent results in 80% of patients; however, a 21% complication rate was reported associated with dysfunction of the ulnar nerve (8). Due to the high incidence of postoperative ulnar nerve symptoms and need for secondary procedures, a muscle-splitting technique without ulnar nerve transposition was developed, which is described in this chapter (18,19). While others routinely transpose the ulnar nerve when performing UCL reconstructions with good outcomes (3), Thompson et al. (19) reported good to excellent results and significantly less ulnar nerve morbidity in 31 of 33 (94%) patients without transposition using this muscle-splitting technique.

Although variations from the original reconstruction technique with respect to graft passage and fixation have been reported, the principles of the surgical technique remain consistent to restore medial elbow stability in the overhead athlete. The insufficient UCL should be reconstructed using a free tendon autograft, with stable fixation, and tensioned at an isometric point through elbow range of motion. In Dr. Jobe's own words, "the goal is to put a good piece of collagen in the right orientation."

DIAGNOSIS AND DECISION MAKING

The diagnosis of valgus instability of the elbow due to UCL insufficiency is based upon an accurate history, physical examination, and radiographic studies. Athletes usually present with medial elbow pain in the late cocking or acceleration phases of repetitive overhand throwing activities (Fig. 2.1) (6). Changes in velocity, accuracy, and stamina while throwing are other important factors to obtain from the patient's history. History may reveal an acute injury of sharp pain and/or a "pop" in the medial elbow with inability to continue performing, a gradual onset of medial-sided pain over time with throwing, or significant pain after a strenuous throwing load with unsuccessful attempts to throw above 50% to 75% of maximum function. Neurologic complaints of paresthesias or radicular symptoms in the ulnar nerve distribution should be elicited and documented.

A complete physical examination of the elbow including range of motion, palpation of the bony landmarks as well as the UCL and flexor-pronator tendon origin, and forearm and elbow muscle strength is performed. Tenderness over the UCL or flexor-pronator muscle unit is indicative of local inflammation. Pain with resisted wrist flexion or pronation should be assessed along with palpation for defects in the tendinous origin which may be indicative of flexor-pronator injury rather than UCL instability. The patient should also be inspected for the presence or absence of a palmaris longus tendon (Fig. 2.2).

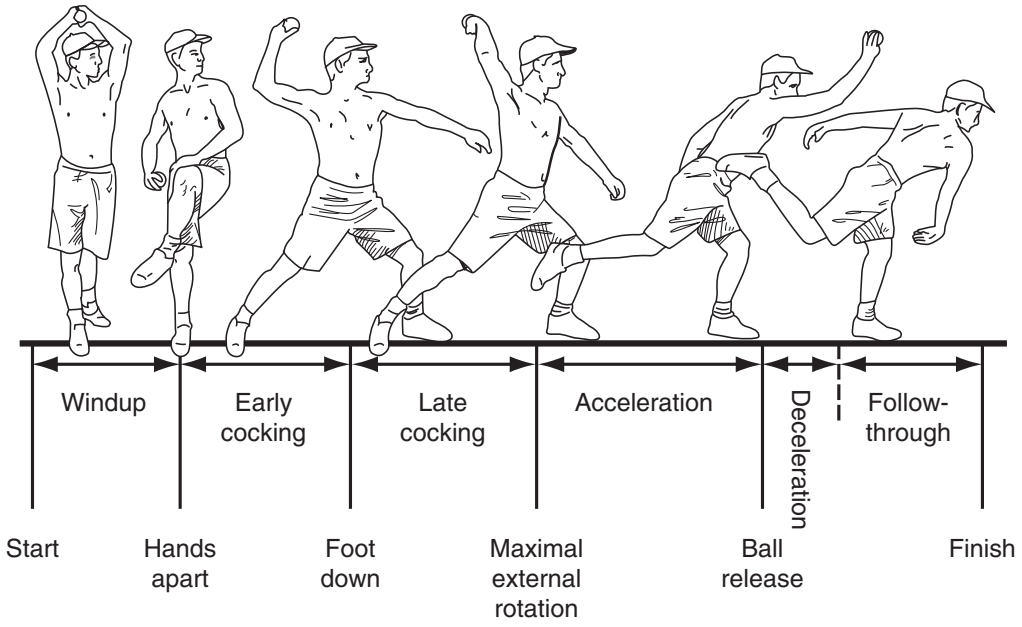

FIGURE 2.1

Phases of pitching. (Reprinted from Chen FS, Rokito AS, Jobe FW. Medial elbow problems in the overhead-throwing athlete. *J Am Acad Orthop Surg*. 2001;9:99–113, with permission; Adapted from DiGiovine, Jobe, Pink, et al. An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg*. 1992;1:15–25.)

A detailed neurovascular assessment is also completed with careful attention paid to ulnar nerve motor and sensory function. Palpation of the ulnar nerve proximal and distal to the epicondyle should be performed, and a gentle anterior force applied proximally will assess if the nerve will sublux over the medial epicondyle out of the cubital tunnel. A Tinel sign is also elicited over the cubital tunnel.

Valgus instability is tested with the elbow in 25 to 30 degrees of flexion and the patient's hand and wrist secured between the examiners forearm and trunk (Fig. 2.3). A valgus force is applied to the elbow while concurrently palpating the UCL. Pain, tenderness, and medial joint space laxity are assessed. The "milking maneuver" is a sensitive test for UCL damage and is performed by grasping the thrower's thumb with the arm in the cocked position (90 degree shoulder abduction and 90 degree elbow flexion) and applying a valgus stress by pulling down on the thumb (4) (Fig. 2.4A). Pain in the medial elbow is a positive result. This maneuver can also be performed dynamically with the shoulder held in 90 degrees of abduction as the elbow is ranged with a constant valgus force applied (Fig. 2.4B–D). Valgus extension overload is tested by the examiner placing a valgus force on the elbow and quickly moving the elbow into maximal extension. Pain in the posterior compartment is consistent with posterior impingement from a posteromedial olecranon osteophyte or olecranon fossa overgrowth.

Radiographic studies are helpful if positive, but a negative study should not rule out the diagnosis of UCL insufficiency. As such, the diagnosis remains a clinical one. Radiographs may add valuable information for preoperative planning such as ossification within the ligament, intra-articular loose bodies, posterior or marginal osteophytes, or osteochondritic lesions of the capitellum. Stress radiographs may demonstrate significant medial joint line widening. Abnormal stress radiographs or calcifications in the ligament without symptoms of pain or instability do not justify surgical intervention.

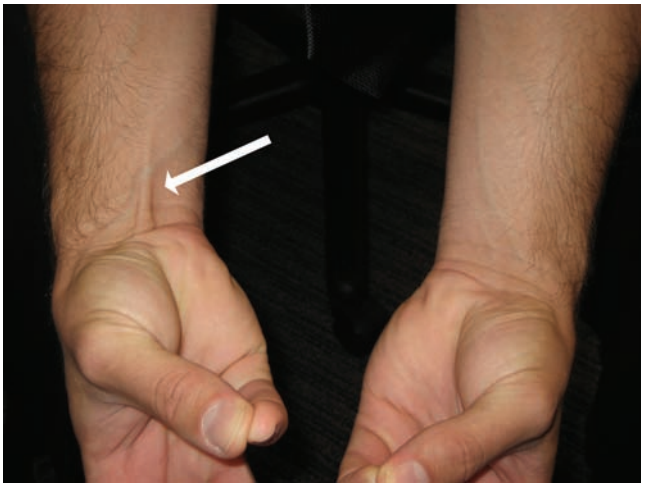

FIGURE 2.2

Presence (patient's right—*arrow*) and absence (patient's left) of Palmaris Longus tendon on physical examination wrist flexion combined with thumb and small finger opposition.

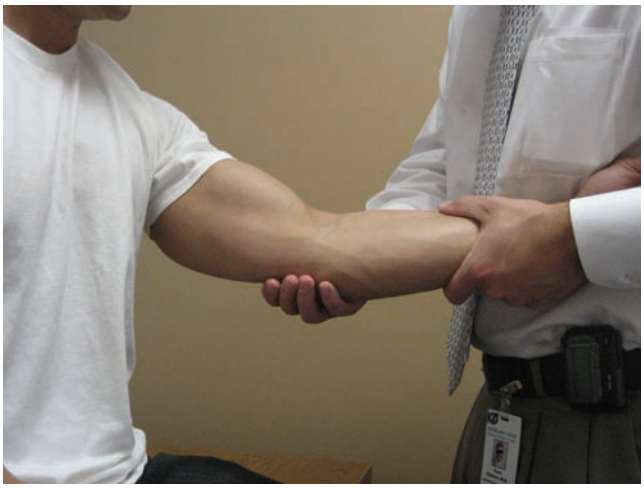

FIGURE 2.3

Valgus instability testing of an athlete's left elbow.

MRI can be very helpful in both the chronic and acute setting to evaluate the UCL (Fig. 2.5A). MRI is also useful in evaluating the articular surfaces, as well as identifying loose bodies. There is debate as to whether or not intra-articular contrast increases the sensitivity of the study in evaluating the UCL. We routinely obtain a noncontrast MRI, except in the setting of an athlete who has already had a reconstruction and the graft is being evaluated (Fig. 2.5B).

Once the diagnosis is made, a course of nonoperative treatment is initiated. Rest from all throwing activities during the initial 4 to 6 weeks is mandatory. Nonsteroidal anti-inflammatories, ice, and other physical modalities are used early to decrease inflammation. Steroid injections are generally avoided as they have not

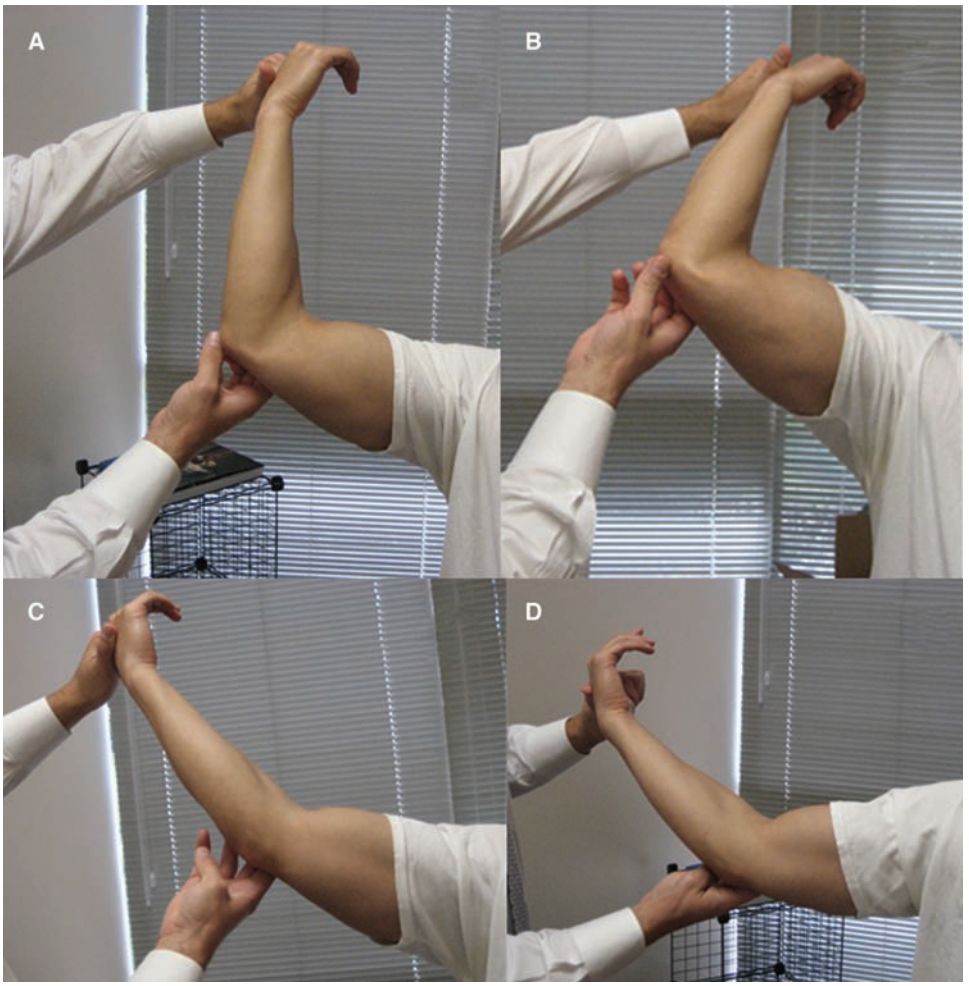

FIGURE 2.4

A: Milking test. **B–D:** Dynamic valgus examination of the elbow in varying degrees of elbow flexion.

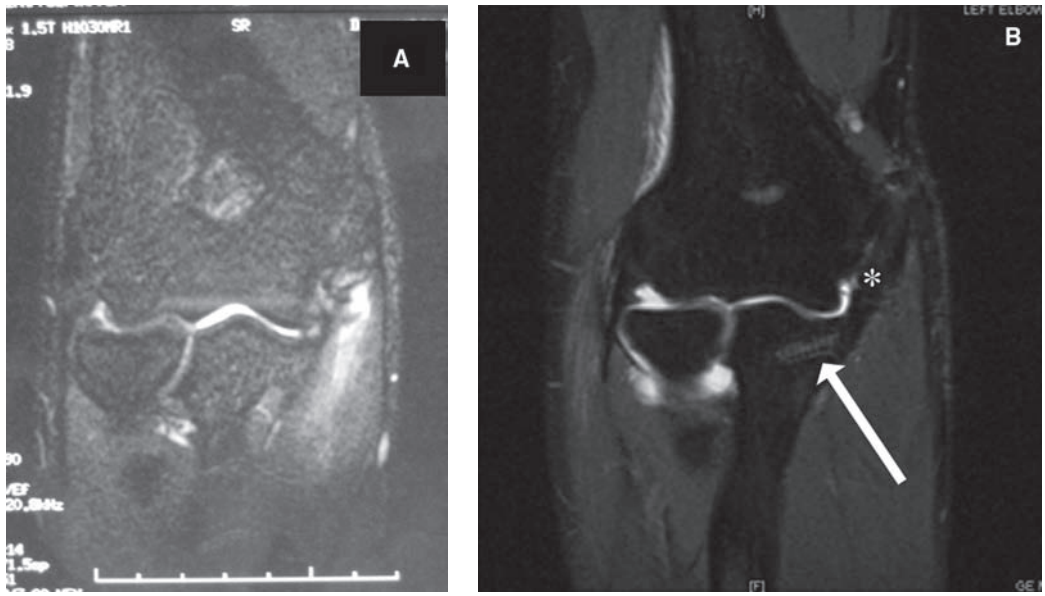

FIGURE 2.5

A: MRI coronal image of UCL rupture. **B:** Gadolinium enhanced MRI after UCL reconstruction showing an intact graft (*asterisk*) and tenodesis screw fixation in the ulna (*arrow*).

been found to be helpful and may cause further ligament degeneration. Although not throwing, a total-body training program as well as periscapular and rotator cuff strengthening programs are begun early. Trunk, core, and shoulder muscle weakness with throwing may increase the valgus forces placed on the elbow and severely hinder attempts to return to throwing. After the rest period and full painless motion is achieved with normal strength, a throwing program is begun.

If elbow stability and pain relief are the main goals, nonoperative treatment is usually successful. This is the case in most noncompetitive, recreational, or occupational circumstances where activity modification can also be incorporated into the nonoperative treatment algorithm. However, surgery is recommended for athletes who desire to return to highly competitive overhead or throwing sports and have failed to improve despite nonoperative treatment.

Medial elbow instability due to UCL insufficiency has been shown to cause ulnar nerve symptoms in 24% (19) to 41% (8) of overhead athletes. Traction on the nerve with repetitive medial joint space widening or abrasion by posteromedial osteophytes may cause paresthesias that affect the player's ability to perform. This situation is also justification for surgical reconstruction to restore medial stability.

In patients without loose bodies, posterior osteophytes requiring removal, or ulnar nerve symptoms, the ulnar nerve is not transposed. This muscle-splitting technique allows adequate exposure for tunnel creation, graft passage, and the flexor-pronator origin to remain attached at the medial epicondyle since the ulnar nerve is not routinely transposed.

REPAIR VERSUS RECONSTRUCTION

Primary repair of the UCL has been reported, but in general has led to inferior results when compared to reconstruction (5). Andrews and Timmerman (2) reviewed the outcome of elbow surgeries in professional baseball players, and the two patients who had direct primary UCL repair were not able to continue to play. Conway et al. (8) reported a 50% return to preinjury level of play with repair, compared to 68% in reconstructed patients. Finally, Azar et al. reported return to competitive throwing in five of eight primary repairs (63%) versus 81% with reconstruction. In younger (average age 17.2 years), nonprofessional athletes, Savoie et al. (16) described good to excellent results in 93% of the patients treated with primary repair. They concluded that primary repair may be a viable option for younger, nonprofessional athletes.

We have found, along with others, more predictable and consistent long-term results with reconstructing the ligament. Therefore, reconstruction of the UCL with free autologous tendon graft is our surgical treatment of choice.

SURGICAL TECHNIQUE

Modified Jobe Technique

The procedure is carried out using a pneumatic tourniquet with the patient in the supine position and the use of an arm board.

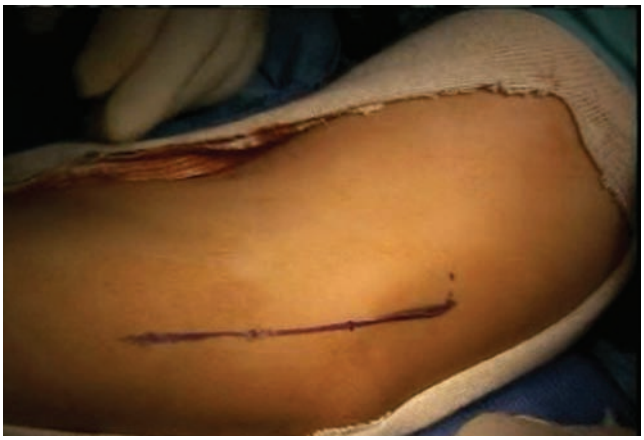

FIGURE 2.6
Planned incision centered of the medial epicondyle.

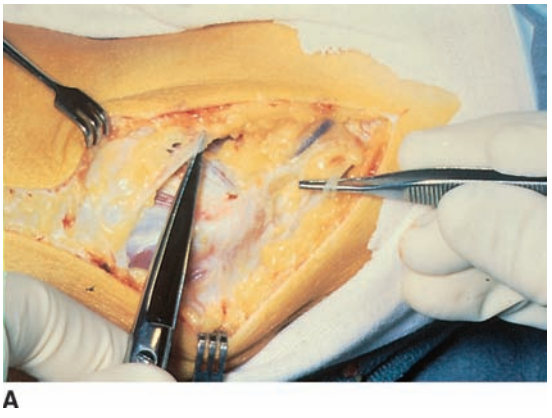

FIGURE 2.7
A, B: The medial antebrachial cutaneous nerve is identified and protected during superficial dissection. The flexor-pronator tendon fascia is identified deep to the nerve. (Reprinted from Morrey BF, *Master Techniques in Orthopaedic Surgery: The Elbow*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:235, with permission.)

The medial epicondyle is palpated and marked, along with the intermuscular septum and the sublime tubercle. The ulnar nerve should also be palpated to ensure its location within the cubital tunnel, posterior to the medial epicondyle. An 8- to 10-cm incision is made centered on the medial epicondyle (Fig. 2.6). The incision is extended proximally along the intermuscular septum in line with the humerus, and distally it is curved in line with the medial epicondyle and the sublime tubercle.

Superficial dissection through the subcutaneous tissue is carried out down to the overlying fascia of the flexor-pronator mass. Careful attention during superficial dissection is made to protect the medial antebrachial cutaneous nerve (Fig. 2.7). Superficial veins in this area are also identified and can be carefully mobilized or cauterized as necessary. Small vessel loops can be used around the neurovascular structures for retraction.

The fasica overlying the flexor-pronator mass is incised from the medial epicondyle to the sublime tubercle. There is commonly a dense raphe along the anterior margin of the flexor carpi ulnaris that is used as the landmark for the muscle-splitting approach (Fig. 2.8). The muscle is then split in line with its fibers from superficial to deep with a small periosteal elevator. The deepest portion of the muscle lies directly on the anterior bundle of the UCL (Fig. 2.9). The overlying muscle is cleared off of the ligament with a periosteal elevator anteriorly and posteriorly from the medial epicondyle to the sublime tubercle.

Once the UCL is exposed, the ligament is split sharply, in line with its fibers along its course from the epicondyle to the tubercle (Fig. 2.10A and B). The ulnar and humeral insertions are left intact so the stability of the elbow can be checked. With the elbow held in 20 to 30 degrees of flexion, a valgus stress is applied. Insufficiency of the UCL should easily allow medial joint space widening of several millimeters (Fig. 2.10 A and B). The ulnar and trochlear chondral surfaces can be inspected for defects or degenerative areas.

Convergent (3.2- or 3.6-mm) drill holes are placed in the medial aspect of the sublime tubercle with a 1-cm bone bridge (Fig. 2.11A). Care should be taken to direct the drill slightly distally, in order to account for the concavity of the articular surface of the ulna and avoid intra-articular penetration.

A single, 4.5-mm drill hole is made at the origin of previously split, native UCL on the medial epicondyle (Fig. 2.11B). This can be performed using a step-drill technique, beginning with a 3.6-mm drill bit, followed by a 4.5-mm bit. Careful attention is paid to not violate the far cortex of the epicondyle.

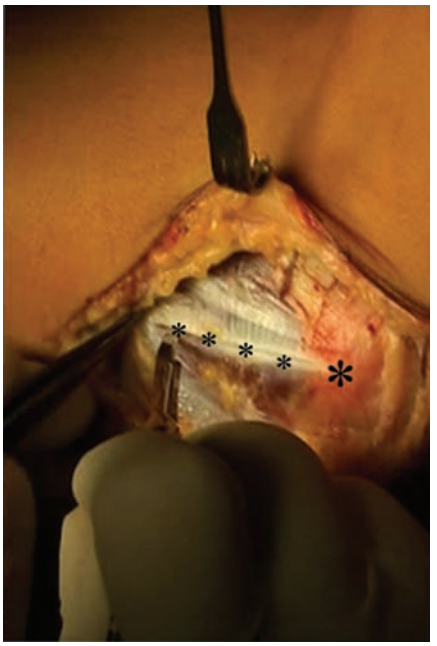

FIGURE 2.8

Longitudinal split in flexor-pronator fascia (*small asterisks*) from the medial epicondyle (*large asterisk*) to the sublime tubercle.

The superior aspect of the medial epicondyle is exposed with an incision in the proximal flexor-pronator fascia, and the muscle is carefully elevated off of the bone. Two 3.2-mm tunnels are then made from a proximal to distal direction beginning on the anterosuperior portion of the epicondyle connecting with the single 4.5-mm inferior tunnel (Fig. 2.11B). A 5- to 8-mm bone bridge is left between the two smaller tunnels.

Once all tunnels are drilled and prepared, the wound is irrigated and attention is turned toward harvesting the selected graft. We prefer the ipsilateral palmaris longus tendon if available. The contralateral palmaris longus or gracilis tendon can be used as alternatives, if an ipsilateral plamaris is not present. Other free tendon graft options include the plantaris or a 3-mm × 15-cm strip of Achilles tendon (13).

The palmaris longus tendon is identified visually and by palpation in the forearm. A 2-cm transverse incision at the level of distal flexor crease of the wrist is created. The median nerve along with its palmar cutaneous branch is protected as the palmaris longus tendon is identified inserting into the palmar fascia. A second transverse incision is made over the tendon approximately 10-cm more proximal in the forearm. A third, and when necessary a fourth incision, is made over the tendon for graft harvest. The more proximal incision should allow visualization of the musculotendinous junction and ensure continuity of the tendon from the muscle to its insertion in the distal incision (Fig. 2.12). The tendon is transected in the distal incision and pulled

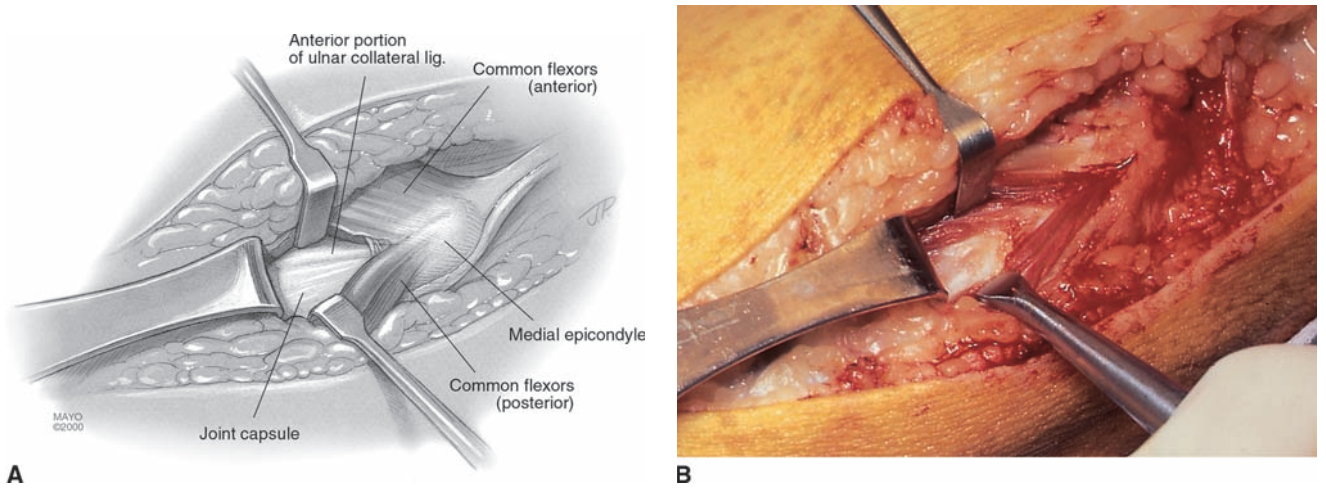

FIGURE 2.9

A, B: Exposure of the UCL through the longitudinal split in the flexor-pronator muscle. (Reprinted from Morrey BF: *Master Techniques in Orthopaedic Surgery: The Elbow*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:236, with permission.)

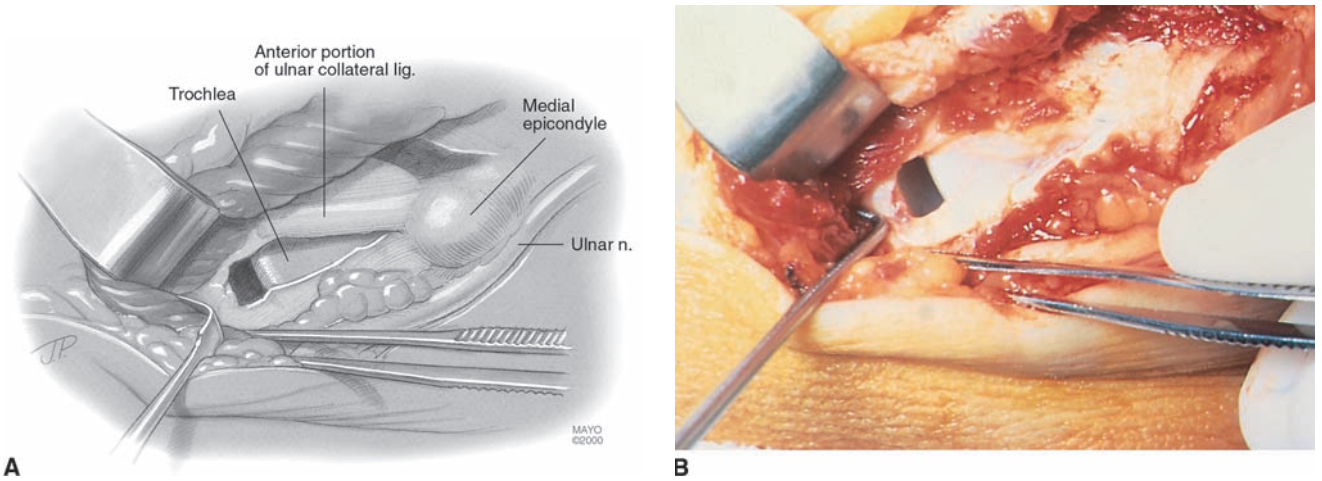

FIGURE 2.10

A, B: The UCL is incised longitudinally and medial joint space widening is seen with a application of a valgus stress. (Reprinted from Morrey BF. *Master Techniques in Orthopaedic Surgery: The Elbow.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:237, with permission.)

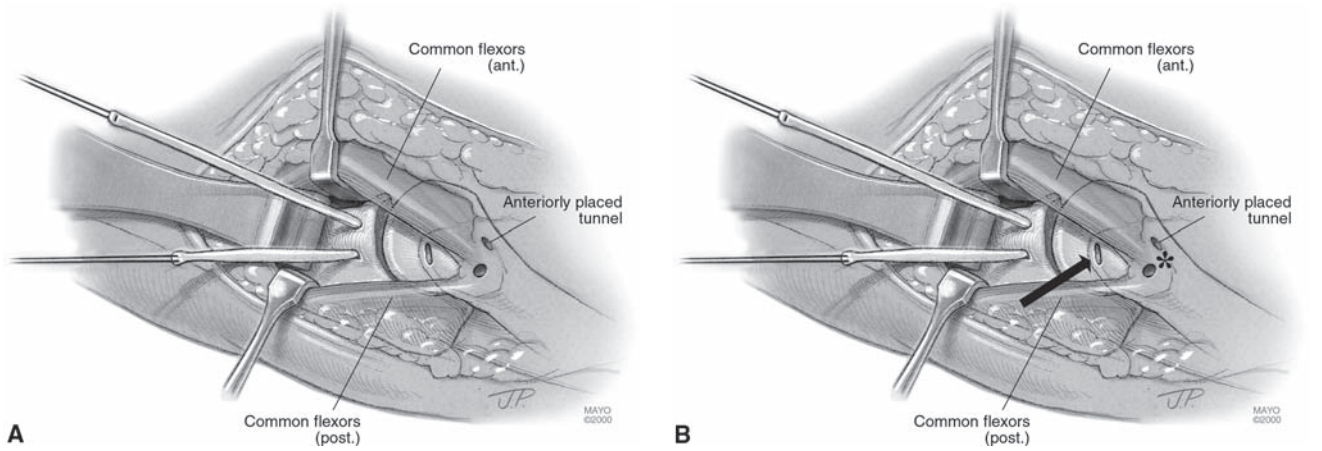

FIGURE 2.11

A: Convergent 3.2- or 3.6-mm drill holes in sublime tubercle (graft in place) with 1-cm bone bridge.
B: 4.5-mm tunnel opening at native UCL insertion (*arrow*) and two 3.2-mm tunnels (*asterisk*) in the medial epicondyle. (Reprinted/adapted from Morrey BF. *Master Techniques in Orthopaedic Surgery: The Elbow.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:2, with permission.)

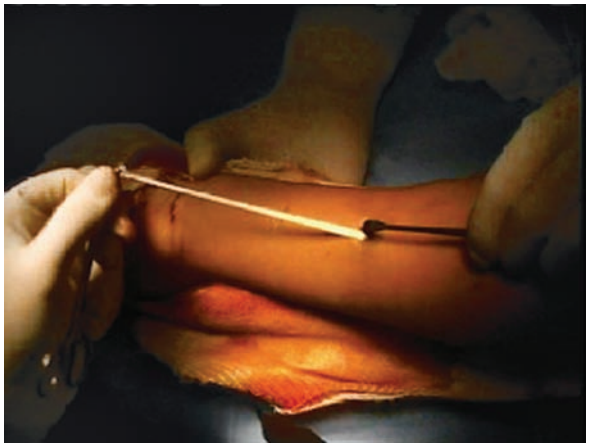

FIGURE 2.12

Palmaris tendon autograft harvest through three transverse incisions.

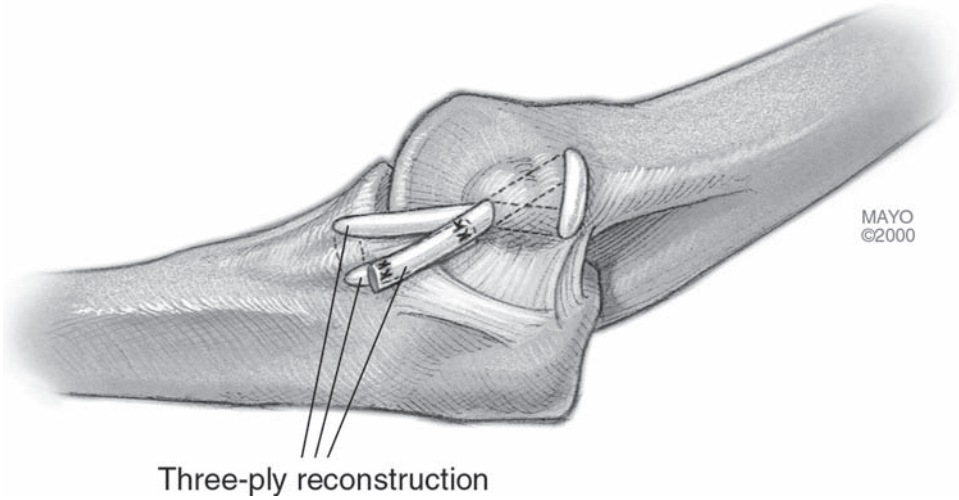

FIGURE 2.13

Sketch of graft after passage in figure-of-eight/three-ply configuration. (Reprinted from Morrey BF. *Master Techniques in Orthopaedic Surgery: The Elbow.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:237, with permission.)

sequentially through the subsequent proximal incisions to the musculotendinous junction and a 15- to 20-cm graft is harvested. The incisions are irrigated and closed in a standard fashion. A 1 nonabsorbable suture is placed into both ends of the free graft for passage.

The elbow is held in 45 degree of flexion and neutral varus/valgus position for graft passage and tensioning. Flexible suture passers or looped suture can be used to facilitate graft passage. The graft is passed in a figure-of-eight pattern and tensioned. The free ends of the graft are secured by suturing the graft to itself. The graft can also be sutured to the remaining native UCL and to the stout soft tissue of the intermuscular septum (Fig. 2.13).

The elbow is taken passively through range of motion to confirm isometry of the graft. A small valgus force can also be applied intraoperatively to ensure medial stability, which will prevent medial joint line widening. Any laxity in the graft can be reduced by placing absorbable, figure-of-eight sutures within the graft (Fig. 2.14).

If ample tissue of the native UCL remains, the split flaps can be closed over the tendon autograft. The wound is irrigated one final time and the flexor-pronator fascia is closed with interrupted sutures. The skin is closed in a standard fashion. The elbow is splinted in 90 degree of flexion and neutral forearm rotation prior to emergence from anesthesia. Immobilization is discontinued after 7 to 10 days and the sutures are removed.

Docking Technique

The docking technique was described as an alternative to early reconstruction techniques where the common flexor-pronator origin was removed from the epicondyle. The surgical approach uses the same muscle-splitting technique previously described; however, the authors perform a routine diagnostic arthroscopy to evaluate and treat lesions of valgus extension overload (12). The ulnar nerve is not routinely transposed.

After transmuscular exposure of the UCL, the ligament is incised longitudinally to expose the medial joint and check for insufficiency. The anterior and superior portions of the sublime tubercle are exposed subperiosteally. Convergent tunnels are created in the sublime tubercle using a 3-mm bur and a small curette with a 2-cm bone bridge.

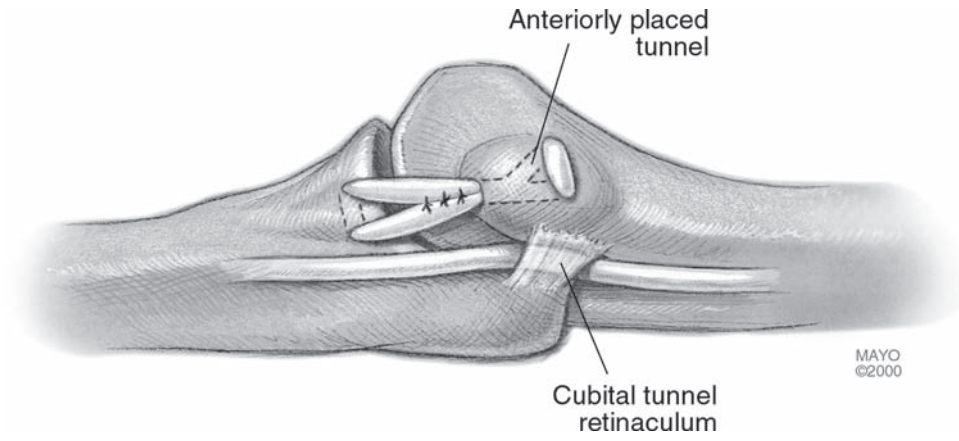

FIGURE 2.14

Figure-of-eight sutures are placed to reduce any remaining slack within the graft. (Reprinted/adapted with permission from Morrey BF. *Master Techniques in Orthopaedic Surgery: The Elbow.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:237, with permission.)

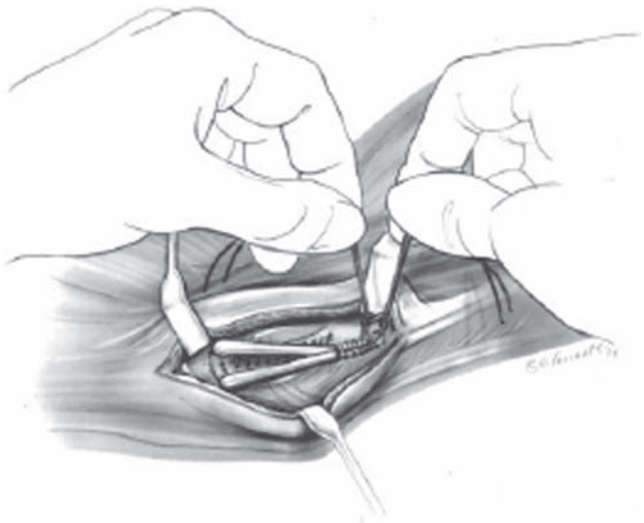

FIGURE 2.15

Docking technique with free sutures passed through the epicondyle tunnels. (Reprinted of Hospital for Special Surgery, New York, NY, with permission.)

A 4-mm bur is used to create a single tunnel in the anterior portion of the native UCL insertion of the medial epicondyle. Two 1.5-mm exit punctures, separated by 5-mm to 1-cm are made on the epicondyle anterior to the intermuscular septum.

The graft is harvested, prepared, and passed through the sublime tubercle tunnel. The posterior limb of the graft is docked into the humeral tunnel with the sutures exiting through one of the 1.5-mm exit holes (Fig. 2.15). The graft is tensioned and the anterior limb is measured and cut to length in order to dock the end of the tendon into the single humeral tunnel, passing its sutures through the second exit hole in the epicondyle. Isometry and tension is checked, and the two suture limbs are tied over the medial epicondyle bone bridge with the elbow in 20 degree of flexion. Standard closure is performed and the elbow is splinted in 45 degree of flexion.

DANE TJ

The DANE TJ procedure described by Conway (7) is a hybrid of the docking (12) and interference screw fixation techniques (1). Again, a muscle-splitting approach is utilized, and routine ulnar nerve transposition is not performed. Ulnar fixation with the DANE TJ technique does not rely on the cortical integrity of the sublime tubercle, which may be compromised due to avulsion injuries or in revision cases.

Fixation on the ulnar side is achieved with the use of a Bio-Tenodesis screw (Arthrex, Inc., Naples, Florida). After the graft is harvested, it is folded in half to produce a double-strand graft. A locking Krackow suture is placed in the folded end, 25-mm in length. This folded end is then sized and used to determine the appropriate diameter of the ulnar tunnel. The drilled tunnel diameter is usually the same as the measured, folded graft and screw diameter is typically the same or slightly smaller than the tunnel diameter. Screw diameters sized 4.75, 5.5, and 6-mm are most commonly used for the DANE TJ technique.

Once tunnel diameter is determined, a guide pin for the Bio-Tenodesis System (Arthrex, Inc., Naples, Florida) is placed in the sublime tubercle. Optimal pin placement will preserve a 2- to 3-mm bony wall between the articular surface of the ulna and the tunnel (Fig. 2.16). Once again, the pin and drill should be directed in a slightly distal direction to avoid disruption of the ulnar articular surface. The guide pin is then overreamed with the appropriate cannulated drill bit.

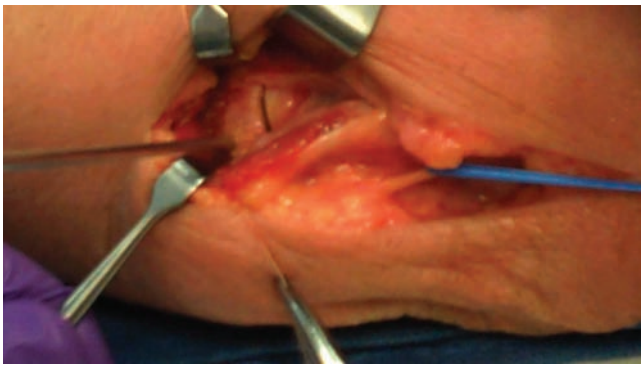

FIGURE 2.16

Ulnar tunnel guide pin is placed 2 to 3 mm from the articular surface in the center of the sublime tubercle.

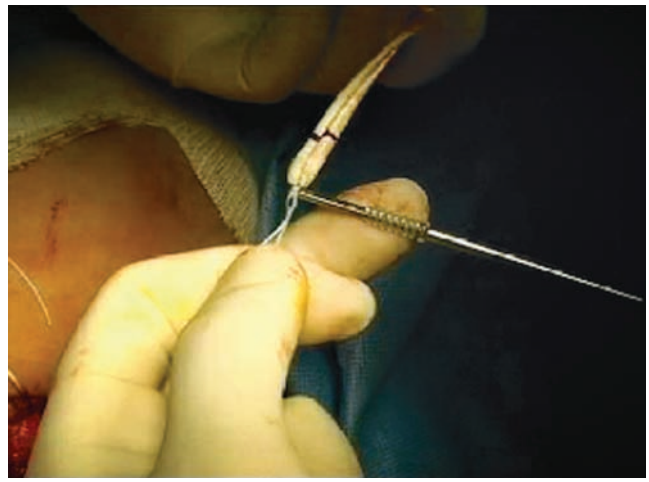

FIGURE 2.17
Palmaris graft and driver construct.

Tunnels in the epicondyle are then created. A single 4.5-mm tunnel is made at the native attachment of UCL. Two 2.7-mm tunnels are made on the anterosuperior epicondyle surface from proximal to distal with a 5- to 8-mm bone bridge between them. If necessary, the 4.5-mm tunnel can be carefully enlarged to a diameter that will allow docking of the free ends of the graft.

An appropriate diameter bioabsorbable screw is chosen and placed onto the Bio-Tenodesis screwdriver (Arthrex, Inc., Naples, Florida). Free ends of a looped 2 FiberWire suture (Arthrex, Inc., Naples, Florida) are passed through the cannulated driver. The graft sutures and graft are passed through the looped suture and the graft is captured at the tip of the driver (Fig. 2.17). Tension is kept on the sutures through the driver and the graft and screw are placed in the ulnar tunnel. The screw is advanced by turning the driver while preventing rotation of the thumb pads on the driver. When the screw is placed at the appropriate depth, the driver is removed. Each free end of suture through the graft is tied to one end of the looped suture that was through the cannulated driver and screw, effectively locking the graft to the interference screw.

The proximal graft ends are cut to the appropriate length to allow docking into the medial epicondyle. Nonabsorbable sutures are placed in both free ends. Isometry is checked and the graft sutures are passed through the humeral tunnels as described previously in the docking technique (Fig. 2.18). The native ligament is closed underneath the graft prior to proximal graft fixation. The graft sutures are tied over the epicondylar osseous bridge with the elbow held in 45 degrees of flexion, or where the graft is at its greatest length to avoid over tensioning.

Standard closure is performed and the elbow is splinted prior to emergence from anesthesia.

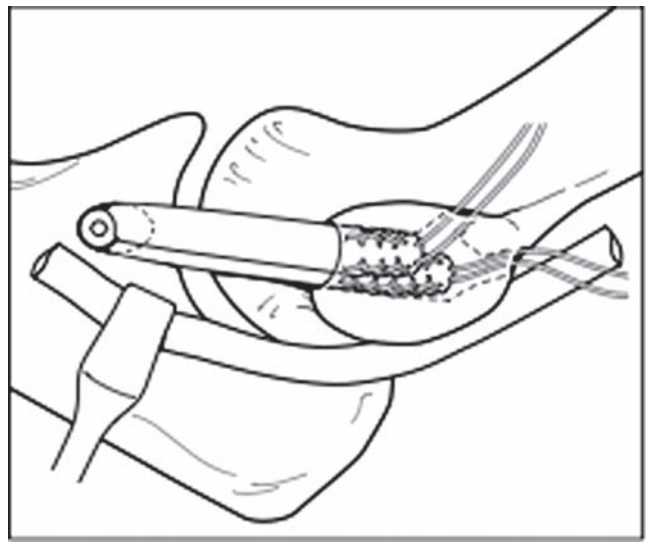

FIGURE 2.18
DANE TJ graft passed after ulnar fixation. (Reprinted from Conway JE. The DANE TJ procedure for elbow medial UCL insufficiency. *Tech Shoulder Elbow Surg.* 2006;7:36–43, with permission.)

REHABILITATION

Differences between individual patients should be taken into consideration during the rehabilitation program. Not all athletes progress in a linear fashion or at the same rate. In general, the goal is to return the athlete to their preinjury level of competition approximately 1 year after UCL reconstruction (17).

Immobilization is discontinued 7 to 10 days postoperatively. Full, active shoulder and wrist motion along with gripping exercises are allowed while immobilized and continued in the early postoperative period. Elbow flexion and extension is allowed after immobilization is discontinued. Full elbow range of motion should be achieved by 4 to 6 weeks, at which point light resistance exercises for elbow and wrist muscle strengthening is initiated. Positions of valgus stress with resistance training are avoided for 4 months.

The importance of a total-body conditioning program including core muscle strengthening, cardiovascular training, and periscapular and rotator cuff strengthening cannot be understated. This should begin early in the postoperative period (with adherence to limitations on valgus stress at the elbow) and continued throughout the player's return.

An easy throwing (tossing) program with no wind up is initiated 3 to 4 months postoperatively if the patient has no swelling and full, pain-free elbow range of motion. Easy tossing is begun in 15 to 20 minutes sessions at a distance of 20 to 30 ft. In general, throwing should be performed 3 to 4 d/wk alternating throwing days with rest days. After 4 to 6 months, throwing days can be alternated with exercise days. Ice is applied after throwing and exercise to decrease inflammation and swelling. Throwing distances may be gradually increased at 2 to 3 week intervals provided there is no swelling or discomfort during the previous level of the throwing program. After 6 months, easy wind up on flat ground is introduced into the program.

At 7 to 8 months postoperatively, supervised throwing off of a mound is allowed at 50% intensity. Proper throwing mechanics are critical when introducing this phase of the program and throughout the rehabilitation period. Throwing sessions are progressively increased to 25 to 30 minutes. During months 8 and 9, pitchers can increase to 70% speed while throwing off of a mound.

Over the final 2 to 3 months, focus on proper throwing mechanics and a total-body conditioning program continues. Pitchers gradually increase throwing intensity in bullpens to eventually simulate a game situation. Throwing in competition is allowed 1 year postoperatively if the player has full shoulder and elbow range of motion, normal upper extremity strength, trunk stability, and is pain-free when throwing. Rhythm, proprioception, and accuracy are the last skills to return and may take several more months. Professional pitchers may require more than 18 months in order to return to full, preinjury levels of competition, whereas position players or other overhead athletes may have a shorter recovery (13).

COMPLICATIONS

The most common complications after UCL reconstruction are associated with dysfunction of the cutaneous nerves of the medial elbow/forearm and the ulnar nerve. When reconstruction is combined with a submuscular transposition of the ulnar nerve, this complication has been documented to be >20% (13). Careful protection of the cutaneous branches of the medial antebrachial cutaneous nerves during surgical dissection, the use of a muscle-splitting approach, and not routinely transposing the ulnar nerve have decreased this complication rate significantly. Postoperative transient ulnar nerve symptoms in <5% of cases have been consistently reported with the use of these techniques (10,15,19). Rarely is a second procedure for ulnar nerve transposition required. Azar et al. (3) have also reported on significantly lower postoperative ulnar nerve complication with routine subcutaneous, rather than submuscular transposition. We consider dissection and anterior transposition of the ulnar nerve only when symptoms of persistent ulnar neuropathy are present or when pathology in the posterior compartment requires exposure through the cubital tunnel.

Reinjury with stretching of the graft or rupture is possible but uncommon. If the elbow becomes dysfunctional, revision reconstruction with a new free tendon autograft is indicated.

OUTCOMES

In the first series of long-term results, Conway et al. (8) reported good to excellent results in 80% of patients. Of the 56 patients who underwent reconstruction, 38 were able to return to their preinjury level of play including professional pitching. Thompson et al. (19) documented 82% of athletes were able to compete at the same level or higher for 12 months after UCL reconstruction using the muscle-splitting approach. This percentage was increased to 93% if the reconstruction was the patient's first surgical procedure on the elbow. Using the docking technique, published results have shown excellent outcomes in 90% of throwing athletes (12). In a combined clinical outcomes study including patients at our institution, 86% excellent results were found using the DANE TJ procedure (10).

In a recent review of the UCL reconstruction literature, Vitale and Ahmad reported an overall excellent result in 83% (20). Transition to the muscle-splitting technique showed better outcomes than flexor-pronator detachment. Superior results were also found without routine transposition of the ulnar nerve, and there were fewer

complications in this group. The docking method of humeral fixation in the literature had a higher percentage of excellent clinical outcomes.

As one might expect, clinical results of revision UCL reconstructions are inferior to those of primary surgeries. Revision surgery has been associated with difficult exposures, altered anatomy, and higher complication rates. In a retrospective review of 15 high-level baseball players, Dines et al. (11) found only 5 (30%) were able to return to same-level competition. They also reported a much higher (40%) complication rate including retear of the revision graft, arthrofibrosis, reactive synovitis, and transient ulnar neuritis.

Since the first procedure in 1974 by Dr. Jobe, UCL reconstruction has provided consistent and predictable results with respect to returning to play for the elite overhead athlete with UCL insufficiency that would otherwise have had their career shortened.

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3 Posterolateral Rotatory Instability

Russell M. Nord and Marc R. Safran

BACKGROUND/ANATOMY/ETIOLOGY

Posterolateral rotatory instability (PLRI) of the elbow was first described by Osborne and Cottrell (18) and the pathoetiology elucidated and diagnosis was popularized by O'Driscoll et al. (14). PLRI is defined by subluxation of the proximal radius from the distal humerus resulting in a posteriorly subluxated radial head. This is different from a radial head dislocation because in PLRI, the proximal radioulnar joint remains intact. It is also differentiated from acute elbow dislocation because in an elbow dislocation, the lateral structures (and occasionally medial structures) are disrupted, while PLRI is reserved as a description of chronic lateral-sided rotatory instability.

The lateral side of the elbow is supported by four structures: the lateral ulnar collateral ligament (LUCL), radial collateral ligament (RCL), annular ligament, and accessory RCL (Fig. 3.1). The LUCL originates on the lateral epicondyle and inserts on the ulnar supinator tubercle and crest. The RCL originates on the lateral epicondyle and inserts on the annular ligament. The annular ligament both originates and inserts on the proximal ulna, enveloping the proximal radius (9). The accessory RCL runs from the inferior portion of the annular ligament to the supinator crest of the ulna (12). Other authors have failed to find discrete ligamentous structures on cadaveric specimens and have instead suggested that one confluent capsule or "conjoint ligament" with various thickenings provides stability to the lateral side of the elbow (3). The overlying muscles and underlying bony architecture also contribute to both dynamic and static stability Table 3.1.

O'Driscoll and colleagues initially implicated the LUCL as the essential anatomic lesion that led to PLRI (14). However, more recently, this has been challenged as the importance of the RCL (4,8) and overlying musculature of the common extensors (3,8) have also been shown to play an important role in lateral-sided elbow stability. Further, Seki and colleagues hypothesized and demonstrated that the lateral ligament complex functions as a Y-shaped structure. Disruption of the anterior band of the Y led to significant laxity to varus torque, while further sectioning of the posterior band resulted in gross instability (Seki). This suggests that isolated distal RCL or LUCL injury (the upper and lower arms of the "Y") may not result in PLRI. However, a proximal injury off of the lateral epicondyle (the base of the "Y") will disrupt the function of the other two arms and can result in PLRI.

The etiology of PLRI is typically posttraumatic. PLRI is most commonly a late sequela of elbow dislocation or subluxation, when the lateral-sided structures are stretched or torn and fail to heal with nonoperative treatment (13). It may also result from a posttraumatic condition where the coronoid is insufficient (16). PLRI may also result from gradual stretching of the lateral structures as a consequence of a malunited pediatric supracondylar humerus fracture that produces cubitus varus (15).

The etiology of PLRI may also be the result of iatrogenic injury. PLRI has been described after radial head resection where an unrecognized LUCL injury was likely (5). Additionally, it has been described after multiple steroid injections for lateral epicondylitis in a series of three middle-aged females (6). Lastly, PLRI has also been described as a consequence of overly aggressive surgery for lateral epicondylitis (11).

DIAGNOSTIC MODALITIES

The diagnosis of PLRI can be elusive. Patients will often present with vague symptoms, though they may note catching, snapping, recurrent instability or apprehension (2,13). Occasionally, the patient may note locking or catching when turning the car steering wheel, with their forearm going into supination.

Once the patient's complaints have raised suspicion for PLRI, confirming the diagnosis is paramount. While the gold standard diagnostic examination is the pivot shift maneuver (Fig 3.2), its usefulness in the office,

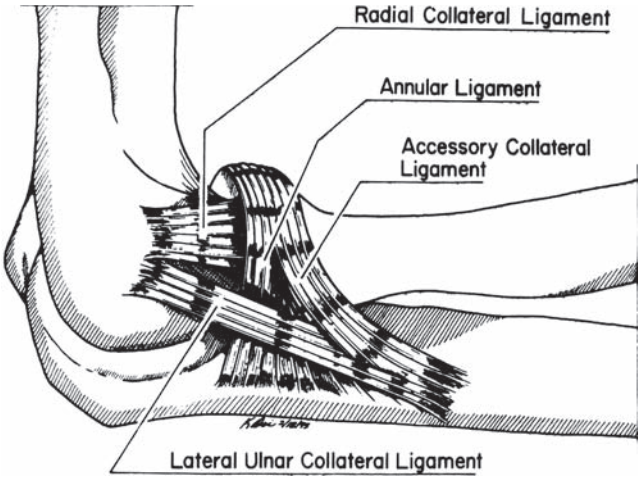


FIGURE 3.1
Ligamentous anatomy of the lateral aspect of the elbow. Note the lateral ulnar collateral ligament, RCL, accessory RCL, and annular ligament.

without anesthesia, is limited, as patients will often guard against subluxation and the examiner may only appreciate apprehension or patient discomfort. The pivot shift test is most reliable when done under anesthesia and the subluxation can actually be appreciated. The pivot shift test is most easily performed with the patient supine, starting with the affected limb overhead and the forearm in full supination and shoulder in full forward elevation. The elbow begins in extension and an axial load with valgus is applied, resulting in posterior subluxation of the radial head, which is often recognized by a prominence of the radial head and a dimple just proximal to it (Fig. 3.2). The elbow is slowly flexed as the axial load and valgus force are applied. As the elbow is flexed, there is a clunk of radial head reduction. This usually occurs at approximately 40 degrees, as the triceps becomes taut and causes the reduction, which is felt by the examiner as a clunk. With greater degrees of laxity of the posterolateral structures of the elbow, greater degrees of elbow flexion are necessary to produce the reduction.

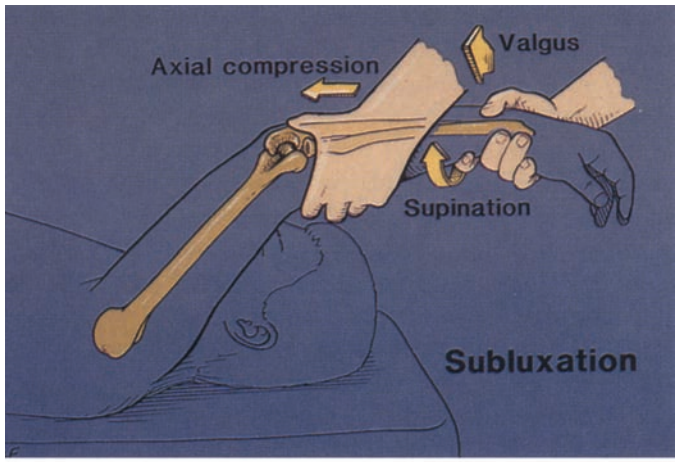
A recent study supports the difficulty of the pivot shift test in the conscious patient. Of eight patients with PLRI, only three had a positive pivot shift test while awake. However, all eight had a positive exam under anesthesia (20).

Other tests performed in the awake patient may suggest a preliminary diagnosis of PLRI, including palpation for posterior radial head subluxation, the chair test, the push-up test, and the table top test. We have found that simply supinating the forearm gently with the elbow at 90 degrees of flexion may lead to a palpable posterior subluxation of the radial head. Regan has shown the efficacy of the chair and push-up tests in aiding the diagnosis of PLRI. These tests are alike in that they position and load the elbow in a fashion similar to the pivot shift test. For the chair test (chair sign), the patient is seated in a chair with arms and the patient puts his or her hands on those arms with the elbows at 90 degrees, forearms supinated and arms abducted slightly beyond shoulder width (Fig. 3.3). The patient then rises from the chair using only the upper extremities for power. Apprehension, reluctance to extend the elbows fully, or subluxation is considered positive. When the forearms are pronated and the test repeated, the patient's symptoms should disappear. In Regan's study, this test was positive in seven out of eight patients with PLRI (20).

TABLE 3.1 Results after Ligament Reconstruction of the Lateral Ulna Collateral Ligament

Author (Date)	Follow-up (Mean)	Outcome
Sanchez-Sotelo et al. (2005)	72 mo	30 of 32 (94%) stable
		27 of 32 (84%) satisfied
Olsen and Sojbjerg (2003)	44 mo	14 of 18 (78%) stable
		17 of 18 (94%) satisfied
Lee et al. (2003)	24 mo	6 of 6 (100%) stable
		6 of 6 (100%) satisfied

Earlier papers from O'Driscoll excluded because patients likely included in series by Sanchez-Sotelo et al.



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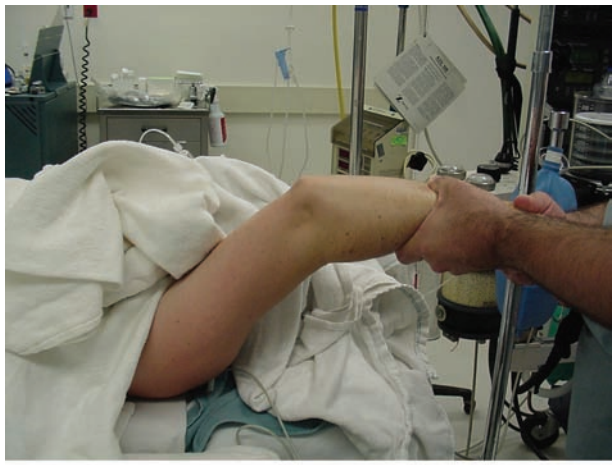

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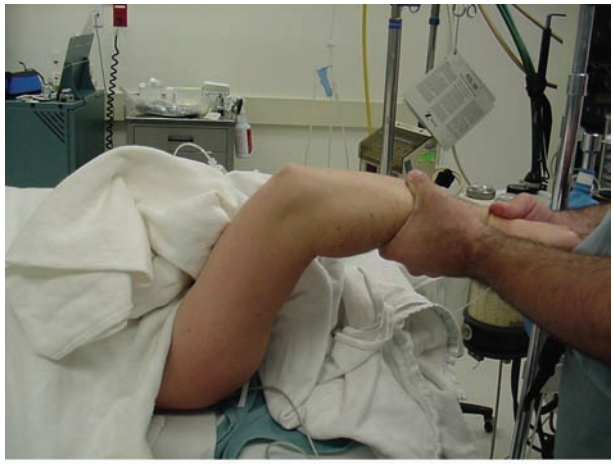
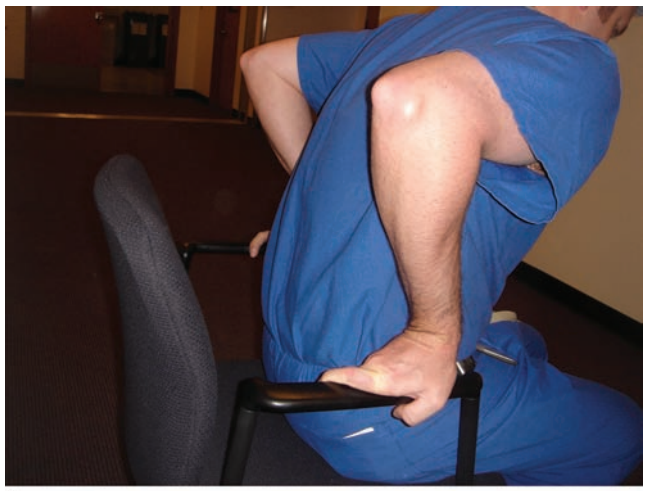


C

FIGURE 3.2

Pivot shift maneuver of the elbow to assess for posterolateral rotatory laxity and instability. **A:** The patient is supine with the arm in full forward elevation. The extended elbow is supinated and a valgus stress applied. The radial head is subluxated posteriorly in this position when there is laxity or injury to the posterolateral ligamentous structures **(B)**. As an axial load is applied, the elbow is flexed, and there is usually a clunk associated with reduction of the radial head **(C)**. This usually occurs at 40 degrees of elbow flexion but may occur in greater degrees of flexion with more ligamentous laxity or injury. In the awake patient, the patient may be apprehensive and may not allow completion of this maneuver. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Fig. 15.3B.)



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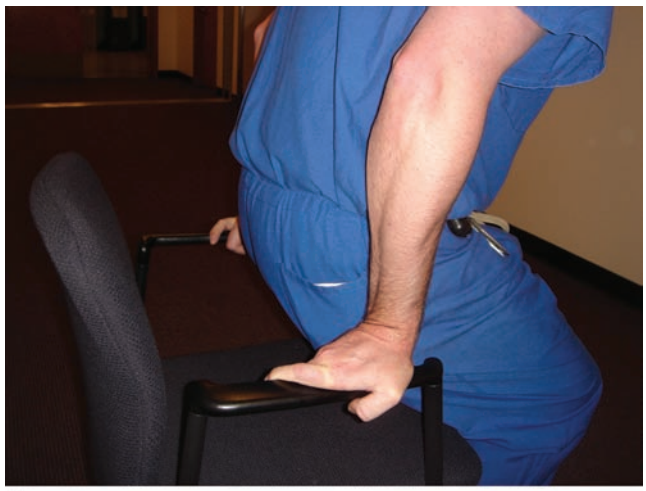


B

FIGURE 3.3

Chair test—Another sign of PLRI is pain, apprehension, or inability to use one's hands to raise from a chair. With the arms in supination, shoulder width apart, and the elbows flexed, the patient attempts to get out of the chair (i.e., from position **A** to position **B**) using his/her arms. Inability to do this or clunking as he/she arises, may be consistent with PLRI.

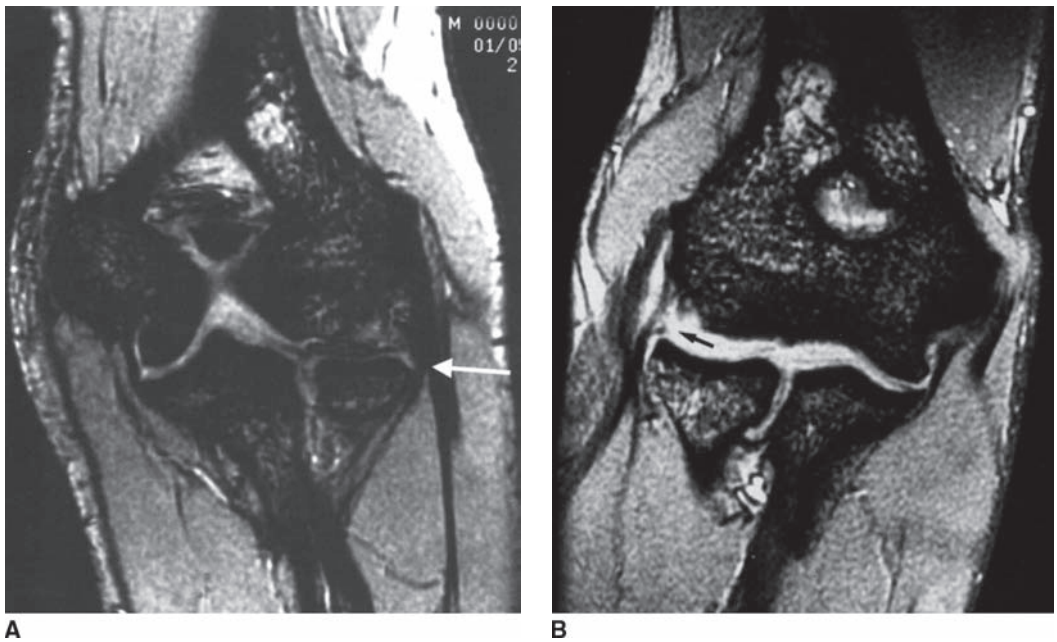
FIGURE 3.4

Push-up test—Another sign of PLRI is pain, apprehension, or inability to use one's hands to perform a push-up with one's arms supinated, shoulder width apart, and the elbows flexed. As the patient attempts to push up, he may have apprehension, pain, or clunking which may be consistent with PLRI.

The push-up test (active floor push-up sign) achieves a similar position. The patient is prone on the floor in the push-up position with the elbows at 90 degrees, forearms supinated and the arms abducted slightly greater than shoulder width (Fig. 3.4). A push-up is then performed. Apprehension with terminal extension, guarding, or dislocation are considered positive. This test was also positive in seven out of eight PLRI patients in Regan's study (20). Another test that may be performed is the tabletop/relocation test. This test involves the patient leaning over a table edge and doing a one-arm press-up on the edge of the table with the forearm in full supination. A positive test is noted with patient apprehension or frank subluxation of the radial head. The test is then repeated with the examiner's thumb stabilizing the radial head, preventing subluxation or apprehension (1). However, we do not routinely use this test, as we have not found it to be more sensitive or specific when compared with the above clinical tests.

We routinely obtain radiographs of the elbow on any patient with a possibility of PLRI to rule out lateral epicondylar avulsion or pathology at the radial head or capitellum. However, we have not found stress x-rays, performed with a varus and posterolateral force, to be helpful in the awake patient due to guarding.

On the contrary, we do advocate preoperative Magnetic Resonance Imaging (MRI) on all patients with a preliminary diagnosis of PLRI (Fig. 3.5). While some authors (23) believe MRI only sensitive to identify the LUCL in half of all normal patients, our experience has been similar to others that have found the MRI to be reliable in evaluating the LUCL (19). Stress radiographs under anesthesia may be useful to document and confirm PLRI of the elbow.



A **B**

FIGURE 3.5

(A) is an MRI of a patient with an intact lateral collateral ligament complex, while **(B)** is an MRI of a patient with PLRI. Note the injury to the lateral collateral ligament complex.

INDICATIONS AND TREATMENT

Other than tolerating the symptoms and activity modification, there is no accepted, effective nonoperative treatment of PLRI. PLRI is different from acute elbow dislocation, which can often be effectively managed nonoperatively. However, repair of the lateral ligament complex is often possible in the acute setting. We have encountered the need to repair the lateral ligament complex acutely when we operate on an acutely dislocated elbow for another reason such as radial head or capitellar fracture, persistent instability despite reduction, and lateral epicondylar avulsion. In this setting, we perform a suture anchor repair with one to two anchors in the lateral epicondyle with either a Krakow or Bunnell type stitch in the avulsed ligamentous sleeve (Fig. 3.6).

In the chronic setting, we typically advocate treating PLRI with reconstruction rather than repair. This recommendation is in concordance with a study retrospectively comparing the outcomes of 12 PLRI patients treated with direct repair with 32 PLRI patients treated with autograft tendon reconstruction (22). In this series, while only 7/12 patients treated with repair were satisfied with their outcome, 27/32 patients in the reconstruction group were satisfied. Certainly caution must be taken when interpreting this study and its results, as this was neither a randomized nor a prospective study.

While the pathophysiology of PLRI may not relate solely to LUCL incompetence, the current reconstructive strategies all focus on LUCL reconstruction. A variety of different autograft and allograft options have been used for LUCL reconstruction, but we recommend using the ipsilateral palmaris as an autograft, when available. This may be harvested through a 1- cm incision at the distal volar wrist crease using a standard tendon stripper. If this is not available, the contralateral palmaris is the next choice. Our third option is a hamstring autograft—either gracilis or semitendinosis. A soft tissue allograft, such as a semitendinosis, gracilis, or tibialis tendon, is favored by some surgeons. These grafts are of adequate size, match the native ligament size well, and fit nicely through bone tunnels of modest, rather than excessive, diameter. The graft must be approximately 20 cm in length.

Our operative technique is similar to that originally described (13,21). Prior to prepping, an exam under anesthesia is performed on both elbows, including a pivot shift test and medial and lateral stability test (21). The patient is positioned supine with the upper extremity on a hand table. The forearm is pronated to minimize risk to the posterior interosseous nerve during the approach. The medial and lateral sides of the elbow are identified to avoid confusion. The lateral side of the elbow is approached via an 8 to 10 cm incision beginning 3 cm proximal to the lateral epicondyle and terminating over the anterior border of the anconeus (Fig. 3.7). Dissection is carried through Kocher interval (extensor carpi ulnaris and anconeus). Proximally, the anconeus and distal triceps may be reflected off the lateral supracondylar ridge and lateral epicondyle to improve exposure. Distally, the extensor carpi ulnaris is elevated off of the annular ligament and reflected anteriorly. The distal anconeus may also be reflected posteriorly to reveal the distal attachment of the lateral ligaments at the supinator crest of the ulna. The origin of the common extensors are elevated off the anterior aspect of the lateral epicondyle, revealing the lateral ligamentous complex. The lateral ligamentous complex and anterior capsule must be protected while elevating the common extensors. This is best accomplished by beginning the dissection distally, where the muscular-capsular interval is more easily defined, and using a Freer or periosteal elevator rather than a knife blade to dissect to prevent inadvertent migration out of this interval.

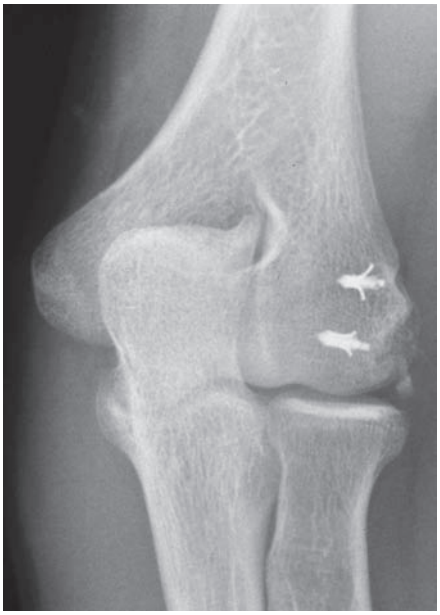


FIGURE 3.6

Radiograph of a 16-year-old male who spontaneously reduced an elbow dislocation following a snowboarding accident. His elbow was unstable to examination awake and under anesthesia. He underwent primary repair of his proximal avulsion of the lateral collateral ligamentous complex using suture anchors.

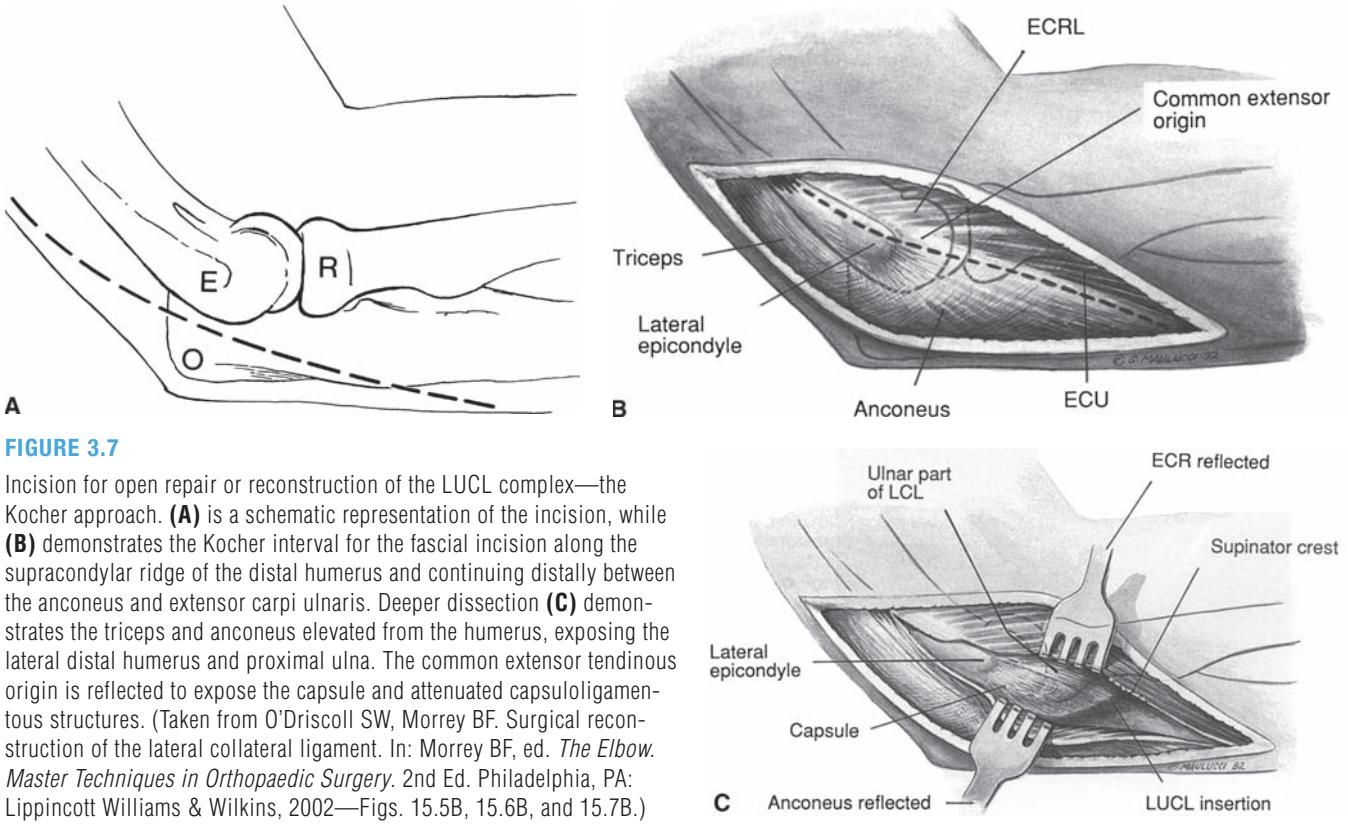


FIGURE 3.7

Incision for open repair or reconstruction of the LUCL complex—the Kocher approach. **(A)** is a schematic representation of the incision, while **(B)** demonstrates the Kocher interval for the fascial incision along the supracondylar ridge of the distal humerus and continuing distally between the anconeus and extensor carpi ulnaris. Deeper dissection **(C)** demonstrates the triceps and anconeus elevated from the humerus, exposing the lateral distal humerus and proximal ulna. The common extensor tendinous origin is reflected to expose the capsule and attenuated capsuloligamentous structures. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Figs. 15.5B, 15.6B, and 15.7B.)

At this point, a stretching or disruption of the lateral ligamentous complex is usually appreciated. If it is unclear, a pivot shift test should clearly illustrate a subluxating radial head. An attempt should be made to preserve all lateral tissue that is present. If very robust, a repair or imbrication can be attempted although we are very selective with this choice given the aforementioned literature that argues against it (22). Otherwise, the tissue can be used to augment the reconstruction and provide additional collagen for healing.

As the ligament complex typically fails proximally, if primary repair is selected, the lateral ligament complex should be reattached to the inferior and posterior portion of the lateral epicondyle. Either suture anchor(s) or transosseous sutures may be employed. We prefer a double-loaded anchor rather than transosseous sutures as it eliminates the risks associated with a bone bridge. The limbs of the sutures are utilized to repair the remaining ligament with a Krakow stitch. If there is any laxity to the capsule, a capsular plication is performed anteriorly and/or posteriorly using imbricating horizontal mattress sutures. Postoperatively, the elbow is splinted in 60 to 90 degrees of flexion with the forearm in pronation.

If reconstruction is elected, the capsule should be incised anterior to the lateral ligamentous complex so the joint can be inspected for loose bodies or articular damage. This incision is later closed in an imbricated fashion.

Next, two 3.5-mm drill holes are placed in the ulna. One of these drill holes is into the supinator tubercle just distal to the lateral capsular attachment and the second is placed 1 to 1.5 cm posterior to the first. These two holes should be oriented so that the line between them is perpendicular to the long axis of the soon-to-be reconstructed LUCL (Fig 3.8). The two holes in the ulna are connected by channeling with a curved awl or curette, taking care to maintain as robust a bony bridge as possible.

The next step is to determine the isometric point on the humeral side. To this end, a suture is passed through the tunnel formed by the two ulnar holes and clamped. This clamp is placed on candidate locations on the humerus and the elbow is taken through a range of motion. If the suture remains taught throughout the range of motion, the isometric point has been identified (Fig. 3.9). A recent study found the isometric point of the LUCL to be approximately 2 mm proximal to the center of the capitellum when viewed on lateral x-ray (10).

A 4.5-mm drill hole is placed just proximal and anterior to the isometric point so that its distal aspect, over which the reconstructed LUCL will be draped, is at the isometric point. If this hole is too posterior, the graft will remain lax in extension, where PLRI typically occurs. This drill hole should be angled medially and proximally. A motorized bur is then used to dilate this hole to 5 to 6 mm in size. A second humeral hole is created just posterior to the supracondylar ridge, 1.5 cm proximal to the first hole using a 3.5-mm drill. Curved curettes or awls are used to make a tunnel by connecting the two holes, once again taking care to maintain the bone bridge. A third, and final, humeral hole is drilled in a similar fashion. This final hole is located 1 to 1.5 cm distal to the second hole. It is connected to the first hole (the hole at the humeral isometric point) by a tunnel using curved

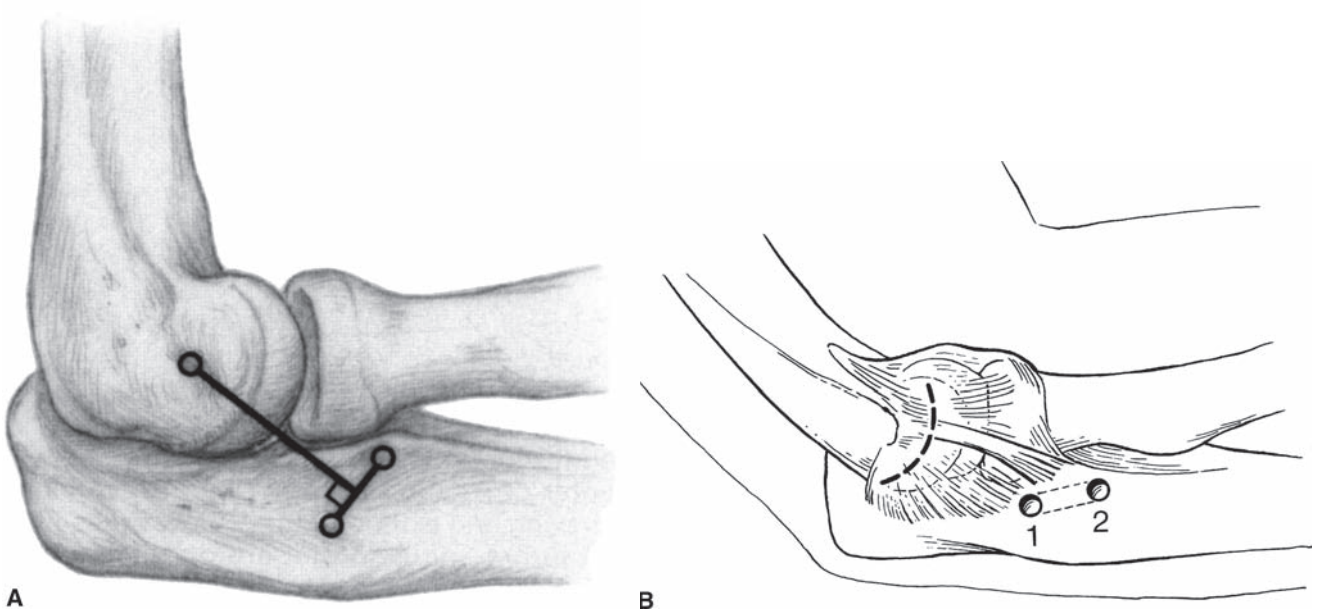


FIGURE 3.8

Ulnar tunnel for LUCL reconstruction made by connecting two drill holes made at the crista supinatoris, perpendicular to the line of the proposed LUCL ligament **(A)**. Capsular incision is also demonstrated for identification of humeral tunnel **(B)**. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Figs. 15.8C and 15.8B.)

curettes or curved awls (Fig. 3.10). Posterior holes are used for the nonisometric humeral holes because the posterior humeral bone is stronger than the anterior bone.

A passing suture is sewn into one end of the graft, leaving a curved needle on the end of the suture. This facilitates graft passage. The graft is then passed through the ulnar tunnel from anterior to posterior. Next, the graft is passed into the isometric hole in the humerus and out the proximal hole in the humerus. The graft is then run along the posterior humeral cortex, into the distal/posterior hole and finally emerging out the isometric hole (Fig. 3.11). A curved 22-gague wire can also be used to assist in graft passage.

The graft is then tensioned with the elbow in 30 to 40 degrees of flexion and the forearm fully pronated, with a gentle valgus load. The end of the graft is then sutured to itself with the tension maintained (Fig 3.12). Care is taken to remove any slack from all segments of the graft's figure-of-eight path. Further tensioning is achieved

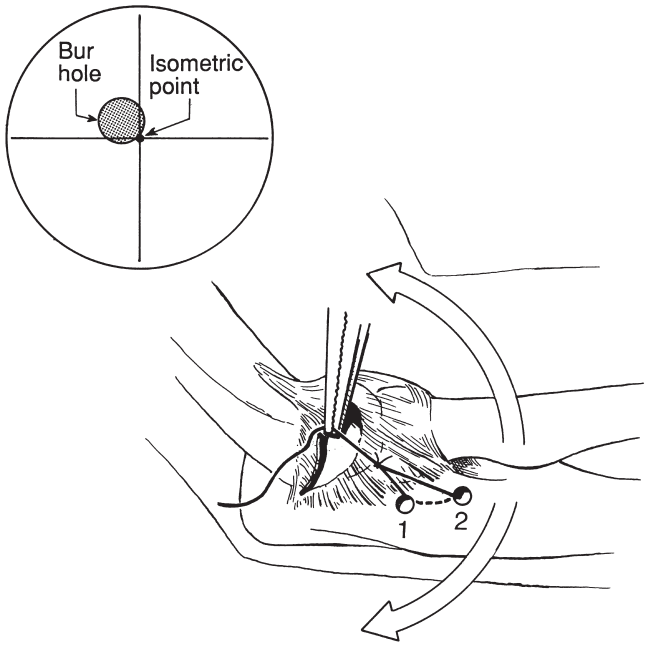


FIGURE 3.9

Identification of the isometric point on the distal humerus for LUCL reconstruction and relative tunnel position to this isometric point slightly proximal and posterior. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 1st Ed. New York, NY: Raven Press, 1994—Fig. 8B.)

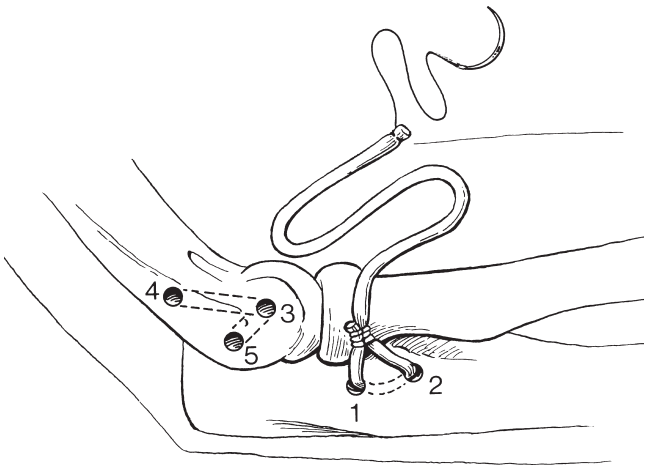


FIGURE 3.10

Humeral tunnels made in a "Y" fashion to allow for passage of the graft in a "figure-of-eight" pattern. The graft, first passed through the ulnar tunnel, is brought in hole 3 and out hole 4. Usually the suture in the tendon is passed using a needle or a looped suture or wire. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Fig. 15.10B.)

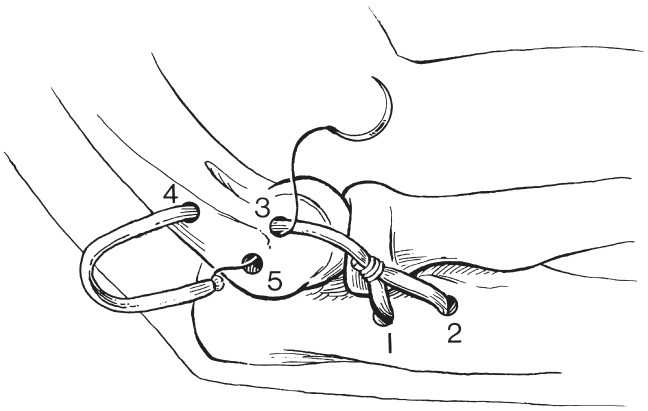


FIGURE 3.11

Graft being passed through the humeral tunnels. The graft being brought in hole 3 and out hole 4 is brought back in hole 5 with a suture, needle or wire, to exit out the isometric point (hole 3). (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Fig. 15.11B.)

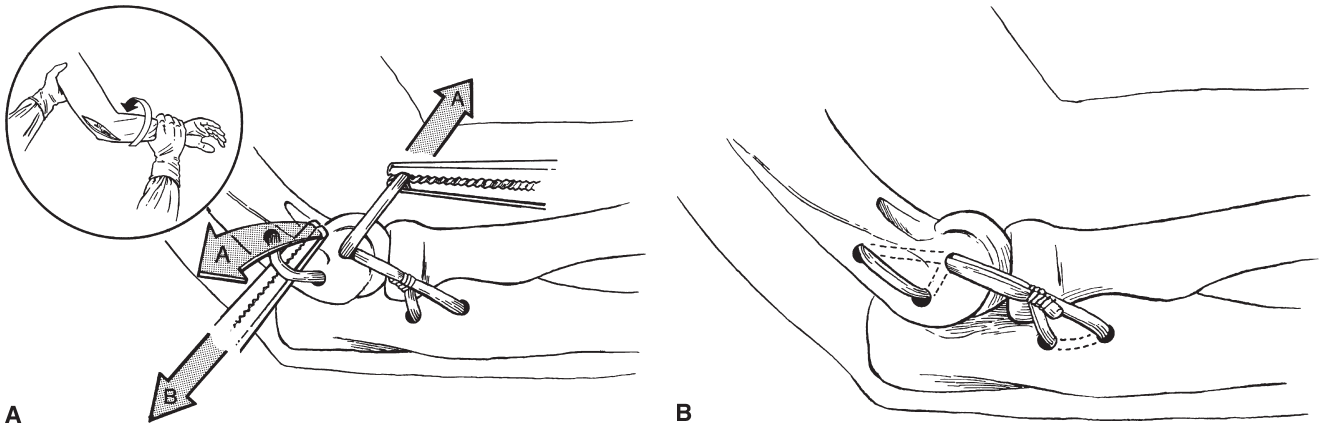


FIGURE 3.12

Graft being tensioned and then sutured to itself. The free limb of the graft is pulled with the elbow flexed 30 to 40 degrees with the forearm in full pronation to tension the graft **(A)**. The graft is then sutured to itself **(B)**. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Figs. 15.12B and 15.13B.)

by pulling the graft anteriorly and suturing it to the capsule (Fig. 13A). Even greater tension within the graft may be generated by suturing limbs of the figure-of-eight to one another, thus reducing the size of the distal loop of the figure-of-eight (Fig. 13B). The capsule is then closed and the soft tissue closed in layers.

Rather than the classic figure-of-eight graft, other constructs may be used for the reconstruction. While we have not had a failure of the ulnar tunnel, if this was to occur, an Endobutton (Smith & Nephew, Andover, Massachusetts) could be used as salvage fixation, by relying on the opposite (radial) cortex of the ulna while

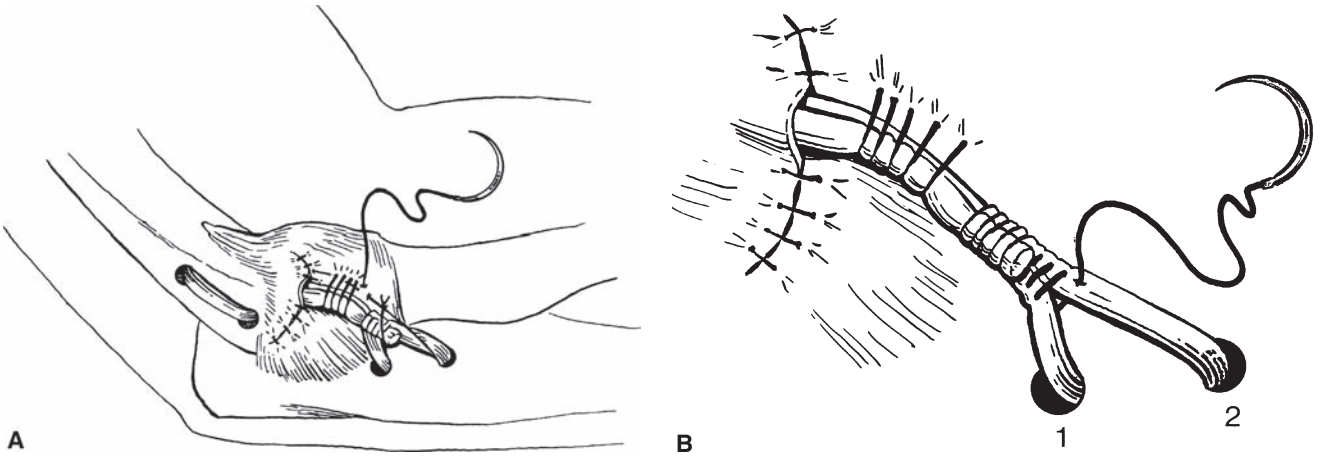


FIGURE 3.13

Graft being sutured to the capsule and native LUCL complex **(A)** and tensioning further by suturing the limbs of the graft to each other. This closes the figure-of-eight and tightens the overall construct **(B)**. (Taken from O'Driscoll SW, Morrey BF. Surgical reconstruction of the lateral collateral ligament. In: Morrey BF, ed. *The Elbow. Master Techniques in Orthopaedic Surgery.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002—Figs. 15-15b and 15-16b.)

bringing the soft tissue into the bone for biologic fixation. Alternatively, an interference screw may also be employed. Also, while we have not encountered this problem on the humeral side either, similar salvage fixation may be used there. However, when drilling for the Endobutton in the humerus, one should aim anteriorly so as to avoid the ulnar nerve on the medial side of the humerus.

Lastly, rather than using a figure-of-eight construct, interference screws in blind tunnels can be used on either, or both, the humeral and ulnar sides. However, this results in a double-stranded, rather than triple-stranded, LUCL reconstruction. This can be compensated for by starting with a slightly larger-sized graft. The capsule is closed and plicated in a similar fashion as in the figure-of-eight construct.

REHABILITATION

Regardless of the method of repair or reconstruction, the elbow must be protected postoperatively. The elbow should be splinted at 90 degrees of flexion with the forearm in full pronation. This splint is removed 1 week postoperatively and exchanged for a hinged brace with a 30-degree extension block. Full range of motion is begun at 6 weeks postoperatively. The brace is used until the patient is three months out from surgery, at which point a gradual strengthening program is begun. Full recovery and return to sport is anticipated at the 6- to 9-month mark depending on the patient, the recovery, and the sport to which they return. One risk of this regimen is the possibility of a mild (<10 degree) flexion contracture. However, this contracture would actually serve a protective role as it would keep the patient out of a position of PLRI.

RESULTS

The results of LUCL reconstruction for PLRI are generally good in terms of both objective stability and subjective patient outcome (7,17,22).

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4 Arthroscopic Management of Elbow Osteochondritis Dissecans Lesions

Guillem Gonzalez-Lomas and Neal S. ElAttrache

INTRODUCTION

The incidence of sport-specific injuries in young athletes has increased with earlier and more rigorous young athlete participation in sports. The radiocapitellar compartment of the young athlete's elbow withstands significant stresses during repetitive activities (such as throwing) or during sports that convert the elbow joint into a weight-bearing joint (such as gymnastics) (1). Specifically, lateral compartment compression can lead to Panner diseases (osteochondrosis) in the very young, preadolescent (6–10-year-old) patient or capitellar osteochondritis dissecans (OCD) in the adolescent or young adult (2–5). OCD may in turn generate loose bodies. This chapter describes Panner disease and OCD, and describes a treatment algorithm, including detailing their arthroscopic management.

PANNER DISEASE

In 1927, Hans Jessen Panner described "osteochondrosis" of the capitellum, remarking on its similarities to Legg-Calve-Perthes of the hip (6). Like other ostochondroses, it consists of noninflammatory disordered endochondral ossification. Its specific etiology and relationship to OCD remain debatable. It is generally accepted, however, that abnormal radiocapitellar compressive forces during a period of vulnerability predispose children to it (2,5,7). Etiologically, it may result from the combination of an avascular insult (likely related to the capitellum's predominantly end-artery supply) and repetitive microtrauma (8).

Epidemiology

Panner disease predominantly affects boys younger than age 10 (9). Young boys tend to be predisposed to it for two reasons. One, compared to girls, they have a delayed appearance and maturation of their secondary growth centers. Two, boys traditionally are more prone to trauma during the more aggressive early childhood activities they select (7). This may change as more girls become involved in higher risk athletic activities at younger ages. Although Panner's can be confused with OCD, and the age of onset may overlap, it distinguishes itself by three epidemiological characteristics. One, Panner disease does not share the strict association with repetitive throwing that OCD does; Two, it is usually self-limiting. And three, it resolves without any long-term sequelae.

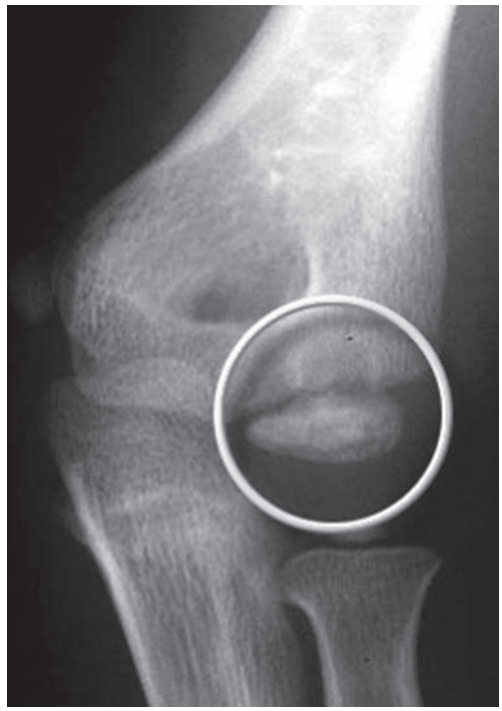

FIGURE 4.1

Panner disease. AP radiograph of the left elbow demonstrating fragmentation and lucency of the capitellum (*circle*) near the chondral surface.

Presentation

Patients with Panner disease will initially present complaining of pain and stiffness in the elbow, relieved by rest. On physical exam, they will have poorly localized tenderness over the lateral elbow. Radiographs will initially show fissuring, lucencies, fragmentation, and irregularity of the capitellum (shown in Fig. 4.1), particularly near or at the chondral surface. Subsequent films, taken at 3 to 5 months, will demonstrate larger radiolucent areas followed by reossification of the bony epiphysis with a corresponding resolution of symptoms. In 1 to 2 years, the epiphysis regains its contour, usually without flattening (4). It should be noted that, as in Legg-Calve-Perthes, radiographs often lag behind clinical symptoms. MRI can also document the extent of the lesion. Typically, edema is localized to the chondral surface with less involvement of the subchondral bone, as compared to OCD (Fig. 4.2).

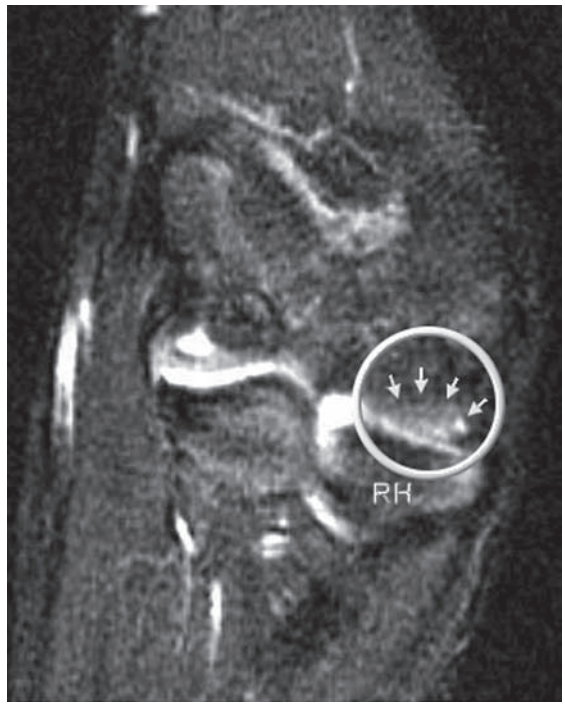

FIGURE 4.2

Panner disease, as seen on T2-weighted MRI. *Circle* surrounds Panner lesion, demarcated by *small arrows*, opposite radial head (RH). Notice the more typical finding of edema adjacent to the capitellar chondral surface, rather than deeper in the subchondral bone as in OCD.

Treatment

Treatment involves complete rest from the activity in question and administering modalities such as ice and anti-inflammatory medication. The elbow may occasionally need to be immobilized for 3 to 4 weeks to control symptoms. Symptoms usually resolve within 6 to 8 weeks, although they occasionally persist for months, and activities should be reinstituted progressively and as tolerated. The condition has excellent long-term prognosis, although in some patients there may be a slight residual flexion contracture.

OSTEOCHONDRITIS DISSECANS

OCD of the capitellum is a noninflammatory degeneration of subchondral bone occurring in the context of repetitive trauma to the lateral compartment of the elbow. Panner disease and OCD may represent two different stages of the same disorder (4). The two conditions, however, do differ in certain characteristics: age of onset, etiology, and natural history. One, while Panner disease affects children under 10, OCD victimizes older athletes between ages 11 and 15 (10). Two, unlike Panner disease, OCD is thought to be directly linked to repetitive trauma. Three, OCD is not always self-limiting. If left unaddressed, it results in profound destruction of the capitellum (10).

Etiology

OCD arises from repetitive and excessive compressive forces generated by either large valgus stresses on the elbow during throwing or racket swinging or from constant axial compressive loads on the elbow such as those endured by gymnasts (10–12). Specific risk factors predispose patients to the condition. In the case of baseball players, throwing sliders and breaking pitches, throwing more than 600 pitches per season, and increased age of the athlete increase the risk of developing OCD (12). In female gymnasts, overtraining involving excessive handstand maneuvers has been linked to OCD (13,14). Other risk factors include genetic predisposition and the tenuous end-artery vascular supply to the capitellum. In the young adult population, the capitellum is supplied by two end arteries coursing from posterior to anterior which are branches of the radial recurrent and interosseous recurrent arteries (Fig. 4.3) (15). As a result of the longitudinal blood supply to the capitellar epiphyseal plate and minimal collateral circulation in the area, blood flow to the capitellum may be disrupted by both repetitive microtrauma resulting in an avascular state, and a single traumatic event leading to posttraumatic subchondral bone bruises (16,17).

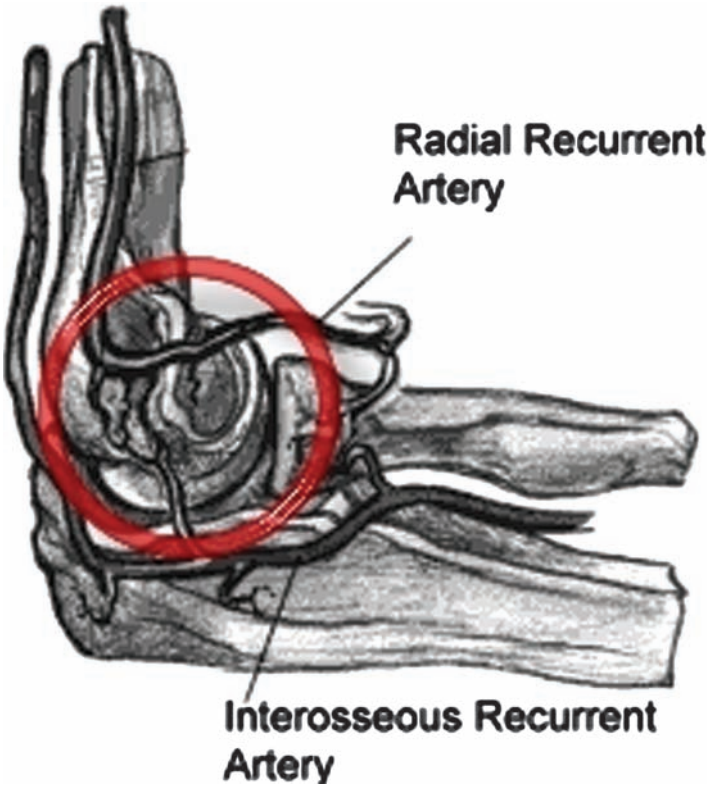

FIGURE 4.3

Capitellar blood supply. In the young adult population (under age 20), the *radial recurrent* and *interosseous recurrent arteries* give off branches that course from posterior to anterior and supply the capitellum (inside *red circle*). This end-artery blood supply makes the capitellum susceptible to an avascular insult.

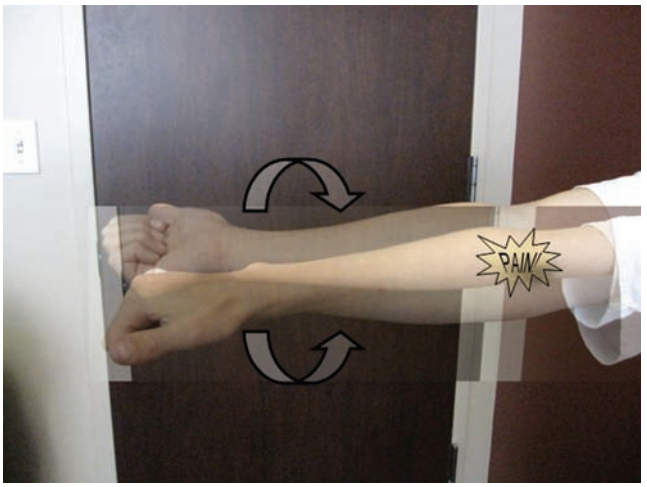

FIGURE 4.4

Radiocapitellar compression test. Pain in lateral elbow when the extended arm is pronated and supinated.

Presentation

Patients with OCD will initially present complaining of pain and stiffness in the elbow, relieved by rest. If left unaddressed, the symptoms may progress to "locking" or "catching" due to intraarticular loose bodies. Physical examination tends to be remarkable for poorly localized lateral elbow tenderness over the radiocapitellar joint. Loss of range of motion with a 15 to 20 degrees flexion contracture is common. Loss of extension is more common than loss of flexion. Radiocapitellar joint provocative maneuvers include the active radiocapitellar compression test (Fig. 4.4). A positive test elicits pain in the lateral compartment of the elbow when the patient pronates and supinates the forearm with the arm in extension.

Imaging

Anterior-posterior in full extension, anterior-posterior in 45 degrees of flexion, and lateral views of the elbow should be obtained. Radiographs may be negative early in the disease process. As the condition progresses, flattening and sclerosis of the capitellum, typically on its anterolateral aspect, will become apparent. Irregular areas of lucency and intraarticular loose bodies also appear. Both the capitellar lesions of OCD and medial-sided epicondylar fragmentation are best seen on an AP at 45 degrees elbow flexion (Fig. 4.5). In suspected OCD, an MRI should always be obtained. It will detect bone edema early in the disease process (18). An MRI arthrogram can further delineate the extent of the injury. The contrast can show separation of a detached or

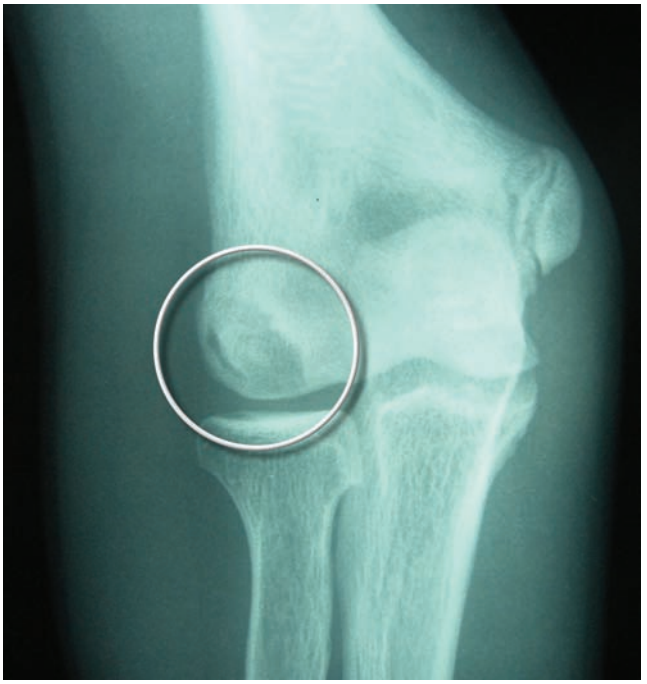

FIGURE 4.5

AP radiograph at 45 degrees flexion. OCD lesion (*circle*) is seen more clearly with elbow flexed to 45 degrees.

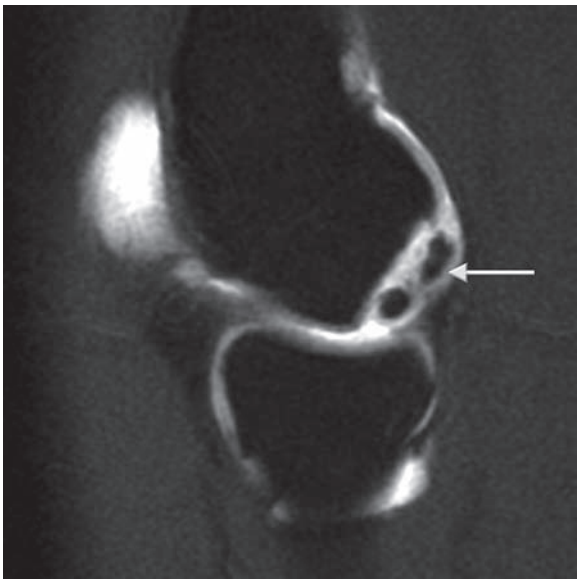

FIGURE 4.6

MR arthrogram showing contrast surrounding unstable OCD fragment (*arrow*).

partially detached piece from subchondral bone (Fig. 4.6). Peiss et al. (19). felt that fragment enhancement (seen in Fig. 4.7B) (as opposed to the perifragment enhancement seen in Fig. 4.6) denotes viability and may be a reasonable indication for nonoperative treatment. They also suggested that enhancement of the fragment-subchondral bone interface is caused by vascular granulation tissue, indicating instability and requiring operative intervention. Of note, it is critically important to distinguish "pseudolesions," appearing on the posteroinferior

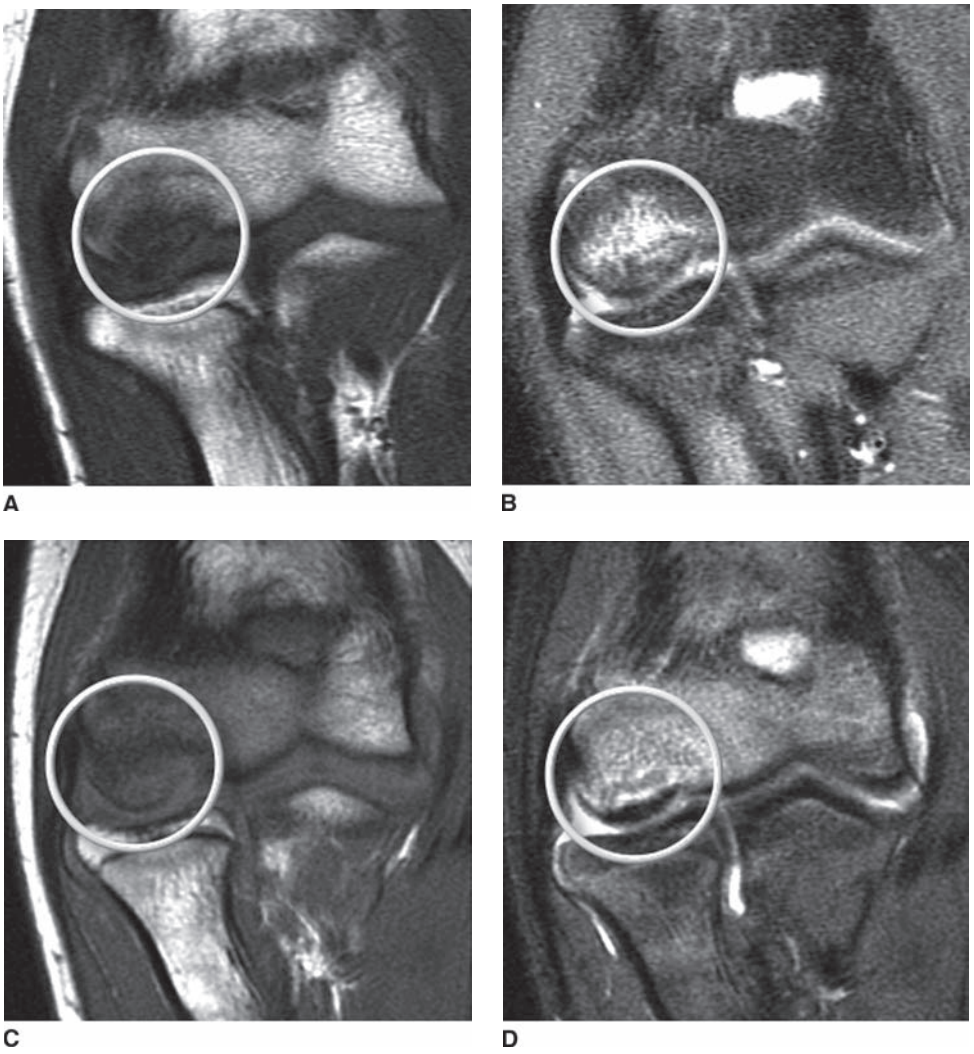

FIGURE 4.7

Stage 1 OCD lesion progress. Stable, intact, nondisplaced fragment (*circles*) with abnormal signal on coronal slices in **(A)** T1 and **(B)** T2 sequences. After 6 months of conservative management **(C)** T1 and **(D)** T2 sequences show reconstitution of subchondral bone in area the lesion. The patient was symptom free at the 6-month follow-up.

TABLE 4.1 Classification and Treatment of Capitellar Osteochondritis Dissecans Lesions

Stability	Stage	MRI Findings	Arthroscopic Findings	Treatment
Stable	I	Normal XR T1 abnormal T2 normal	Intact articular cartilage Subchondral bone edema but structurally sound	1. Hinged elbow brace: 3–6 wk 2. PT 3. NSAIDs 4. Follow-up XR and or MRI at 3–6 mo
Unstable	II	Abnormal XR T1/2 abnormal Contrast shows margin around lesion	Partially detached fragment Cartilage fracture Subchondral bone collapse **Lateral buttress involved:** poorer prognosis	1. ***Acute:*** Consider fragment fixation, but higher success treating as chronic (below). 2. ***Chronic:*** a) **<6–7 mm lateral buttress involved/radial head does NOT engage:** Fragment removal + microfracture/drilling b) **>6–7 mm lateral buttress involved/head engages:** Removal + osteochondral autograft/synthetic graft
	III	Loose bodies	Completely detached Loose bodies	1. Loose body removal 2. Treat as Stage II
		Associated radial head OCD	Any of the above	1. **<30% radial head involvement:** Treat as Stage II 2. **>30%:** No osteochondral grafting; Microfracture drilling ok

junction of the articular and nonarticular portions of the capitellum, from OCD which almost always presents on the anterolateral aspect. In addition, whether or not the capitellar physis is open or closed should be noted.

Management

Management of OCD lesions is based primarily on the status and stability of the overlying cartilage. The size and location of the lesion and the patency of the capitellar growth plate also influence decision making (20–22). In order to guide treatment, detailed classification systems based on radiographic (23,24) and arthroscopic (20) findings have been delineated (25,26). We have chosen to simplify these algorithms into a succinct, three-stage classification that provides a template for management. Table 4.1 illustrates the classification.

Stage 1 In Stage 1, the osteochondral fragment is intact, stable, and nondisplaced. Radiographs are often negative. Signal on MRI is variable, typically abnormal on T1 and normal on T2, although T2 signal may also be abnormal. Figure 7A and B show a Stage 1 lesion with coronal slice abnormal signal on both T1 and T2. Arthroscopically, the articular cartilage is intact with a general preservation of subchondral stability. This stage is best treated nonoperatively. All activity involving the affected arm should be stopped. The elbow should be rested in a hinged elbow brace for 3 to 6 weeks. Progressive physical therapy should ensue as symptoms abate. Return to sport usually can be expected at 3 to 6 months and should be governed primarily by the patient's clinical response, since radiographic changes often lag behind the clinical symptoms by several months or years. Nevertheless, follow-up radiographs and MRIs should be obtained at 2 to 3 month intervals to track progress. Figure 7C and D show the same patient as in Figure 7A and B at 6-month follow-up after conservative treatment, with clear reconstitution of the subchondral bone. If symptoms return, additional rest is mandated. With persistently refractory symptoms, pitchers may have to change positions and gymnasts may have to change sports. Lesions that progress to Stage 2 should be treated accordingly.

Stage 2 In Stage 2, the osteochondral fragment is partially separated as documented both radiographically and arthroscopically. Radiographs will demonstrate fissuring, lucencies, and fragmentation. On MRI, both T1 and T2 sequences will show an abnormal signal and a margin around the fragment, denoting its instability (Fig. 4.8). CT scan may also reveal the partially separated fragment. Arthroscopically, the cartilage is fractured and the subchondral bone is unstable and partially displaced (Fig. 4.9). When an unstable lesion is identified, conservative treatment should be bypassed. It warrants prompt surgical intervention in order to return the athlete to their sport or activities of daily living as soon as possible. In Stage 2 lesions, the size and location of the lesion govern treatment. For smaller lesions, debridement is an option. Patients typically have immediate relief of symptoms but their long-term natural history includes arthritis. Fragment fixation has been advocated by some for this stage, although questions linger concerning the long-term healing potential of fixed fragments and clinical results of the procedure (23,24,27,28). Finally, osteochondral autografts or synthetic grafts can address large, radial head-engaging defects involving the lateral buttress of the capitellum. If the decision rests between fixation and osteochondral restoration, our preference is for osteochondral or synthetic plug grafting as this has generated more reliable results.

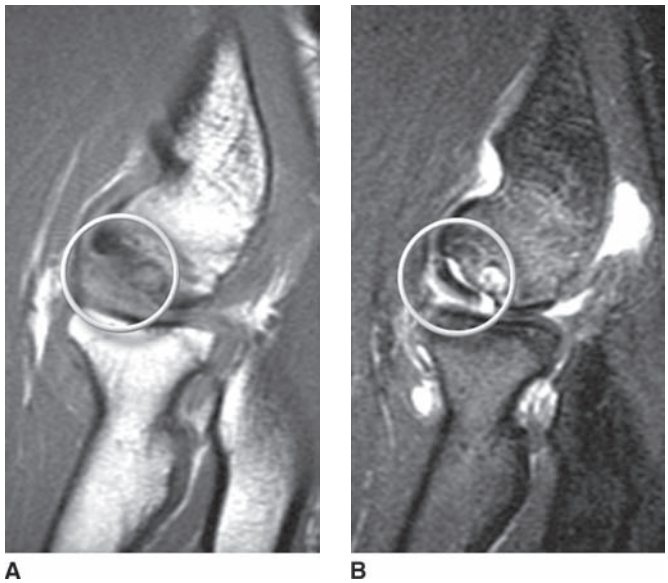

FIGURE 4.8

Stage 2 OCD lesion as seen on MRI. **(A)** T1 and **(B)** T2 sequences showing a margin around the OCD fragment (*circles*) denoting its instability.

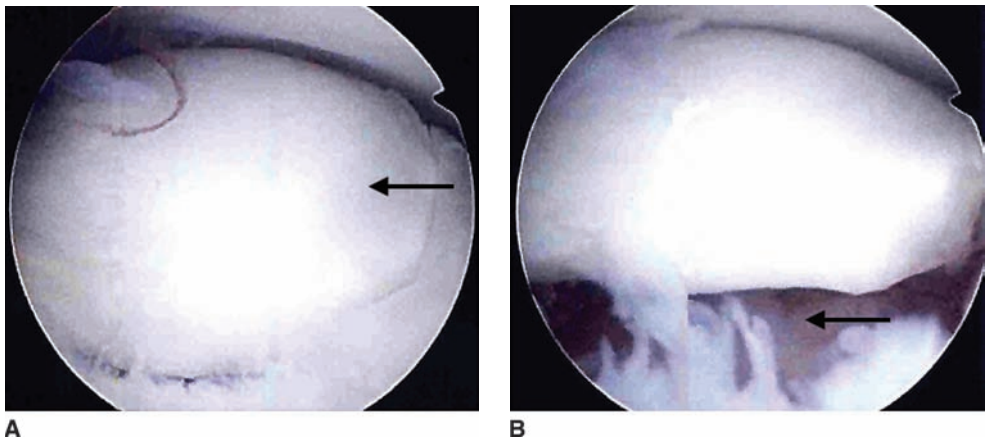

FIGURE 4.9

Stage 2 OCD lesion as seen arthroscopically. **A:** *Arrow* points to osteochondral fragment located at its donor site. **B:** *Arrow* points to space between osteochondral fragment and bone, denoting fractured cartilage and instability.

Size. Takahara et al. (29) differentiated between small (<5% of the capitellum on an anterior-posterior radiograph of the elbow, <60 degree angle formed by lines drawn along the borders of the lesion on a lateral radiograph), moderate (5%–70%), and large (>70%, >90 degrees) lesions. They concluded that large lesions should be addressed operatively. Shimada et al. (30). suggested that smaller lesions (<1 cm^2) can be treated with debridement, chondroplasty, and possibly microfracture or drilling as described by Bradley and Dandy (31). Larger lesions (>1 cm^2) should be treated with osteochondral autografts.

Location. In our opinion, the location of the lesion may be more important in guiding treatment. Extension of the lesion into the lateral margin of the capitellum, as described by ElAttrache (32) and Ruch et al. (33), is associated with a potentially poorer prognosis. The lateral column of the capitellum supports large compressive forces when the elbow is stressed in valgus or with axial loading. When the lateral column is intact, a defect treated with microfracture alone is relatively protected and fibrocartilage healing may occur. Lesions that do not involve a significant portion of the lateral buttress of the capitellum and do not engage the radial head during arthroscopic observation (pronation and supination with the elbow in extension) have been successfully treated with microfracture or retrograde or antegrade subchondral drilling. Figure 4.10 shows an OCD lesion with a predominantly intact lateral column.

Conversely, lateral column involvement of more than about 6 to 7 mm cannot be dealt with acceptably by microfracture. In this case, the absence of a lateral buttress forestalls fibrocartilage healing, by subjecting the defect to increased radiocapitellar forces. Furthermore, engagement of the radial head in the defect also compromises healing and may lead to accelerated radiocapitellar arthrosis. For these larger, engaging defects or those that extend substantially into the lateral buttress (over 6–7 mm) (Fig. 4. 11), we recommend removal of the loose fragment and osteochondral restoration by means of mosaicplasty or osteochondral autofraft transfer system (OATS). In the case of early partially detached fragments, the detached portion (usually central)

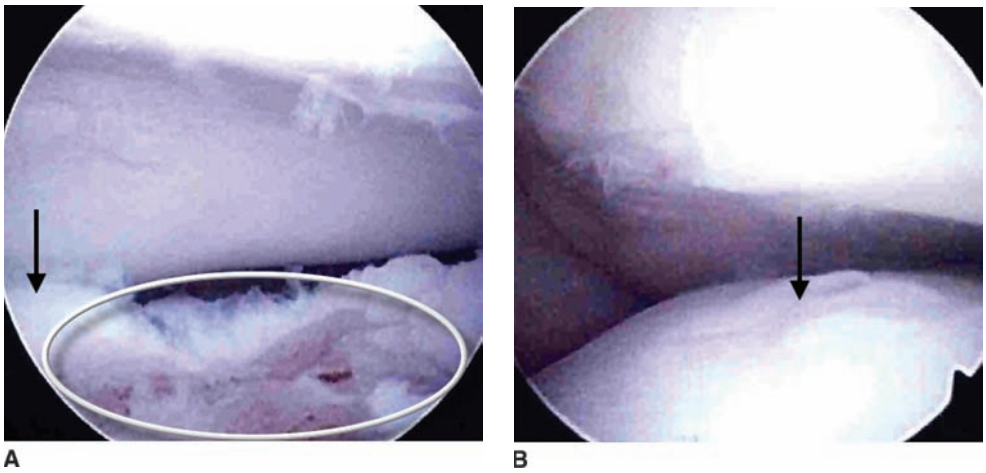

FIGURE 4.10

OCD lesion with intact lateral column. **A:** OCD lesion (*oval*) adjacent to significant portion of intact lateral column (*arrow*). **B:** Lateral column (*arrow*) supports RH and does not permit engagement with defect.

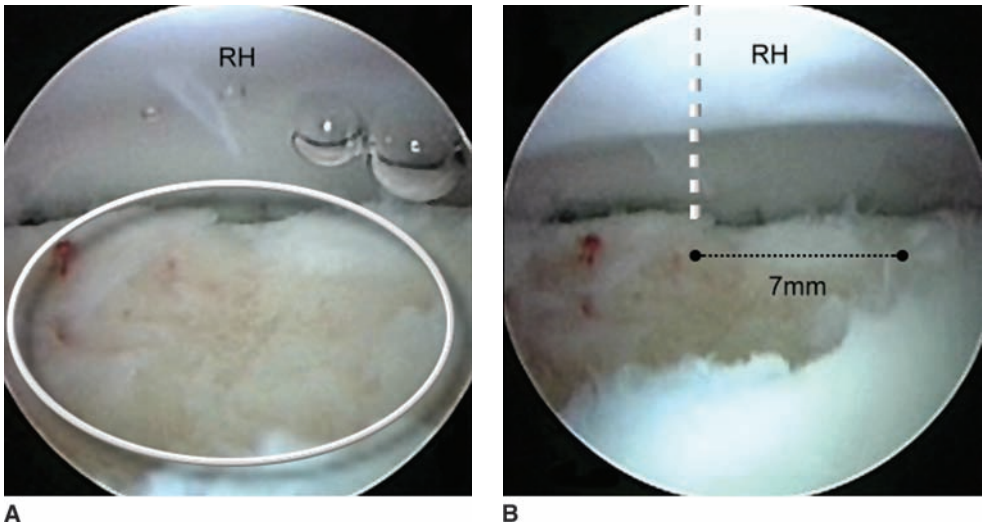

FIGURE 4.11

Lesion extends into lateral column. **A:** OCD lesion (*circle*). **B:** *White dotted line* denotes ulnar margin of lateral column. Lesion extends 7 mm into lateral column (*black dotted line*) and allows RH to engage.

should be debrided from central to lateral. Once stable osteochondral borders have been obtained, the lesion is carefully evaluated arthroscopically to ascertain how much of the lateral column is involved and if the radial head engages with the defect. Chappell and ElAttrache (32) reported that lesions >1 cm^2 (average 1.32 cm^2) and no lateral column involvement were treated successfully with microfracture while those involving the lateral column did well with osteochondral grafting. Fragment fixation is an option as well, but we have had superior and more consistent results with grafting.

Stage 3 In Stage 3, the fragment is fully displaced and has become or is imminently becoming a loose body. Figure 4.12 shows an example of a Stage 3 lesion on MRI and arthroscopically. Patients may present with mechanical symptoms related to loose bodies, such as locking. In this stage, debridement, drilling, or osteochondral replacement is indicated. If the loose osteochondral piece is shown to be acutely displaced in a patient with previously documented OCD, one can attempt to fix it to its donor site. Results of fixation are, however, inconsistent. Chronically present loose bodies (documented by serial XR or MRI) should be removed and the donor bed debrided in preparation for one of the aforementioned treatment options, following the same algorithm. These patients will often be unable to return to sports and the long-term prognosis usually includes radiocapitellar arthrosis.

Radial Head Involvement

Radial head involvement, in addition to capitellar pathology, indicates advanced disease and does not generally occur in athletes. If the radial lesion is <30% of the radial head, then treatment of the capitellar OCD should proceed as delineated above. For radial lesions >30%, treatment of the capitellar lesion should be limited to debridement, drilling, and microfracture (9). Severe radiocapitellar degenerative arthritis is a relative contraindication to mosaicplasty.

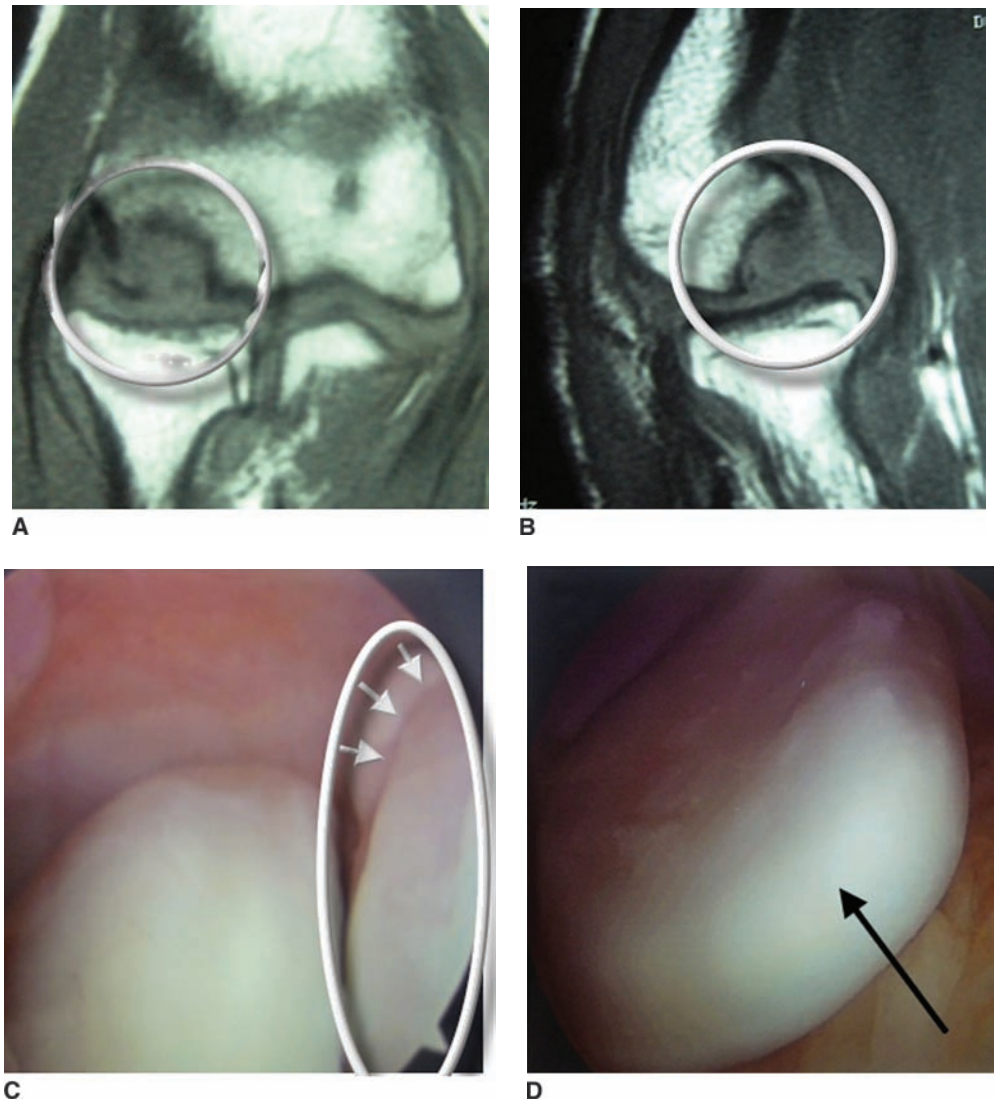

FIGURE 4.12

Stage 3 OCD lesion. **A:** T1 coronal and **B:** T1 sagittal MRI showing unroofed OCD lesion. **C:** Arthroscopic image showing OCD lesion (*oval*) with no overlying cartilage. *Small arrows* demarcate edge of lesion. **D:** The loose body osteochondral fragment (*arrow*) is found in the joint.

Radiocapitellar Plica

A comorbid condition that may be found in throwing athletes at the time of arthroscopy for OCD includes posterolateral elbow impingement caused by a thickened radiocapitellar plica (34–36). The plica can cause chondromalacic changes on the radial head and capitellum (34). Symptoms may include painful clicking or catching and effusions and can overlap with those from the OCD lesion. If there is snapping, it often occurs at >90 degrees of elbow flexion with the forearm in pronation (34,36). If found during arthroscopic inspection, the plica should be resected. Kim et al. (35) reported excellent results after plica debridement in throwing athletes and golfers.

Outcomes

Nonoperative Treatment Nonoperative treatment is indicated for Stage 1 OCD with a stable lesion and in patients with open capitellar growth plates. Recently, Takahara et al. (23,24) retrospectively reviewed 106 cases of capitellar OCD with an average 7-year follow-up. They found that stable lesions that healed completely with nonoperative treatment had the following three common characteristics at initial presentation: one, an *open capitellar growth plate*, two, localized flattening or *radiolucency of the subchondral bone* and three, *good elbow motion*.

Nonoperative treatment mandates complete cessation of elbow use including activities such as throwing, gymnastics, arm wrestling, push-ups, and weightlifting. The arm may be immobilized, but for no more than 3 weeks (26). Gentle range of motion should be instituted immediately after this period of immobilization if this treatment route is chosen. The patient is followed clinically at regular intervals (every 4–6 weeks) with serial radiographs. Gentle exercises are performed for the first 3 to 4 months, advancing to strengthening at 4 to 5 months. At that point, an interval throwing program can be initiated based on satisfactory clinical and radiographic findings. Return to sports should be governed by patient symptoms because radiographic changes can persist for years (37,38).

Rest. Takahara et al. (29,38) noted that repetitive forces on existing OCD lesions led to an increase in lesion size. Therefore, cessation of repetitive stress on the elbow needs to be categorically emphasized to the athlete's parents, trainers and coaches. They need to be reminded that this is a potentially sport-ending injury, with degenerative arthritis as a possible outcome. Highlighting this, the incidence of residual capitellar deformity in high-level pitchers is, in fact, very low (39). This suggests that athletes who develop a degenerative elbow from failed OCD treatment do not go on to play high-level baseball.

Stage. Early-stage OCD responds better to nonoperative treatment than advanced stage, so identifying the disease promptly can have a significant impact on prognosis. Matsuura et al. (40) found that 91% of early-stage OCD but only 53% of advanced-stage OCD improved after nonoperative treatment.

Stability. Stability of the fragment also affects the final outcome. If the fragment is stable, Mitsunaga et al. (41) showed that <50% of those lesions will go on to become unstable in the long term. However, Takahara et al. (23) demonstrated that those fragments that do become unstable have a low rate of healing.

Patient Age and Growth Plate Status. Age has not been correlated with likelihood of healing (33,37) Mihara et al. (22) noted, however, a significant correlation between open capitellar growth plates and healing. In their study, 94% of early-stage patients with open growth plates healed, while the rate in those with closed growth plates was only 71%.

Operative Treatment

Failure of conservative treatment for early-stage, stable lesions (about 6 weeks of no improvement or 4 to 6 months of persistent symptoms), or diagnosis of an advanced-stage, unstable lesion, are indications for pursuing operative treatment. The ultimate goals of surgery are to eliminate mechanical symptoms and stimulate a healing response. Takahara et al. (24) found that unstable lesions that did well with surgery compared to elbow rest had the following common findings at initial presentation: One, a *closed capitellar growth plate*; two, *radiographic fragmentation* and three, *restriction of elbow motion >20 degrees*. Patients with closed capitellar physes did significantly better with surgery than with elbow rest. In larger lesions, they also noted better results with reconstruction of the articular surface than with simple fragment fixation.

Surgical Techniques

Arthroscopic Positioning

Elbow arthroscopy can proceed with the patient either supine, prone, or in the lateral decubitus position. We use the supine position because it facilitates general anesthesia and provides an easy conversion to an open procedure if needed (Fig. 4.13). Structures may lie in a more anatomic

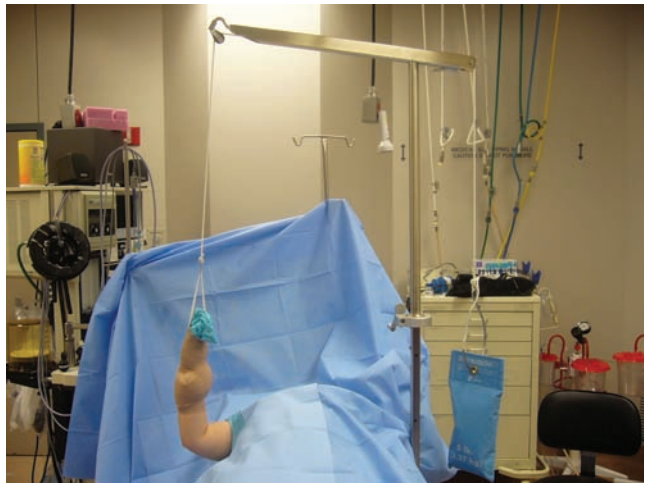

FIGURE 4.13
Supine position

orientation in this position as well. In the supine position, the elbow is positioned at 90 degrees of elbow flexion and 90 degrees of shoulder abduction with the hand suspended from a pulley, using 5 lb of traction. The lateral position gives improved posterior compartment access. The prone position also gives good posterior compartment access and does not require traction. General anesthesia provides complete muscle relaxation and obviates the need for a regional block that may prevent diagnosing a postoperative neurologic problem. A tourniquet may or may not be used.

Arthroscopic Technique 2.9- and 4.0-mm, 30-degree arthroscopes, burrs, and shavers should be available. The elbow is distended with 30 to 50 mL of saline through the direct-lateral portal. Standard arthroscopic portals are created and a diagnostic arthroscopy to evaluate for the presence of loose bodies, osteophytes, and chondral damage is performed, usually with the arthroscope in the anteromedial portal and working instrumentation in the anterolateral portal. In throwers, a valgus stress test with the elbow flexed to 70 degrees can be performed during the diagnostic portion of the procedure. A 1 to 2 mm opening of the ulnohumeral joint denotes laxity of the ulnar collateral ligament, although clinical correlation is mandatory. Once the initial arthroscopic examination is complete, a mid-lateral portal (lateral soft spot) is created in line with the lateral epicondylar ridge and entered with the arthroscope. The radial head, capitellum, trochlear notch, and trochlear ridge are best seen through this portal. Care should be taken to avoid the posterior antebrachial cutaneous nerve, at risk near this portal. A working portal is created adjacent and slightly ulnar to the midlateral portal. Carefully placed dual direct lateral portals have been shown to not damage lateral ligamentous structures and provide superior exposure to the capitellum (42). Patients with OCD and lateral compartment symptoms will occasionally also have a thickened radiocapitellar plica (Fig. 4.14). If found, the plica should be resected.

The OCD lesion is evaluated and graded. If unstable and loose, the lesion is prepared by removing any loose fragments, shaving loose fragments of cartilage down to subchondral bone, and establishing healthy cartilage borders (Fig. 4.15). The size of the lesions is determined by a calibrated probe. If osteochondral grafting is planned, the portals must allow access to the required 4 to 6 mm instruments. At this point, depending on the indication, one of the following procedures can be performed: Abrasion chondroplasty, drilling, microfracture, fixation of large fragments, and osteochondral autograft transfer (mosaicplasty).

Microfracture and Subchondral Drilling The indications for microfracture or subchondral drilling are similar: Early-stage lesions with cartilage fibrillation and fissuring and small Stage 2 lesions with exposed bone that do not significantly involve the lateral column of the capitellum. The lesion bed is prepared as stated above (Fig. 4.15). Detached fragments or loose bodies are removed. With the arthroscope in the direct lateral portal, a 0.062 in Kirschner wire is inserted through the accessory lateral portal and used to perforate the lesion (Fig. 4.16A). Multiple holes are made in the lesion (Fig. 4.16B). Marrow elements released from the holes induce a fibrocartilage healing response.

If microfracture is elected, a similar approach can be employed using microfracture awls instead of pins. Bojanic et al. (43) reported symptom resolution in three adolescent (13–15-year-old) gymnasts 5 months after arthroscopic debridement and microfracture of lesions around Stage 2. They remained symptom free one year postoperatively. Using microfracture in 11 athletes with an average age of 15, Chappell and ElAttrache (32)

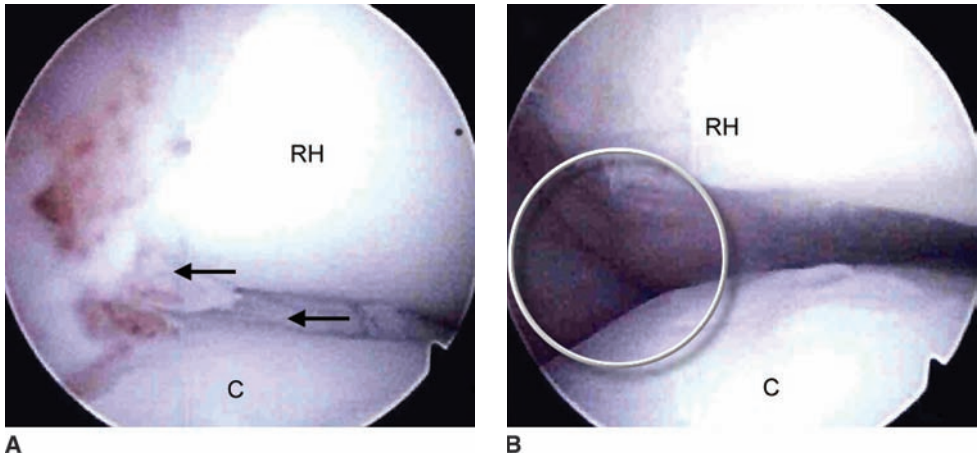

FIGURE 4.14

Radiocapitellar plica. **A:** *Arrows* point to radiocapitellar plica which may cause abrasion of RH and capitellar (C) chondral surfaces. **B:** *Post-plica resection*: *Circle* demarcates region formerly occupied by plica, now cleared.

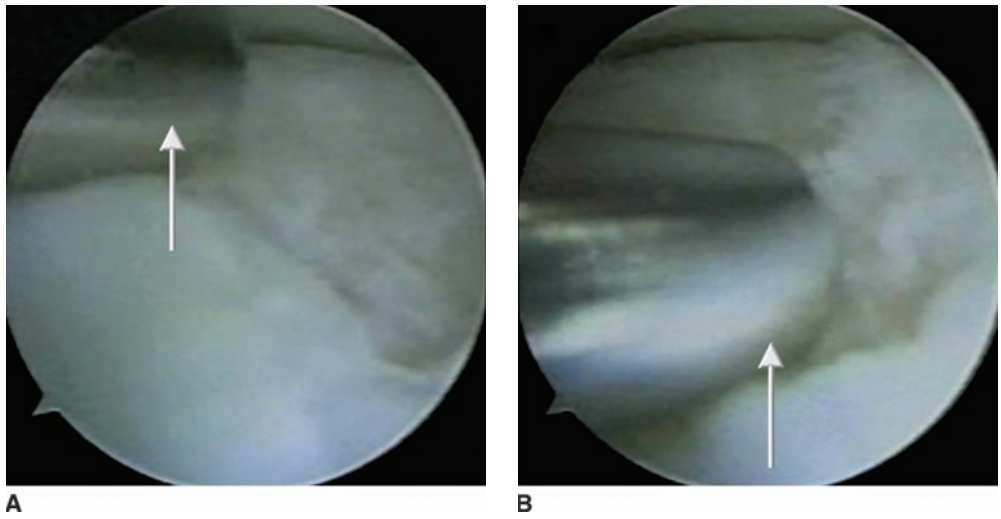

FIGURE 4.15

A: OCD lesion is debrided with shaver (*arrow*) to **(B)** stable borders.

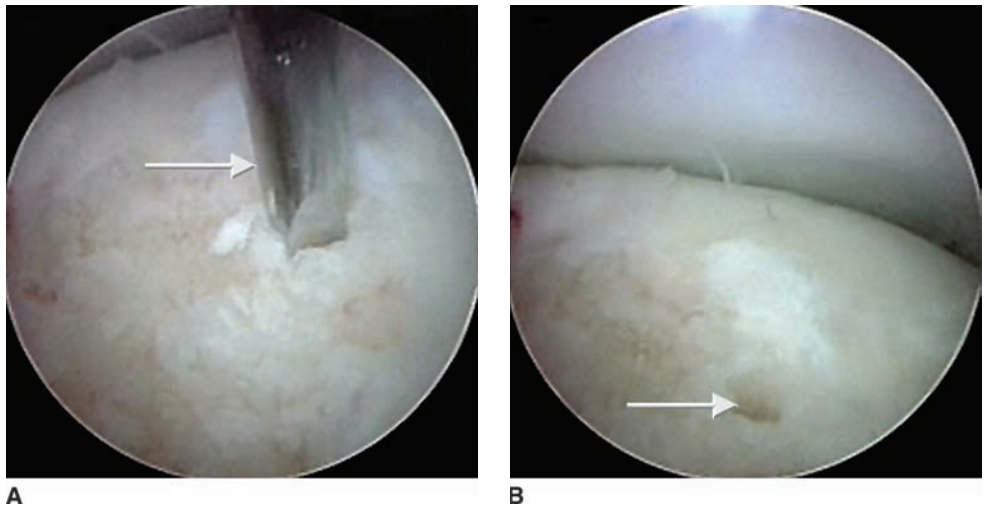

FIGURE 4.16

Microfracture technique. **A:** A 0.062 in Kirschner wire (*arrow*) is inserted through the accessory midlateral portal and used to perforate the lesion. **B:** Holes (*arrow*) in the lesion allow marrow elements to induce a fibrocartilage healing response.

obtained excellent results at 3 years follow-up with a return to previous level in all 11. The size of the OCD lesions ranged from 7 × 6 mm to 17 × 15 mm.

Mosaicplasty Mosaicplasty (OATS) has been recently applied in the context of elbow OCD lesions. In this procedure, small-sized cylindrical osteochondral grafts are obtained from the lateral periphery or trochlear edge of the femoral condyles and transplanted to prepared osteochondral defects (44). Mosaicplasty is indicated when a large capitellar lesion engages the radial head, as observed while rotating the extended arm during arthroscopy or when there is significant (over 6–7 mm) lateral column involvement (Fig. 4.17A). Radial head degeneration and severe deformities of the capitellum are relative contraindications.

A midlateral working portal is used to establish healthy, stable cartilage borders. In the case of a partially detached fragment, the detached area is first evaluated. Often, the detached region is located centrally. In this situation, the senior author (NSE) recommends debriding the partially detached portion beginning centrally and proceeding laterally, toward the lateral column. Debridement proceeds until an area of

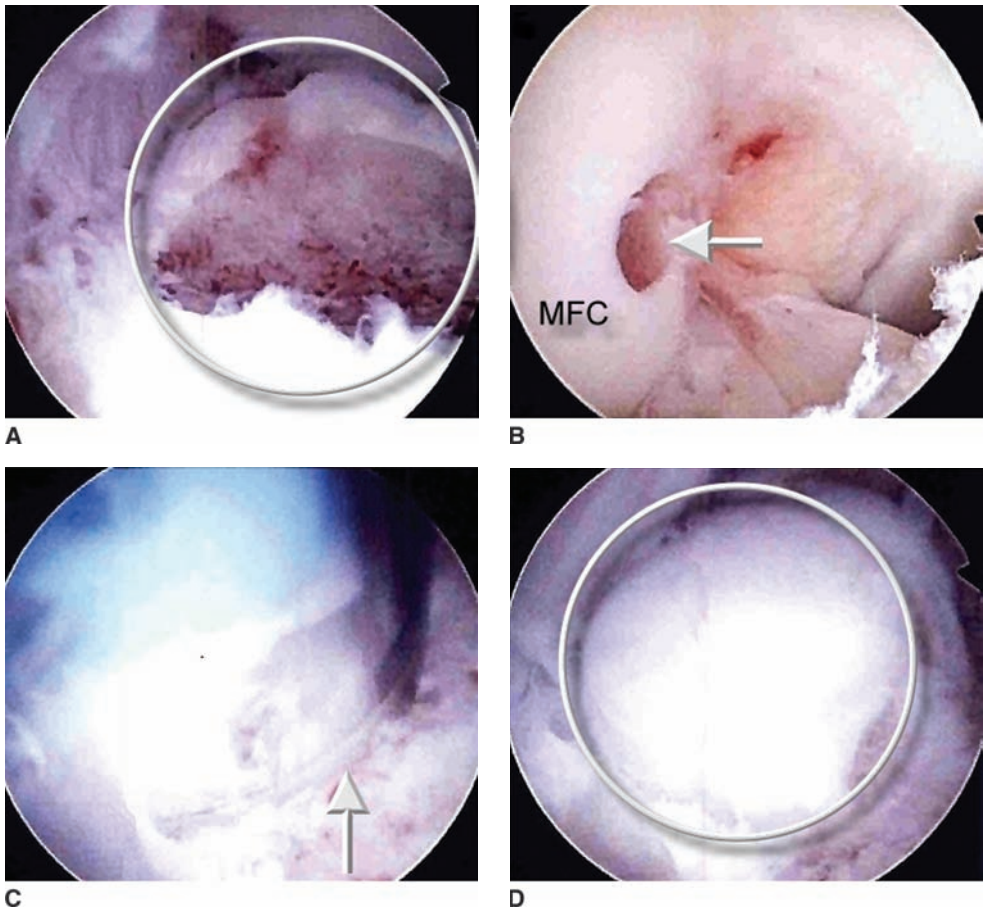

FIGURE 4.17

Osteochondral plug reconstruction of capitellar OCD defect extending into lateral column. **A:** OCD defect extending into lateral column of capitellum (*circle*). **B:** *Arrow* points to donor site for osteochondral plug (6 mm in diameter, 1 cm in depth), harvested from medial trochlea of knee, on lateral aspect of MFC. **C:** *Arrow* points to implantation of osteochondral plug using inserter. **D:** *Circle* demarcates osteochondral plug, postimplantation.

bony integrity, consisting of an osseous connection between the fragment and the subchondral bone, is encountered, if there is one present. The extent of posterolateral column involvement is then determined (Fig. 4.17A), and an arthroscopic evaluation (consisting of supination and pronation of the extended forearm) of radial head engagement in the defect is performed. If more than 6 to 7 mm of the lateral column is involved or the radial head engages in the defect, osteochondral grafting proceeds. The goal should be to restore a bony buttress to prevent radial head subluxation into the defect, not necessarily replace every millimeter of the lesion.

If osteochondral grafting is elected, the elbow is then flexed 90 to 100 degrees and a spinal needle is introduced through the anconeus to gauge the feasibility of a perfectly perpendicular approach to the lesion. The incision is widened to provide access for a 4- to 6-mm-diameter plug, so that it is in line with the perpendicular path delineated by the needle. After bluntly spreading the soft tissue to avoid neurovascular structures, the recipient site is then drilled as perpendicular to the chondral surface as possible creating a tunnel of the necessary diameter. At this point, the knee, which has been prepped, undergoes an arthroscopic harvest of an identically sized chondral plug from the intercondylar notch. The arthroscope is placed into an anterolateral portal. Instrumentation is inserted through an anteromedial portal. Using the harvesting instrumentation, a 6 mm in diameter, 1 cm in depth plug is harvested from the trochlear edge off the medial femoral condyle (MFC) (Fig. 4.17B). Usually one plug is sufficient because of the small size of the capitellar lesions. The plug is introduced into the recipient site and impacted flush with the surrounding cartilage (Fig. 17C and D). The goal should be to reconstitute the lateral buttress (Fig. 18A and B) so that the radial head does not sublux (engage) into the defect. The process of osteochondral grafting is repeated until the lateral column integrity is adequately restored. If some corners of the lesion cannot be fully replaced, they are treated with drilling or microfracture (Fig. 18C and D). If autograft is unavailable, allograft or synthetic scaffolding can be used.

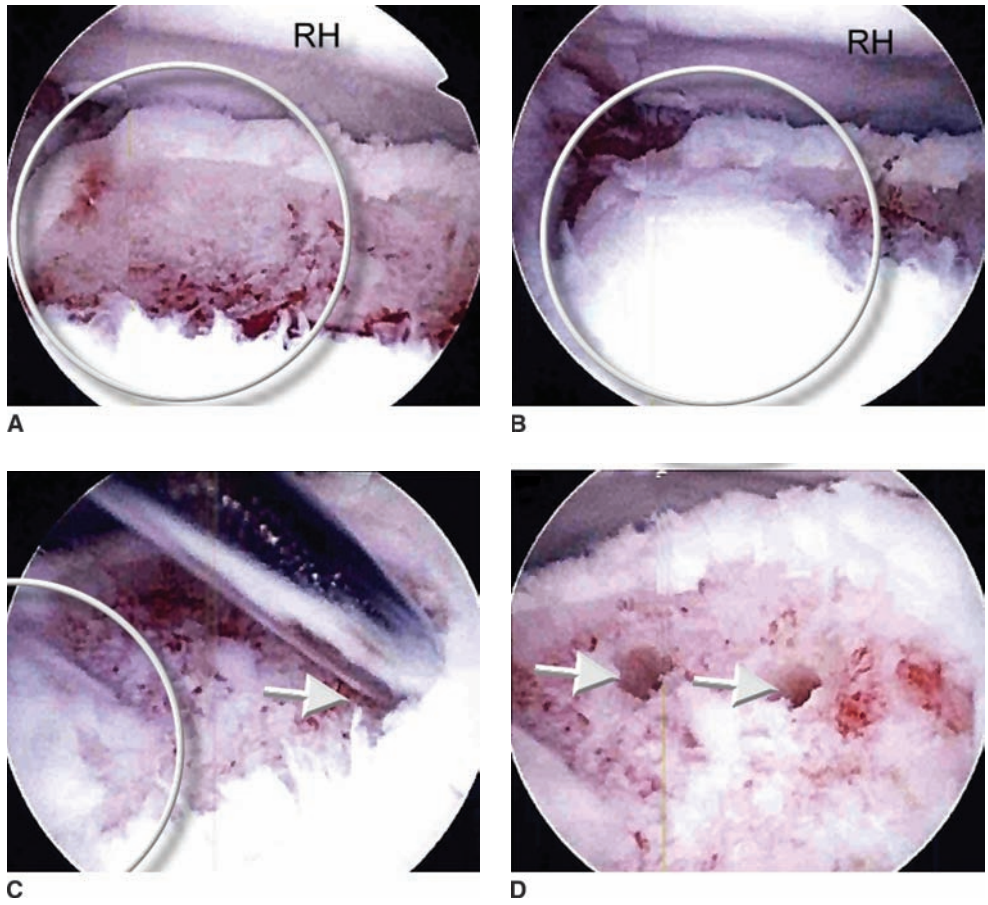

FIGURE 4.18

Lateral buttress of capitellum reconstructed with osteochondral autograft. **A:** OCD lesion extending into lateral column of capitellum (*circle*); During arthroscopic exam (pronation/supination in extension), RH engages defect. **B:** Osteochondral plug (*circle*) placed in lateral aspect of capitellum, reconstituting lateral buttress. RH no longer engages. **C:** *Circle* surrounds osteochondral plug, *arrow* points to remaining OCD lesion addressed with microfracture using 0.0062 in Kirschner wire. **D:** Postmicrofracture: *Arrows* point to holes allowing release of marrow elements.

With this method, Iwasaki obtained good or excellent results in seven out of eight teenaged baseball players with OCD. Yamamoto et al. found that six of nine adolescents with Grade 3 and eight of nine with Grade 4 OCD returned to competitive baseball after an OATS procedure. Chappell and ElAttrache (32) treated five baseball players with OCD using OATS. All five returned to competitive baseball and were still playing 5 years postoperatively. The authors recommended the procedure particularly when more than 6 to 7 mm of the lateral column is involved, and the radial head is seen to be engaging with the lesion with a careful arthroscopic examination during supination/pronation and flexion/extension of the forearm.

Fragment Fixation Fragment fixation has been performed in patients with unstable, partially open OCD lesions (27). Kuwahata et al. (28) described using cancellous bone grafts and a Herbert screw via an open technique. At 32-month follow-up they reported pain-free return to sport and a range of motion improvement of 18 degrees in all seven patients who underwent the procedure. Takahara et al. (23,24) described using bone pegs harvested from the lateral olecranon to fix partially attached lesions. This was also done through an open approach. Newer bioabsorbable implants may allow fragment fixation to be performed routinely arthroscopically. While these authors have reported encouraging results, reports on fixation are still preliminary. Our recommendation at this time remains excision and drilling or grafting for partially detached lesions.

Closed-Wedge Osteotomy Closed-wedge osteotomy of the lateral distal humerus for OCD has also been applied for early lesions to unload the lateral compartment of the elbow. Kiyoshige et al. (45) performed a closed-wedge osteotomy developed by Yoshizu 2 cm proximal to the lateral epicondyle with a 10 degrees

intervening angle in seven 7 to 12-year-old male baseball pitchers and obtained good results and a return to baseball in six of the seven patients.

Postoperative Management Postoperatively, all patients should be protected for 2 to 3 weeks with a long arm cast or hinged brace. Active motion should not be started until bony union is seen on radiographs. Gentle resistance exercises are initiated at 3 months, progressing to greater resistance at 4 months. For throwing athletes, a throwing program is started at 5 months. Full effort return to sport is usually achieved 6 months after surgery. Athletes that have undergone simple debridment and drilling or microfracture can usually return one to two months sooner depending on their rehabilitation progress.

Return to Sport

Return to sports has been variable. Historically, gymnasts have had inferior outcomes compared to throwers, perhaps related to significantly increased axial loads borne by their elbows. Jackson et al. (3) treated 10 female gymnasts with removal of loose bodies and drilling after failure of nonoperative treatment. Only one returned to sport. They concluded that while surgery for lesions refractory to conservative treatment may improve symptoms, a return to gymnastics is unlikely. Newer technical advancements and lesion-specific management, however, may be improving these outcomes. Recently, Bojanic et al. (43) found that three of three female gymnasts successfully returned to their previous level after loose body removal and microfracture. And while Byrd et al. (46) suggested that arthroscopic surgery reliably improved symptoms but only returned four of ten adolescent baseball players to competitive baseball, Yamamoto et al. (47) recently reported on a return to competitive level in 14 of 18 male baseball players with unstable fragments (either in situ or displaced) after osteochondral autografting. Chappell and ElAttrache (32) had eight of eight male baseball players return to their sport and previous level at an average 3 years follow-up after either microfracture or osteochondral autografting.

Prognosis

Prognosis for OCD of the capitellum is good when caught early at Stage 1. Unfortunately, most cases are diagnosed at Stage 2. While surgery will usually alleviate symptoms and allow a return to play, these patients have a less favorable long-term outcome. Longitudinal studies have documented that 50% of radiocapitellar OCD patients will go on to eventually develop osteoarthritis (48). Nevertheless, newer techniques, including osteochondral grafting (mosaicplasty) may mitigate the onset of long-term degenerative joint disease. Ultimately, prevention is the best treatment. For throwers, pitch counts should be monitored and kept under 600/wk. Players or gymnasts should never pitch or practice when in pain and should never be medicated to play.

CONCLUSION

Young throwers and gymnasts are at risk for Panner disease and OCD as performance demands and expectations escalate. For Panner disease and early OCD, nonoperative treatment, consisting primarily of strict activity cessation, forms the mainstay of management. Advanced OCD lesions require operative intervention, which is feasible arthroscopically. The size and location of the lesion as well as its functional relationship to the radial head help guide management. As always, prevention, by monitoring and limiting pitch counts and excessive training and educating athletes, parents, and coaches on early warning signs, provides the most reproducible solution for these potentially sport-ending conditions.

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5 Distal Biceps Tendon Rupture in the Athlete

Bernard F. Morrey

Once thought to be an uncommon injury, the avulsion of the distal biceps tendon from the radial tuberosity is being seen in increasing numbers in both competitive and recreational athletes. In general it is of interest that the injury occurs almost exclusively in males, usually those with heavy lifting requirements of work or avocation.

PATHOLOGY

The distal biceps tendon complex may be injured at the musculotendinous junction, by a disruption of the tendon itself in continuity, or a complete or partial tear or avulsion of the tendon from the radial tuberosity (Fig. 5.1). By far the most common lesion is the avulsion from the tuberosity and this is the only lesion that will be dealt with in this chapter.

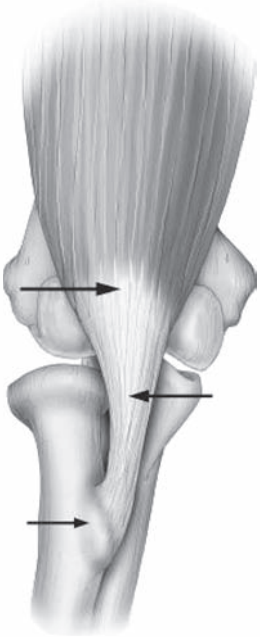


FIGURE 5.1

The biceps mechanism may be injured at the muscle/tendinous junction, intratendinous, or at the tuberosity.

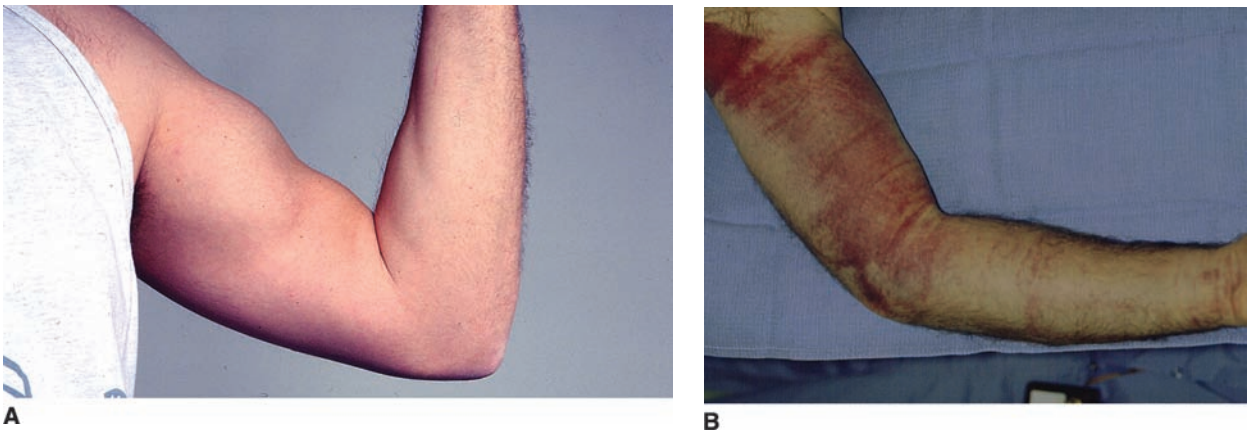


FIGURE 5.2

In most instances, proximal retraction is diagnostic **(A).** Ecchmosis is uncommon. In this instance, this competitive athlete had been on high-dose aspirin at the time of injury **(B).**

Of the tears from the radial tuberosity, approximately 95% are complete ruptures whereas about 5% are partial tears. Both conditions, along with delayed reconstruction, will be addressed in this chapter.

THE DIAGNOSIS

Complete rupture is easy to diagnose in most instances due to retraction of the distal biceps muscle belly with elbow flexion. The history is that of eccentric loading during flexion. Hematoma formation is variable, as is the location of the pain (Fig. 5.2).

Imaging

In recent years, there has been a significant improvement in the ability to diagnose the biceps tendon injury, especially incomplete rupture, with MRI. By placing the arm overhead the course of the biceps tendon may be brought in plane thus allowing a more accurate assessment of the pathology. This position was described by Giuffre and Moss (9) and is termed the "flexion abduction supination 'FABS' " view (Fig. 5.3). In addition to this improvement in patient position, three dimensional reconstructions are also improving our preoperative understanding of the precise location and extent of the pathology present. This is of particular value in instances of partial rupture.

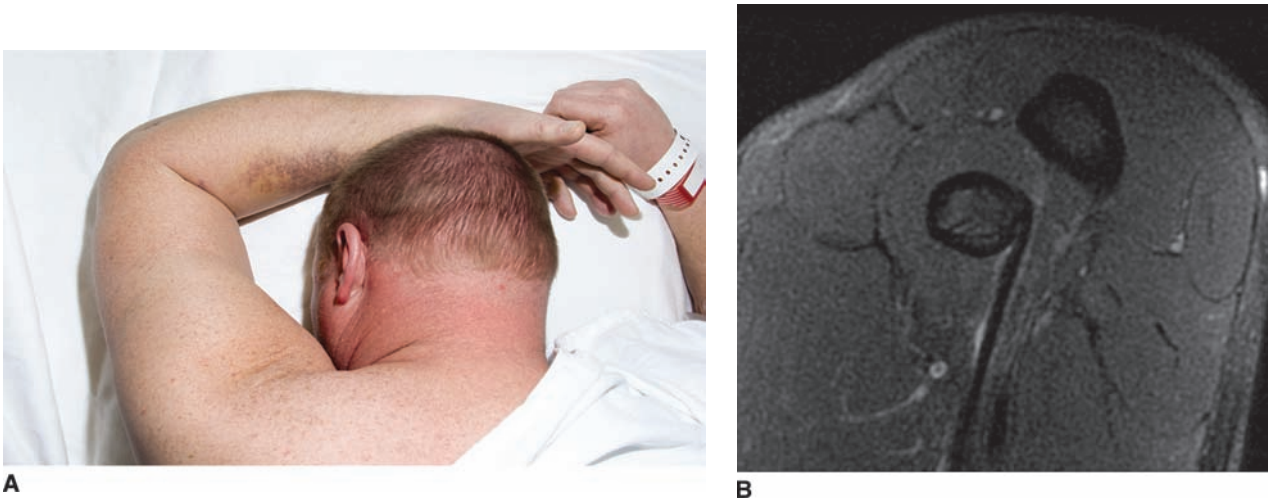


FIGURE 5.3

The FABS view **(A)** brings the entire tendon and its attachment into profile with MRI **(B).**

INDICATIONS/CONTRAINDICATIONS

In my judgment there is little question that in the athlete particularly distal biceps tendon rupture should be repaired as soon as possible (1,3,15,17,19). There have been several studies including our own attempting to estimate and evaluate both subjective and objective dysfunction following the nonrepaired biceps tendon. These studies have generally shown reasonable function under most circumstances with minimal pain. However, with excessive exertion the patients do have pain and lack endurance, hence the need for reconstruction in some patients if the repair is not performed acutely. The average age of patients with the injury is approximately 55 and virtually every report has documented the almost exclusive occurrence in the male. In our practice at Mayo, we have treated only two females from among over 100 with this diagnosis, both with partial ruptures. Usually, the patient is involved with heavy labor or athletic activity, which further emphasizes the need of early definitive treatment.

Delayed reattachment is difficult because the tendon retracts. If this has occurred, reattachment or embedding the biceps tendon into the brachialis is easy but not considered acceptable today. Reconstruction for selected patients has been effective in recent years but this is a difficult surgical procedure (11) and typically is referred to those surgeons with experience with this procedure. The author prefers the achilles allograft for this procedure as described herein.

Contraindications

Reattachment is contraindicated in patients who do not have significant functional impairment. This is not very applicable in the athlete but might be considered in a sedentary patient—but rarely does such an individual sustain this injury. Attempts to reattach this tendon if there has been a delay of over 3 weeks requires careful thought as the tendon typically is retracted into the biceps muscle and the tendon track is scarred. If the delay is prolonged there may not be adequate length to reach to the radial tuberosity (17). Furthermore, the tract of the tendon to the tuberosity will have scarred and become obliterated, making the surgery much more difficult with a higher complication rate (13).

Surgical Considerations

The surgeon has two interrelated technical considerations when addressing these patients. The first is the selection of either a one or two-incision technique. The second is the mode of fixation. In this chapter, we will deal with three types of fixation which with their variations reflect virtually all of the approaches used today: bone tunnel, suture anchor, and endo button.

The surgical approach is clearly the preference of the surgeon. Surgical procedures have been described using a modified Henry approach (7,15) or through a two-incision approach described by Boyd and Anderson (5). The advantage of the anterior Henry approach is that it is felt to be less likely to create ectopic bone. The disadvantage is that it puts the radial nerve at jeopardy (7,15,19). However, it must be emphasized that the two-incision approach currently used is *NOT* that described by Boyd and Anderson. The advantage of the two-incision technique is that it lessens and virtually eliminates the likelihood of injury to the radial nerve (17). The original Boyd-Anderson approach exposes the ulna, and hence can be associated with ectopic bone (8). Through the years we have employed the Mayo modification of the Boyd-Anderson approach which does *NOT* expose the ulna, and hence is associated with very little ectopic bone (13).

The author continues to use the two-incision technique with excellent results and minimal complications (13). It is recognized that the one-incision technique is also popular with the thought that it lessens the likelihood of ectopic bone formation. This has not been demonstrated to be the case but it does motivate many to use a single anterior approach. The direct exposure is correlated with the mode of fixation. An anterior approach can be used for the endo button or the suture anchor. For bone tunnels, a two-incision technique is required.

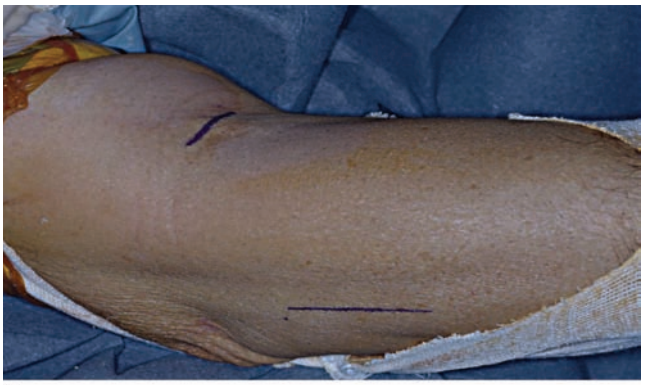
PREOPERATIVE PLANNING

If the injury is more than 4 weeks since onset, be prepared to perform a more detailed dissection in the antecubital space. If the tendon has retracted, direct reattachment to the tuberosity with the elbow flexed up to 90 degrees is preferred. If this is not possible, restoration of length with an achilles tendon allograft is preferred. The patient must be prepared for these eventualities.

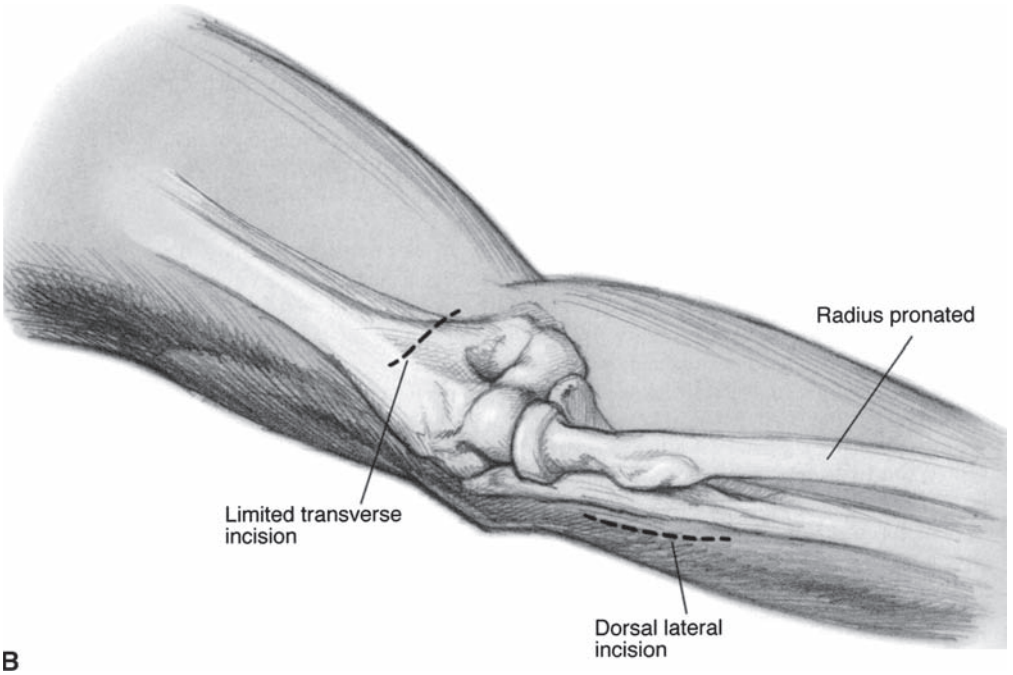
TECHNIQUE

Complete Rupture—Immediate Reattachment

Incision The arm is prepped and draped with the patient supine. A sandbag may be placed under the shoulder to allow the arm to comfortably be brought across the chest. Under a general anesthesia, a single 4-cm transverse incision in the antecubital crease is employed (Fig. 5.4).



A



B

FIGURE 5.4

The two-incision technique employs a simple 4-cm transverse incision in the antecubital space **(A)** and a 5- to 7-cm incision over the posterior aspect of the proximal forearm **(B)**.

Tendon Preparation. By digital palpation or limited dissection, the tendon is identified, dissected free of soft tissue, and is delivered from the wound (Fig. 5.5). The end of the tendon tends to be bulbous and is trimmed in order to allow it to fit well into the tuberosity. After the tendon has been trimmed, two 5 Mersilene sutures are placed through the torn portion entering the end of the tendon. A crisscrossed (Bunnell) suture or locking stitch (Krakow) is employed (Fig. 5.6).

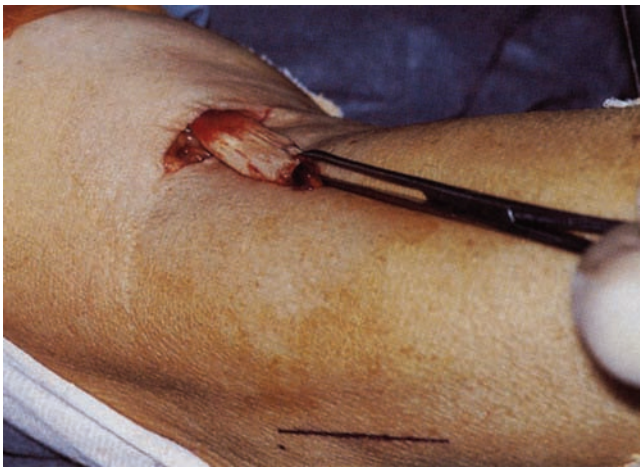
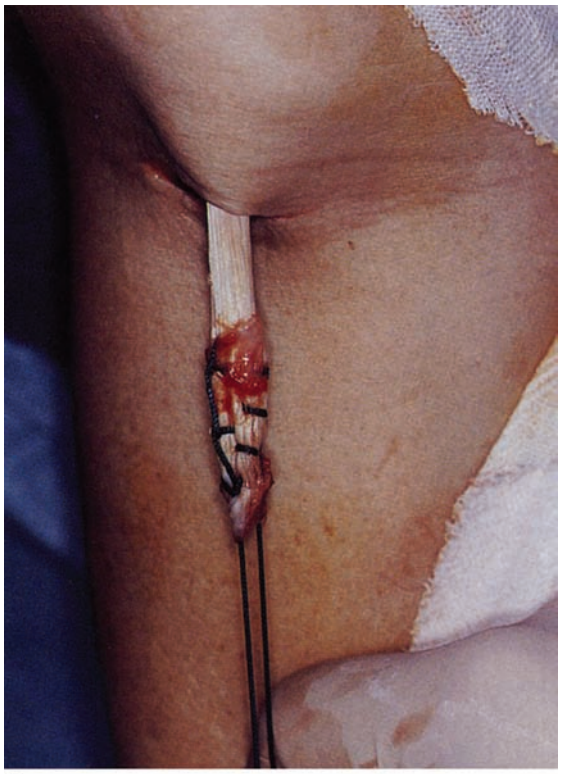
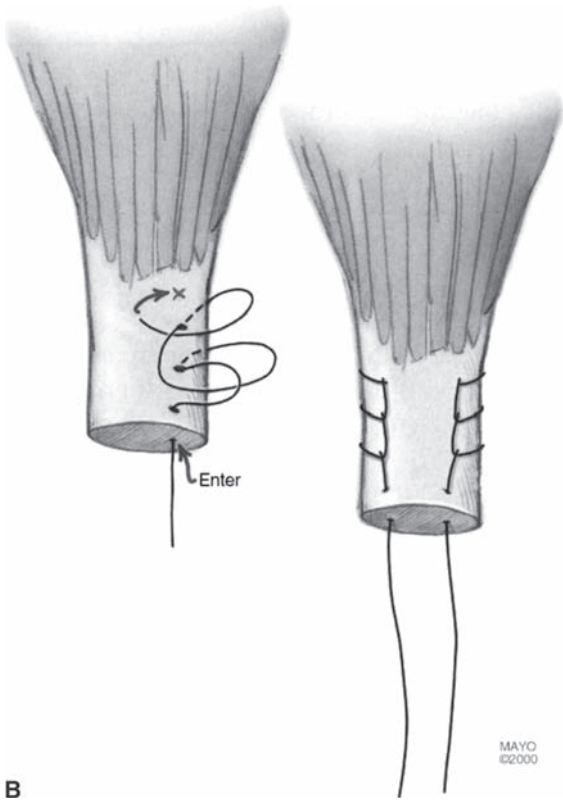


FIGURE 5.5

The tendon is identified by digital palpation and delivered through the skin incision revealing a bulbous degenerative process at the site of disruption.





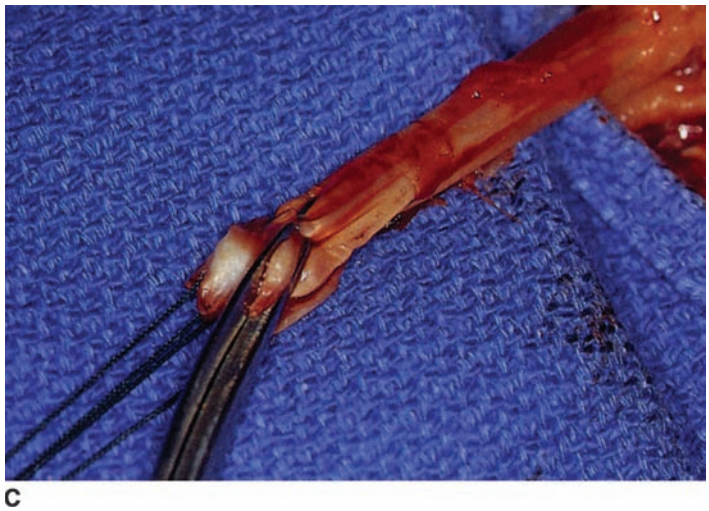
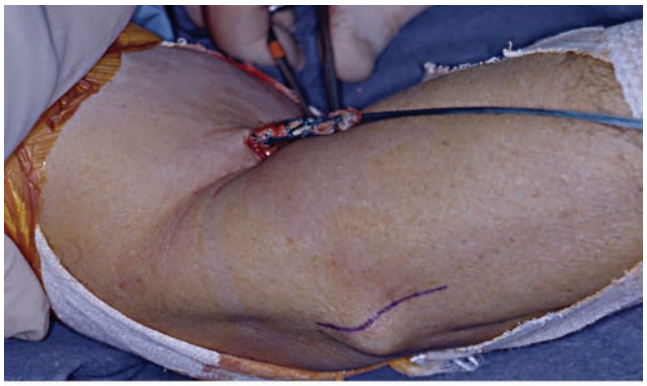


FIGURE 5.6

A–C: Two 5 nonabsorbable sutures are inserted by the crisscross Bunnell or Krakow locking technique.

Forearm Incision A curved clamp is then introduced into the tunnel previously occupied by the biceps tendon (Fig. 5.7). It is directed by palpation to and then past the tuberosity between the radius and ulna. Rotation of the forearm confirms proper position of the instrument on the ulnar side of the radius. A lead suture is grasped by the curved hemostat and is advanced until it punctures the muscle and subcutaneous tissues of the dorsal aspect of the forearm. An incision is then made over the site of prominence splitting the common extensor and supinator muscles (Fig. 5.8).



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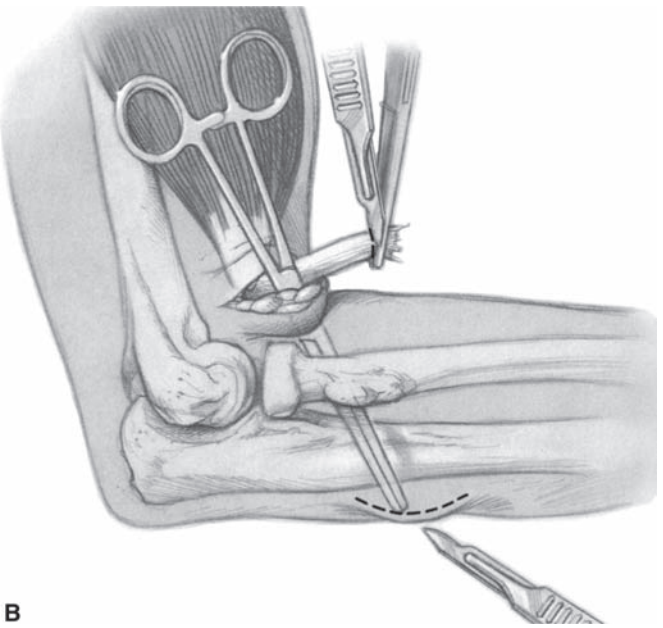
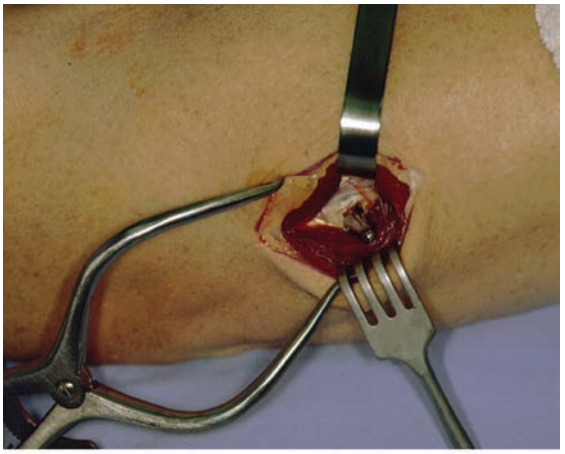


B

FIGURE 5.7

The curved hemostat is passed between the radial tuberosity and the ulna **(A)** to emerge through the common extensor muscle mass and tent the skin on the proximal posterolateral aspect of the forearm **(B).**



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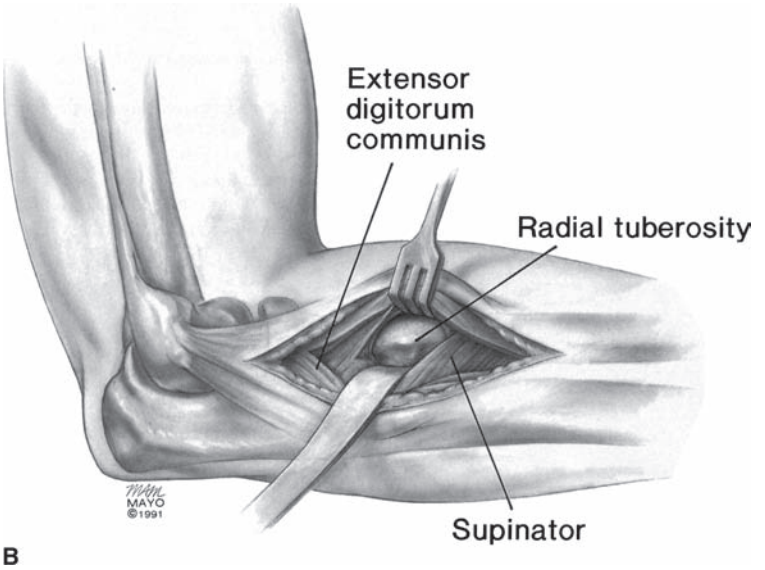

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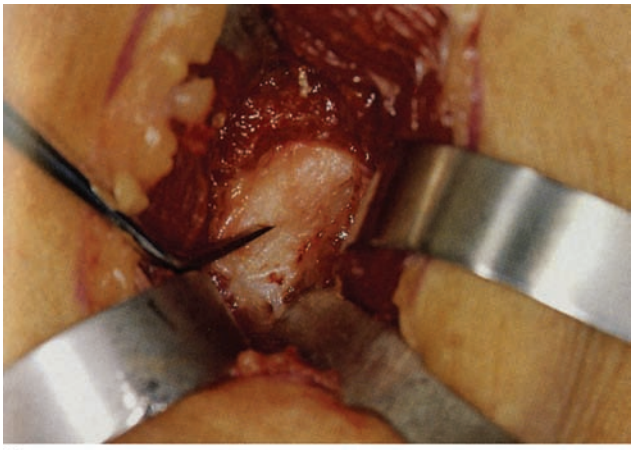


C

FIGURE 5.8

A–C: An incision is made over this prominence, the muscle is split, the forearm is fully pronated, and the tuberosity is exposed.

Tuberosity Identity and Preparation With full forearm pronation the tuberosity is identified and cleaned of soft tissue.

A high-speed burr is used to excavate the cancellous bone from the midportion of the tuberosity (Fig. 5.9). After an adequate orifice of 10 to 12 mm × 7 to 8 mm has been made to receive the tendon, the forearm is partially segmented and three drill holes are placed on the radial side of the tuberosity (Fig. 5.10). Allowing the forearm to supinate slightly brings this margin of the radial tuberosity into better alignment. The holes should be placed in such a way as to leave sufficient bone to avoid osseous rupture or pullout of the sutures (Fig. 5.11).

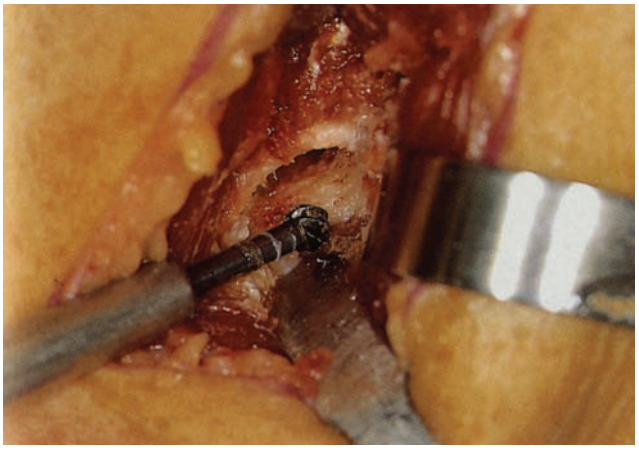
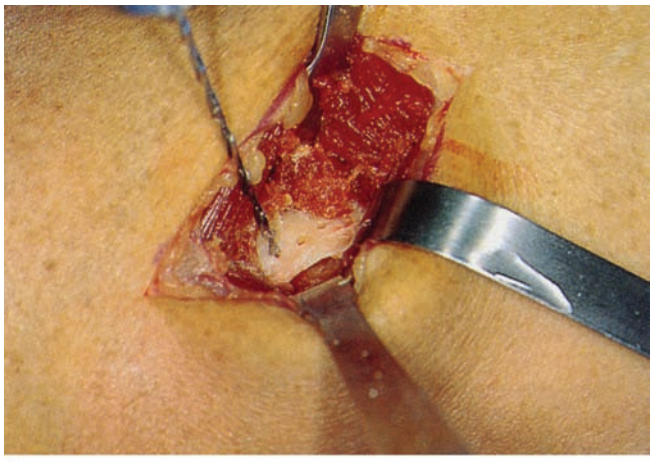
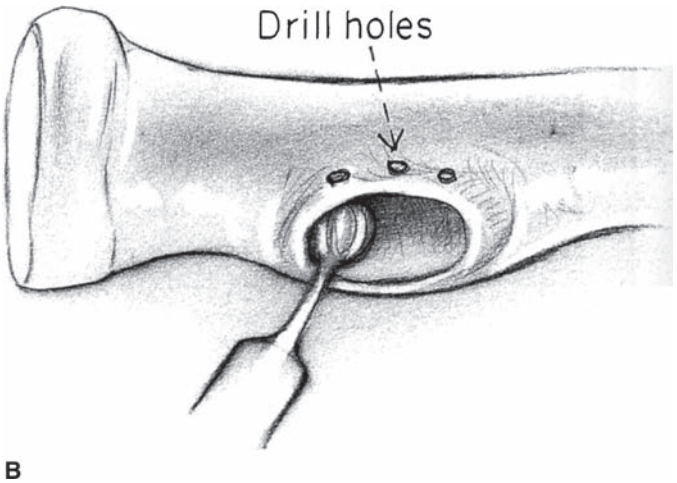


FIGURE 5.9

The greater tuberosity is excavated with a high-speed bur in such a way as to receive the distal biceps tendon.



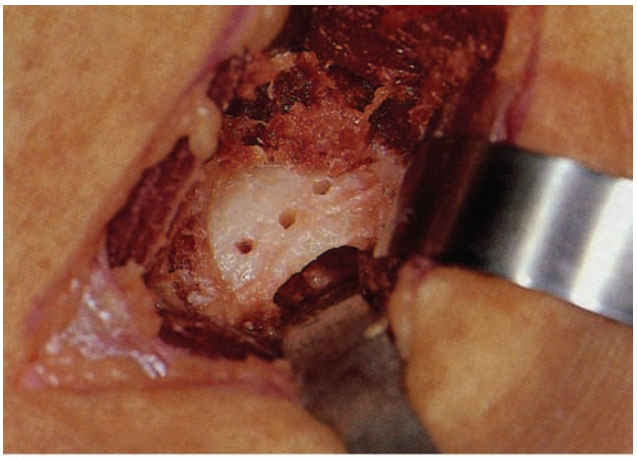
A



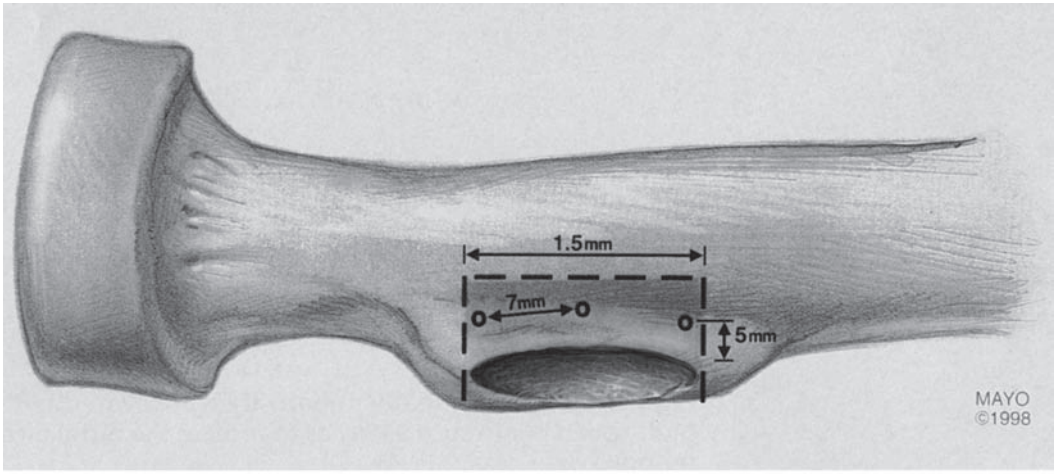
B

FIGURE 5.10

A,B: The tuberosity is prepared by releasing some of the pronation and three holes are drilled in the radial aspect of the tuberosity.



A



B

FIGURE 5.11

A,B: Care is taken to provide sufficient space between the holes to provide secure fixation in bone.

Reattachment of the Tendon The tendon is then brought through the tunnel from the antecubital space (Fig. 5.12) and drawn past the ulnar side of the tuberosity with the lead suture (Fig. 5.13). The sutures are threaded into each of the holes at the margin of the tuberosity. One suture is brought into the proximal and distal, and two into the central hole (Fig. 5.14). The biceps tendon is threaded into the tuberosity; once again this is facilitated by slightly supinating the forearm. With the arm remaining in less than full pronation, the sutures are tied (Fig. 5.15).

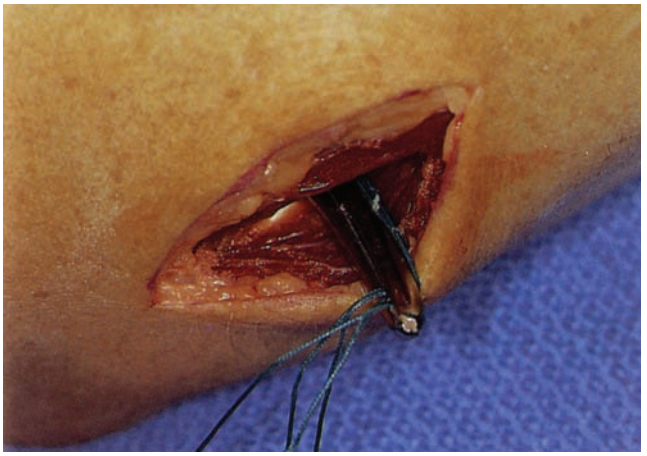
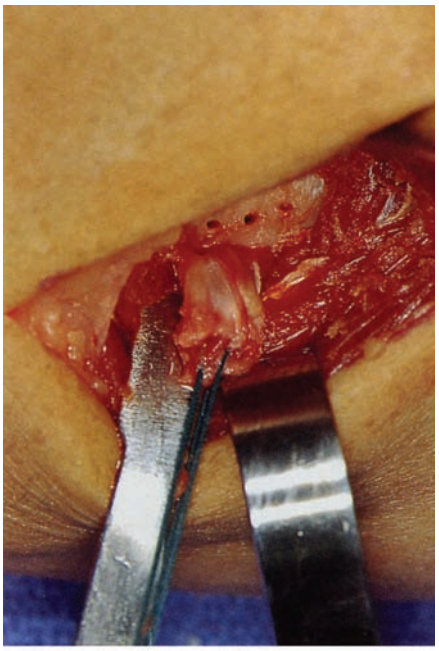
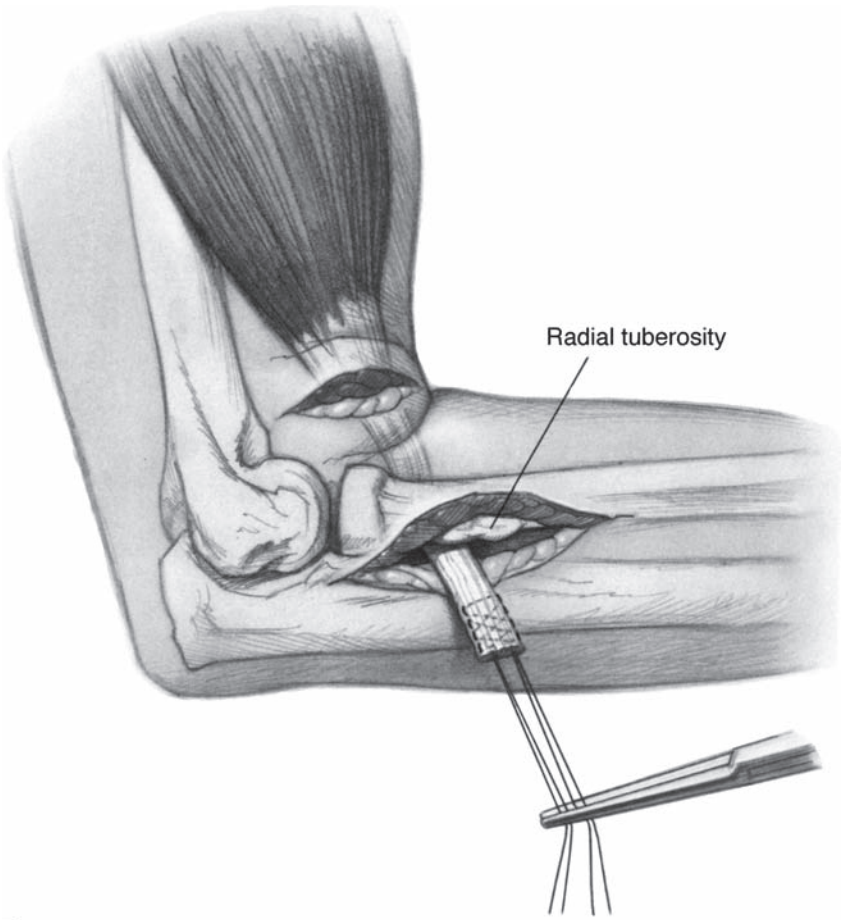


FIGURE 5.12

The sutures are grasped again with a curved hemostat and introduced through the tunnel of the biceps tendon to emerge through the forearm incision.



A



B

FIGURE 5.13

A,B: The tendon is then pulled through the forearm wound.

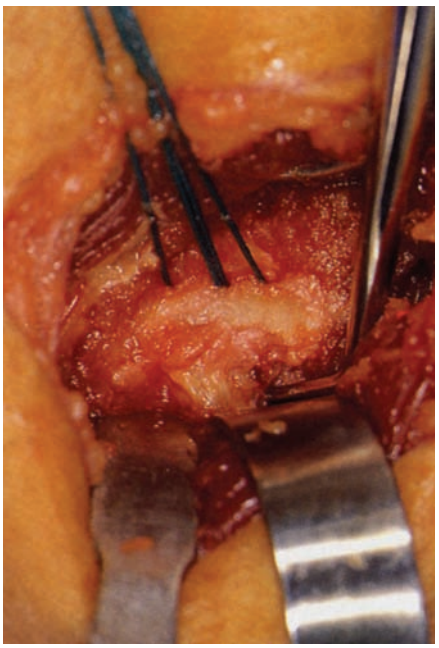
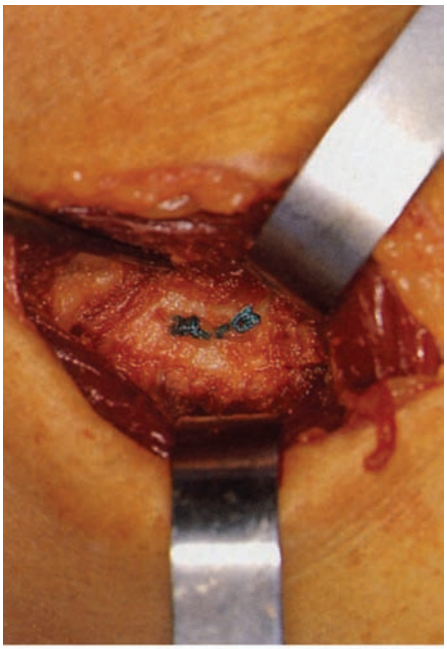
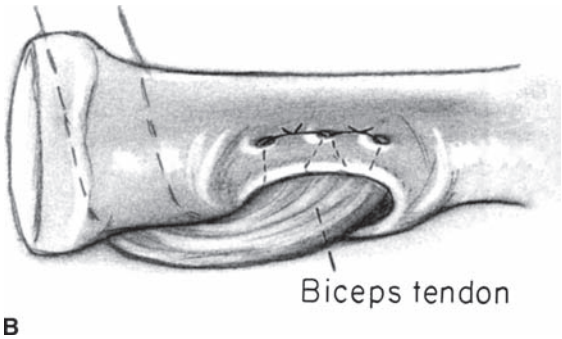


FIGURE 5.14

The distal aspect of the biceps tendon is threaded into the excavated portion of the radial tuberosity. The sutures are brought through the three holes, with the center hole used for one arm of each of the sutures.



A



B

FIGURE 5.15

A,B: The sutures are tied while the forearm is allowed to supinate slightly to facilitate this process.

Closure Pronation and supination are gently tested to assure that there is not impingement with the ulna. Extension is assessed to determine tautness for the biceps repair. The incisions are then closed in a routine fashion. At the proximal forearm, the fascia over the split muscle is closed with a 2-0 absorbable suture and a subcutaneous and skin suture of choice is used. In the antecubital space the tissues are allowed to resume their former position, a drain is left in the antecubital space, and the remainder of the wound is closed in layers as desired.

ANTERIOR APPROACHES/SUTURE ANCHORS

Suture anchors employ a Henry or modified Henry skin incision (Fig. 5.16). The radial nerve is identified at the lateral margin of the biceps muscle and followed distally to the supinator muscles (Fig. 5.17). The fascia is split and the recurrent radial artery is ligated, allowing exposure of the tuberosity (Fig. 5.18).

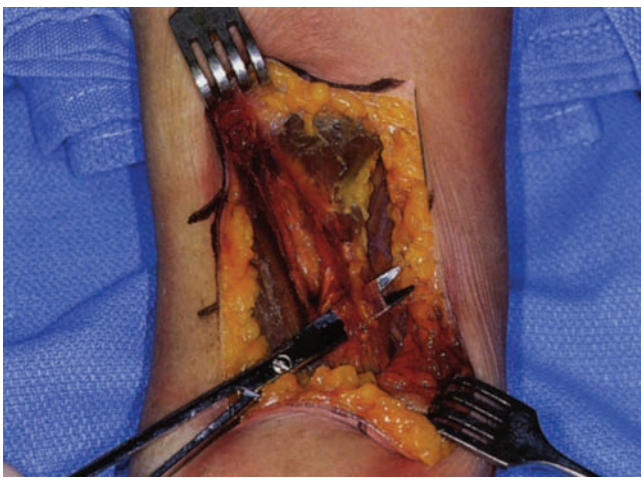


FIGURE 5.16

Many are Henry anterior exposures identifying the tendon and lacertus fibrosis. The extent of this exposure is surgeon preference.

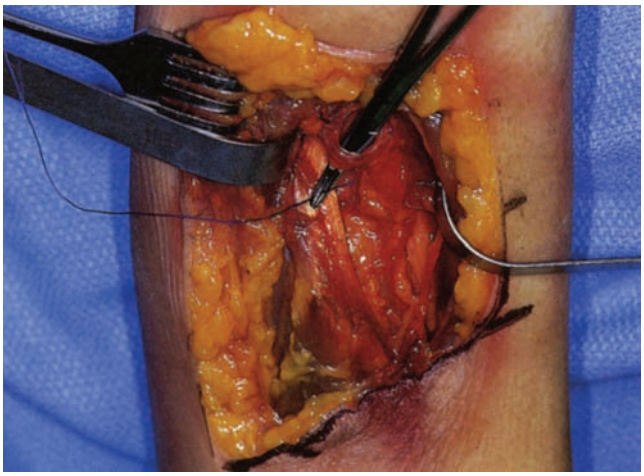


FIGURE 5.17

The radial nerve is identified emerging from the interval between the brachial radialis and lateral aspect of the biceps (above retractor). The recurrent radial artery is identified and ligated.

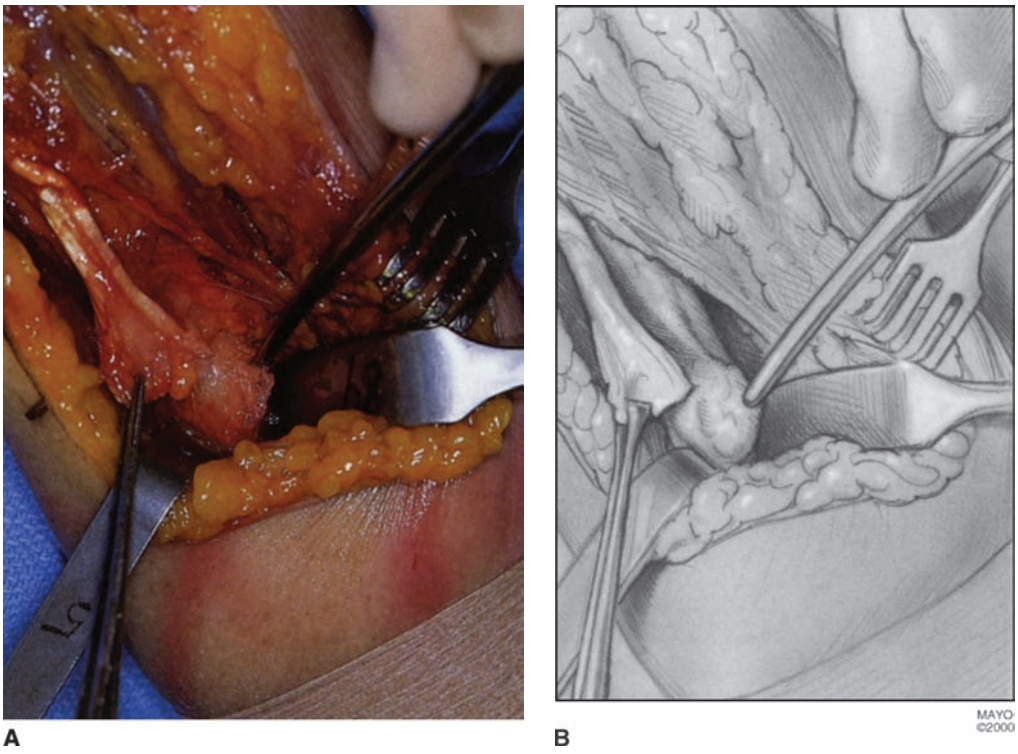


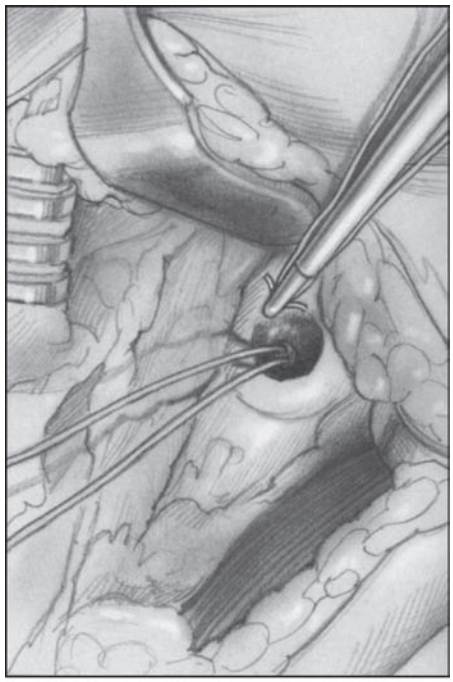
FIGURE 5.18

A,B: The tuberosity is exposed.

If a suture anchor is used, the tuberosity is excavated and two anchors are embedded in the base of the excavated bone (Fig. 5.19).

The sutures are passed through the end of the tendon and threaded proximally while the tendon is being teased distally into the prepared tuberosity bed (Fig. 5.20). The sutures are tied with the forearm in neutral rotation.

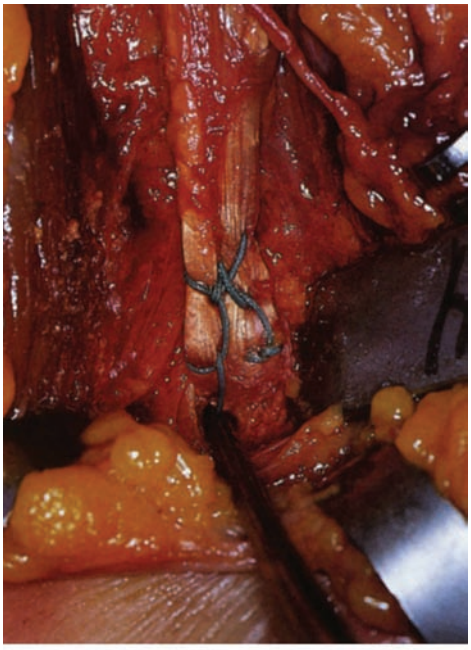
A



B

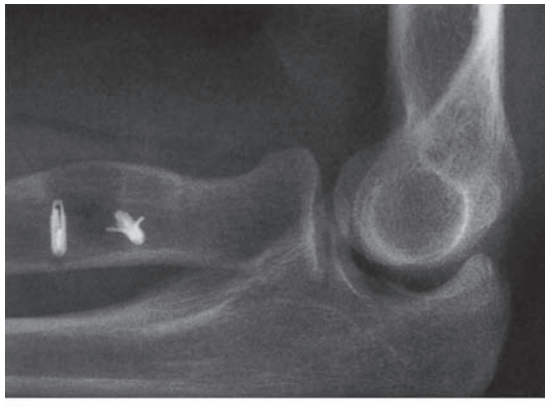
FIGURE 5.19

A,B: The tuberosity is excavated and two suture anchors are embedded in the tuberosity.



A

B



C

FIGURE 5.20

A crisscross or Krackow stitch is used to secure the tendon, which is then advanced into the tuberosity **(A)** as demonstrated radiographically **(B,C)**.

Endo Button

The endo button technique (ACUSEX, Smith & Nephew, Andover, Massachusetts) was described by Bain et al. (2) in 2000 and enjoys some popularity. The reason for this is that it clearly offers the most secure immediate fixation of any of the described techniques to date (10).

Technique

1. The bicipital tuberosity is exposed as described for the suture anchor technique above (see Fig. 16.17).
2. The forearm is fully extended and placed in maximum supination. An elliptical cortical window approximately 6 × 12 mm is made in the most medial portion of the tuberosity.

Note: Either a burr or an adequate sized drill bit may be used for this step.

3. The contralateral cortical window is achieved drilling a 2-mm guide wire, protected by a drill guide, through the tuberosity and penetrating the opposite cortex (Fig. 5.21).
4. The opposite cortex is opened with a 4.5-mm drill in order to allow the passage of the endo button (Fig. 5.22).
5. The degenerated tendon is trimmed as noted previously. The endo button is secured according to surgeon preference and connected to the tendon with a running locked stitch. A gap of 2 to 3 mm is maintained between the end of the tendon and the endo button (Fig. 5.23). This allows the endo button to tilt through the defect and engage the opposite cortex of the radius.

Note: I prefer 5 nonabsorbable suture for this step. A fiber wire may also be employed. Either a Bunnell or a whip stitch may be used in the tendon according to the surgeon's preference.

6. Two sutures of different colors are placed at either end of the endo button. These sutures should be strong enough as tension is applied to pull the endo button through the hole created in the radius for this purpose. Both sutures are threaded through a single large Keith type needle (Fig. 5.24).
7. The forearm is flexed to 90 degrees and maximally supinated. The needle is then passed through the prepared bicipital tuberosity, through the defect in the opposite cortex and then through the skin of the dorsal forearm (Fig. 5.25).

Note: The needle is directed in a more ulnar direction but it should not touch the ulna. This lessens the likelihood of injury to the posterior interosseous nerve.

8. Using the color code, the lead suture is tensioned to deliver the endo button through the radial defect. Tension is then placed on the trailing suture in order to flip the end button and prevent it from passing back through the dorsal surface of the radius (Fig. 5.26).

Note: Intraoperative confirmation can be done with fluoroscopy (Fig. 5.27). The sutures are then pulled through the skin and closure is routine.

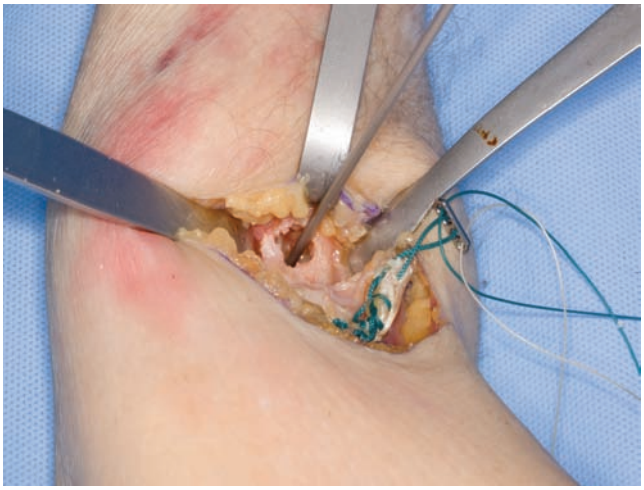


FIGURE 5.21

Endo button. A 2-mm pin is drilled into the cortex opposite to the tuberosity.

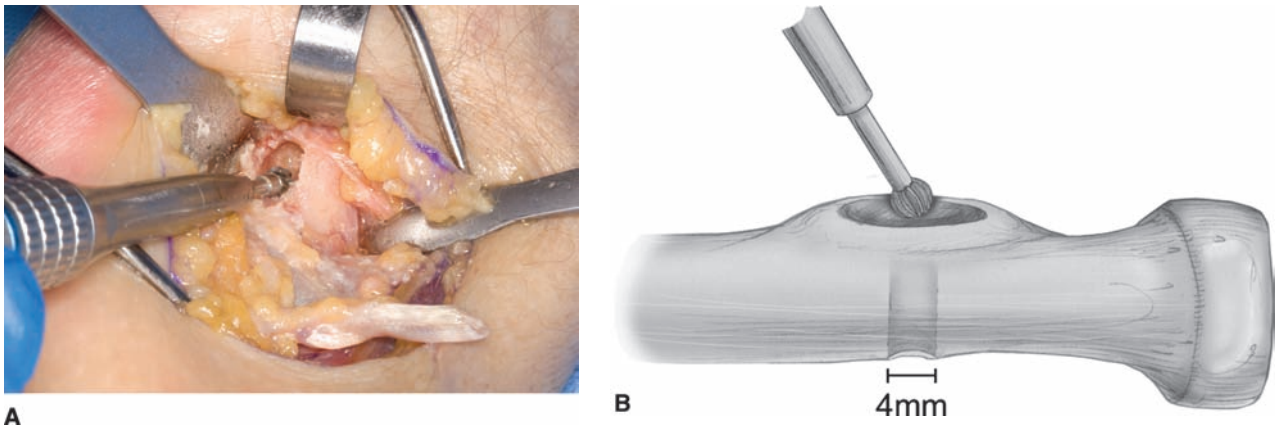


FIGURE 5.22

The opening is enlarged at the entrance of the tuberosity with a 4.5-mm drill bit or a burr **(A,B)**.

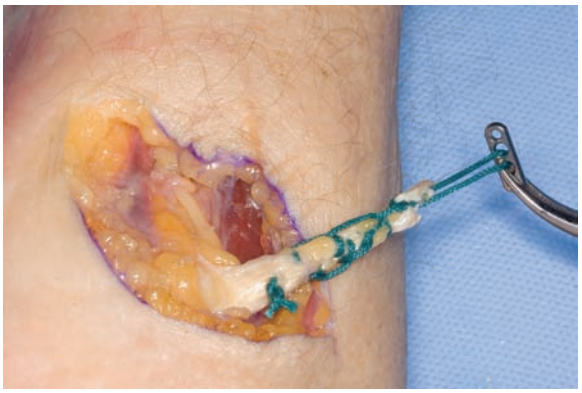


FIGURE 5.23

A running locked stitch begins proximally and includes the endo button. Care is taken to allow 4 to 5 mm space between the tendon and button for its deployment through the window in the radial cortex.

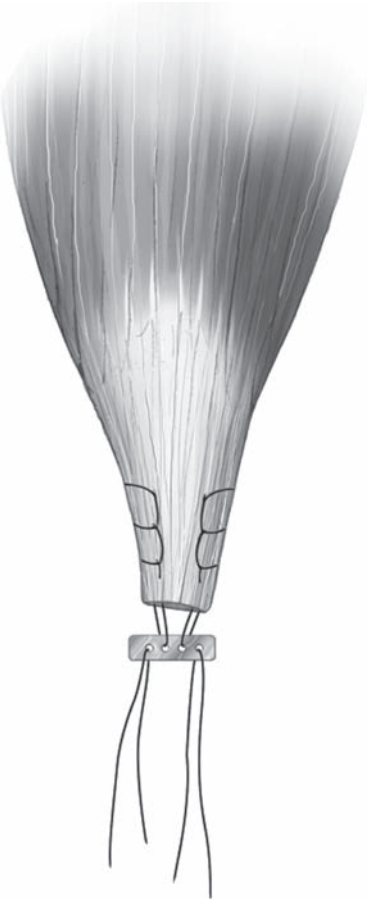
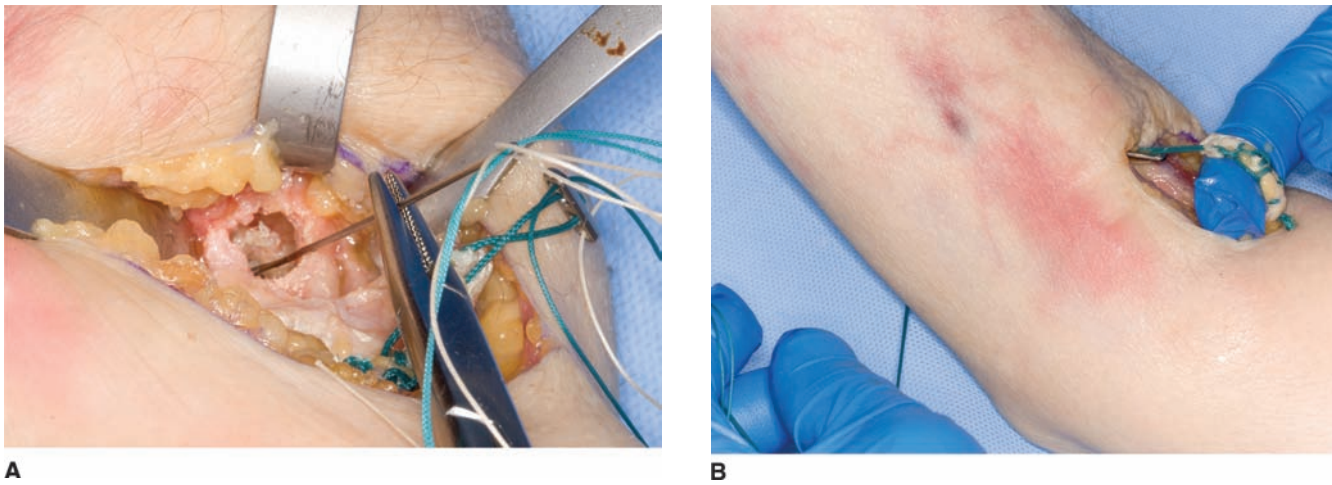


FIGURE 5.24

Lead sutures of opposite colors are threaded through each marginal hole and through the eye of a Keith needle.



A B

FIGURE 5.25

In 90 degrees of flexion, the needle is passed through the tuberosity **(A),** out the opposite cortex, and penetrates the skin **(B).**

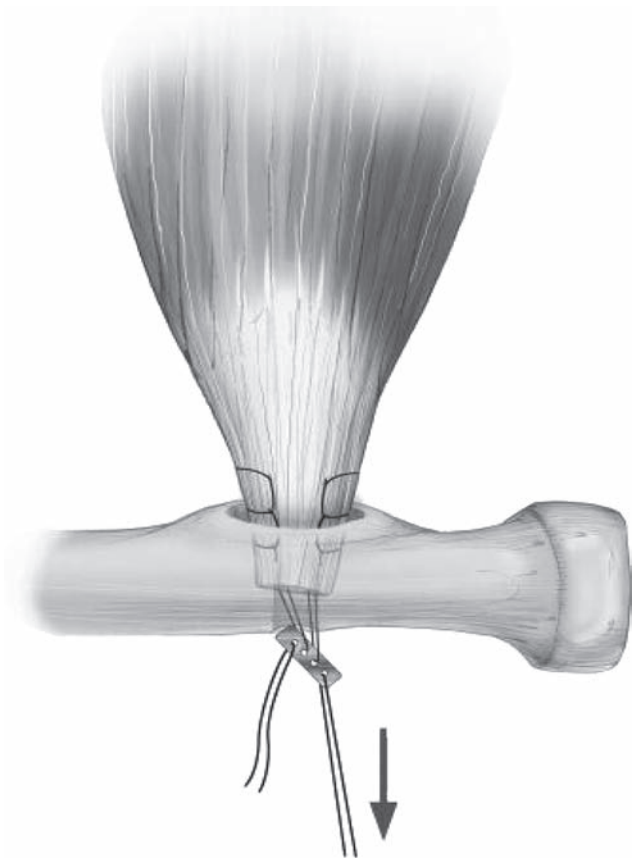


FIGURE 5.26

The button is deployed first by pulling on the lead suture, purple, and secured by pulling on the white "flip" suture.

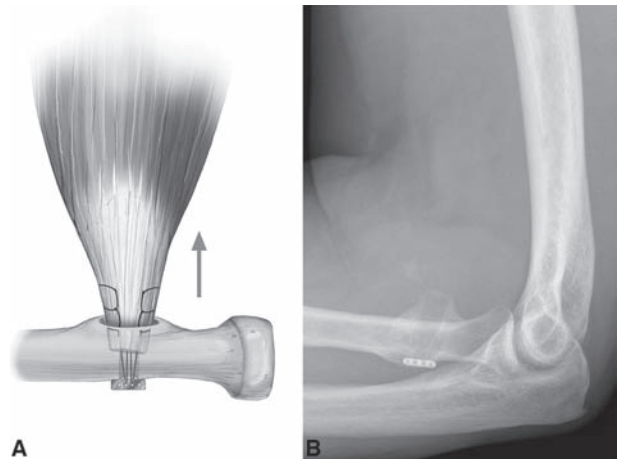


FIGURE 5.27

Proper development **(A)** confirmed by radiograph **(B)**.

Incomplete Distal Biceps Tendon Rupture This is a relatively uncommon problem (4). The important features are that the tendon once partially torn, in the author's experience, does not heal, and hence surgery will be required (4). This is especially true in the athlete. The second major point is that remnants of the tendon cannot be sutured to bone but rather the partial rupture must be completed surgically, the degenerative tissue trimmed and then the tendon reattached into the tuberosity. The one important feature from a technical standpoint is since the tendon still is attached to the tuberosity, one can potentially retrieve the tendon by the single dorsal incision over the forearm as is described below. Otherwise, any of the techniques above are used to reattach the tendon once the remaining fibers have been surgically released.

Surgical Technique: Partial Tendon Rupture Position. As in many of the previous techniques, we employ the supine position with the arm brought across the chest.

Incision

1. A 5-cm incision is made over the forearm similar to the second incision that is made in the two-incision technique (Fig. 5.28).
2. The author prefers to palpate the interval between the anconeus and the extensor carpi ulnaris to assure that this incision is well anterior to the ulna (Fig. 5.29).
3. The extensor muscle mass and supinator are split until the tuberosity is palpated.
4. In most instances, the remaining fibers are those most proximal in the wound. A 0 nonabsorbable suture is placed in the tendon to prevent its retraction and the remaining fibers of the biceps tendon are released from the tuberosity (Fig. 5.30).
5. The soft tissue is cleared from the tuberosity and the arm is brought into maximum pronation.

Note: Bursal reactive tissue is commonly encountered with this step and may be quite extensive (Fig. 5.31).

6. The biceps tendon should be able to be brought fully into the wound sufficiently to allow first the trimming of the degenerative end and second placement of the sutures as noted in the steps above (Fig. 5.32). At this juncture, the preparation of the tuberosity is as shown above for the two-incision technique (Figs. 5.33 and 5.34). The placement of the sutures and the securing of the tendon are identical.

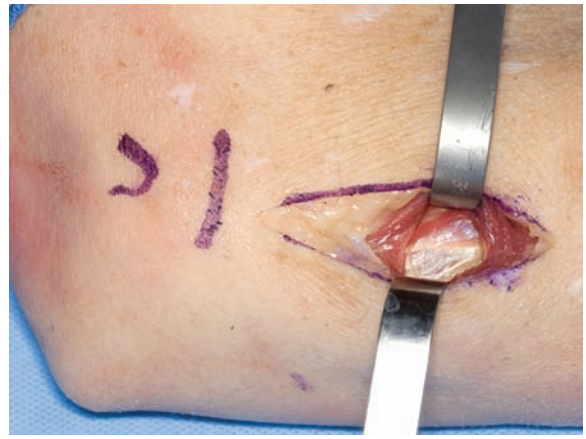


FIGURE 5.28

A 5-cm incision is made over the dorsal lateral proximal forearm beginning about 2.5 cm from and extending on a line distal to the lateral epicondyle.

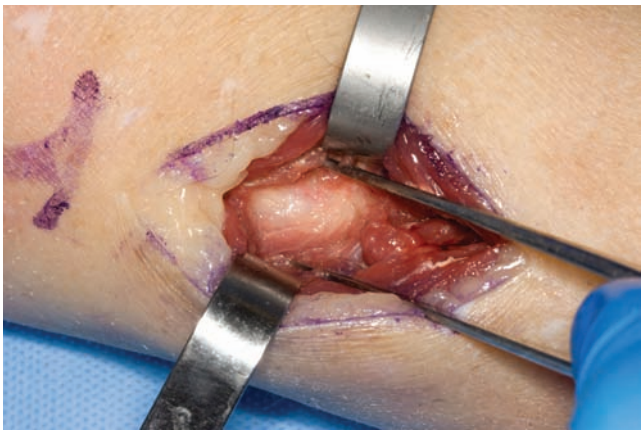


FIGURE 5.29

Palpation with the arm in free pronation provides the location of the radial tuberosity.

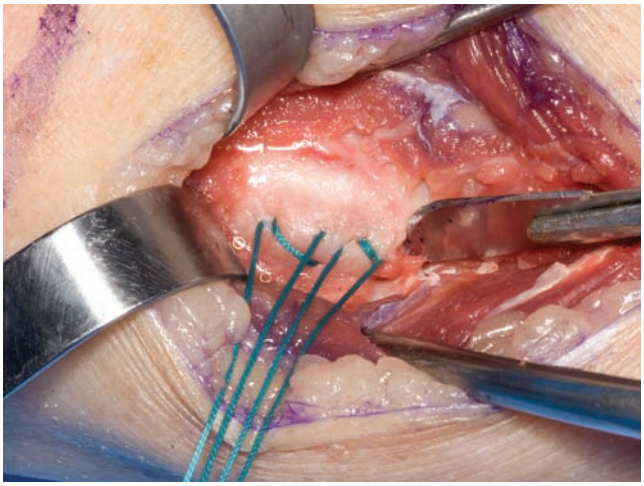


FIGURE 5.30

Two 0 sutures are placed in the portion of the tendon still attached to the tuberosity.

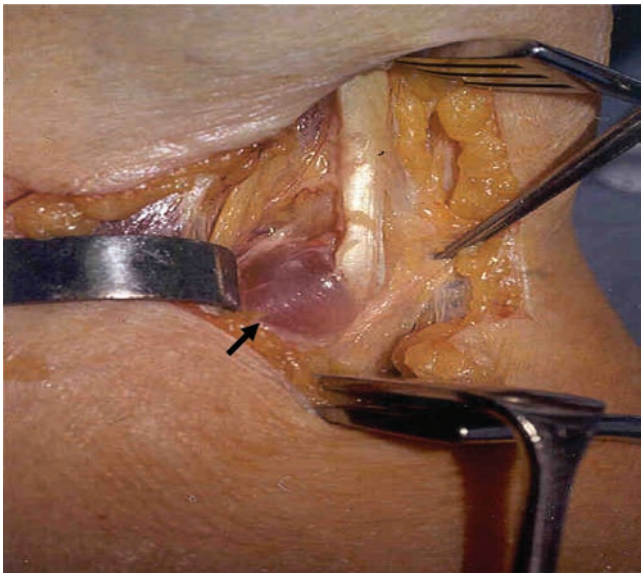


FIGURE 5.31

In some instances, extensive reaction occurs around the distal tendinous attachment, as shown by *arrow.*

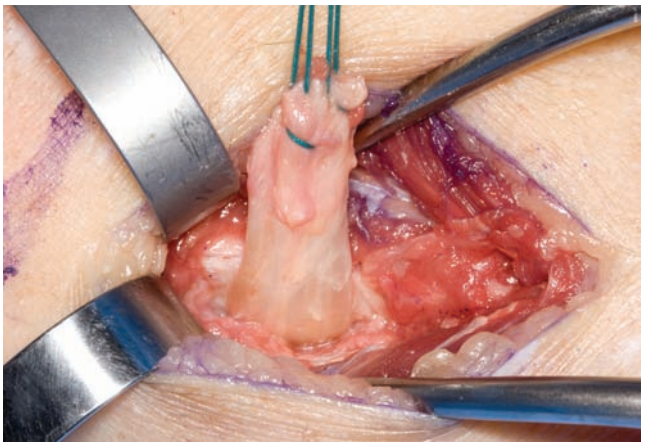


FIGURE 5.32

The tendon is released and drawn into the wound.

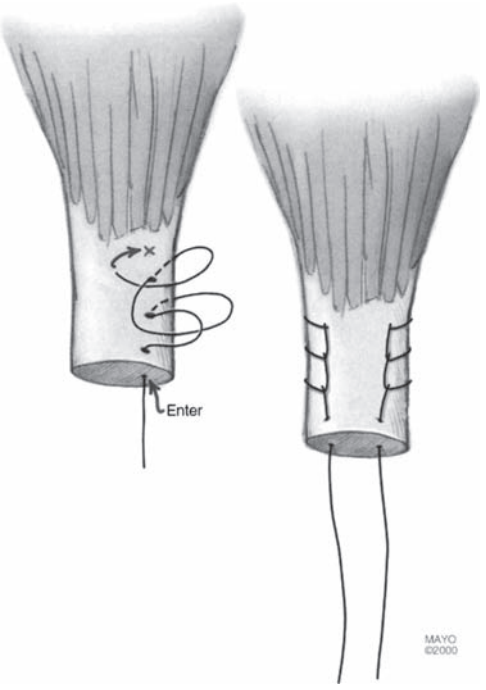


FIGURE 5.33

Two securing locked sutures are placed in the distal tendon after it has been trimmed.

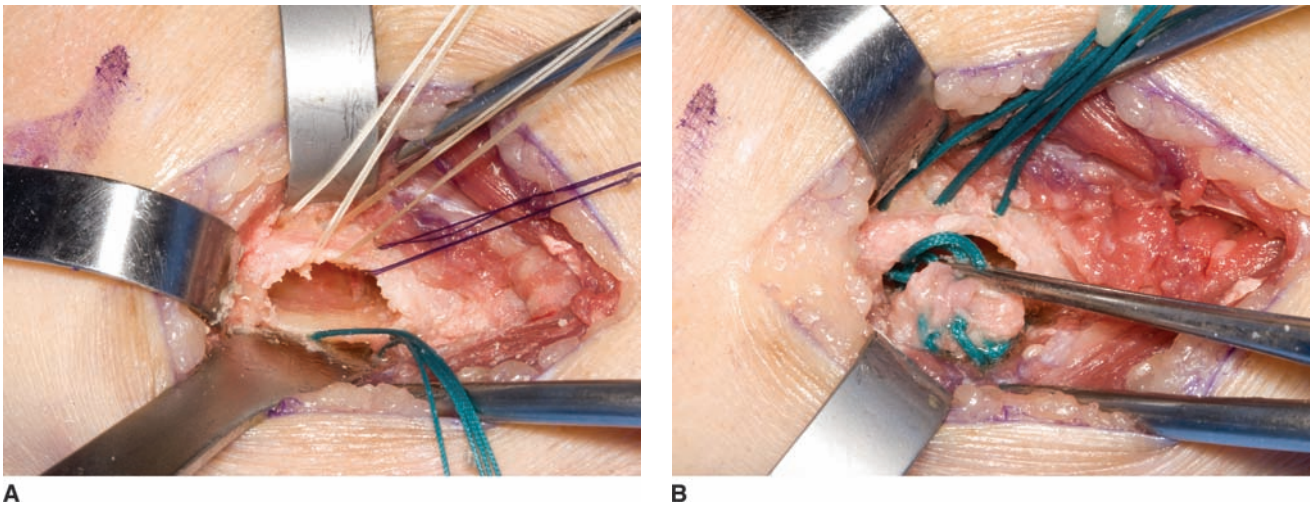


FIGURE 5.34

Lead sutures are placed in the excavated tuberosity **(A)** and the tendon is drawn into the prepared tuberosity **(B).**

RESULTS

The results of virtually all of the reattachment techniques have been exceptionally good. In general, patients may be advised that there is a 90% chance of restoring more than 90% of normal function. In the majority of instances, patients will have essentially a normal elbow. The two reasons to prevent this is the development of ectopic bone or a radial nerve palsy (3,14,16,20).

DELAYED RECONSTRUCTION

Frequency of delayed reconstruction appears to be slightly increasing in recent years. However, we have discontinued preserving the fleck of calcaneus and simply embed the allograft tendon as noted below.

When the tendon has retracted to the point that it cannot be reattached directly to the tuberosity, augmentation with an Achilles tendon allograft is our technique of choice. Of note, and as noted above, if the host tendon can be attached with the elbow at 90 degrees, this is preferable to reconstruction. The 90-degree contracture will stretch out to near normal extension with time and function is excellent.

Technique: Achilles Tendon Allograft

1. The exposure is more extensive as the biceps muscle belly must be exposed (Fig. 5.35).
2. After it is determined that the biceps tendon is inadequate for reattachment (Fig. 5.36), the tuberosity is exposed by blunt and sharp dissection as needed and the curved hemostat identifies the site of the forearm incision (Fig. 5.37).
3. The tuberosity is exposed and excavated as described above (Fig. 5.38).
4. A 5 nonabsorbable suture is placed in the allograft tendon as in the acute rupture.
5. The tendon is then threaded from the anterior exposure into the forearm incision (Fig. 5.39).
6. This is inserted into the tuberosity and secured through the holes in the tuberosity (Fig. 5.40).
7. With the elbow at about 80 to 90 degrees of flexion, the Achilles fascia is secured around its margin to the biceps muscle which has been retracted distally as much as possible to develop appropriate resting tension (Fig. 5.41).

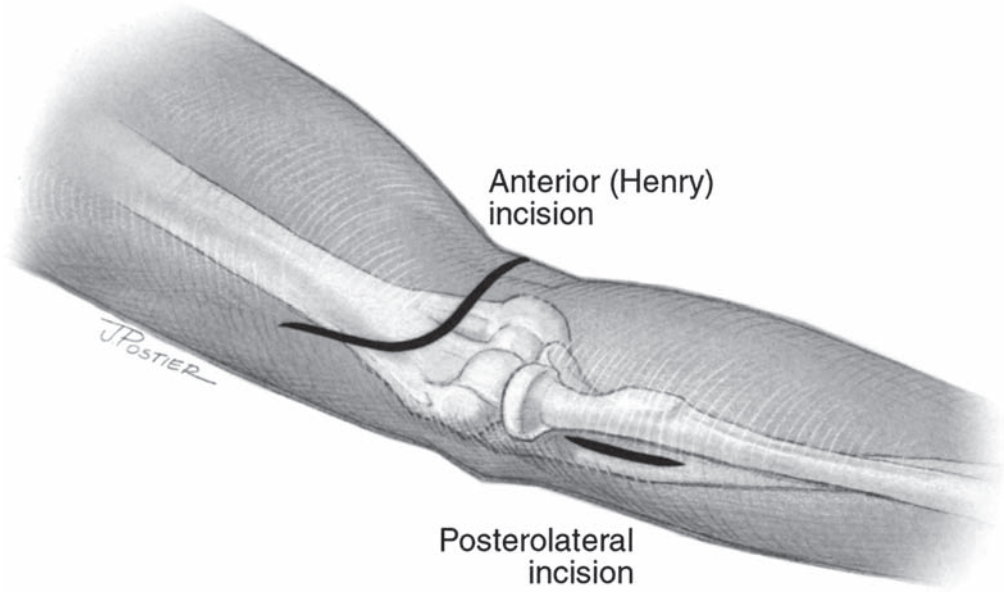


FIGURE 5.35

The two-incision technique is used and employs a Henry-type incision in the antecubital space and a 4-cm incision over the posterolateral aspect of the proximal forearm. The anterior incision is extended as needed to expose the biceps muscle.

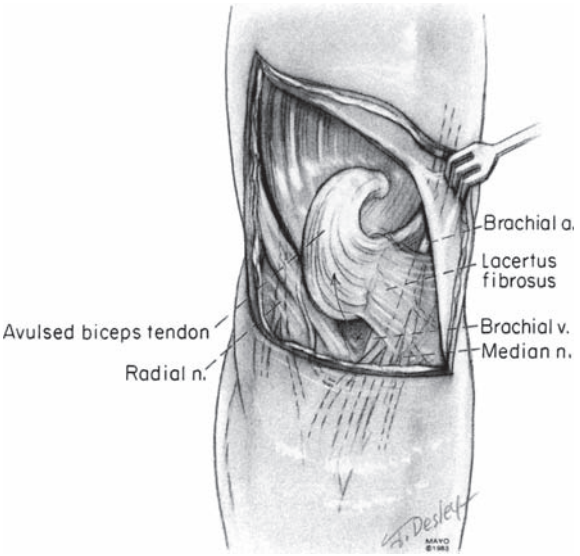
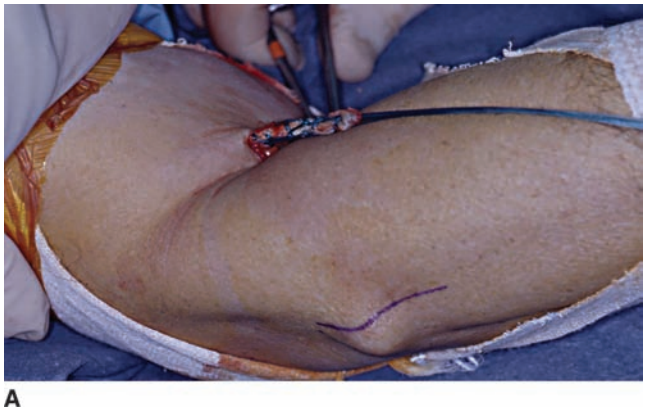
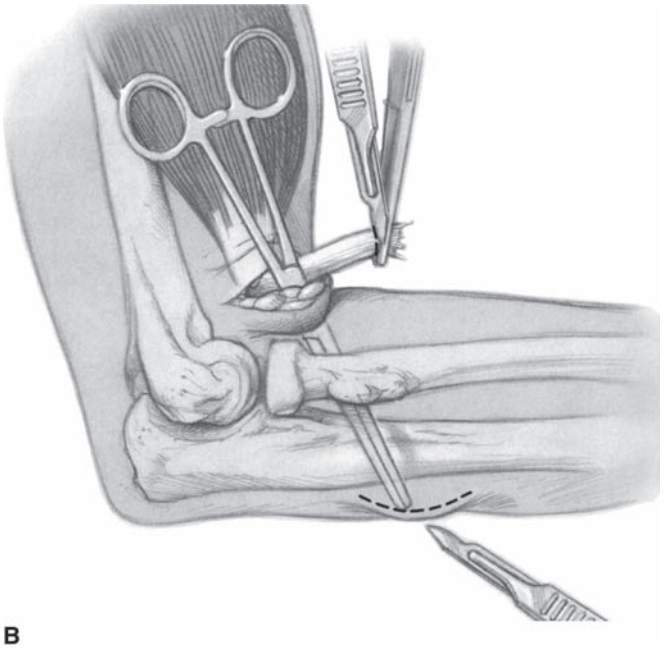


FIGURE 5.36

The tendon usually has recoiled and is of variable length, but the biceps stump is adequate to secure to the tendon allograft.



A



B

FIGURE 5.37

A,B: A more detailed dissection in the anticubital space is required to identify the radial tuberosity. Then, a curved hemostat is passed between the radial tuberosity and the ulna to emerge through the common extensor muscle mass and tent the skin on the proximal posterolateral aspect of the forearm as is done for acute injuries.

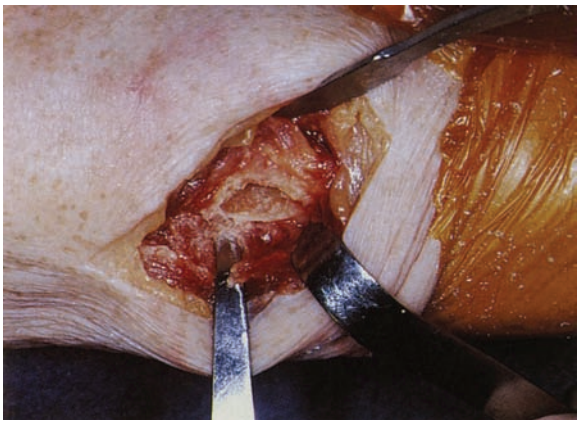


FIGURE 5.38

The exposure and preparation of the tuberosity is identified to that described above for acute injuries.

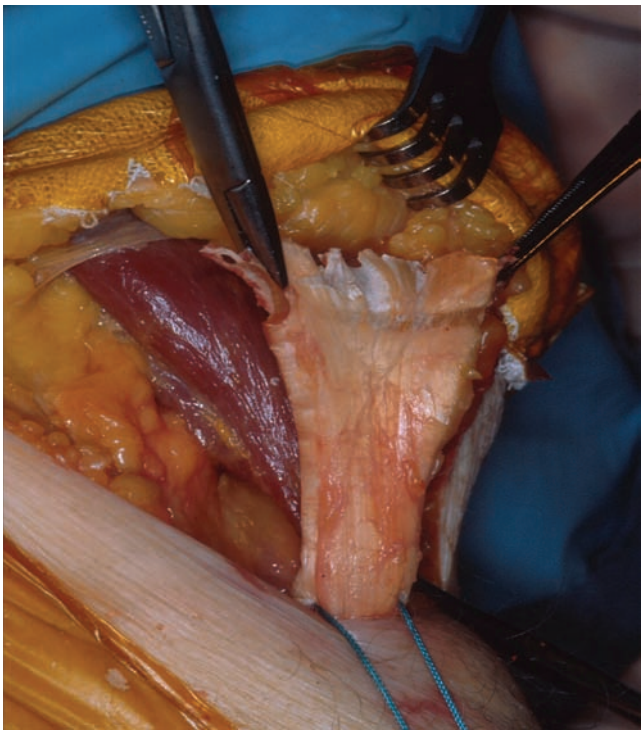


FIGURE 5.39

The Achilles tendon allograft is inserted from the anterior incision to emerge through the forearm incision.

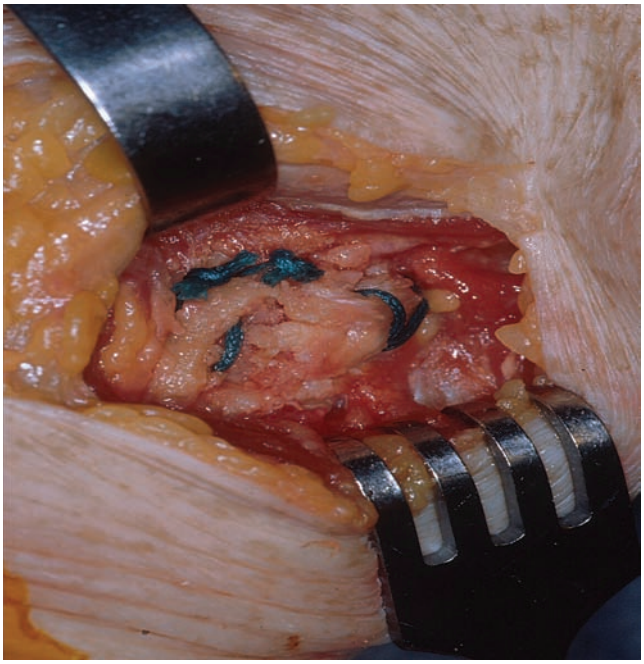


FIGURE 5.40

The tendon is inserted into the tuberosity and secured with sutures placed through the margin of the tuberosity in the acute injury.

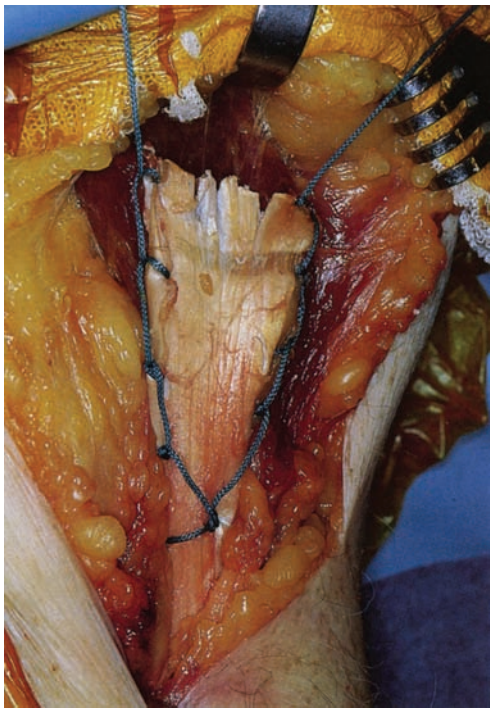


FIGURE 5.41
With the elbow at 80 to 90 degrees of flexion, the biceps muscle is "enveloped" with the achilles fascia.

POSTOPERATIVE MANAGEMENT

Acute Repair

The patient is placed in a posterior splint with the elbow in 90 degrees of flexion and the forearm in neutral rotation. This is kept in place for 3 to 7 days.

At 1 week or less the posterior splint is removed and gentle passive flexion is allowed. Active extension to 30 degrees is allowed and encouraged from the first week after surgery. Full extension is allowed as tolerated and generally attained by the third week. Four weeks after surgery, the patient is allowed to flex and extend against gravity as able. At 6 weeks a gentle flexion strengthening program is allowed starting with 1 kg. Activity as tolerated is permitted at 3 months. Full activity without restriction is allowed 6 months after surgery.

Note: This program is also effective if elbow flexion is required for reattachment. The time frame is adjusted according to patient progress.

Allograft Reconstruction

The program is delayed somewhat when an allograft is used. The patient is protected for 3 weeks. Passive assisted motion is begun at 3 and continued to 6 weeks. Full extension is avoided until the sixth week. Active motion for activities of daily living is allowed at 6 to 12 weeks. Activity as tolerated progresses from the fourth to the eighth month.

RESULTS

Regardless of technique, the results of immediate reattachment of the tendon are very good. Studies have shown virtually 100% improvement for restoration of flexion and supination strength (1,3,11,15,17). Loss of motion is not seen and we have observed only one rerupture after an acute repair. Although popular, the clinical experience with suture anchors is limited. To date, what data are available reveal no problems from several combined sources (6,14,21–23). Laboratory studies, however, reveal a statistically significant ($p < 0.01$) greater initial strength with the transosseous holes than suture anchor. The endo button technique has been shown to provide the best, most secure initial fixation of any of these techniques. Clinically all techniques described are reported as effective.

COMPLICATIONS

There are two major complications associated with this procedure: radial nerve injury and ectopic bone formation. Rerupture is uncommon. Radial nerve injury has been reported and may be seen as often as 5% after distal biceps tendon reattachment through anterior modified Henry approach (5,11). Ectopic bone is a recognized complication of the two-incision technique and bridges the proximal radius and ulna (Fig. 5.42). This, however, can be minimized or avoided not by exposing the periosteal surface of the ulna with the forearm incision (Fig. 5.43), but rather splitting the muscle fibers as the tuberosity is exposed (Fig. 5.44) (7).

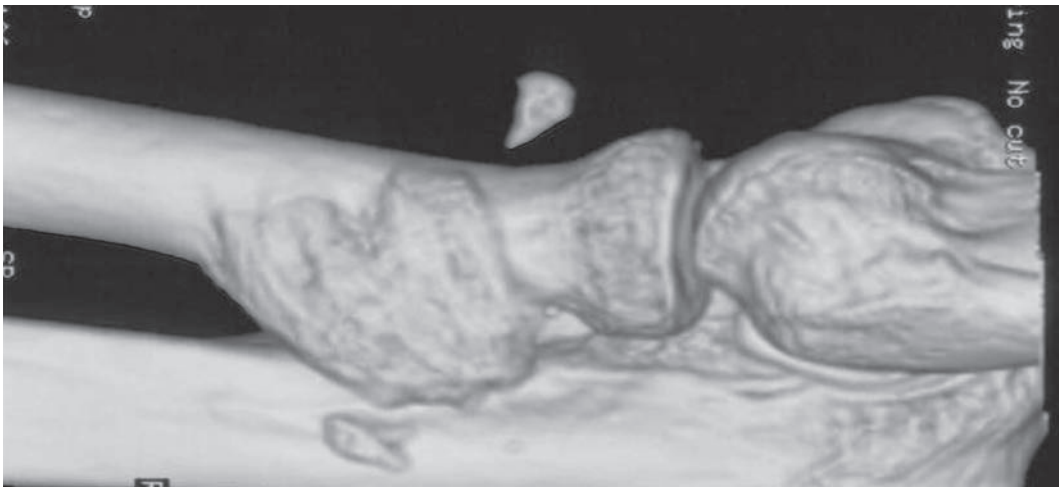


FIGURE 5.42

Ectopic bone bridging the proximal ulna and radius. The exposure of the radial tuberosity was across the periosteal surface of the ulna.

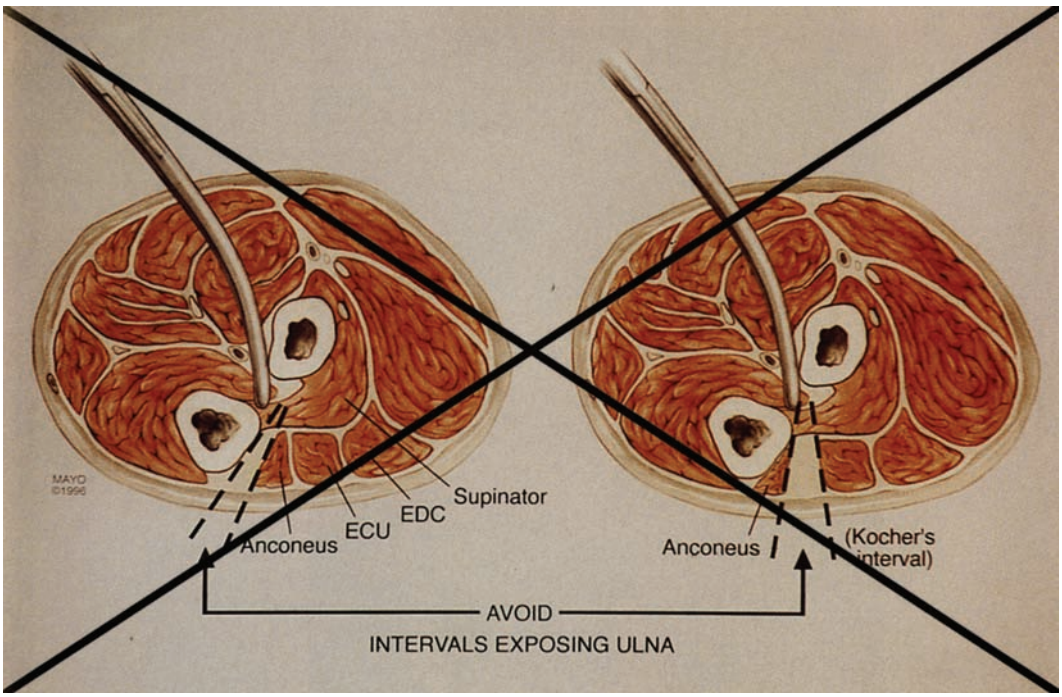


FIGURE 5.43

The forearm incision should not be through Kocher interval or otherwise expose the periosteal surface of the proximal ulna.

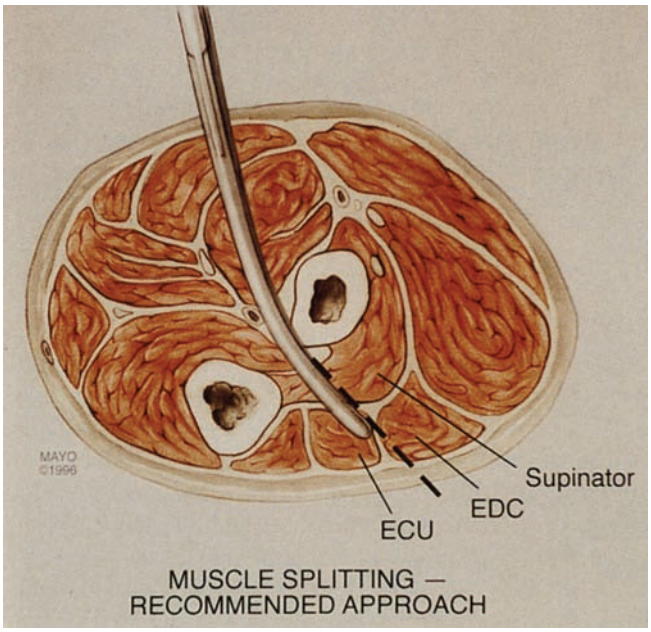


FIGURE 5.44

The forearm incision is a muscle-splitting approach.

If a synostosis occurs, it significantly limits function. After at least 6 months or when the radiograph demonstrates maturity, the osseous bar may be resected. The exposure is generally through the previously used forearm incision. Care should be taken during the exposure to avoid excessive retraction on the supinator muscle, which may injure the posterior interosseous nerve. Occasionally, the reattached biceps tendon itself is involved in the ectopic bone. In this instance the tendon may be released during the ectopic bone removal (Fig. 5.45) and is then reattached at the end of the excision.

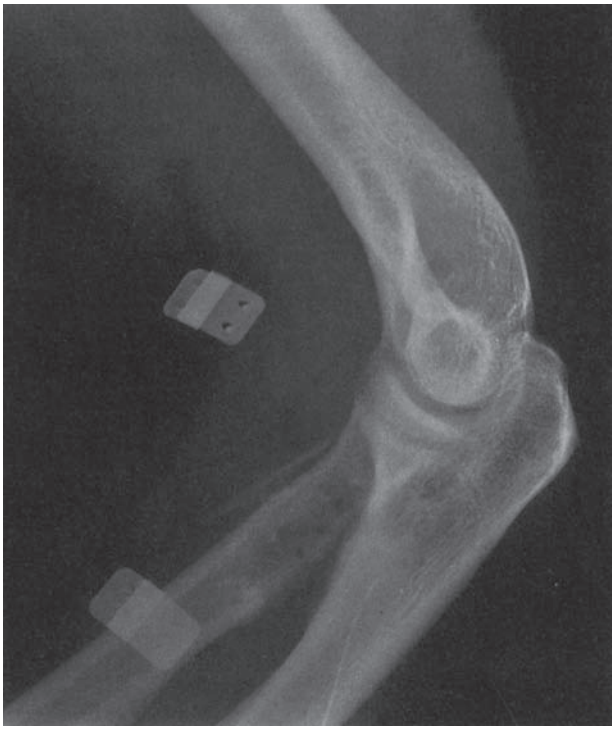


FIGURE 5.45

Removal of the ectopic bone restores functional forearm rotation in most patients. In this instance (Fig. 5.42), the tendon insertion was involved and required reattachment.

MAYO EXPERIENCE

Our original experience was quite favorable with virtual 100% return of function in 90% of patients (Morrey). More recently, assessment of nine patients who were not treated revealed a mean flexion torque of 26 nm compared to the uninjured torque of 41 (37% reduction). Supination torque was 4.5 in the involved and 8.3 in the uninvolved (46% reduction) (18). The Mayo experience was further reported with a focus on complications after 88 procedures by Kelly et al. Overall the satisfactory rate was over 90%. One rerupture occurred in a patient requiring active use with wheelchair transfer the day after surgery. No synostosis occurred after 74 Mayo modified two-incision approaches. Of note is that the rate of complication doubles ($p < 0.05$) if a delay to repair is >21 days (9).

We have also recently reviewed our experience with resecting the osseous bridging in 12 cases referred to Mayo for management. In this sample, at a mean of 6.7 years after surgery, all 12 were pain free with excellent strength and averaged 122 degrees of pronation and supination (12).

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6 Triceps Tendon Repair and Reconstruction in the Athlete

Bernard F. Morrey

Fortunately, triceps tendon dysfunction is not common in the athlete but if present it occurs most frequently in serious power lifters and body builders (8,10,14), football players and other athletic endeavors and anabolic steroids used as a strength enhancement have been implicated. The injury has much more variation in the pathoanatomy than distal biceps injury, with the failure occurring at the central tendinous attachment with or without osseous avulsion (6) at the musculotendinous fixation or even in the muscle belly itself (1,11,14,15,17). The important characteristic of this tendon injury is that an immediate repair is the treatment of choice; however, unlike the biceps tendon, the duration of recovery is more prolonged. In our experience, it is similar to a medial collateral ligament reconstruction at the elbow and may take a full year to completely recover. Once again, this is unlike the distal biceps tendon avulsion, a condition which usually is normally functional at 6 months. We will discuss both acute repair and delayed reconstruction in this chapter.

DIAGNOSIS

The diagnosis of tendon injury is usually not difficult. The problem in making a decision regarding intervention is that some residual strength is almost always present. This is because the anconeus and its attachment to the lateral triceps aponeurosis are rarely included in the injury. An associated ulnar nerve stretch has also been reported (with this injury in a power lifter) (5,8).

Today imaging modalities have significantly improved our ability to diagnose triceps injury and to characterize the extent of the pathology (7,18). The diagnosis is more difficult than at the distal biceps tendon rupture since lateral continuity with the anconeus often preserves some extension strength. The radiograph showing an avulsion of the osseous attachment is pathognomonic but an uncommon finding as is the classic dimpling of the skin proximal to the olecranon (Fig. 6.1). Today MR imaging can and should be used to confirm the diagnosis especially if any doubt exists (Fig. 6.2). The common central slip ruptures do well if repaired acutely, but do less well if repaired or reconstructed at a later date.

Acute Rupture/Repair

Indications

1. An acute rupture exhibiting functional extension weakness or fatigue pain and weakness in a patient who requires extension strength (this includes almost everybody)
2. Failure to regain extensor strength after several weeks of nonoperative management
3. Persistent pain, even if strength is not a major complaint

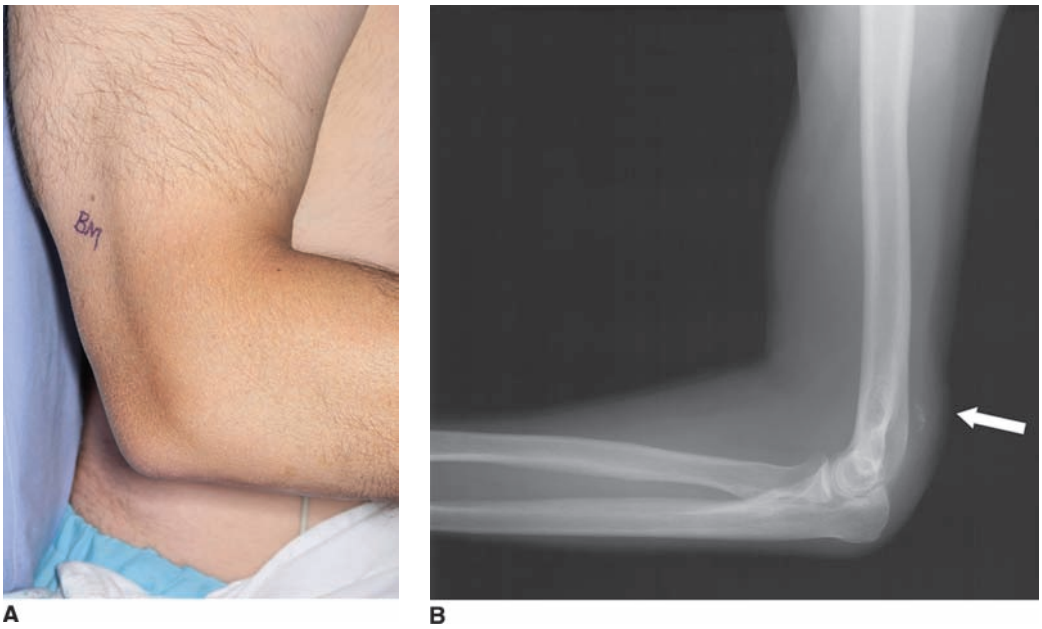


FIGURE 6.1

The clinical finding of a dimple or deficiency at the site of attachment is a valuable but uncommon finding **(A).** An x-ray with bone fleck signifying triceps avulsion is also helpful but it likewise is an uncommon finding **(B).**

Contraindications

1. Few, if the patient is symptomatic and if the diagnosis has been accurately made
2. Willingness to perform rehabilitation
3. Ongoing or generalized enthesopathy and morbidity that will not be addressed by triceps reconstitution

Surgical Technique

1. Position. The patient is placed supine on the operating table. The arm is prepped and draped but the tourniquet is not inflated.
2. Incision. A straight posterior skin incision is made and centered just medial to the tip of the olecranon (Fig. 6.3). The dissection carries through the triceps fascia and the defect is identified. In most instances, the avulsion is from the central tendinous attachment to the olecranon. The triceps disruption is mobilized.
3. Cruciate drill holes are placed in the proximal ulna (Fig. 6.4).
4. A 5 nonabsorbable suture is introduced from distal to proximal and enters the torn portion of tendon at its torn surface.

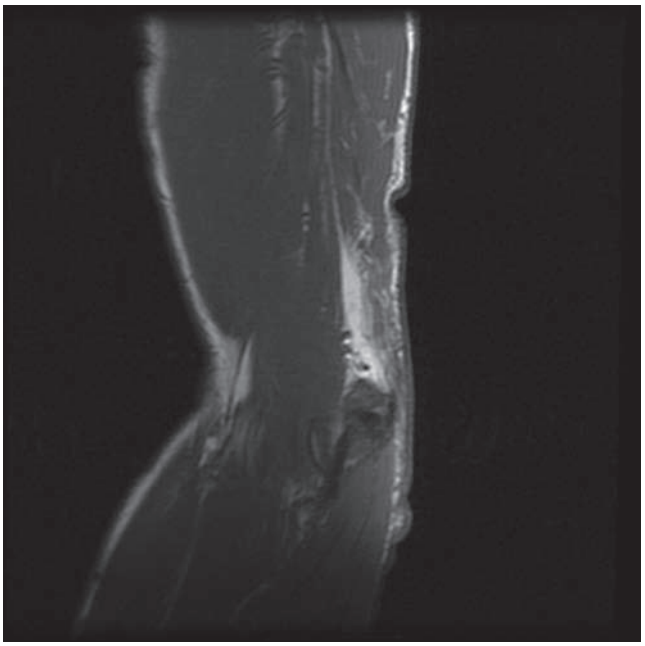


FIGURE 6.2

The MRI is quite effective in demonstrating triceps disruption.

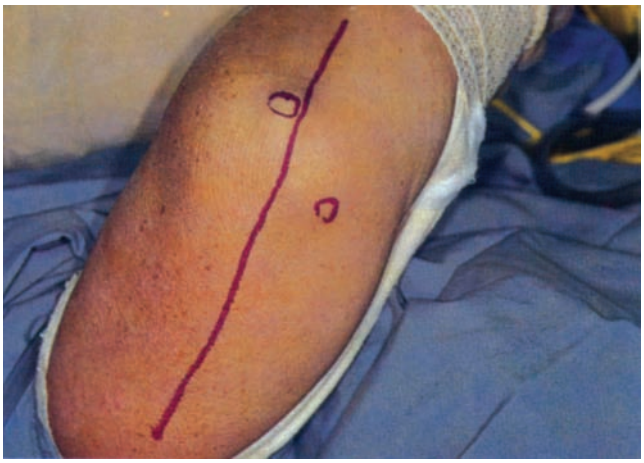


FIGURE 6.3
Midline incision showing tip of olecranon and medial epicondyle.

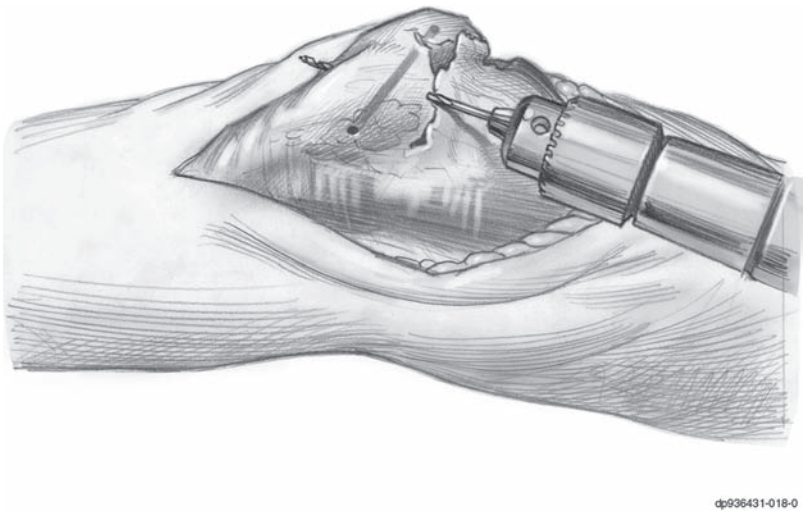


FIGURE 6.4
Cruciate drill holes are placed in the olecranon

5. A running locked type of stitch is then placed with three to four passes on each side of the mid-tendinous portion of the triceps tendon.
6. The suture is then brought back through the opposite cruciate hole (Fig. 6.5). This results in a very firm and adequate repair but a second transverse drill hole may be placed and a second direct suture if there is any question about the security of the attachment. Note: The precise site of disruption is roughened with a rongeur to enhance healing.
7. Sutures are tied at the margin of the subcutaneous border of the ulna with the elbow in approximately 20 to 30 degrees of extension.
8. The arm is elevated and an anterior splint is applied with the elbow in approximately 30 degrees of flexion.

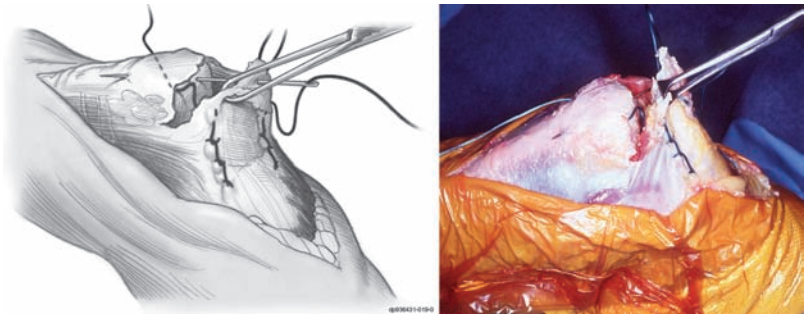


FIGURE 6.5
A Krachow stitch secures the tendon as the suture is being brought back across the olecranon. Note: The tissue is handled with an Allis clamp to avoid crush injury.

Postoperative Management The elbow is maintained in the anterior splint for approximately 4 to 5 days after which gentle passive assisted flexion to 60 degrees is allowed. At 3 weeks, flexion is allowed to 90 degrees. At the end of 3 weeks, flexion past 90 degrees is encouraged and allowed by active assist. Passively, assisted extension occurs with gravity and with the opposite extremity. At 4 to 6 weeks, active flexion and extension is allowed but no forced extension is permitted for an additional 4 weeks. At 10 weeks, routine daily activities are permitted but no extension force >10 lb is permitted. After 3 months, if there is no pain, the patient can gradually resume full daily activities. Over the next 3 months, full extension activity and strength exercises are allowed.

Reconstruction

We have regularly performed two reconstructive procedures for chronic dysfunction (13). One is the so-called anconeus slide, in which the anconeus is identified at Kocher interval between the superior margin of the anconeus and the extensor carpi ulnaris (Fig. 6.6). The anconeus is elevated from the lateral bed of the ulna and importantly, the humeral attachment of the anconeus is released. The entire mechanism is then displaced from lateral to medial and is centralized over the olecranon. This maneuver is used in those in whom there is inadequate tendinous tissue of the central tendon to perform a direct attachment but there is still an anconeus mechanism which is in continuity.

Note: Our observation has been that while this may be an effective means for restoring some extension strength in patients with total elbow arthroplasty, it is less reliable for the athlete who needs as much extension strength as possible (3). For this reason, we would typically not recommend the anconeus slide in the athlete. Thus, we describe in detail the technique of triceps augmentation with the Achilles tendon allograft.

Indications

1. Failure of an acute repair
2. Weakness which has become a major limitation of one's sporting activities or occupation
3. No improvement over the prior 3 months
4. Note: Pain is rarely a major factor but is commonly present

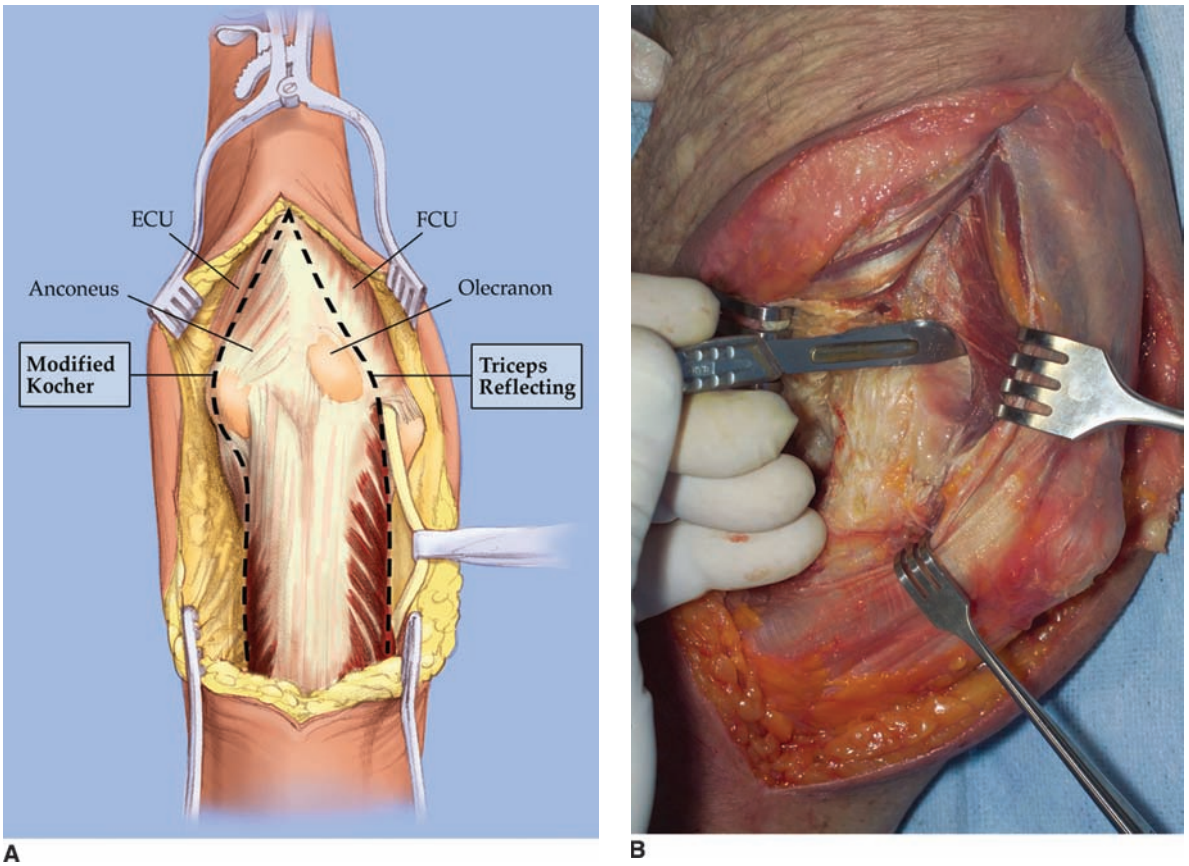


FIGURE 6.6

A: The anconeus is an extension of the extensor mechanism laterally. **B:** It can be readily mobilized by elevating the ulnar and humeral attachments.

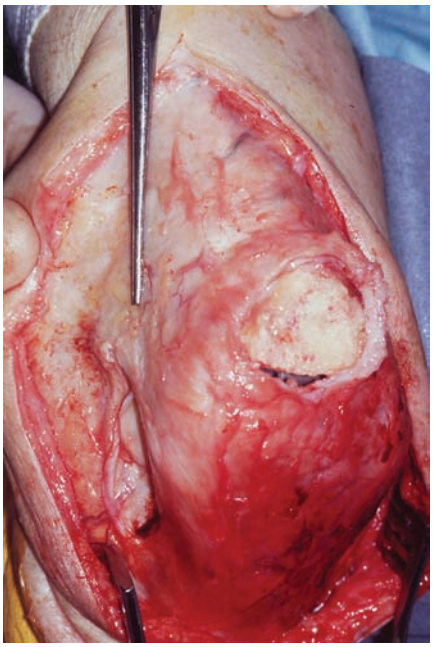


FIGURE 6.7

Large defect at the central attachment of the triceps in patient with total elbow arthroplasty.

Contraindications

1. Unclear or unreasonable expectations
2. Inability or unwillingness to participate in the postoperative program or to accept the period of postoperative recovery

Techniques

Anconeus rotational reconstruction—not typically performed in the athlete.

1. Position and incision. The positioning, prepping, draping and initial skin incision is as described above.
2. If the residual tendon is contracted and cannot be advanced to bone (Fig. 6.7) and if the anconeus is present, the interval (Kocher) between the anconeus and extensor carpi ulnaris is identified.
3. Kocher interval is entered and the anconeus is mobilized from its humeral attachment (Fig. 6.8). Ideally, the translocated muscle is left intact distally and the proximal fascial attachment to the triceps is preserved.
4. The muscle is elevated from the ulna and rotated medially. The proximal ulna is cleaned of soft tissue and prepared with cruciate drill holes as for the acute repair.

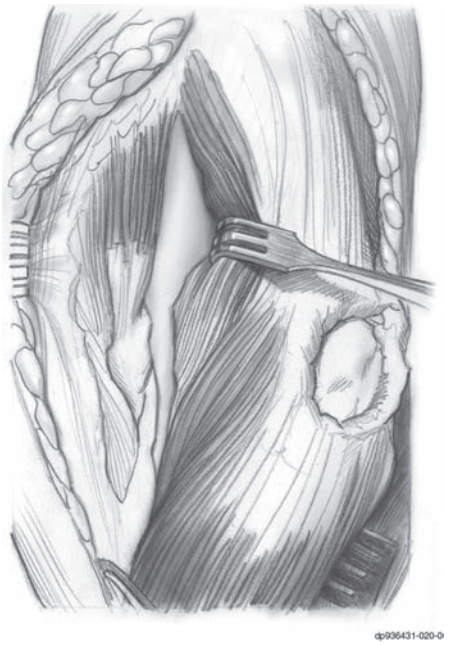


FIGURE 6.8

The anconeus is mobilized to cover the proximal ulna leaving its distal attachment intact.

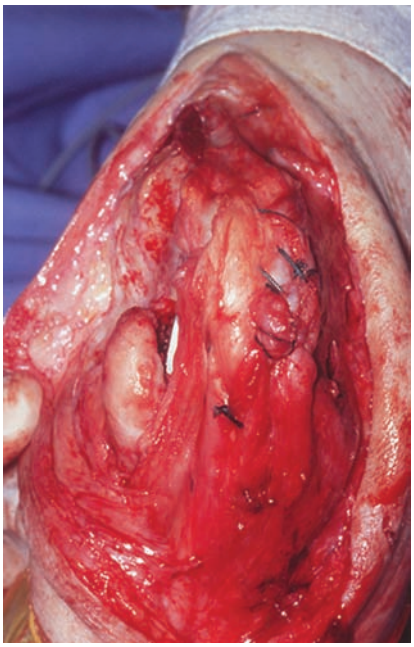


FIGURE 6.9
It is secured to the ulna through drill holes in the olecranon process.

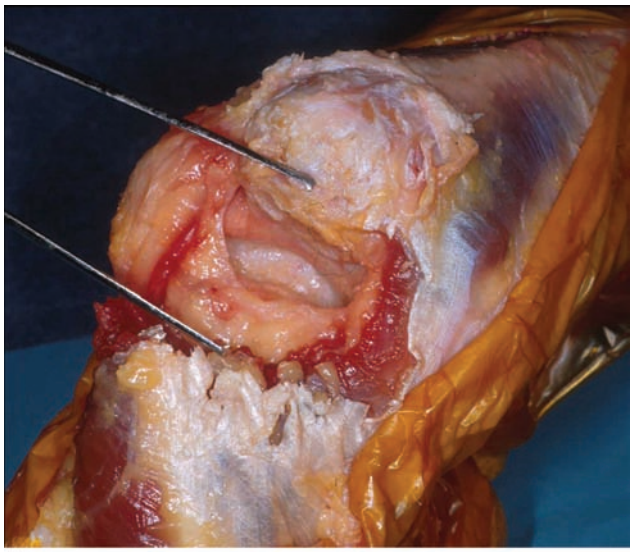
5. With the elbow in about 30 degrees of flexion, a 5 nonabsorbable suture is used to secure the rotated anconeus/triceps mechanism (Fig. 6.9).
6. An additional suture is placed in the original remnant of tendon and rotated in the residual triceps attachment.

Aftercare. This is similar to that of the acute rupture described above.

Achilles Tendon Allograft If the defect is massive or the anconeus is inadequate, an Achilles tendon allograft reconstruction is employed (Fig. 6.10).

Note: The calcaneus is no longer employed unless the olecranon was resorbed. This is seen after elbow replacement but is uncommon in the athlete.

1. Positioning and incision is as for the acute injury.
2. Care is taken to dissect and mobilize the triceps sufficiently to ensure the maximum possible excursion.
3. The proximal ulna is prepared by creating a groove on the subcutaneous border of the olecranon (Fig. 6.11).
4. The tendon is placed in the groove (Fig. 6.12A) and secured with two to three 5 nonabsorbable sutures placed through transverse drill holes (Fig. 6.12B).



A

B

FIGURE 6.10
A: Large defect in the triceps does not allow direct repair to bone. Violation of the anconeus attachment precludes anconeus rotation as a solution.
B: Achilles tendon allograft with calcaneus resected is an excellent tissue for reconstruction.

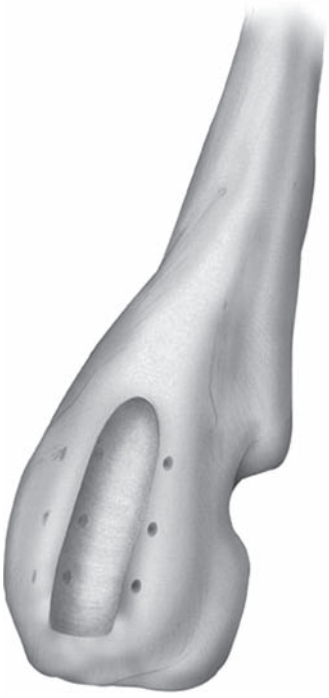
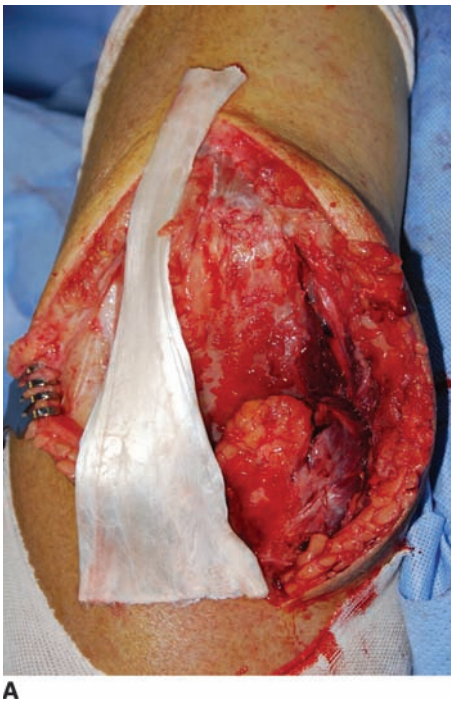
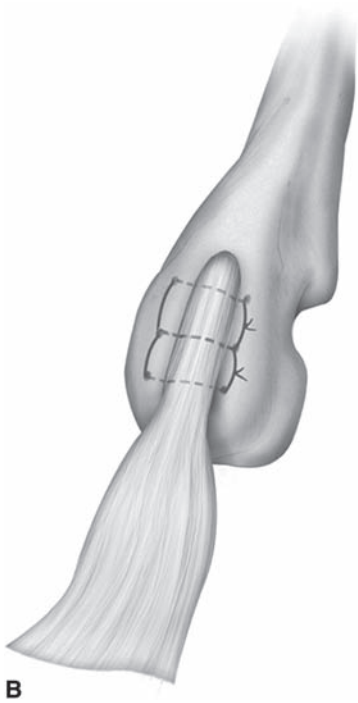


FIGURE 6.11
A trough is created in the proximal ulna to receive the triceps tendon.



A



B

FIGURE 6.12
A,B: The distal aspect of the triceps graft is placed in the groove created in the olecranon **(A)** and is securely attached to the proximal ulna with a No. 5 nonabsorable suture **(B).**

5. After the distal attachment has been secured, the triceps is brought as far distally as possible according to the dictates of the pathology. The central portion of the triceps which contains the residual triceps tendon is secured with a locked stitch and the triceps is then attached to the allograft tendon graft in the midline as far distally in the allograft as possible with the elbow in about 20 degrees of extension (Fig. 6.13).
6. Once this tension has been secured, the remainder of the proximal portion of the Achilles graft is used to envelope the triceps musculature (Fig. 6.14). An absorbable O suture is used as a running stitch to further secure the allograft to the triceps musculature.

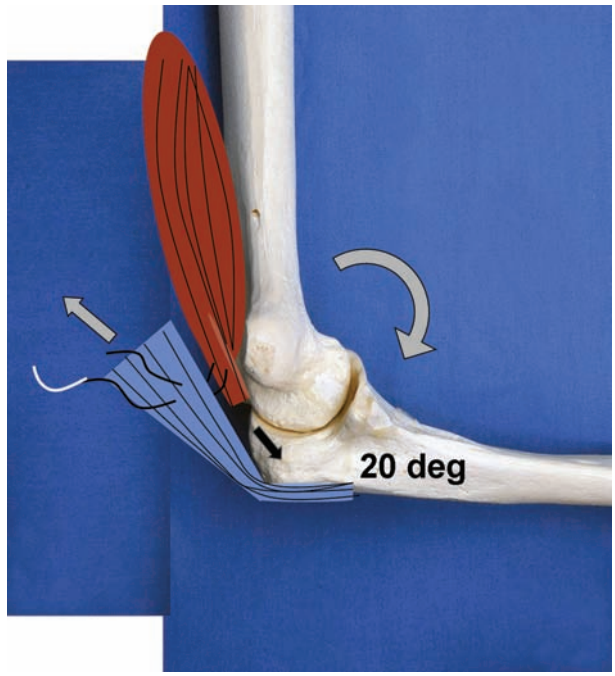


FIGURE 6.13

The residual tendon of the triceps is mobilized and displaced distally. This is stabilized to the graft with a 5 nonabsorbable stitch.

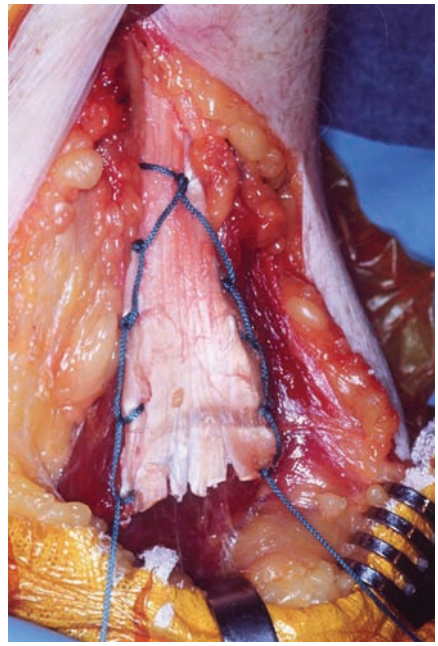


FIGURE 6.14

The triceps allograft is enveloped around the triceps and secured at the margins with a running locked stitch.

Postoperative Management This is similar to the acute repair; however, we delay efforts to regain strength allowing only sedentary stretching and unloaded extension for up to 3 months. The recovery period is dictated by the features of the case. I go cautiously.

RESULTS

There are few detailed reports regarding surgical intervention for triceps deficiency. Most communiqués are case reports (2,4,5,8–10,12,15). If the avulsion includes a fairly large portion of bone, the AO tension band method of fixation generally allows virtually normal function.

MAYO EXPERIENCE

We have recently reviewed the experience with 23 procedures for triceps deficiency; only two had radiographic evidence of osseous avulsions (16). An acute repair was carried out in 14 and a reconstructive procedure in the other nine. Of these, eight were considered partial, principally involving the central tendinous attachment. After treatment, isokinetic strength studied in 10 revealed an average of 82% of the "normal" opposite extremity; endurance was 99% of normal. Subjectively, 90% were satisfied with their outcome. Final motion averaged 10 to 135 degrees. The time to recovery was somewhat prolonged, however, averaging over 6 months with some having a reconstruction still demonstrating improvement more than a year after surgery.

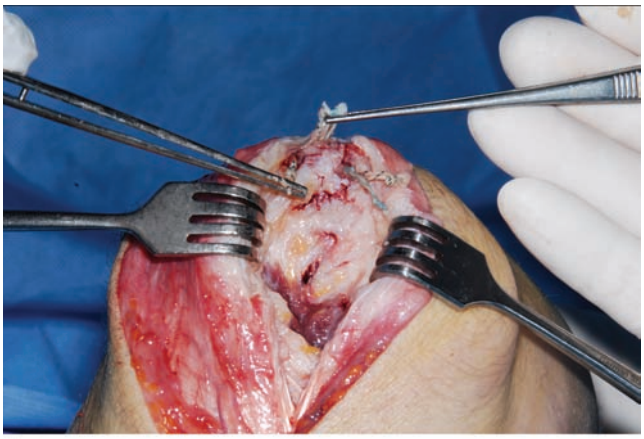
COMPLICATIONS

In the Mayo experience, there were no permanent complications. Transient ulnar nerve palsy, rerupture, persistent weakness, and discomfort are recognized as potential problems with surgery or with the pathology.

NOTE: These patients take a longer period for return of function than biceps tendon. In our experience, rarely is significant strength improvement noted before 6 months with continued improvement up to 1 year.

CASE PRESENTATION

A 28-year-old football professional tight end ruptured the central slip of his triceps tendon while shielding a block by extending his elbow against resistance. A failed effort at suture anchor repair (Fig. 6.15A) prompted further assessment and required a reoperation (Fig. 6.15B). Since his career depended on "normal" function, a reconstructive procedure with an Achilles graft was performed (Fig. 6.15C). He returned for a successful season after this surgery.



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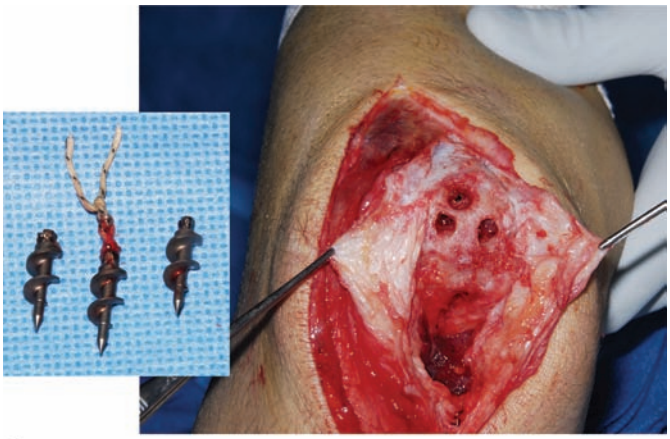

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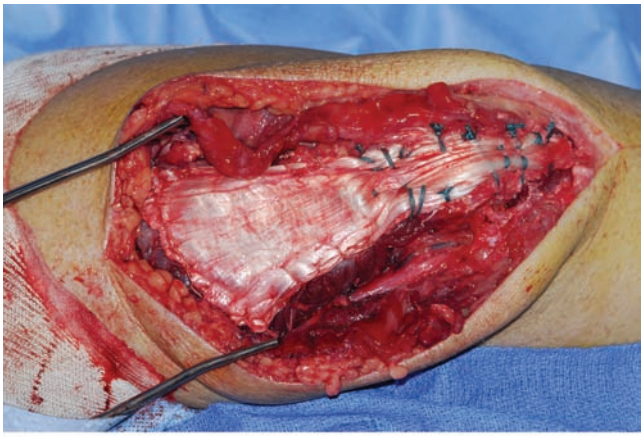

C

FIGURE 6.15

The suture anchor repair failed causing a painful bursitis and weakness **(A)**. The anchors were removed, the debridement resulted in triceps tissue loss **(B).** An Achilles tendon allograft was successfully applied as described above **(C).**

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PART TWO
SHOULDER

7 Proximal Biceps Injury—Open Versus Arthroscopic Tenodesis

James R. Romanowski and Mark W. Rodosky

INDICATIONS/CONTRAINDICATIONS

Despite the minor contributions to shoulder stability and function, the long head of the biceps tendon (LHBT) may contribute to significant shoulder pain and disability (7). Rarely does primary biceps pathology occur independently, with 95% of biceps tendinitis, tears, and degeneration related to secondary causes (6). The long head of the biceps tendon is torn in 5% of all shoulder arthroscopies, most commonly associated with rotator cuff tears (75%) and anterior instability (7.5%) (4). Synovitis resistant to conservative treatment evolves into fraying with cellular infiltration and fibrosis as part of the degenerative process (2). The anatomic constrictions of the bicipital tunnel provide little room for tendinitis and adhesions, with pain typically the end result.

Both primary and secondary biceps tendinitis are initially treated with rest, activity modifications, and anti-inflammatory medications. Steroid injections into the bicipital sheath may be helpful; however, the risk of iatrogenic damage to the tendon precludes this modality and should be performed only by experienced physicians or with ultrasound guidance. Given the high association of concomitant shoulder pathology, physical therapy modalities should focus on the rotator cuff, labrum, instability, and impingement as indicated.

Failure of conservative therapeutic modalities is an indication for operative intervention of biceps-related dysfunction. Arthroscopy allows for global assessment of the glenohumeral joint, including the LHBT. Age, activity, and degree of LHBT damage are considerations for performing débridement, tenotomy, or tenodesis. Débridement may remove synovitis and partial tearing; however, the possibility for progressive

LHBT degeneration exists and should be reserved for only the most minor of biceps damage. A tenotomy of the tendon is recommended for tears in older, sedentary patients who accept the potential cosmetic "Popeye" deformity. Cramping and fatigue of the biceps brachii may result, but is rarely reported in individuals >60 years old (5).

Tenodesis is an attractive option because the anatomy is relatively preserved while removing the diseased segment. The length, tension, and cosmesis of the biceps brachii are maintained with minimal loss of strength and shoulder function. The disadvantages are the increased complexity of the intervention and longer postoperative immobility and rehabilitation. Surgical candidates include all patients with >25% biceps tears, particularly in younger, active individuals. In cases of LHBT instability, subluxation, and dislocation, tenodesis is recommended given the poor results of reflection pulley reconstruction.

Contraindications for biceps tenodesis include medical instability, active infection, or in patients with true pseudoparalysis of the shoulder with rotator cuff tears.

PREOPERATIVE PLANNING

Patient Evaluation

Critical to the evaluation and preoperative planning of patients with suspected LHBT dysfunction is a thorough history and physical examination. The association of multiple concomitant shoulder issues makes isolated biceps disease an exception rather than the norm. Identification of all the pathology is necessary for the patient to make an informed decision about surgical intervention and to allow the surgeon to maximize patient outcome by addressing all the potential pain and dysfunction generators.

Patients often complain of anterior shoulder pain that is focused over the proximal humerus. Pain with overhead activities is common, however nonspecific as compression at the coracoacromial arch affects multiple shoulder structures. Pain related to the LHBT may be referred distal to the shoulder into the anterior arm. Occasionally with chronic cases, and rarely in the acute traumatic cases, the patient may complain of a "Popeye" deformity related to a complete tear and retraction of the LHBT.

Physical examination begins with inspection and visualization of both shoulders. Biceps specific maneuvers include Speed, Yergason, and Biceps Instability tests, but none have a particularly high sensitivity or specificity. Direct palpation of the bicipital groove often will illicit pain and is a more sensitive test (4). A complete shoulder exam should be performed given the association of additional shoulder pathology and subsequent influence on surgical planning.

Imaging

Radiographs play a minor role in the evaluation of patients with biceps-related complaints. Standard x-rays include true anterior-posterior (AP), axillary, and outlet views. Additional radiographic techniques (Fisk view) allow for visualization of the bicipital groove that may demonstrate spurring or narrowing (1). X-rays primarily rule out other causes of shoulder pain including fractures, arthritis, and glenohumeral dislocation.

Magnetic resonance imaging (MRI) provides valuable information concerning the biceps tendon. The ability to view the LHBT in multiple planes readily identifies both inflammation and tears of the tendon (10). As a sensitive diagnostic modality, MRI allows for identification of additional contributors to shoulder pathology, which improves preoperative planning. The addition of contrast may increase imaging sensitivity, but is rarely necessary.

Decision Making

Once it has been decided to proceed with surgical intervention and all the pathologic contributors to the patient's shoulder pain and dysfunction have been identified, it is necessary to select a surgical approach to the long head of the biceps tenodesis. For the majority of patients, arthroscopic techniques are readily employed and open approaches are rarely needed. For surgeons comfortable with basic arthroscopy, an arthroscopically assisted, miniopen approach is a reasonable alternative to an all inside soft tissue or bony biceps tenodesis. When the preoperative evaluation reveals a substantial subscapularis tendon tear and/or dislocation of the LHBT, then an open deltopectoral approach is a good option for both fixation of the rotator cuff and bony tenodesis of the biceps tendon.

SURGICAL TECHNIQUE

Anesthesia

An anesthetic regimen is determined after discussion between the patient, anesthesiologist, and orthopaedic surgeon. Depending on the skill and comfort of the anesthesiologist, patients may elect to undergo regional or general anesthesia. Regional nerve blocks provide the added benefit of less postoperative pain, earlier discharge,

and lower admission rates (8). Interscalene blocks, expertly performed under ultrasound guidance and a nerve stimulator, provide adequate anesthesia of the upper extremity when appropriately placed. Patients should be well informed of the potential rare complications including, but not limited to, pneumothorax, Horner syndrome, recurrent laryngeal nerve and phrenic nerve paralysis. The operative site is identified, initialed by the surgeon, and marked "yes" prior to entry into the operating room.

Setup

Shoulder arthroscopy is typically performed in either the "Beachchair" or lateral decubitus position depending on the training and comfort of the orthopaedic surgeon. Regardless of the position, it is essential that the patient is appropriately placed with all susceptible neurovascular structures and bony prominences well padded. The eyes must also be protected from inadvertent maneuvers or instrumentation during the procedure. An advantage of regional nerve blocks is that the patient may be positioned and questioned about comfort prior to the start of the procedure. Both arthroscopic and miniopen biceps tenodesis may be performed in either the beachchair or lateral decubitus position. Open biceps tenodesis should be performed in the beachchair position; however, if a diagnostic arthroscopy is not part of the procedure, it may be performed supine.

Beachchair Position The patient is placed supine on the operating table with a head support. The table is then flexed at the waist to approximately 80 degrees, the hips flexed 20 degrees, the knees flexed 30 degrees, and 15 degrees of Trendelenburg. Several attachments are available for the operating table that allow for securing the patient's head or gaining increased access to the shoulder by removing a posterior support. Regardless of the table, the patient's head, neck, and torso should be secured in a natural, neutral position. The nonoperative arm is padded and secured to the waist or arm holder (Fig. 7.1).

Lateral Decubitus The patient is placed supine on a supportive beanbag on the operating table. After induction of anesthesia, the patient is placed in the lateral decubitus position with the operative extremity toward the ceiling. An axillary roll is placed just distal to axilla under the thorax of the nonoperative arm that is supported on an armboard. The head and neck padded and secured in a neutral position. The beanbag is insufflated to the contour of the patient's body with particular padding in the breast and the genital area. The operative extremity is placed into the foam arm sleeve, abducted 30 to 45 degrees, and attached to the traction tower. No more than 15 lb. of traction weight should be applied as to minimize strain on the brachial plexus (Fig. 7.2).

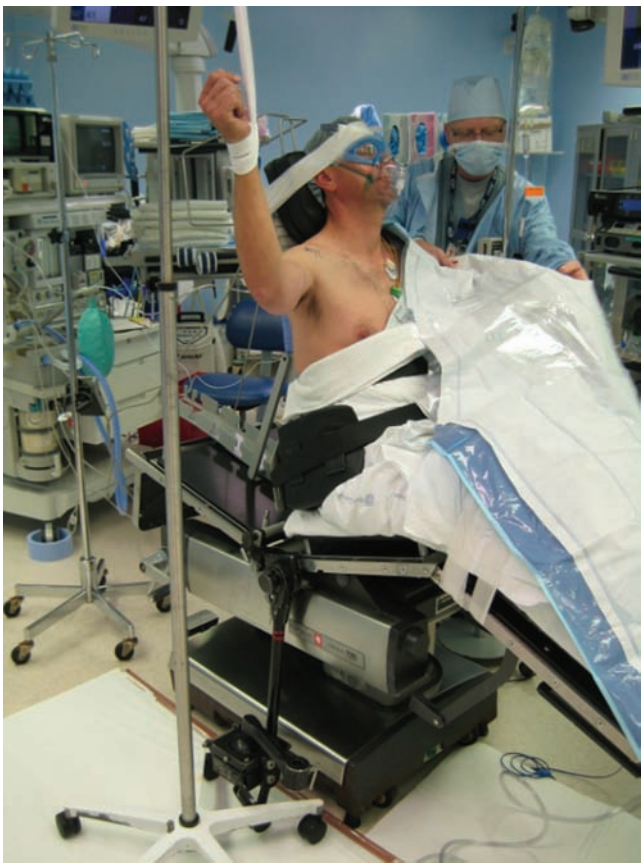


FIGURE 7.1

Beachchair position. The patient is flexed at the waist to approximately 80 degrees, the hips flexed 20 degrees, the knees flexed 30 degrees, and 15 degrees of Trendelenburg. The arm is positioned for prepping.

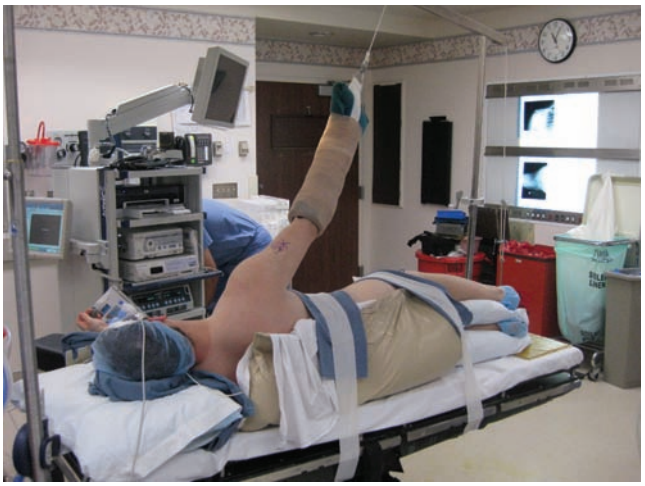


FIGURE 7.2

Lateral decubitus position. The operative extremity is placed into a foam arm sleeve, abducted 30 to 45 degrees, and attached to the traction tower.

Surface Landmarks/Portal Placement/Diagnostic Arthroscopy

The anatomic landmarks of the shoulder are identified and include the borders of the clavicle, acromion, and scapular spine (Fig. 7.3). The coracoid process is also marked. An exam under anesthesia is performed for all cases, but has limited value for primary pathology of the LHBT. The patient is sterilely prepped and draped. The glenohumeral joint is insufflated with 60 mL of Lactated Ringer solution using a No. 18 gauge needle through the posterior shoulder. Filling the joint allows for easier arthroscopic trochar placement and helps avoid damage to the articular cartilage.

The posterior viewing portal is established using a No. 11 blade scalpel 2 cm medial and inferior to the posterolateral corner of the acromion. The trochar is inserted and the joint viewed. A diagnostic arthroscopy is performed to not only evaluate the biceps tendon, but also to assess the surrounding structures including the capsule, rotator cuff, labrum, and articular cartilage that is not easily accessible through a single incision open approach (Fig. 7.4). After assessment of the glenohumeral joint, an anterior working portal is established.

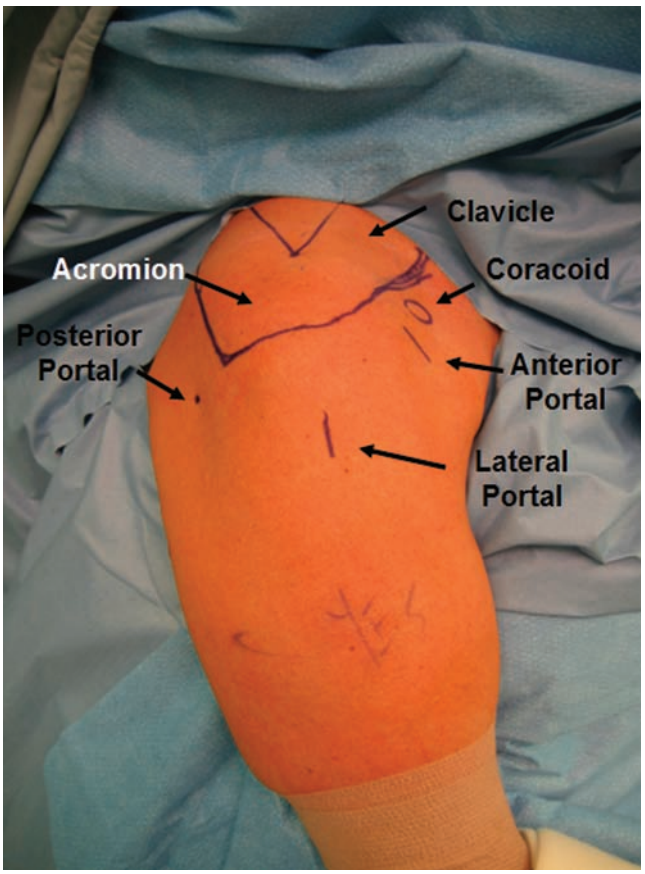


FIGURE 7.3

Identification of landmarks and portal placement.

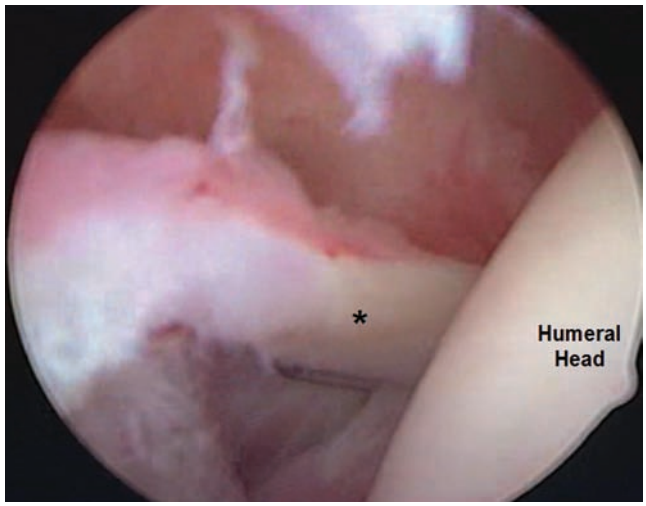


FIGURE 7.4

Arthroscopic view from posterior portal. The humeral head is visualized with the long head of the biceps (*asterisk*) demonstrating both synovitis and fraying.

A No. 18 gauge spinal needle is placed into the rotator interval anteriorly, at the level of and just lateral to the coracoid process to plan the portal. A No. 11 blade scalpel is used to make the skin incision and a cannula is inserted. Cannula sizes vary by manufacturer but need to be large enough (>6.0 mm) to accommodate the various arthroscopic instruments and anchors that the surgeon typically uses. Larger-sized or additional cannulas may be required based on the pathology that needs addressed. When only a biceps release or tenotomy is performed, it is possible to avoid using a cannula and create a smaller capsulotomy with a blunt 4.5-mm obturator or trochar that allows the arthroscopic synovator, grasper, and scissors to enter the joint with little damage to the capsule. The proximal LHBT may be further inspected for disease by pulling the tunnel portion into the joint with an arthroscopic grasper.

Percutaneous Intra-Articular Tendon Tenodesis Technique

The percutaneous intra-articular tendon tenodesis (PITT) technique is categorized as an arthroscopic soft tissue tenodesis of the proximal long head of the biceps brachii tendon (3). This provides a minimally invasive all inside method for removing the diseased biceps tendon while maintaining the length, tension, and cosmesis characteristics of the native biceps. With the arthroscope in the posterior portal, the anterior portal is used as the working portal. An arthroscopic grasper is inserted and grabs the LBHT tendon at the entrance to the biceps tunnel (Fig. 7.5). The tendon is pulled into the joint and an assistant maintains tension and the position of the tendon during the glenohumeral portion of the tenodesis (Fig. 7.6). Using a Meniscal Mender set (Smith & Nephew, Andover, Massachusetts) (Fig. 7.7), a needle with stylet is placed percutaneously through the transverse humeral ligament, coracohumeral ligament (CHL), biceps tendon, and visualized in the joint (Fig. 7.8). A second needle is passed percutaneously into the tendon, spaced approximately 1 cm from the first needle (Fig. 7.9). The stylets are then removed from the needles.

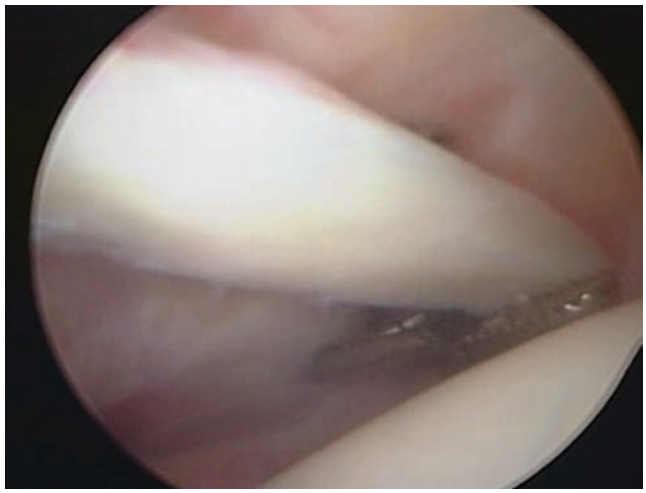


FIGURE 7.5

Arthroscopic grasper reaching for the LHBT at the entry to the bicipital groove. View from posterior portal. Grasper is in anterior portal.

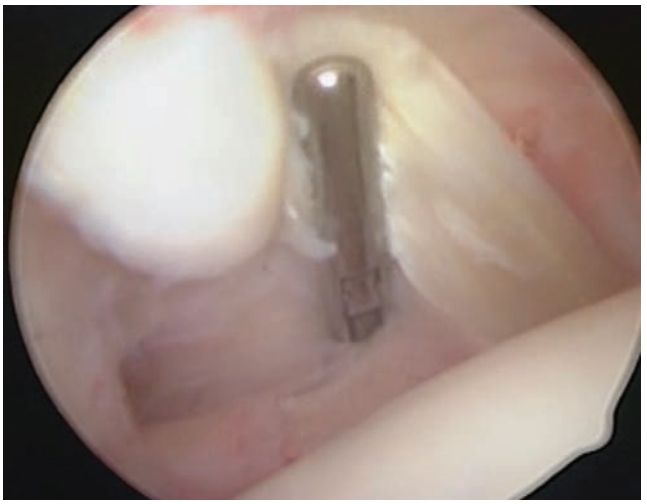


FIGURE 7.6
The LHBT is pulled into the glenohumeral joint and held in position.

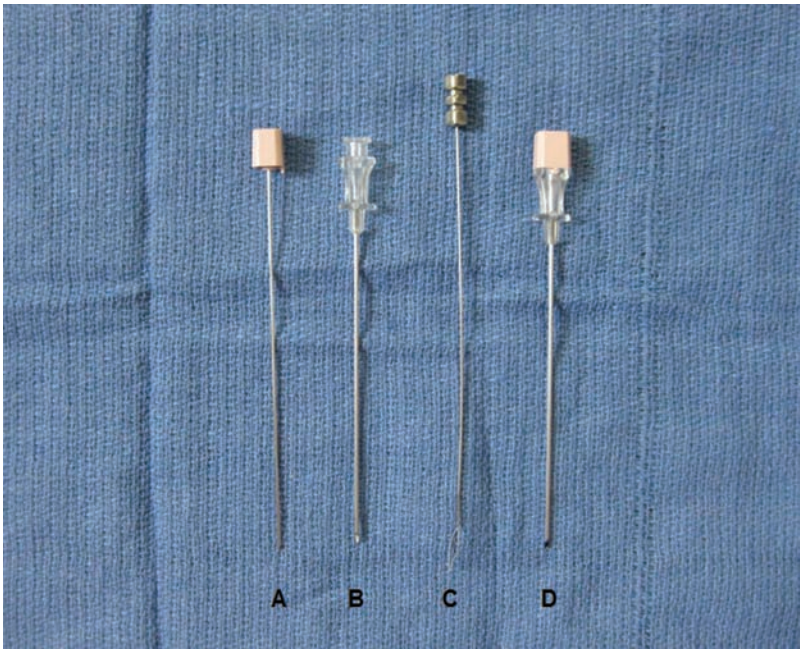


FIGURE 7.7
Meniscal Mender set for arthroscopic biceps tenodesis (Smith & Nephew, Andover, Massachusetts). **A:** Needle stylet. **B:** No. 18 gauge needle. **C:** Loop stylet. **D:** Needle stylet within No. 18 gauge needle.

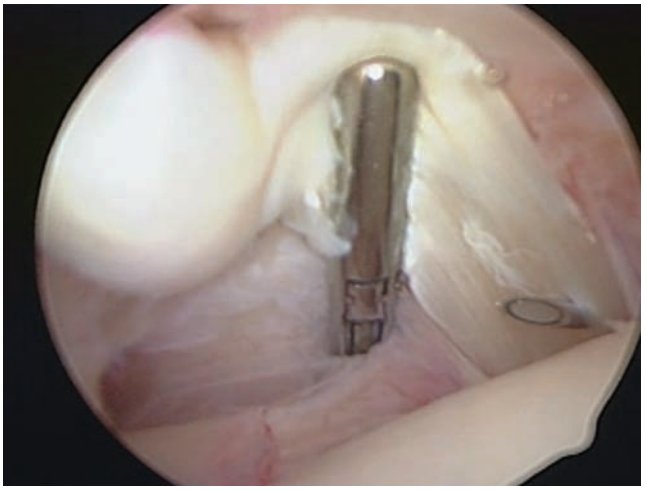


FIGURE 7.8
Placement of stylet/needle percutaneously into the LHBT.

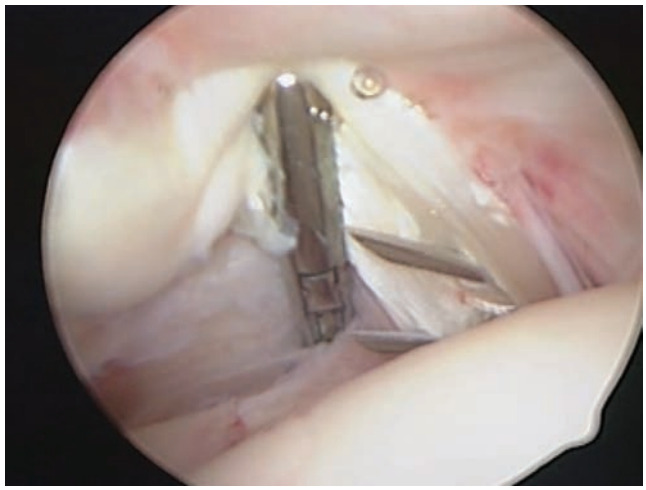
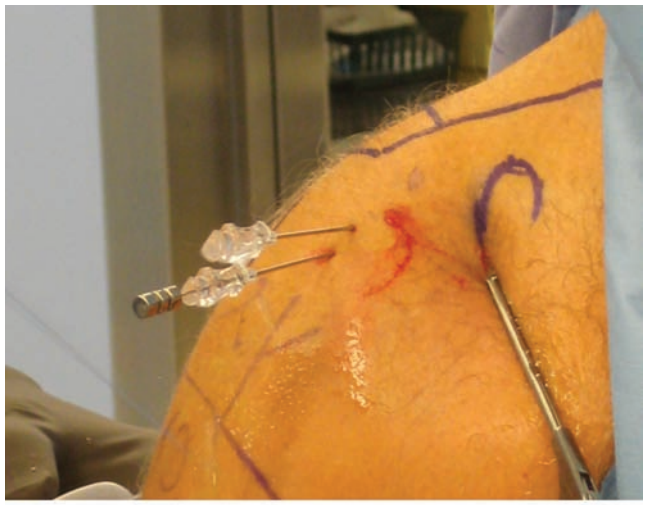


FIGURE 7.9

Placement of second stylet/needle into LHBT.

The looped stylet is placed within one of the needles and advanced until the metallic lasso is fully loaded into the joint (Fig. 7.10A–C). The other needle is then threaded through the lasso and once engaged, a 2 Ticron suture (Covidien, Mansfield, Massachusetts) is passed through the needle and loop (Fig. 7.11A and B). At least 8 cm of suture should be loaded into the joint and forward pressure kept on the suture to resist the fluid pressure attempts to push it back out of the needle. Now that the looped stylet is loaded with the suture, it is slowly removed from the joint allowing the suture to engage the tendon and pull it against the transverse humeral ligament (Fig. 7.12A and B). A hemostat is placed on the two suture ends for temporary security until tied in



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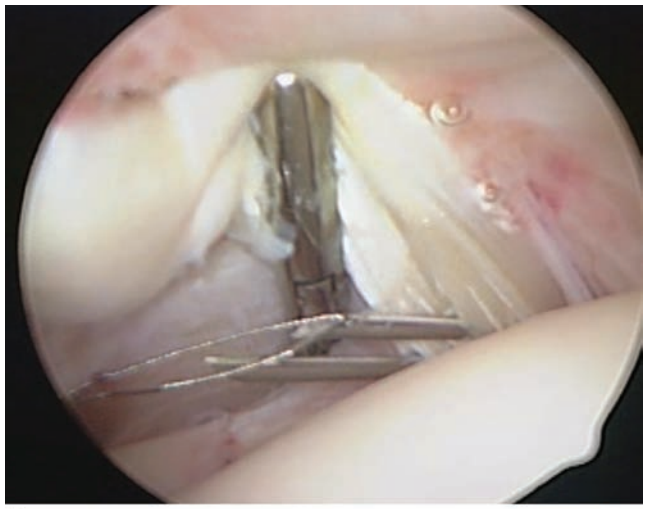

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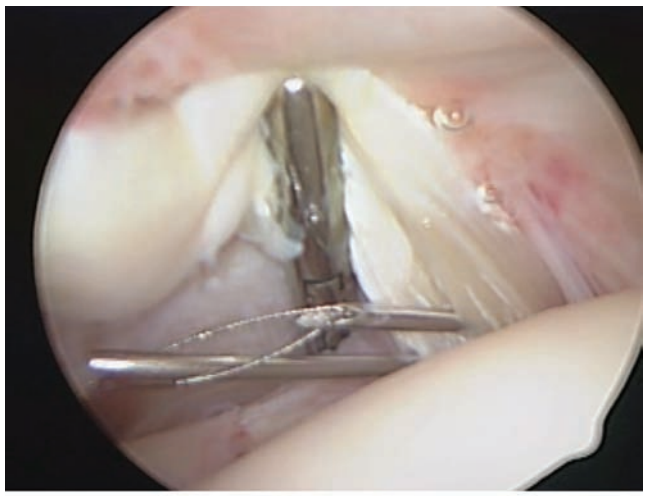

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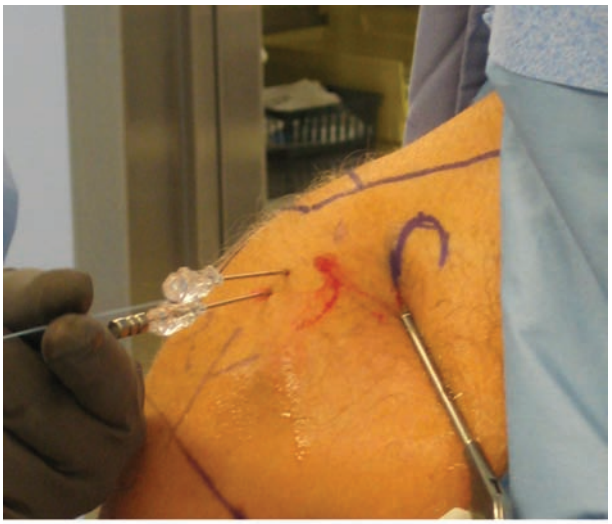
FIGURE 7.10

Placement of the loop stylet into the No. 18 gauge needle. **A:** External view showing the anterior shoulder with the stylet placed. **B:** Arthroscopic view from the posterior portal. **C:** The needle is advanced through the loop stylet.



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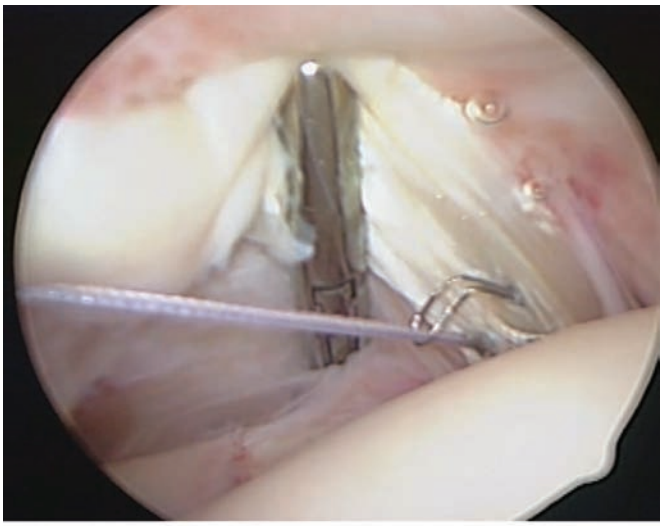

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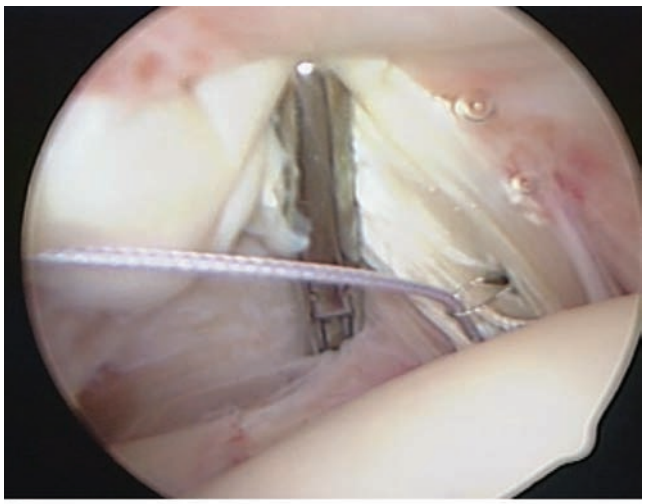
FIGURE 7.11

Suture loading. **A:** The 2 nonabsorbable suture is loaded into the empty needle. **B:** Arthroscopic view of suture loading into the loop stylet.



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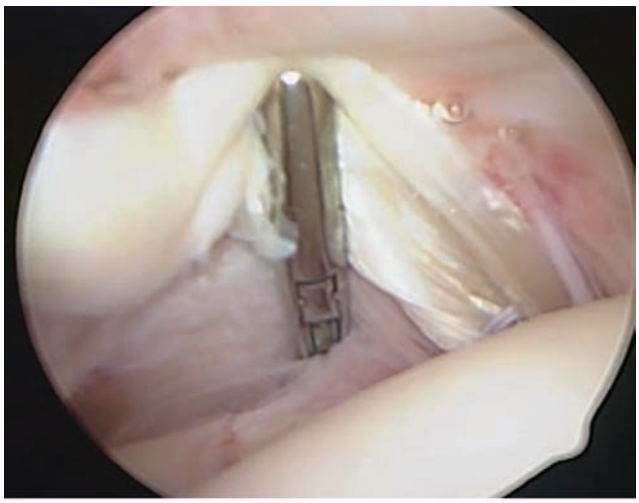

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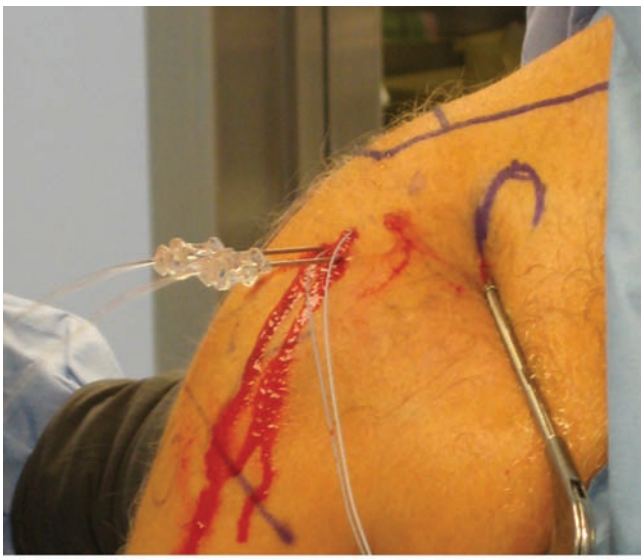

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FIGURE 7.12

Engagement of the LHBT. **A:** The stylet loop pulls the suture toward tendon. **B:** The suture is pulled through the tendon. **C:** External view showing suture ends with second set of needles now ready for additional suture.

the subacromial space. A second set of sutures is passed through the transverse humeral ligament, CHL, and LBHT in a similar fashion. A different colored suture should be used for management purposes.

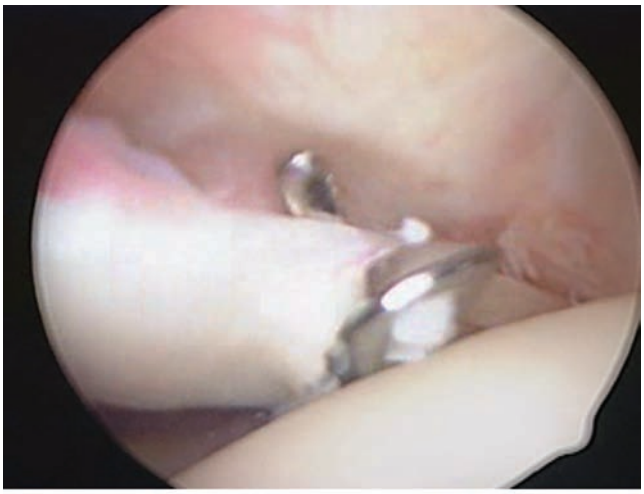
The arthroscopic grasper is removed and biceps tenotomy is performed (Fig. 7.13A–C). An arthroscopic basket punch or scissor is inserted through the anterior portal and the LHBT is released just proximal to the sutures. An arthroscopic synovator is then used to remove the intra-articular portion of the LHBT to the level of its origin on the superior glenoid. The instrumentation is removed; attention is now directed toward the subacromial space.

Using the same posterior skin incision, the subacromial space is entered. A lateral portal is created approximately 1 cm lateral to anterolateral border of the acromion after a No. 18 gauge spinal needle determines appropriate trajectory. A cannula is placed to help with suture management. A bursectomy, if necessary, is performed with an arthroscopic synovator to improve visualization and make suture retrieval easier (Fig. 7.14A and B). A subacromial decompression and rotator cuff repair are completed at this time as indicated.

An arthroscopic grasper, or icetong, is used to bring one set of the color coated biceps sutures out of the lateral portal (Fig. 7.15). Using a knot pusher, the suture is then tied and the suture ends cut (Fig. 7.16A and B). The process is repeated for the remaining biceps suture. Arthroscopic percutaneous intra-articular biceps tenodesis is now complete. The wounds are closed with 3-0 nylon sutures.

Deltoid Splitting Miniopen Biceps Tenodesis

An alternative approach toward soft tissue biceps tenodesis techniques is tendon to bone constructs. A variety of fixation choices are available and most commonly involve suture anchors or interference screws. Both devices may be used with this approach depending on surgeon preference. The deltoid splitting miniopen biceps tenodesis takes advantage of arthroscopy to not only visualize the joint, but also minimize the invasiveness of open techniques while incorporating the strength of the bone-tendon interface fixation.



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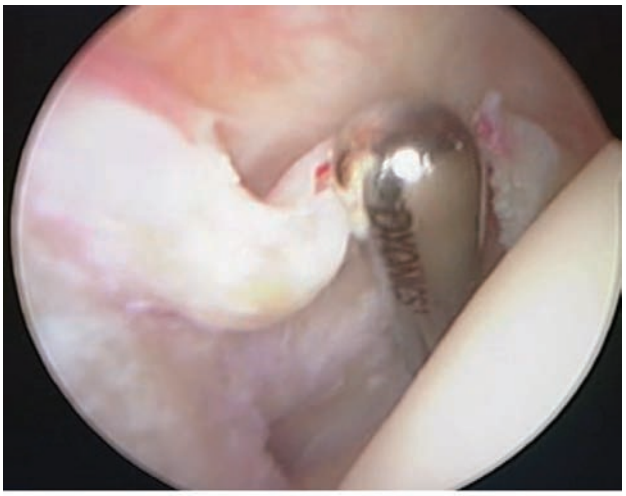

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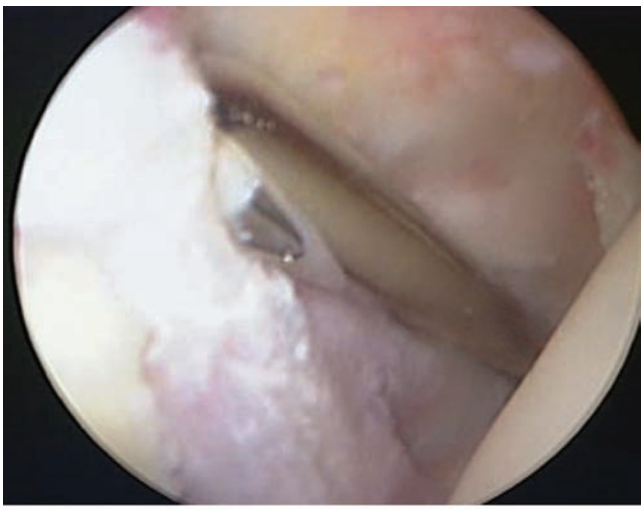

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FIGURE 7.13

Biceps tenotomy. **A:** An arthroscopic punch is inserted through the anterior portal and the biceps is released at its entry to the bicipital groove. **B:** An arthroscopic synovator removes the proximal portion of the LHBT to its origin on the superior glenoid/labrum. **C:** Final glenohumeral arthroscopic appearance of biceps tenodesis.

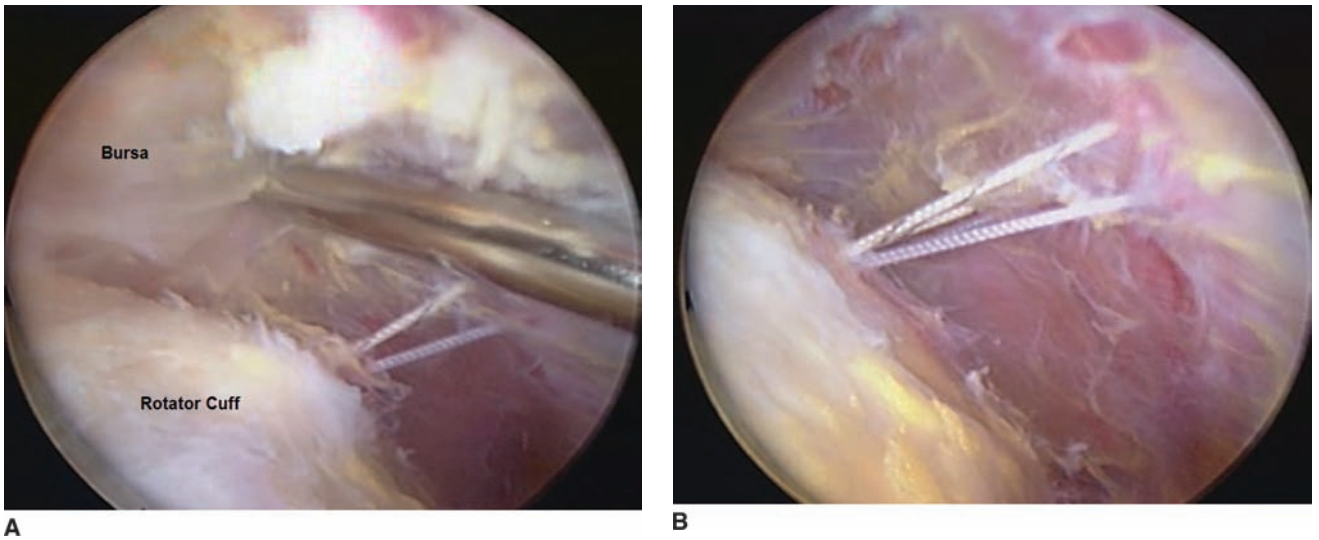


FIGURE 7.14

Subacromial preparation. View from posterior portal. **A:** A bursectomy is performed with an arthroscopic synovator to allow for suture visualization in the subacromial space. The rotator cuff is labeled. **B:** The subacromial space is now prepared and sutures clearly visualized.

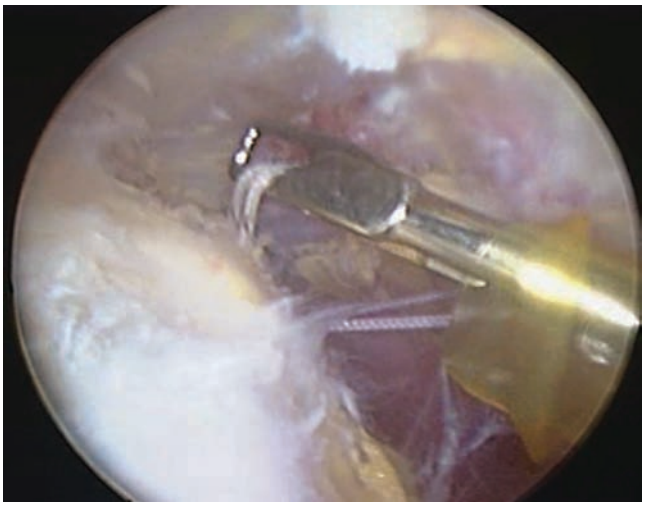


FIGURE 7.15

Retrieval of suture pairs through lateral portal.

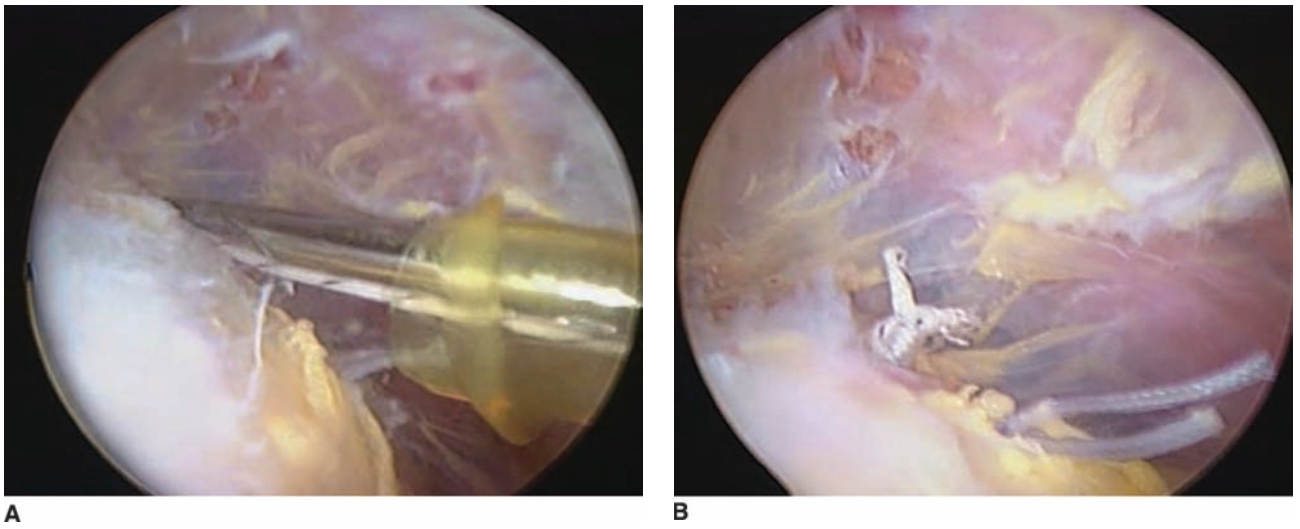


FIGURE 7.16

Suture tying. **A:** Suture pairs are tied in the subacromial space using a knot pusher through the lateral portal. **B:** Final appearance of biceps tenodesis in subacromial space.

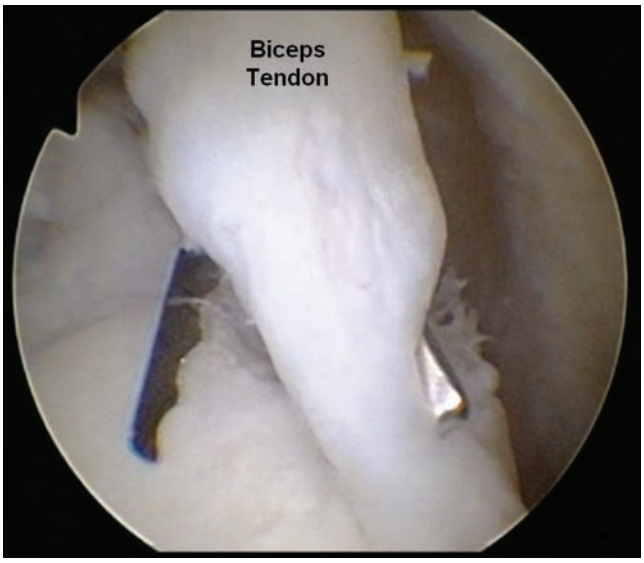


FIGURE 7.17
Arthroscopic biceps tenotomy.

Similar to the PITT technique, a diagnostic arthroscopy is performed to assess the spectrum of potential shoulder pathologies. Once all the issues have been identified and addressed, an arthroscopic scissor or basket punch is placed via the standard anterior portal to release the LHBT at the origin on the superior glenoid (Fig. 7.17). An arthroscopic synovator is used as needed to round the superior labrum. The length of the LHBT is preserved to ensure retrieval through miniopen incision and prevent total retraction. The arthroscopic instrumentation is removed.

A 3 to 4 cm skin incision is made from the anterolateral corner of the acromion toward the axilla (Fig. 7.18). The underlying deltoid fascia is identified and released in line with the deltoid muscle fibers using a No. 15 blade scalpel. Blunt finger dissection allows for the deltoid fibers to separate revealing the underlying proximal humerus. The arm is internally/externally rotated to allow for palpation and identification of the bicipital groove. The deltoid muscle is retracted out of the way, and a No. 15 blade scalpel is used to release the roof of the biceps tunnel (coracohumeral and transverse humeral ligaments) to reveal the LHBT. The biceps tenotomy performed during the arthroscopic portion of the procedure allows for the LHBT to be brought antegrade into the wound and tagged with a suture (Fig. 7.19). Retraction of the tendon allows for the floor of the biceps tunnel to be visualized and débrided. A rongeur and curette are used to prepare the bony surface and encourage healing at the tenodesis site.

The bicipital groove is now prepared for placement of the two suture anchors. An anchor drill with a soft tissue protector creates the pilot holes, and depending on the manufacturer, the holes are tapped (Fig. 7.20A and B). The suture anchors preloaded with 2 nonabsorbable, braided sutures are inserted into the holes. Tension is then set within the LHBT and the sutures are woven through the tendon (Fig. 7.21). The tendon is tied down and remaining length proximally is amputated with a No. 10 blade scalpel (Fig. 7.22). It is not necessary to reapproximate the CHL and transverse humeral ligaments as this may be a source of pain. The wounds are irrigated well with normal saline and closed. A 0 Vicryl suture (Ethicon, Somerville, New Jersey) is used to close

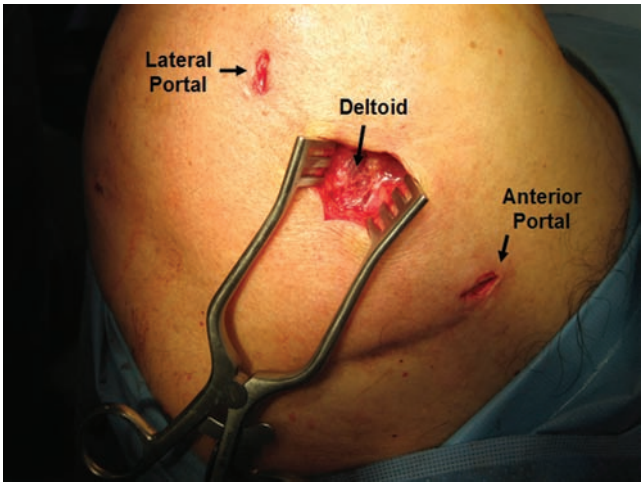


FIGURE 7.18
Skin incision. A 4-cm incision is made from the anterolateral corner of the acromion toward the axilla. The deltoid fascia is split inline with the muscle fibers. The arthroscopic portals are identified.

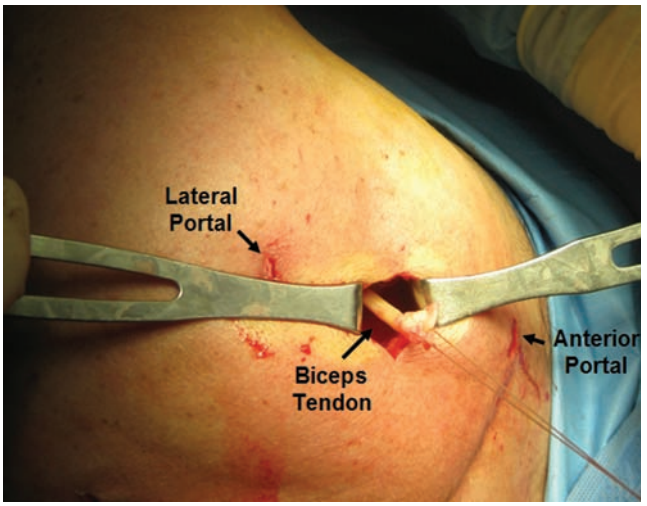


FIGURE 7.19

LHBT retrieval. Once the transverse humeral ligament is released, the LHBT is brought into the wound and tagged with a suture.

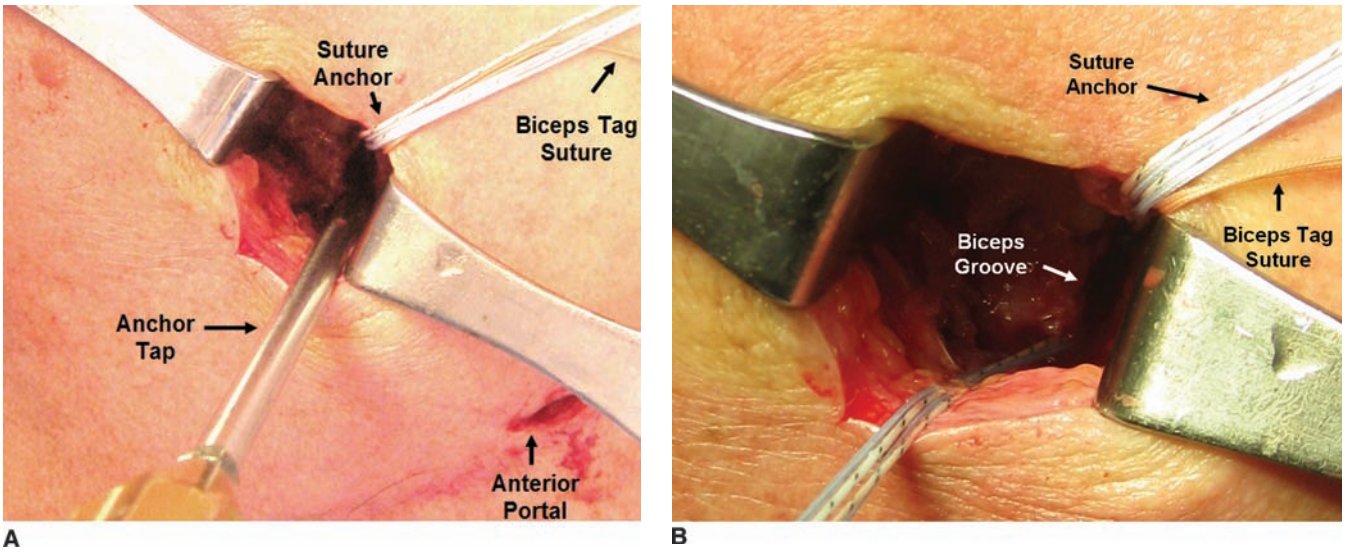


FIGURE 7.20

Preparation of the bicipital groove. Deltoid retraction reveals underlying Bicipital groove. **A:** After the floor of the bicipital groove is débrided, a tap is used for suture anchor placement. **B:** Placement of the second suture anchor 1 cm away from first anchor.

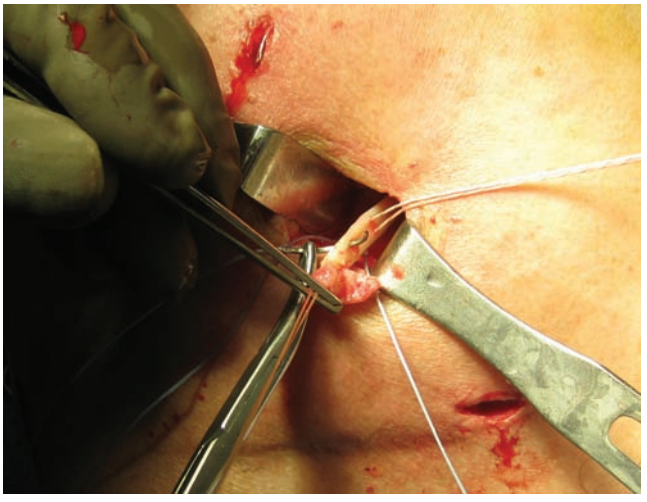


FIGURE 7.21

Suture placement. The suture ends from the anchors are placed into the LHBT.

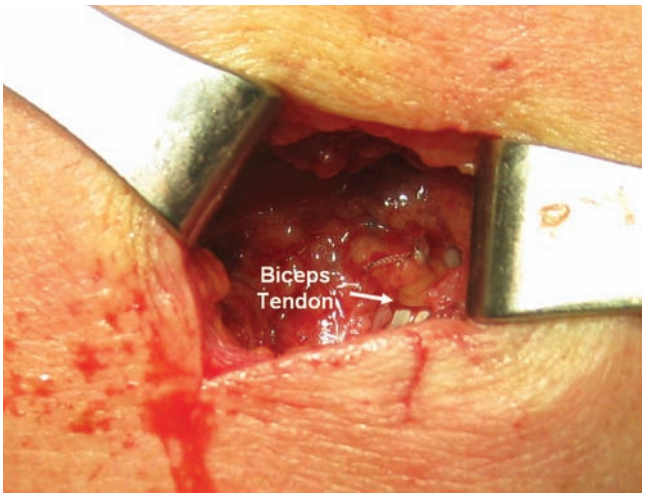


FIGURE 7.22
Final position of the LHBT after tenodesis.

the deltoid fascial layer, 2-0 Vicryl is placed subcutaneously, and a 4-0 Monocryl suture (Ethicon, Somerville, New Jersey) is placed in a subcuticular fashion. Steri-strips (3M, St. Paul, Minnesota) are applied to the incision and the portal sites are closed using a 3-0 nylon suture in simple, interrupted fashion.

Open Deltopectoral Biceps Tenodesis

Even though arthroscopic and miniopen methods have lowered the surgical invasiveness of biceps tenodesis, open approaches are not obsolete. An indication for open deltopectoral biceps tenodesis is when the complexity of the associated shoulder pathology exceeds the utility and efficiency of the arthroscopic and miniopen biceps tenodesis techniques. One particularly common scenario involves LBHT dislocations and their association with tears of the subscapularis tendon at its insertion on the lesser tuberosity of the proximal humerus (Fig. 7.23).

The patient is placed in the beachchair position. Lateral positioning is not recommended for anterior approaches to the shoulder because of difficulty with visualization. As with the other procedures, a diagnostic arthroscopy may be performed depending on the history and clinical exam. A biceps tenotomy may be performed with the arthroscope; however, this is not necessary. The coracoid is identified as the starting point for the 10-cm incision made along the deltopectoral groove (Fig. 7.24A–D). Careful dissection is performed with retraction of the skin and subcutaneous tissue. The cephalic vein should be identified in the deltopectoral interval. Exploiting the internervous plane of the deltoid (axillary n.) and the pectoralis major (medial and lateral pectoral n.), the muscle bellies are retracted laterally and medially, respectively. The cephalic vein is usually retracted laterally with the deltoid as to not disrupt the numerous venous tributaries from the muscle. Gentle medial retraction on the conjoint tendon (short head of the biceps brachii and coracobrachialis) allows for improved visualization of the of the underlying subscapularis insertion. Avoid excessive retraction as undue stress may be placed on the musculocutaneous nerve as it courses through the coracobrachialis muscle. Internal rotation of the arm often will allow for the long head of the biceps to be

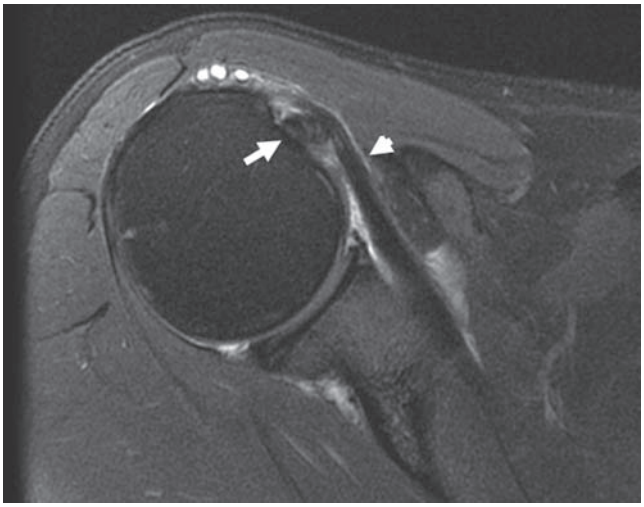


FIGURE 7.23
MRI. An axial PD FSE MRI illustrates dislocation of the LHBT (*arrow*) under a torn subscapularis insertion (*arrowhead*).

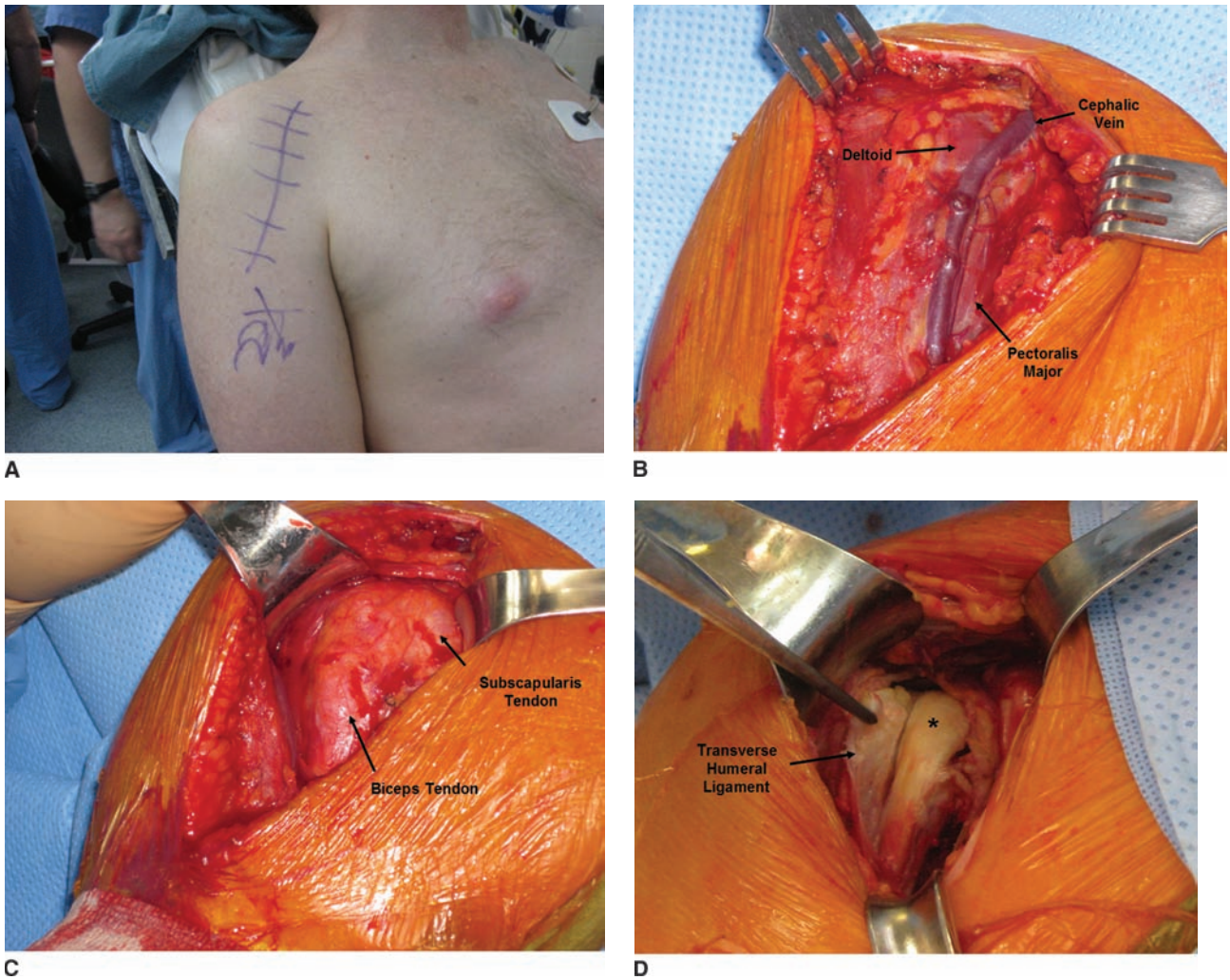


FIGURE 7.24

Surgical approach to the LHBT. **A:** Surgical skin marking along the deltopectoral groove. Proximal skin marking begins at the coracoid process. **B:** The cephalic vein is identified at the deltopectoral junction. **C:** The deltoid and pectoralis muscles are retracted, revealing the underlying LHBT and subscapularis tendon insertion on the lesser tuberosity. **D:** The LHBT (*asterisk*) is visualized after release of the transverse humeral ligament. Not the "hourglass" shape of the tendon within the bicipital groove.

palpated within the bicipital groove. As in the above scenario, the subscapularis tendon is often torn and the defect may now be identified at its insertion on the lesser tuberosity of the proximal humerus. A No. 15 blade scalpel is used to release the transverse humeral ligament inline with the bicipital tunnel revealing the underlying biceps tendon. If the origin of the LHBT was released earlier with arthroscopy, then the tendon is pulled into the wound and tagged with a 0 suture. If not released, it is necessary to dissect and release a portion of the superior reflection pulley to gain access through the rotator interval. The CHL may be palpated as a tight band at the superior edge of the biceps tunnel. A Mayo or curved scissor is used to release the CHL, and with entry into the glenohumeral joint, the long head of the biceps is released from its origin on the superior glenoid. With the LHBT retracted, the floor of the bicipital groove is visualized and débrided with a rongeur and curette (Fig. 7.25). Two suture anchors are placed within the groove, spaced approximated 1 to 2 cm apart. With tension placed on the LHBT, the sutures from the anchors are placed through the tendon (Fig. 7.26A–C). With the LHBT reapproximated to its native position within the groove, the sutures tails are tied and the remaining proximal portion of the LHBT amputated. The subscapularis may be fixed and reattached per surgeon preference—typically after bony débridement and placement of multiple suture anchors within the footprint on the lesser tuberosity.

The wounds are irrigated out copiously with normal saline and attention is now paid toward closure. The deltopectoral interval is reapproximated using an absorbable 0 suture with careful attention toward avoiding the cephalic vein. The subcutaneous tissue is closed using an absorbable 2-0 suture and the skin is closed with an absorbable 4-0 suture. The arthroscopic portals are closed as dictated. Steri-strips are applied with gauze, tape, and a sling immobilizer.

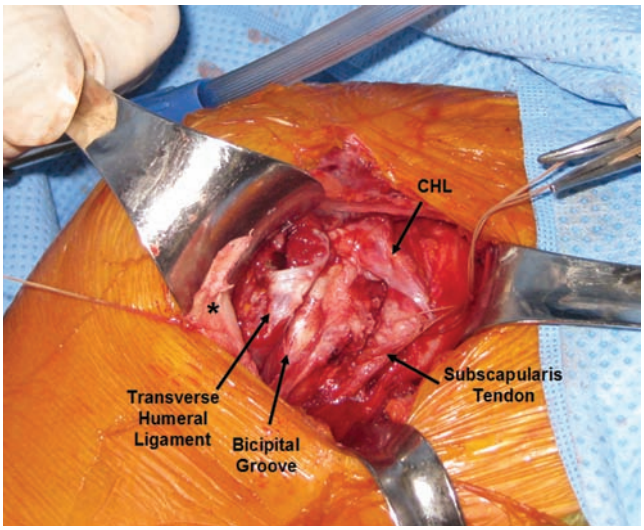


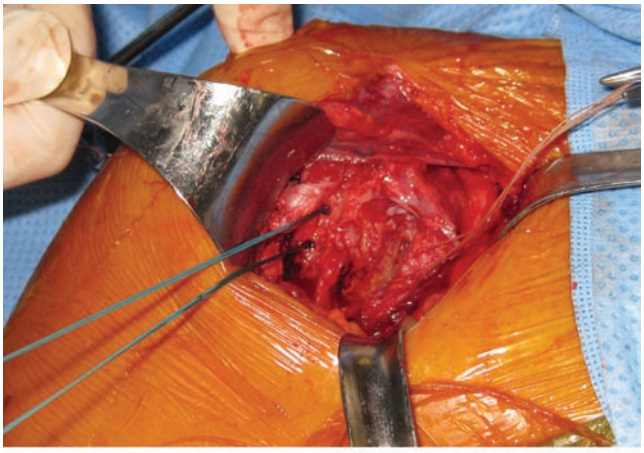
FIGURE 7.25

Biceps tenotomy/retraction (*asterisk*). The LHBT is retrieved into the wound and out of the bicipital groove. The transverse humeral ligament, CHL, and subscapularis tendon are identified.

POSTOPERATIVE MANAGEMENT

Rehabilitation

For patients who have isolated tenodesis of the LHBT, rehabilitation begins the day of surgery. Active wrist and hand range-of-motion exercises are encouraged. One week postoperatively, the patient starts a supervised physical therapy program with gentle passive range of motion of the shoulder and elbow. A sling is worn on



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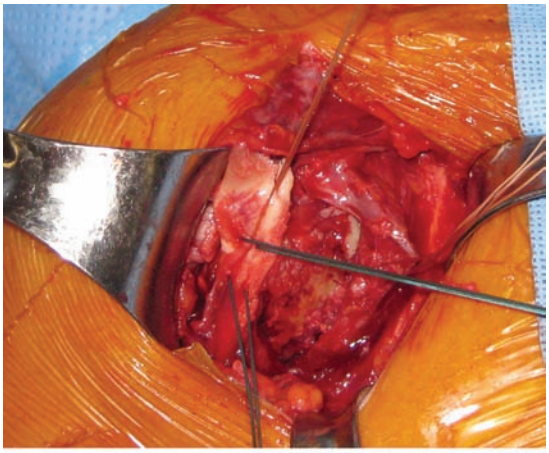

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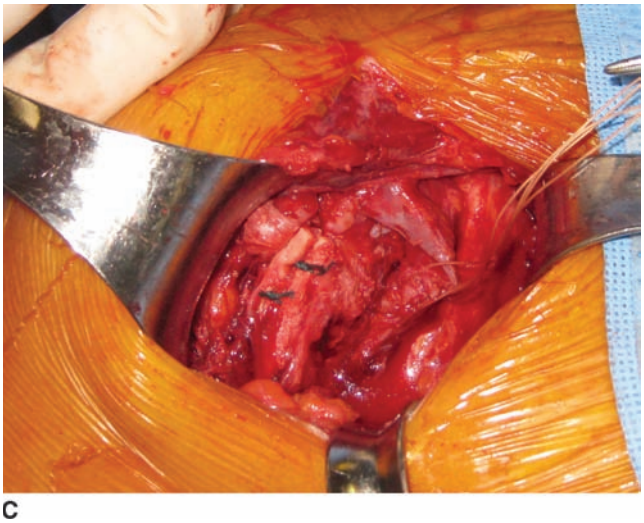

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FIGURE 7.26

Biceps tenodesis. **A:** Suture anchors are placed within the débrided bicipital groove. They should be spaced 1 to 2 cm apart. **B:** The suture ends are woven through the LHBT after proper tension has been set. **C:** The tendon is tied and secured to the floor of the bicipital groove.

the extremity for approximately 4 weeks. At 8 weeks, active motion of the shoulder and elbow begins as well as low resistance strengthening. Formal physical therapy is typically not needed more than three months and individuals are placed on a home exercise program focused on continued strengthening and motion. Return to play or unrestricted functional activities may occur as early as 4 months postoperatively.

Given that the majority of patients have associated shoulder damage, rehabilitation in these scenarios is deferred to the demands of the respective protocol with integration of isolated LBHT therapy as allowed.

Complications

Complications related to the surgery include wound infection, deep vein thrombosis, nerve damage, and failure of the tenodesis. Continued, chronic postoperative pain may also be considered a failure and is often related to improper identification of all preoperative pathology and residual tenosynovitis of the biceps sheath. Postoperative anesthetic problems range from general medical problems such as cardiovascular events, nausea, vomiting to issues with regional anesthesia such as phrenic nerve paralysis, peripheral nerve damage, pneumothorax, and failure of the block. With proper evaluation and technique, these issues are rare.

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8 Internal Impingement/ SLAP Lesions

Armando F. Vidal and Kevin M. McGee

INTRODUCTION

Over the past 15 to 20 years, there has been increasing interest associated with internal impingement of the shoulder and the spectrum of pathology associated with this syndrome. The fascination surrounding internal impingement is equally distributed among sports fans and clinicians, due to its association with overhead athletes and the so-called dead arm. Shoulder problems in overhead athletes have been recognized for decades, especially in their relation to baseball pitchers. The physician's understanding of the condition has evolved from psychopathology to external impingement to internal impingement. There is still controversy over the underlying cause of internal impingement, but the resultant spectrum of shoulder pathology is well recognized and includes posterior labral tears, SLAP tears, posterior glenoid erosion, greater tuberosity cysts, and partial-thickness rotator cuff tears. There is now documentation in the literature of this spectrum of pathology in the general population, not just overhead athletes (1,2). This recognition makes the diagnosis and treatment of internal impingement all the more relevant for the orthopaedic surgeon.

PATHOPHYSIOLOGY/PATHOLOGY

There is some controversy in the literature regarding the essential anatomic abnormality that sets off the cascade leading to the shoulder pathology seen at arthroscopy in patients with internal impingement. The major difference in theories surrounding internal impingement is a question of laxity and glenohumeral translation. Are these shoulders too tight or too loose? There are studies to support both theories with good outcomes (3–12). It may be that both phenomena can lead to posterior-superior shoulder pathology. It is important to discuss these two theories because it may alter your ultimate treatment of patients with internal impingement.

Microinstability

Jobe and colleagues have described anterior instability in the overhead athlete (7–9,12). They note that there is often a continuum of instability in the throwing athlete and that it may present as occult or subtle. These authors have documented that rotator cuff injury in throwers results from increased glenohumeral motion that arises from instability (12). A subtle increase in motion can result in internal impingement of rotator cuff between the greater tuberosity and the posterosuperior glenoid. They believe that this contact leads to the spectrum of pathology seen in internal impingement. The degree and chronicity of the instability and impingement will affect the severity of injury. This is often related to the age of the athlete and how long they have been throwing or participating in overhead athletics.

Both static and dynamic stabilizers act to prevent shoulder instability. Secondary or dynamic stabilizers may be fatigued with repetitive throwing or overhead motions (serving motion in tennis and volleyball). The static stabilizers may be stretched or disrupted with a single traumatic event or, more often, through microtraumatic events associated with overhead sports. Davidson et al. (13) noted that increases in glenohumeral motion can arise from stretching of the inferior glenohumeral ligament (IGHL) complex or labral tearing.

In support of the instability theory, Jobe et al. (7) reported high rates of return to competitive play in throwers who were treated with anterior capsular labral reconstruction. Levitz et al. (11) also reported favorable results when capsular laxity in throwers was addressed at time of arthroscopy. In their study, patients were divided into two groups based on treatment. The first group of baseball throwers underwent débridement and or repair of labral and rotator cuff tears. The second group underwent this same treatment plus thermal capsulorrhaphy. At 30 months after surgery, 90% of the thermal capsulorrhaphy group was back to competition compared to 67% of the débridement/repair-only group.

GIRD

Burkhart et al. (4,5) have popularized the concept of an internal rotation defect as a cause of the pathology seen with internal impingement. They propose that internal impingement is a natural phenomenon in all shoulders, a concept that is supported by Halbrecht et al. (6) and Walch et al. (2). They explain that it is actually a tightening of the posteroinferior capsule that leads to the changes seen in the posterosuperior shoulder of overhead athletes. This contracture secondarily leads to hyperexternal rotation in abduction. They gave an extensive explanation of their theory in 2003 (5). We will try to highlight the key points of their theory.

The definition of glenohumeral internal rotation deficit (GIRD) is the loss of internal rotation in degrees when comparing the symptomatic shoulder to the contralateral shoulder. It is measured with the shoulder in 90 degrees of abduction (Fig. 8.1). The IGHL complex functions as a hammock to stabilize the shoulder in abduction. It is composed of the posterior inferior glenohumeral ligament (PIGHL) and the anterior inferior glenohumeral ligament that act as interdependent cables. Contracture of the PIGHL can shift the center of rotation of the glenohumeral joint posterosuperiorly with the shoulder in abduction. This allows increased external rotation as the greater tuberosity can now rotate further before contacting the posterior glenoid (Fig. 8.2). This posterosuperior shift in the contact point and greater tuberosity clearance leads to a decrease in the CAM effect of the proximal humeral calcar (Fig. 8.3). Reducing the CAM effect decreased tension on the anterior capsule causing capsular redundancy. Burkhart et al. believe that this redundancy can be misinterpreted as anterior instability. A shoulder that abducts and excessively externally rotates is prone to overuse injury. The biceps anchor and posterosuperior labrum can fail due to shear forces via the peel back mechanism. The posterosuperior rotator cuff sees both increased shear and torsional stresses, which can lead to undersurface fiber failure. Thus, with time, the thrower with GIRD can develop the pathologic changes seen with internal impingement.

CLINICAL PRESENTATION

Physical Exam

Patients with internal impingement can have a variety of findings on physical exam. A thorough shoulder exam with comparison to the uninvolved shoulder is very important. Evaluation of range of motion, rotator cuff strength, palpation, impingement maneuvers, scapular mechanics, stability, and biceps anchor or SLAP stress tests are all part of the exam. Exam findings will vary with length and severity of symptoms. Overhead athletes

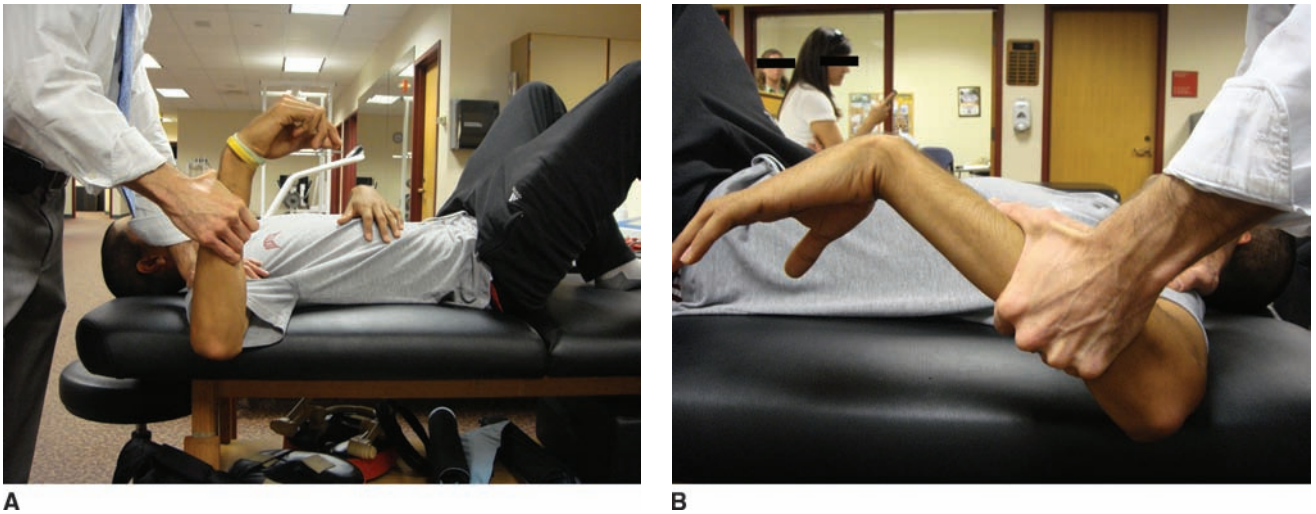


FIGURE 8.1

Severe GIRD in a collegiate tennis player. **A:** 0-degree internal rotation dominant shoulder. **B:** 60-degree internal rotation nondominant shoulder.

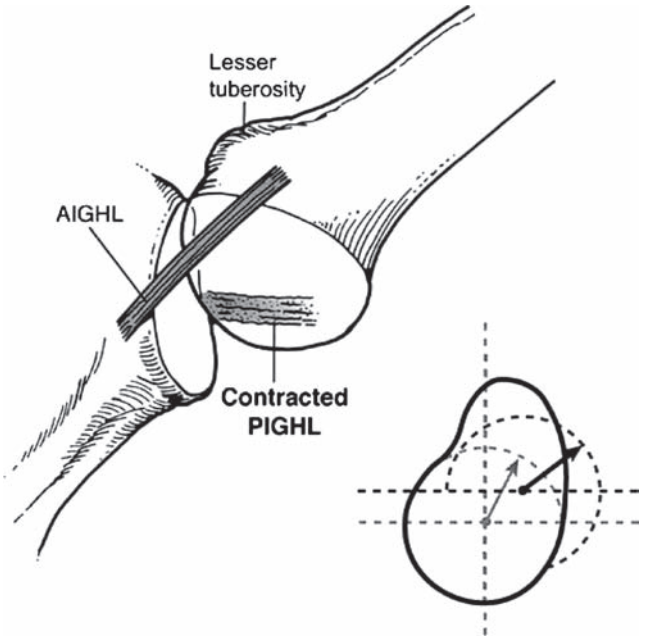


FIGURE 8.2

Reciprocal cable model of the IGHL complex. When the posterior cable shortens (contracted posterior band), the glenohumeral contact point shifts posterosuperiorly and the allowable arc of external rotation (before the greater tuberosity contacts the posterior glenoid) significantly increases (*dotted lines*). (Reprinted from Elsevier, with permission.)

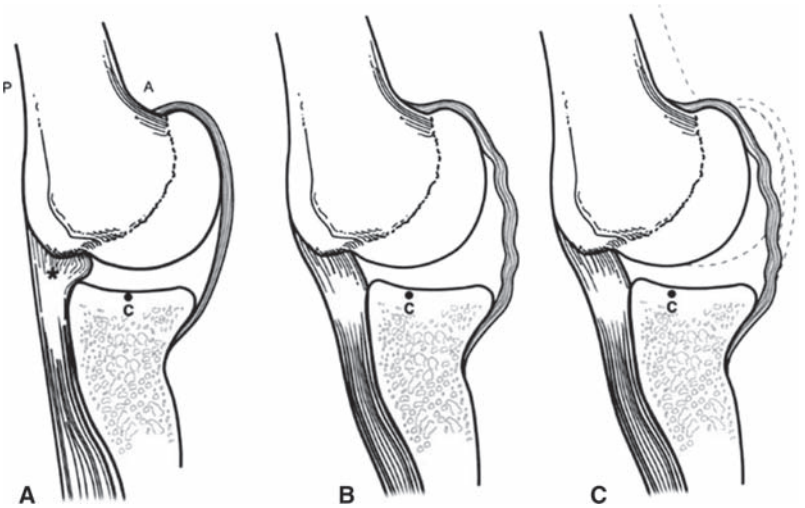


FIGURE 8.3

A: With the arm in a position of abduction and external rotation, the humeral head and the proximal humeral calcar produce a significant cam effect of the anteroinferior capsule, tensioning the capsule by virtue of the space-occupying effect. **B:** With the posterosuperior shift of the glenohumeral contact point, the space-occupying effect of the proximal humerus on the anteroinferior capsule is reduced (reduction of the cam effect). This creates a relative redundancy in the anteroinferior capsule that has probably been misinterpreted in the past as microinstability. **C:** Superimposed neutral position (*dotted line*) shows the magnitude of the capsular redundancy that occurs as a result of the shift in the glenohumeral contact point. (Reprinted from Elsevier, with permission.)

with chronic symptoms will frequently develop pain with external impingement maneuvers due to rotator cuff tendinopathy and subacromial inflammation. It is important to determine if these symptoms are secondary to internal impingement, as success with just subacromial decompression in overhead athletes is quite poor (14).

Overhead athletes, especially throwers, have characteristic adaptations with regard to range of motion. As mentioned previously, GIRD has been associated with internal impingement (4,5,15). Forward flexion and abduction are often normal or near normal. Rotation should be assessed with the shoulder in adduction and 90 degrees of abduction. In abduction, these patients will often have increased external rotation that can be quite substantial, especially in baseball pitchers. Internal rotation in abduction is often decreased. In many instances, the loss of internal rotation is greater than the gain in external rotation. It is important to compare motion to the uninvolved shoulder. A 20-degree difference in total arc of motion associated with a >20-degree loss of internal rotation between shoulders (20 degrees of GIRD) is considered pathologic (5).

Evaluation of scapular mechanics is essential for any patient with shoulder pain, especially the overhead athlete. Burkhart et al. (16) have discussed the importance of the SICK scapula and its relation to shoulder dysfunction. Correction of scapular position and function can have a large impact on shoulder dysfunction and pain in the overhead athlete.

Stability of the shoulder should be examined, as well as generalized ligamentous laxity. With the patient supine, apprehension, relocation, and load and shift can all be performed. These patients usually do not have gross instability on exam. Jobe et al. described the relocation test (1,13). It is positive when patients experience

posterior shoulder pain when placed in an abducted and maximally externally rotated position that is relieved with a posteriorly directed force on the shoulder. The pain is different from the feeling of apprehension and anterior shoulder pain in patients with anterior instability.

Rotator cuff strength is usually normal but may be decreased or painful with inflammation or high-grade partial-thickness tears. External impingement maneuvers may cause pain, although there is some disagreement among authors about both the frequency of this finding and its significance. Patients sometimes have posterior joint line or bicipital tenderness with palpation. SLAP or biceps anchor provocative tests may also elicit pain. There is controversy regarding the validity of many of the physical exam maneuvers to detect SLAP tears. Given the high frequency of superior labral pathology in this population, some combination of tests to load the biceps and superior labrum is warranted.

Imaging

Standard plain radiographic views of the shoulder in patients suspected to have internal impingement should at the very least include standard AP, axillary, and scapular Y views. In addition, West Point and Stryker notch views can be helpful. There are four radiographic findings that have been associated with internal impingement. These include exostosis for the posteroinferior glenoid (Bennett lesion), sclerotic changes of the greater tuberosity, posterior humeral head osteochondral lesions, and rounding of the posterior glenoid rim (17). Although these findings can be seen with internal impingement, it is important to note that plain radiographs are often unremarkable in these patients.

Regardless of findings on plain radiography, the majority of overhead athletes with shoulder pain will get an MRI. If there is suspected labral pathology, many authors recommend using magnetic resonance arthrography (18–24). This may change in the future as the images obtained with new, more powerful MRI scanners (3 T) show incredible detail without the need for arthrography. In addition to standard axial, coronal, and sagittal scans, it can be helpful to obtain MRI scanning with the shoulder in an abducted and externally rotated (ABER) position (25).

Typical MRI findings in patients with internal impingement are very similar to those described at arthroscopy by many authors. Labral tears, including SLAP lesions and posterior lesions, are common. Partial-thickness articular sided rotator cuff tears of the supraspinatus and/or the infraspinatus can be seen. Findings on plain radiographs, including Bennett lesions, humeral head cysts, and posterior glenoid erosion are all seen on MRI as well. MRI performed on both shoulders in ten asymptomatic collegiate baseball players in the ABER position showed contact between the rotator cuff and posterosuperior glenoid in all shoulders (6). Halbrecht et al. concluded that this contact was a normal occurrence in all shoulders. They did note pathologic findings in some of the throwing shoulders that were not present in any of the nonthrowing shoulders. Four of the throwing shoulders demonstrated findings consistent with rotator cuff tendinosis and three had labral tears with associated paralabral cysts. Other authors have also documented pathologic findings on MRI in asymptomatic overhead athletes (26,27). The surgeon must be cautious to correlate findings on history and physical exam with pathology found on radiographic studies.

TREATMENT

Nonoperative

As with the majority of overuse injuries, the initial approach to the patient with internal impingement should be conservative. Rest, ice, and a short course of oral nonsteroidal anti-inflammatory medication can all be beneficial in internal impingement. The workhorse of nonoperative treatment is physical therapy. Exercises are addressed at both stretching and strengthening. Given the reportedly high rate of GIRD associated with internal impingement, posterior capsular stretching exercises should be prescribed to any patient demonstrating a contracture on exam. Burkhart et al. (5) found that most GIRD could be reduced to acceptable levels in just 2 weeks with a good stretching program. Popular and affective exercises include the sleeper stretches (Fig. 8.4). Strengthening exercises should focus on the rotator cuff and periscapular muscles. Burkhart et al. (16) reported a 100% return rate with a scapular exercise program in athletes with SICK scapula syndrome.

Operative

Surgical intervention in patients with internal impingement may be considered if an extensive trial of nonoperative treatment, including physical therapy focused on pathologic findings found on exam and imaging, fails to bring symptomatic relief or allow return to play. Since several authors have documented pathologic findings in asymptomatic individuals, the surgeon must be careful not to jump to operative treatment without a course of conservative management. Due to the variety of pathology seen in internal impingement, the operative treatment performed will depend on several factors including physical exam, exam under anesthesia (EUA), pathology seen on imaging, and diagnostic arthroscopy. It is important to perform a good EUA on all patients and compare findings to the uninvolved shoulder. Particular attention should be paid to range of motion, especially GIRD, and instability, including the presence of a sulcus.

FIGURE 8.4

Dedicated posterior inferior capsular stretches. **A:** Sleeper stretch. **B:** Rollover sleeper stretch. **C:** Crossarm stretch. **D:** Doorway stretch.

Every patient undergoing surgery should be subject to a thorough diagnostic arthroscopy. Many patients with internal impingement have concomitant pathology and all sites of injury must be identified at arthroscopy. As noted previously, particular attention should be paid to the articular surface of the rotator cuff, posterosuperior glenoid and labrum, anterior capsulolabral complex, and the humeral head. Diagnostic arthroscopy includes examination of the subacromial space looking at the bursal side of the rotator cuff and for bursitis. If significant bursitis is present, then bursectomy is warranted without subsequent acromioplasty. Many authors have documented the poor return to play results with acromioplasty in athletes (14). Some have even hinted that internal impingement is a contraindication to acromioplasty (28). However, since patients with internal impingement can get secondary subacromial bursitis, we believe that a simple bursectomy should be performed in those patients with arthroscopically evident bursitis.

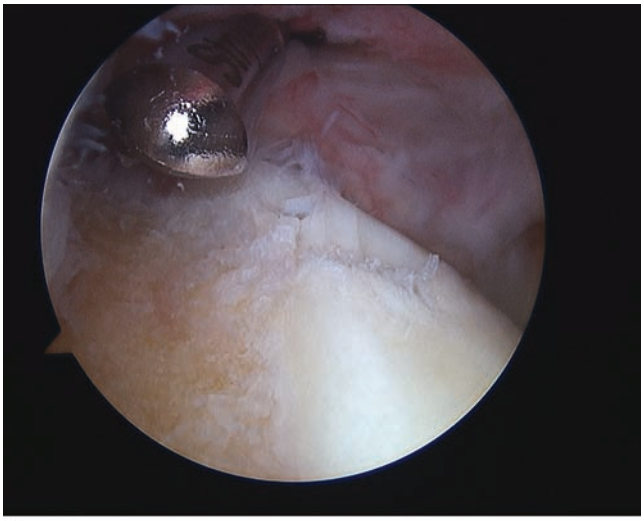
Rotator Cuff

Rotator cuff pathology is probably the most common finding in internal impingement. Most often, the site of pathology is the articular surface of the posterosuperior rotator cuff. This encompasses the posterior aspect of the supraspinatus and anterior infraspinatus. Fraying or partial tears can be seen at the musculotendinous junction or at the insertion of the rotator cuff on the greater tuberosity. Tears at the musculotendinous junction are

almost always minor and respond well to débridement alone. Tears at the insertion of the rotator cuff are seen more often in the older overhead athlete with internal impingement. These footprint tears can vary in severity. We perform débridement for low-grade partial-thickness tears. High-grade tears and full-thickness tears require repair. There are two techniques used to repair these partial tears. Partial articular-side tendon avulsion (PASTA) repair involves repairing the tear by placing anchors and suture through the rotator cuff without taking down the insertion site. The other option is completion of the tear at its insertion on the greater tuberosity followed by standard single- or double-row repair techniques. It should be noted that results for return to play in overhead athletes undergoing rotator cuff repair are generally poor (29). This may be due to the age of the patient and the severity of the injury. The results of débridement alone for partial-thickness rotator cuff tears are more favorable (28,30), but these may represent less significant injuries.

PASTA Technique

For the PASTA repair technique, suture anchors are placed transtendinous. Standard anterior and posterior portals are made. A thorough diagnostic glenohumeral arthroscopy is performed and the degree of pathology is determined. In order to do a PASTA repair technique, a subacromial bursectomy must be performed prior to suture anchor placement. This is to allow visualization and prevent damage to sutures in the latter portion of the procedure. After busectomy, an 8.25-mm screw-in canula is placed in the lateral portal in the subacromial space for later suture retrieval and knot tying. Next, we return the arthroscope to the glenohumeral joint, viewing from the posterior portal. The exposed portion of the greater tuberosity footprint is débrided down to a bleeding bed with a shaver through the anterior portal (Fig. 5A and B). Anchors (usually only one or two double-loaded anchors are needed) are placed through the tendon into the footprint (Fig. 5C). Suture passage is performed with a shuttling technique using a PDS suture, which is percutaneously placed through the rotator



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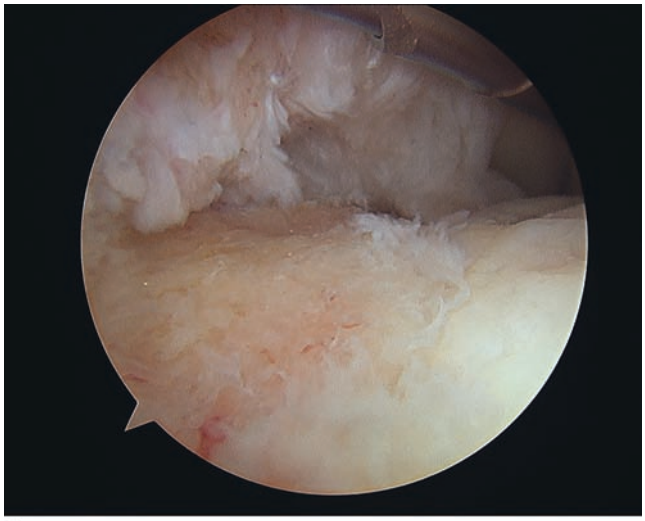

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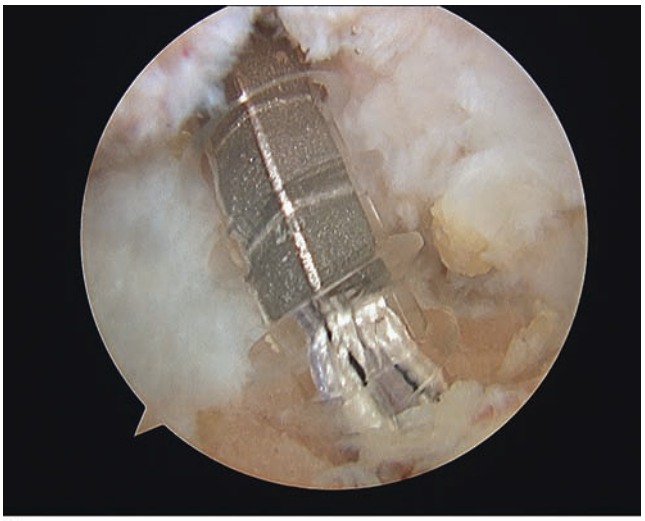

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FIGURE 8.5

PASTA repair. **A:** Preparation of footprint. **B:** Footprint débrided down to bleeding bed. **C:** Transtendinous placement of suture anchor in footprint.

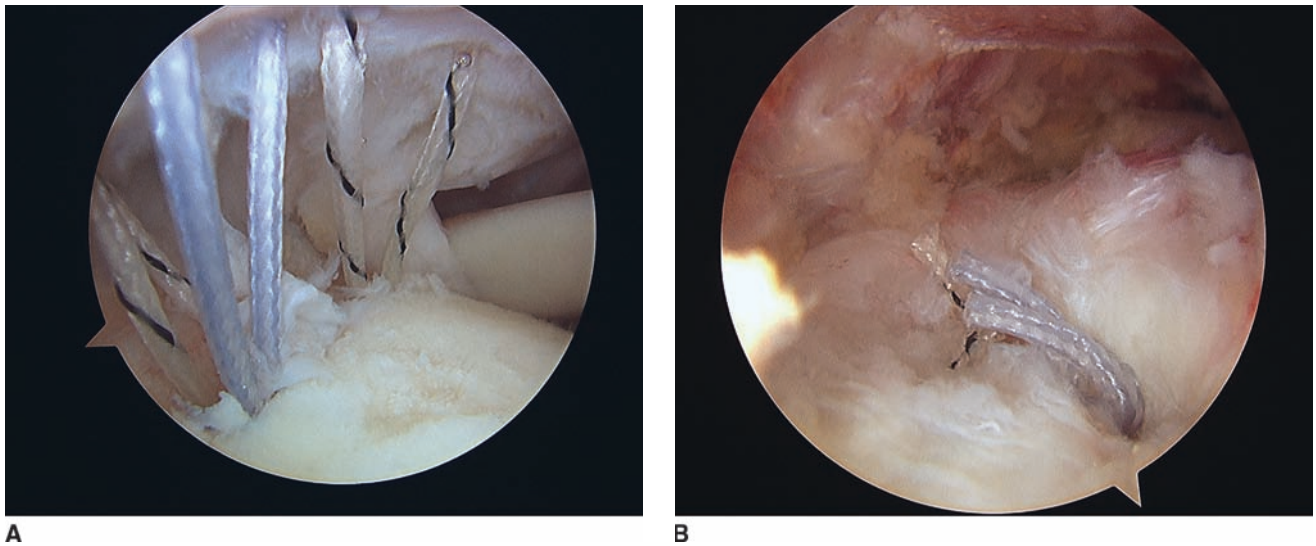


FIGURE 8.6

PASTA repair. **A:** Intra-articular view of sutures passed through the rotator cuff before knot tying. **B:** View from subacromial space of PASTA repair after knot tying.

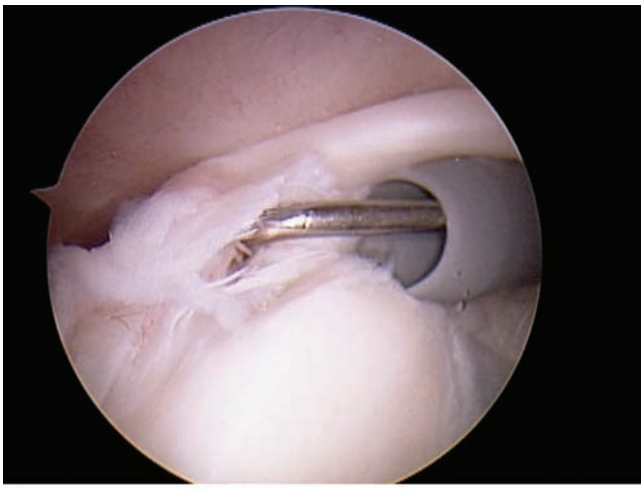
cuff using an 18-gauge spinal needle. The spinal needle is placed percutaneously through the rotator cuff medial to the edge of the tear. A 1 PDS suture is then shuttled through the spinal needle into the joint. This can be retrieved through the anterior portal along with one of the sutures from the anchor. The PDS is then tied around the anchor suture and it is shuttled back through the tendon. This process is repeated until all sutures from the anchors are passed through the rotator cuff in a horizontal mattress fashion (Fig. 6A). The arthroscope is then placed back in the subacromial space. As stated before, it is critical that a thorough subacromial bursectomy was performed prior to anchor placement so that the sutures can be visualized for knot tying. The sutures are then retrieved through the lateral canula one at a time and tied down securely on the rotator cuff using an arthroscopic locking knot (we prefer the Weston knot) followed by three half-hitches (Fig. 6B). The arthroscope is then placed back into the joint to inspect the repair. The previously exposed footprint should now be covered with tendon from the repair.

Standard Repair

In order to use standard single- or double-row repair techniques for partial-thickness rotator cuff tears, the tear must be completed. This can be done in many ways, but we prefer to use the shaver. Once the tear has been complete and the ends of the rotator cuff are débrided, a thorough subacromial decompression with or without acromioplasty is completed. Two canulas are then placed into the subacromial space. One is placed directly lateral off the acromion and the second is placed just off the anterior lateral corner of the acromion. The greater tuberosity is then débrided to a good bleeding bed. The arthroscope is placed in the lateral canula for viewing. The suture anchor(s) can be placed through the anterolateral canula. The sutures are retrieved out through a stab incision approximately 2 cm anterior and distal to the lateral canula using a loop grasper. This will keep the sutures out of the way while subsequently passing separate suture through the tendon. There are many methods for passing suture through the rotator cuff. For small tears such as these, the Scorpion (Arthrex) or ExpresSew (Mitek) work well. The advantage with these instruments is that they pass the suture through the tendon in one step. We also like to use the Spectrum suture passer (Linvatec). The advantage with this device is precise placement of the suture through the tendon, but it does require shuttling a monofilament suture (1 PDS) through the tendon, tying the PDS around the suture from the anchor, and then shuttling it through the tendon. The repair can be complete with either a single- or double-row technique, although most of these tears are small enough that a single row is all that is needed. Arthroscopic knots are tied through the anterolateral canula while continuing to view through the lateral canula.

SLAP Tears

Type II SLAP tears have long been associated with overhead athletes. In these patients, the tear is more likely to extend posterior to the biceps anchor than anterior. We prefer to use the lateral position for SLAP tears in overhead athletes, as the tear often extends around the posterior labrum. The lateral position offers excellent visualization of the posterior labrum. Using a standard posterior viewing portal and anterior working portal,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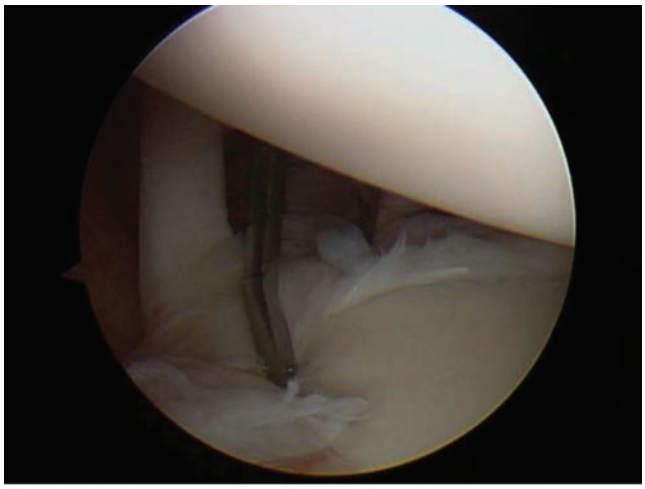
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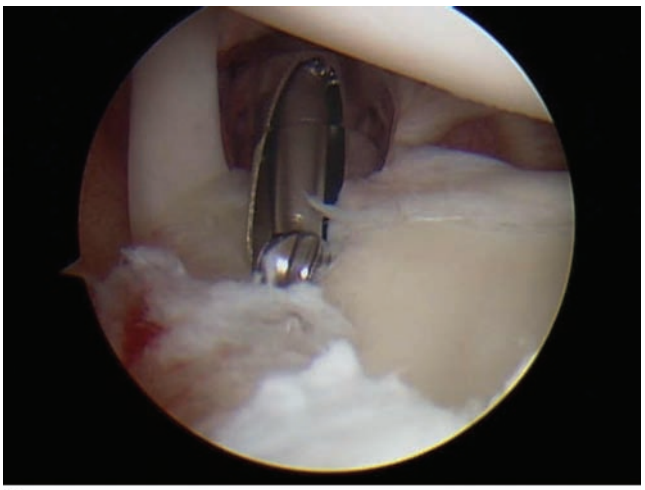
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FIGURE 8.7

SLAP repair. **A:** Type II SLAP tear. **B:** Elevation of the superior labrum. **C:** Preparation of the glenoid using an arthroscopic burr.

the superior labrum is examined. A probe is used to test the stability of the anchor. If the biceps is stable and there is only fraying present, then a débridement alone will suffice. If there is a true type II SLAP tear present with instability of the biceps anchor, then it should be repaired (Fig. 8.7A). If a repair is to be completed, the labrum and glenoid must be prepared prior to suture anchor placement. The labrum should be elevated off of the superior glenoid. This is usually fairly complete by the injury itself but can be accomplished with an arthroscopic elevator as well (Fig. 7B). Any fraying of the labrum should be gently débrided using a shaver. The glenoid is prepared by using the shaver in burr mode or a small round burr and débriding the bone down to a bleeding bed to promote healing of the labral repair (Fig. 8.7C). We then place an 8.25-mm screw-in canula through both the anterior and the posterior portals. We prefer to use a double-loaded glenoid anchor at the 12 o'clock position using a "harness" technique. We use single-loaded anchors as needed posterior to this. The number of anchors depends on the posterior extent of the tear. The anchors are placed transtendinous through a Wilmington portal. The double-loaded anchor is placed anterior at the 12 o'clock position under the biceps anchor and the single-loaded anchor is placed posterior to this at about the 11 o'clock position (right shoulder) (Fig. 8A). The sutures from the double-loaded anchor are immediately retrieved through the anterior canula, and the drill guide is left in the glenohumeral joint for placement of the second anchor. This is to minimize trauma to the rotator cuff, which can occur with multiple passes of the drill guide through the tendon. From the anterior anchor, one suture limb is passed through the superior labrum anterior to the biceps tendon. We prefer using the Spectrum suture passer (Linvatec) to pass a 1 PDS through the labrum and shuttling the suture from the anchor through the labrum. This anterior limb is tied first with the knot being anterior to the biceps tendon using an arthroscopic locking knot followed by three half-hitches (Fig. 8.8B). The arthroscope is then switched to the anterior portal and the posterior limb from the 12 o'clock anchor is passed through the labrum and tied posterior to the biceps tendon through the posterior portal (Fig. 8C). The remaining sutures are passed and tied from this position (viewing from the anterior portal and passing/tying sutures through the posterior portal).

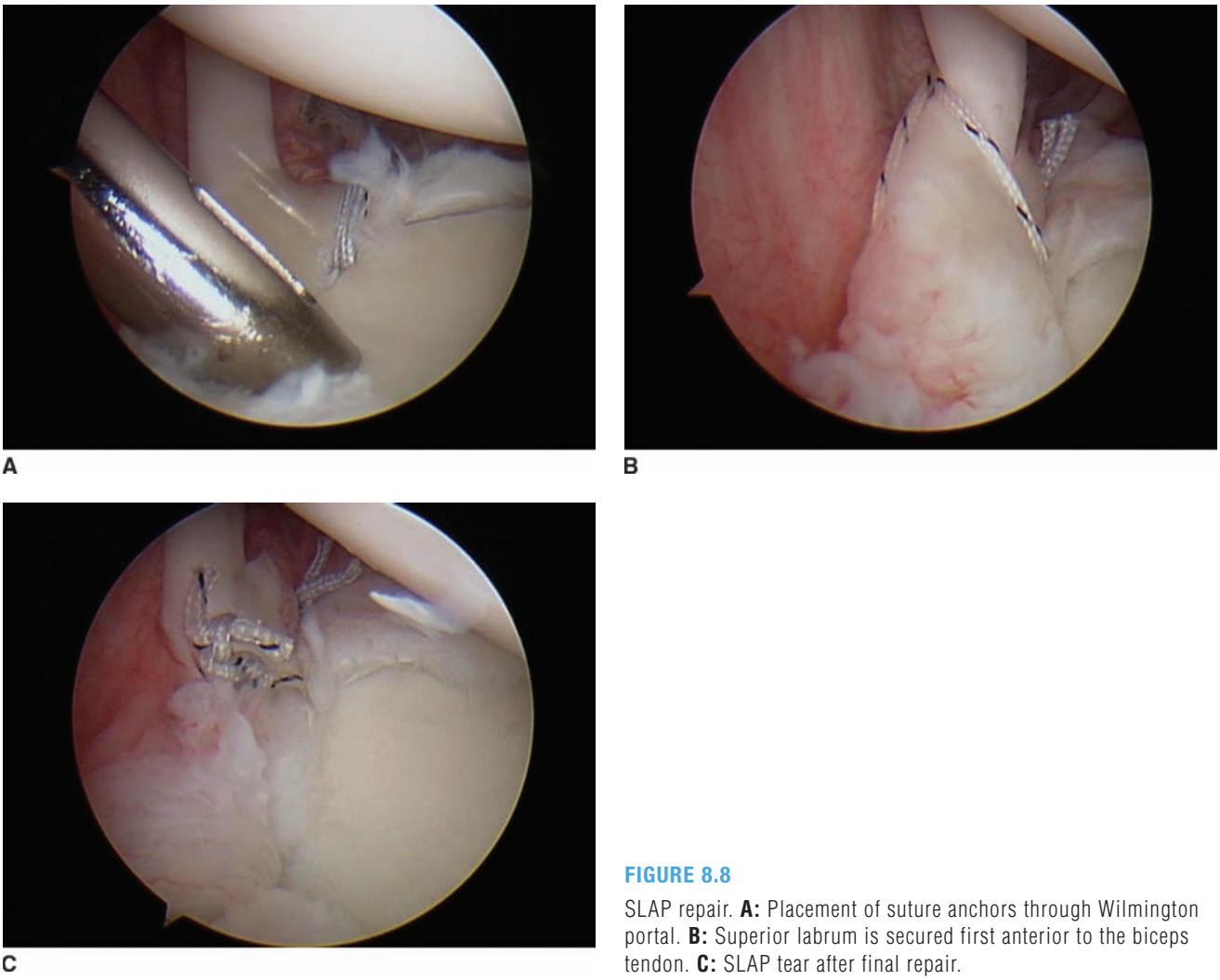

FIGURE 8.8

SLAP repair. **A:** Placement of suture anchors through Wilmington portal. **B:** Superior labrum is secured first anterior to the biceps tendon. **C:** SLAP tear after final repair.

Posteroinferior Capsulotomy

Patients with severe GIRD that does not respond to stretching may be candidates for a selective posteroinferior capsulotomy (5). These athletes tend to have long-standing symptoms and be older, elite pitchers with chronic shoulder problems. As with all patients with internal impingement, they often have associated intra-articular pathology (type II SLAP tears, partial-thickness rotator cuff tears). In addition to addressing these lesions, Burkhart et al. (5) have described a thickened and contracted posterior capsule in the area of the PIGHL. By selectively performing a capsulotomy in this region, they report an immediate 65-degree increase in internal rotation. This can be done using a hooked bovie (Fig. 8.9). The tissue can be 6 mm thick or more in these patients. An immediate postoperative stretching protocol must be started to maintain the gain in motion and prevent the capsulotomy from closing down.

SUMMARY

Internal impingement is becoming an increasingly important part of the shoulder surgeon's practice. This is likely secondary to our increasing awareness of the spectrum of pathology involved with internal impingement than an actual increase in incidence. Nonoperative treatment consisting of scapular stabilization and stretching exercises is often successful in treating the overhead athlete with shoulder pain. In shoulders that remain painful and dysfunctional despite adequate therapy, shoulder arthroscopy gives the orthopaedic surgeon an opportunity to address the patient's pathology in a relatively minimally invasive manner. Adequate treatment of all pathology at the time of arthroscopy can lead to good outcomes in most patients with internal impingement.

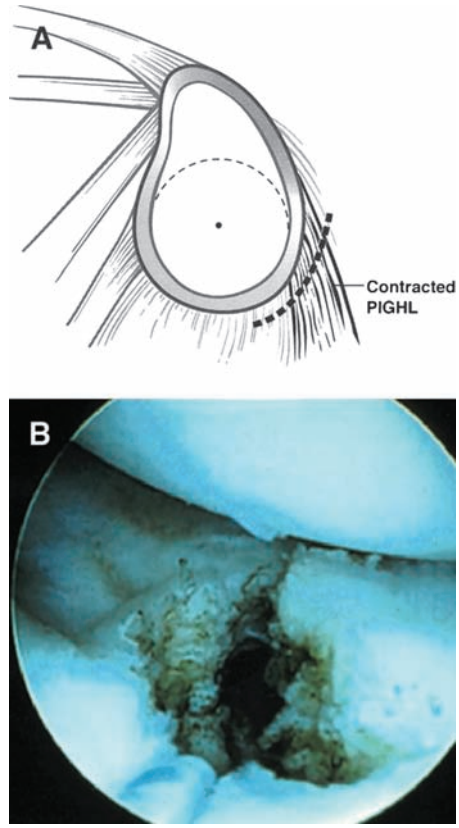

FIGURE 8.9

Selective posteroinferior capsulotomy. **A:** The capsular contracture is located in the posteroinferior quadrant of the capsule in the zone of the posterior band of the IGHL complex. The capsulotomy is made ¼ in away from the labrum from the 9 or 3 o'clock position to the 6 o'clock position. **B:** On arthroscopic inspection after the capsulotomy is made, note how thick the capsule in this zone has become. (Reprinted from Elsevier, with permission.)

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9 Anterior Shoulder Stabilization

Brian T. Feeley and C. Benjamin Ma

INTRODUCTION

Anterior shoulder instability is one of the most common injuries about the shoulder and accounts for one third of all emergency cases related to the shoulder. Recurrence is common and is directly related to the age of the patient. Some studies have found anterior instability to recur in >80% of patients younger than 20 years of age (19). Recurrence rates decrease to <50% by the time the patient reaches 30 years of age (18).

The treatment of patients with a traumatic first-time anterior shoulder dislocation is somewhat controversial. Some authors advocate surgical stabilization immediately, especially in young athletes (13). Others recommend nonoperative management with an emphasis on physical therapy and rehabilitation. However, the preferred treatment of a patient who has undergone multiple anterior shoulder dislocations is usually surgical, as the risk for articular and bony damage increases with subsequent dislocations.

The gold standard for anterior stabilization procedures remains the open Bankart procedure for anatomic reconstruction of the anteroinferior labrum. Arthroscopic techniques, originally described by Caspari and Morgan, have gained acceptance as the primary surgical treatment option in patients with recurrent anterior shoulder dislocations and no loss of the anteroinferior glenoid—the so-called Bony Bankart lesion. Early results with tacks and transglenoid sutures were less than promising, with recurrence rates ranging from 20% to 43% (10,11).

Newer arthroscopic techniques including suture anchor fixation and capsulolabral repair have increased the success rates of arthroscopic anterior shoulder stabilization to the level of an open Bankart repair in many series (5). Current techniques are highly reproducible and allow for consistent outcomes in the hands of an experienced shoulder surgeon.

INDICATIONS/CONTRAINDICATIONS

The indications for surgical treatment of anterior shoulder instability include patients who have had more than one traumatic dislocation and patients with a single traumatic dislocation but continue to have symptoms of instability or subtle subluxation despite a trial of physical therapy. The indications for arthroscopic anterior stabilization are as follows (7):

- Noncontact athlete under the age of 30
- Acute, traumatic injury
- Presence of a Bankart lesion on magnetic resonance imaging (MRI)
- Normal laxity on physical exam
- Well-developed inferior glenohumeral ligament complex

Open surgical stabilization is considered the optimal treatment in select cases (7):

- Significant glenoid bone loss
- Significant humeral bone loss
- Capsular deficiency
- Humeral avulsion of the glenohumeral ligament (HAGL lesion)
- Failed prior arthroscopic management

However, as arthroscopic techniques continue to improve, the indications for arthroscopic rather than open stabilization have been expanding. Some surgeons will consider revision arthroscopic stabilization, and treatment of a HAGL lesion can be performed arthroscopically as well (17,20). It remains controversial as to how to treat

contact athletes. Although many surgeons will perform an arthroscopic stabilization, the rate of recurrence has been shown to be higher in this patient population (6,15).

Contraindications for undergoing surgical stabilization include recurrent voluntary dislocators, multidirectional instability, and patients who are poorly motivated or unable to comply with the postoperative treatment program.

PREOPERATIVE PLANNING

History

As with any orthopaedic problem, the first step toward a diagnosis is a thorough history. For anterior shoulder instability, the mechanism of injury should be obtained in order to determine if the injury was of high energy or low energy. Patients with lower-energy dislocations may have a component of excess laxity and should be evaluated accordingly. The patient is asked if the shoulder subluxed or truly dislocated, and whether they were able to reduce the shoulder on their own or if it required anesthesia to achieve reduction. Clearly, the most important question to ask is if this dislocation was the first dislocation, and if not, how many previous dislocations have occurred on the affected shoulder.

Examination

Physical exam of the shoulder begins with visual inspection of the shoulder girdle. The contour of the deltoid should be evaluated to assess for an axillary nerve injury, which is an uncommon but reported complication following a shoulder dislocation. Range of motion is assessed and is typically normal. Isometric testing of the rotator cuff is performed. A rotator cuff tear is unlikely in a young patient with anterior instability; however, there is increasing frequency of rotator cuff tears as the patient ages. The apprehension sign, which is performed by bringing the arm into the abduction and external rotation position, is typically quite positive following a recent dislocation. The relocation test is likewise positive in most patients with anterior instability. A load and shift test can be performed in the office setting as well, but it may be difficult for the patient to relax enough to determine the correct amount of instability. The sulcus sign is performed by pulling down on the arm with the patient in a seated position. When positive, there is increased translation between the acromion and the humeral head, suggesting laxity in the rotator interval. In patients with suspected multidirectional instability, the sulcus sign is usually positive; other joints should be evaluated for signs of generalized ligamentous laxity.

Imaging

We typically obtain a true AP view of the shoulder, an axillary view, a scapular Y view, and a stryker-notch view. Bony Bankart lesions are best assessed on the true AP of the shoulder and the axillary view of the shoulder. A Hill-Sachs lesion is best seen on the Stryker-notch view.

MRI has become the gold standard for the diagnosis of anterior labral tears. It is particularly useful in determining concomitant pathology such as superior labral tears, biceps lesions, and posterior labral tears. It is also helpful in determining if the instability is due to a Bankart lesion or a HAGL lesion, which would alter the operative plan considerably. In our institution, we use contrast enhanced MR arthrograms for shoulder dislocations more than 3 weeks old to evaluate labral pathology, but other radiologists find it as accurate to perform noncontrast MRI to evaluate shoulder labral pathology (8,9) (Fig. 9.1). Contrast is not needed in the acute evaluation of shoulder instability due to the presence of a hematoma.

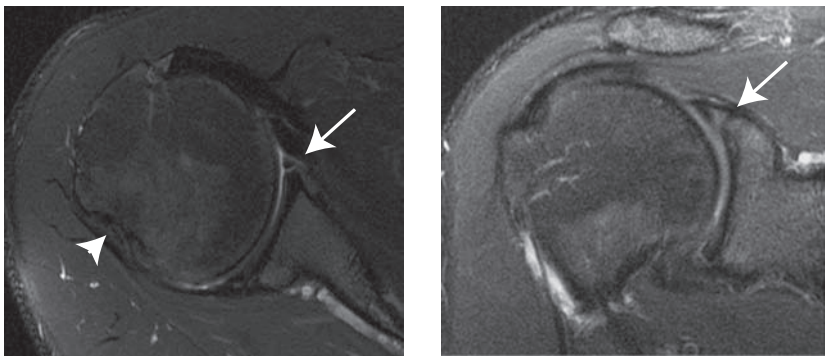

FIGURE 9.1

A: T2 FSE Noncontrast axial MRI demonstrating an anterior labral tear (*arrow*) with an associated Hill-Sachs lesion (*arrowhead*). **B:** T2 FSE Noncontrast coronal MRI demonstrating a concomitant Type III SLAP tear (*arrow*).

SURGICAL PROCEDURE

Anesthesia and Positioning

A majority of the patients receive an interscalene nerve block and general anesthesia. The interscalene block is helpful in limiting intraoperative narcotics and decreases postoperative pain and nausea.

The patient is anesthetized supine on a full-length bean bag and the operating table is configured into the beach chair position. The procedure can be performed in either the lateral decubitus position or the beach chair position and is largely surgeon dependent. The advantage of the lateral decubitus position is that traction on the arm can allow for better visualization and easier placement of anchor in the inferior aspect of the anterior glenoid.

Once the patient is properly positioned, the bean bag is inflated to secure the patient in the upright position. The bean bag must be properly folded to leave the entire medial border of the scapula free. This set up allows excellent control of the head and body during the procedure, and is easy to adapt for people of any body habitus. Once the beanbag is inflated, the patient and the beanbag are brought laterally to the edge of the bed, allowing complete exposure of the shoulder to the medial border of the scapula (Fig. 9.2). The arm is prepped and draped in standard fashion. In cases where an open procedure is performed, we routinely use an Ioban dressing in the axilla in order to decrease the risk of infection. A McConnell arm holder is used for both arthroscopic and open stabilizations. It is extremely useful to provide distal traction during the stabilization procedure.

Exam under Anesthesia

Prior to any incision, it is critical to perform an examination of the shoulder under anesthesia. The examination should be performed on both shoulders to assess asymmetry in the exam compared to the contralateral side. Range of motion is recorded as well. Exam under anesthesia should confirm grade 2 to 3+ anterior instability without any posterior or inferior translation. In some cases of inferior laxity, however, there will be some degree of inferior subluxation, and this should be accounted for in the capsular placation or rotator interval closure.

Portal Placement

There are typically three portals used for anterior stabilization of the shoulder. The primary viewing portal is made posteriorly in line with the glenohumeral joint. This portal is located 2 cm distal and medial to the posterolateral tip of the acromion. There are two anterior portals, and these must be carefully placed in order to facilitate the remainder of the procedure. The first portal is placed with an outside in technique with a spinal needle. It is placed in the rotator interval, just above the subscapularis tendon, laterally enough to facilitate placement of anchors at a 45-degree angle to the glenoid. The final portal is placed in the superior aspect of the rotator interval, just anterior to the biceps tendon. This facilitates suture management and can be utilized for anchor placement if a SLAP repair is necessary. We typically use a 7 to 8 mm clear cannula so that all instrumentation can be managed via either anterior portal.

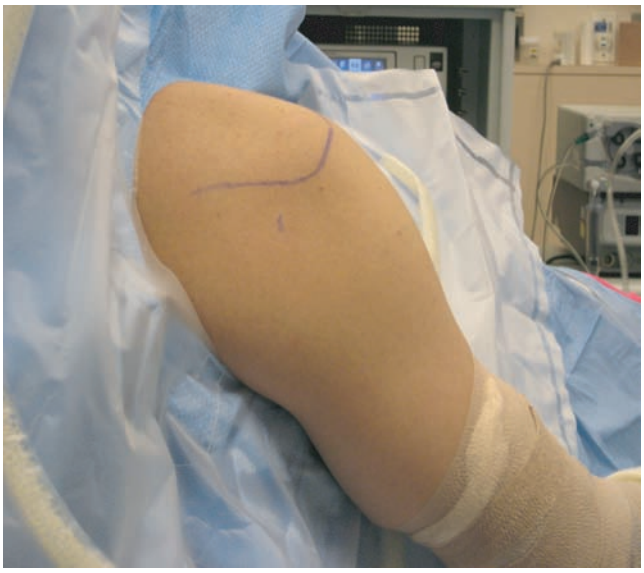

FIGURE 9.2

Beach chair positioning for the anterior stabilization. The posterior portal is placed more medially and inferiorly compared to a rotator cuff repair. The arm is draped free and the body is positioned off the bed so as to allow free motion with the arthroscope.

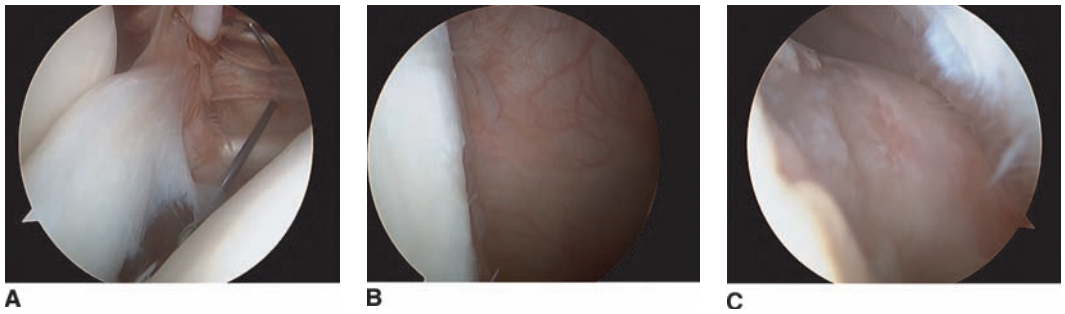

FIGURE 9.3

Diagnostic arthroscopy images. **A:** Disruption of the anterior inferior labrum and medialization of the labrum. **B:** Type III SLAP tear with inferior displacement of the superior labrum into the glenohumeral joint. **C:** Large engaging-type Hill-Sachs lesion.

Diagnostic Arthroscopy

In cases where we suspect that an open procedure is necessary, we routinely perform a diagnostic arthroscopy to evaluate the status of the entire glenohumeral joint. The injury is classified based on the type of lesion that is found on the anteroinferior glenoid. A Bankart lesion is a disruption of the labrum off the glenoid rim, with or without disruption of the glenohumeral ligaments (Fig. 9.3). A Perthes lesion occurs when there is a periosteal avulsion of the labrum together with the glenohumeral ligaments off the glenoid neck. If the labrum scars medially following this injury, it is termed an ALSPA lesion (anterior labrum periosteal sleeve avulsion).

Following evaluation of the anteroinferior labrum, attention is turned to the remainder of the labrum. In high-energy injuries, there can be concomitant injuries to the superior labrum or posterior labrum as well, and these should be critically evaluated in any shoulder stabilization procedure. Placing the camera through the anterior portal is helpful in evaluating the posterior labrum.

The glenohumeral ligaments are often injured in cases of recurrent shoulder instability and should be carefully evaluated during the arthroscopy. With a probe, the insertion sites of the IGHL and the MGHL should be checked on the inferior labrum to determine whether they have been disrupted or whether they have scarred in medially along the glenoid neck. The humeral insertion site should be carefully evaluated to assess for the presence of a HAGL lesion.

Finally, the chondral surfaces of the humeral head and glenoid should be carefully evaluated. Chondral defects of the anterior glenoid rim (GLAD lesions—glenoid labrum articular disruptions) typically cause pain and feelings of subluxation, but without frank dislocation. The humeral head is evaluated to determine the size of the Hill Sachs lesion. A Hill Sachs lesion that is >30% of the humeral sphere may require bone grafting or remplissage procedure (Fig. 9.3C).

Anterior Bankart Repair

There are several key steps in performing an adequate arthroscopic anterior Bankart repair:

1. Release of the labrum off the glenoid neck
2. Decortication of the glenoid neck
3. Accurate and safe placement of the suture anchors
4. Capsulolabral fixation
5. Stable knot tying

Release of the labrum off the glenoid neck

In a majority of cases, the labrum has scarred medially along the glenoid neck, and adequate mobilization of the labrum is quite difficult. A 30-degree tissue elevator is advanced through the anteroinferior portal carefully up to the junction of the glenoid neck and labrum, and used to create a tissue plane between the labrum and neck. Start at the superior aspect of the Bankart lesion and work down toward the inferior extent of the lesion (Fig. 9.4). It is often helpful to look down on this lesion by placing the arthroscope in the anterosuperior portal during this aspect of the procedure. Work the release medially with the use of an electrocautery device and the elevator until the labrum is completely free and detached from the glenoid neck. The subscapularis muscle should be able to be visualized if an adequate release has been performed.

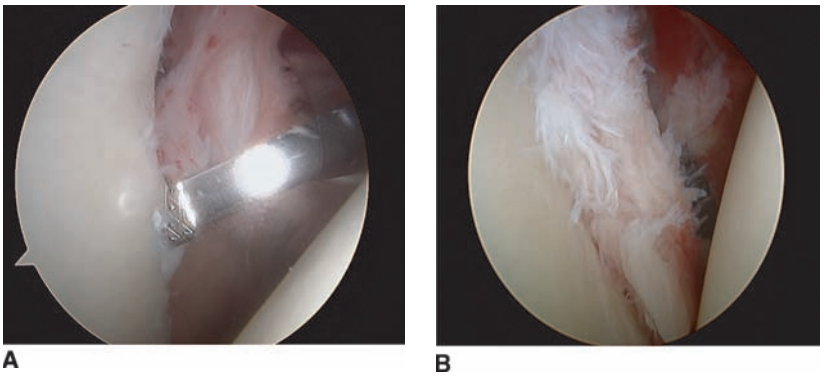

FIGURE 9.4

Elevation of the anterior-inferior labrum with a 30-degree tissue elevator. **A:** The elevator is started at the superior aspect of the tear and slowly advanced distally and medially to fully elevate the capsulolabral complex. **B:** Image of labrum following complete release and elevation of the tissue.

Decortication of the Glenoid Neck

Decortication of the glenoid neck is performed with the arthroscopic shaver placed in the anteroinferior portal. This step is critical for developing a healing bed for the labrum along the glenoid neck. A 3.5- or 4-mm shaver is used with the blades facing toward the neck of the glenoid and it is done until bleeding has been achieved. It is important to protect the free labrum from inadvertent damage from the shaver. A meniscal rasp or a 4-mm burr can be used alternatively, although a shaver is adequate at most times.

Capsulolabral Placation and Anchor Placement

Although some surgeons place the suture anchor prior to capsulolabral placation, we feel it is easier to perform this step first. Using a shuttle relay device (Spectrum, Linvatec Corp.) or a Suture Lasso (Arthrex, Naples Florida), the capsule is pierced at a level below the inferior extension of the labral tear in order to advance the capsule superiorly (Fig. 9.5). The bite of capsule should begin approximately 1 cm off the glenoid, and 8 to 10 mm inferior to the inferior extension of the tear. The labrum is then pierced separately and the suture or the shuttle device is advanced into the joint and retrieved through the accessory portal.

Although arthroscopic stabilization was originally described with transglenoid sutures and bioabsorbable tacks, a majority of the procedures are performed with suture anchors. Both metal and bioabsorbable anchors are available, and selection is based largely on surgeons' preference. The pullout strength of both types of anchors is more than sufficient to achieve adequate fixation strength (2,3). We use bioabsorbable anchors due to this risk of implant dislocation or misplacement and damage to the articular surfaces.

The first step in placing the anchor is placement of the spear and trochar through the anteroinferior portal, and place the instrument at approximately the 5 to 5:30 position. The trochar should sit up on the glenoid articular margin and be angled at approximately 45 degrees so that a good bone tunnel is generated and the labrum is accurately reduced (Fig. 9.6). Placement too medial on the glenoid neck will result in malreduction of the labrum. Too shallow of an entry angle can cause the anchor to skive under the cartilage and cause significant damage to the articular surface. The central trochar is tapped into the cortical bone to begin a pilot hole and then removed. Depending on the anchor used, either a tap is advanced into the bone (as in the case with most bioabsorbable anchors) or the anchor is drilled directly into the bone (for metal anchors).

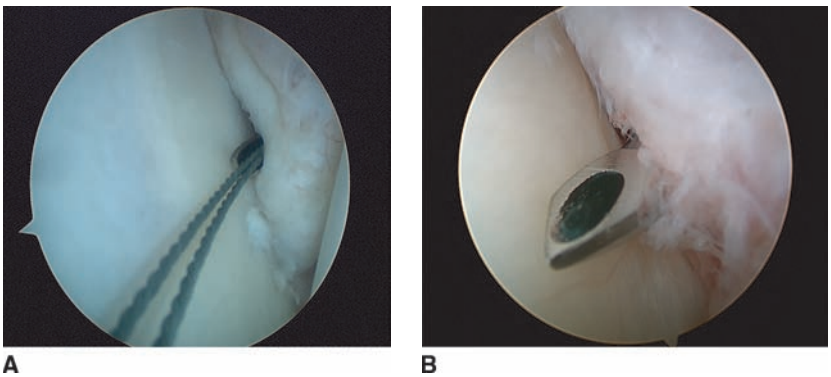

FIGURE 9.5

Placement of either a suture lasso **(A)** or a Spectrum **(B)** for passing the initial passing suture at the inferior aspect of the capsulolabral repair. Approximately 8 to 10 mm of tissue should be retrieved and the tissue is advanced from inferior to superior.

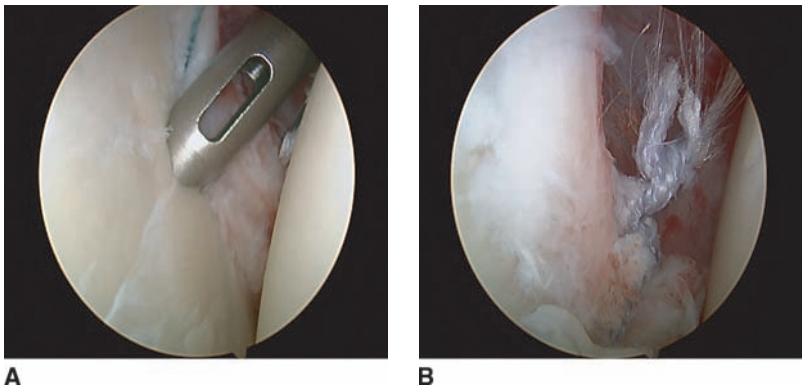

FIGURE 9.6

A: The anchor trochar is placed on the anterior rim of the glenoid and angled 45 degrees so that there is sufficient capture of the bone. **B:** Following placement of the first anchor.

Once the tap is removed, the anchor is screwed into place. There is typically a laser line on the inserter that will allow the anchor to be sunk to the correct depth. The anchor should be below the cortical rim so as to not risk articular damage. Too deep, however, and the sutures can become frayed on the edge of the bone. Once the anchor is placed, the sutures are tugged on to ensure an adequate fixation. The free end of the PDS is tied to the posterior suture of the anchor and the anchor suture is shuttled through the labrum and capsule.

We typically use an alternative technique to place our anchors, which we feel makes the procedure considerably easier (Fig. 9.7). Using a suture lasso, the capsule and labrum are penetrated and the lasso is advanced into the joint. The anchor and trochar are then placed through the closed loop and positioned onto the glenoid rim. The anchor is placed as described above, with the two suture anchor limbs now residing through the closed suture lasso loop. Using a suture retriever from the auxillary anterior portal, one of the sutures is retrieved and clamped. The suture lasso is then pulled back, pulling the suture through the capsule and labrum. This suture becomes the post. The suture retriever is then used to retrieve the anterior limb and the sutures are tied down in standard fashion.

Stable Knot Tying

The choice of arthroscopic knot is based on surgeons' preference. The most important aspect of arthroscopic knot tying is the use of a knot that the surgeon can reproducibly secure without difficulty. There are many knot tying techniques although we prefer an alternating half-hitch knot. Both sutures are retrieved and in the same portal. The limb that runs through the labrum and capsule acts as the post and is shortened accordingly. Two simple sutures are thrown and the post is pulled upon until the knot advances down to the level of the labrum. If the anchor was correctly placed, this should reduce the capsule and labrum to the glenoid rim. A knot pusher is then advanced and the knot is secured with the knot medial to the repair so as not to put the knot on the articular surface. We place a total of five knots for each suture anchor, and a fiberwire cutter is used to cut the ends.

For most Bankart repairs, two to four suture anchors are necessary for a complete repair. They should be separated by at least 4 to 5 mm. It is rare that less than two anchors are used as this provides only one stable fixation point for the labrum.

CONCOMITANT PROCEDURES

Rotator Interval Closure

In cases with a significant component of multidirectional instability, we will typically perform a rotator interval closure as well. The arthroscope is placed back in the posterior portal and the rotator interval is viewed anteriorly. A nonabsorbable suture is loading into a penetrator and the penetrator is advanced from the anterior portal through the capsule. This should be placed 1 cm lateral to the glenoid and just above the subscapularis tendon. A suture grasper is used to secure the suture within the joint. The penetrator is advanced again into the joint, this time piercing the superior glenohumeral ligament. The free suture is grasped and transported out the portal. The knot is tied blindly outside the capsule with the arm at 30 degree of external rotation so as to not overtighten the shoulder. This can be repeated with two to three sutures. Shoulder range of motion should be checked to ensure that there has not been excessive loss of external rotation.

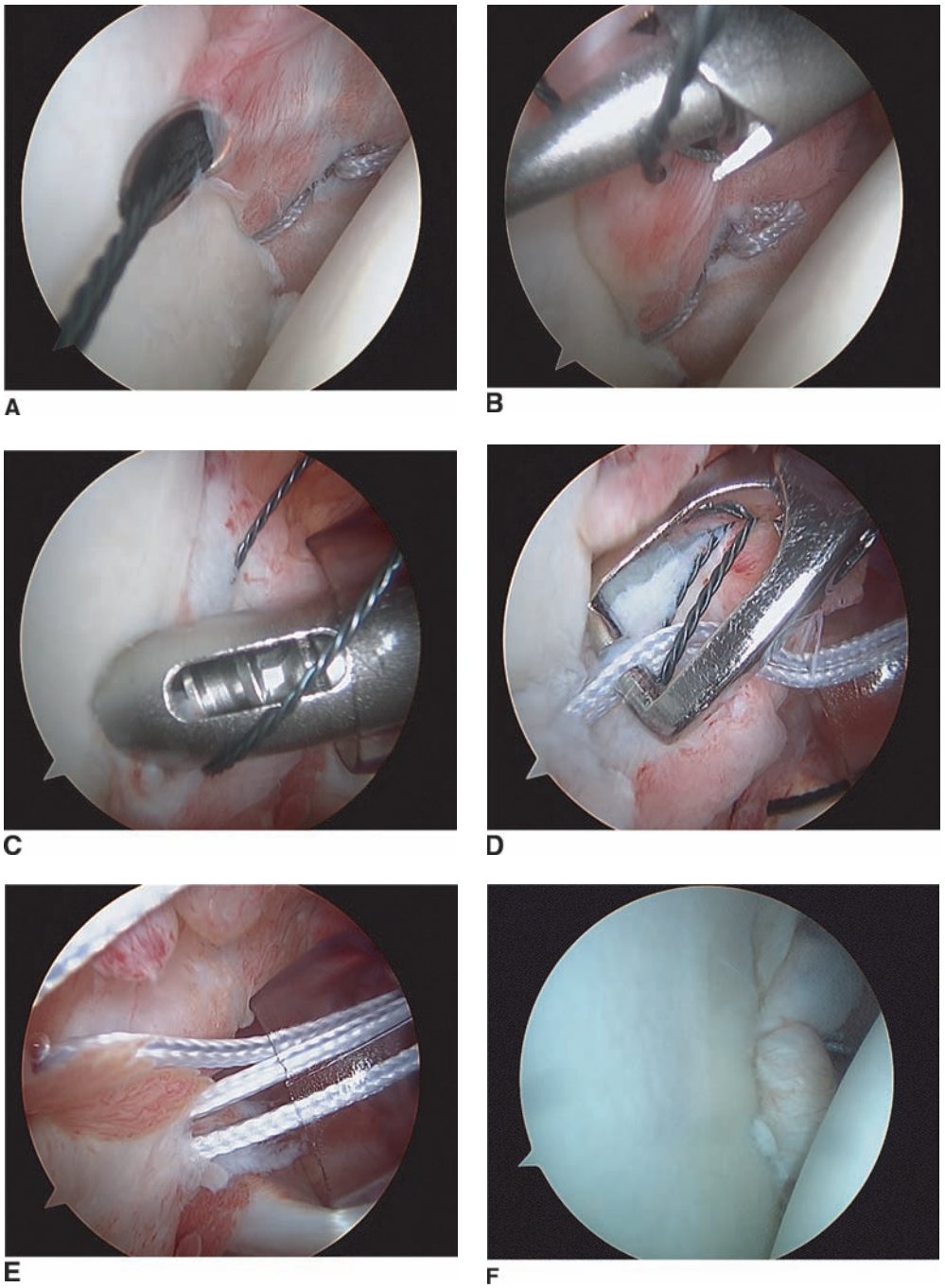

FIGURE 9.7

A: The shuttle relay is placed through the capsulolabral complex (in this case, the first anchor has been placed at the 5:00 position). **B:** The anchor trochar and guide is place through the closed loop of the shuttle relay. **C:** The anchor is drilled to completely bury the anchor in bone. **D:** Using a suture retriever from the anterior superior portal, the anterior limb of the suture anchor is retrieved, freeing it from the suture lasso. **E:** The lasso is then used to pull the posterior limb through the capsule. This limb becomes the post. **F:** The knot is tied down via the anteroinferior portal and the repair is secured. The final repair demonstrates reduction of the humeral head into the center of the glenoid.

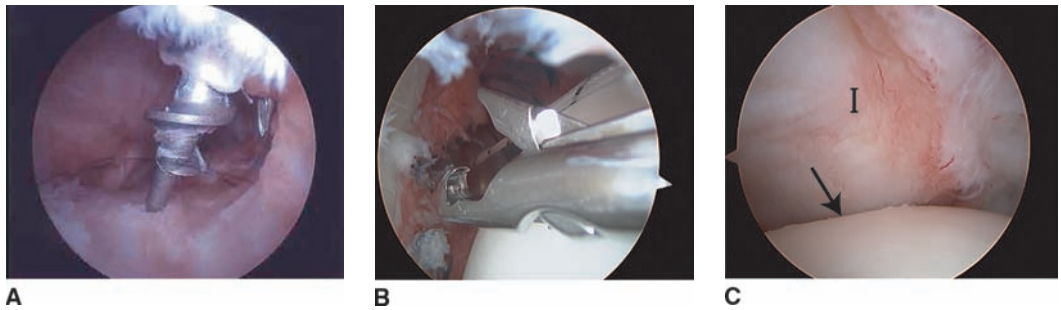

FIGURE 9.8

Remplissage of a large Hill-Sachs lesion. **A:** The 5-mm Corkscrew anchor is placed in the center of the defect with the arm externally rotated. **B:** After a knot pusher is used to advance the suture into the joint, a penetrator is used to pierce the infraspinatus and capture the suture. A horizontal or simple suture can be used. The knot is tied blindly. **C:** When viewed from the anterior portal, the infraspinatus (I) fills the Hill-Sachs defect (*arrow*).

SLAP REPAIR

In cases where the tear extends superiorly into the superior labrum, the SLAP tear must be identified and debrided or repaired accordingly. The arthroscope is placed in the posterior portal, and the SLAP tear is visualized easily. The steps for SLAP repair are quite similar to the steps for Bankart repair. The superior labrum is mobilized with an elevator and the rim of bone underneath is decorticed with a rasp or shaver. The trochar and spear are advanced into the anterosuperior portal and the trochar is placed at approximately the 11 to 11:30 position (in a right shoulder; 12:30 to 1 position in the left). The anchor is placed and the sutures are retrieved. We use a spinal needle through the Neviaser portal to shuttle the suture through the superior labrum, although a curved suture passer can also be utilized via the anterior portal. With a spinal needle though the Neviasier portal, a 0-PDS is advanced and retrieved through the anterior portal. The medial suture limb is also retrieved and the PDS is used to shuttle the suture through the superior labrum. Both sutures are retrieved and tied down in standard fashion. This is repeated posterior to the biceps, and a third anchor can be added if the posterior superior labrum is injured as well.

REMPLISSAGE

In cases with a large, engaging Hill-Sachs lesion, it may be beneficial to use a soft tissue augmentation to decrease this defect. The remplissage (French for "to fill") technique utilizes an infraspinatus tenodesis into the defect to decrease the risk of engaging the lesion (Fig. 9.8). The arm is externally rotated and the arthroscope is placed either in the posterior or in the anterosuperior portal. An accessory posterolateral portal is established with a spinal needle in line with the Hill Sachs defect. A metal 5 corkscrew anchor is then placed percutaneously into the defect. This bone is often quite hard, and it may need to be tapped prior to placement of the anchor. One limb is shuttled anteriorly into the joint with a knot pusher, and a straight penetrator is placed through the infraspinatus tendon to retrieve the suture anchor. This will then allow a mattress-type suture through the infraspinatus tendon. The limbs are then tied down blindly to tenodese the infraspinatus into the defect.

POSTOPERATIVE MANAGEMENT

Arthroscopic stabilization is performed on an outpatient basis, and the patients are placed in a sling postoperatively. Pain medication and anti-inflammatories are given for pain relief. During the first 3 weeks, passive range of motion exercises are initiated with a goal and limit of 30-degree abduction, no external rotation, 30-degree forward flexion, and 60-degree internal rotation. Abduction and forward flexion are increased to 90 degrees from 3 to 6 weeks. After 6 weeks, range of motion limits are removed and strengthening is commenced. Return to sports usually occurs at approximately 6 months.

OPEN BANKART STABILIZATION

The patient is positioned in the beach chair position, but more recumbent than for arthroscopy. The arm is placed in a McConnell shoulder holder with the shoulder in a neutral position. The shoulder is prepped and draped with a sterile Ioban dressing over the shoulder and in the axilla to decrease the risk of perioperative contamination from the skin flora. The arm is adducted across the body to identify the normal axillary skin crease and the incision is marked from the corocoid process in line with the skin crease. The skin is injected

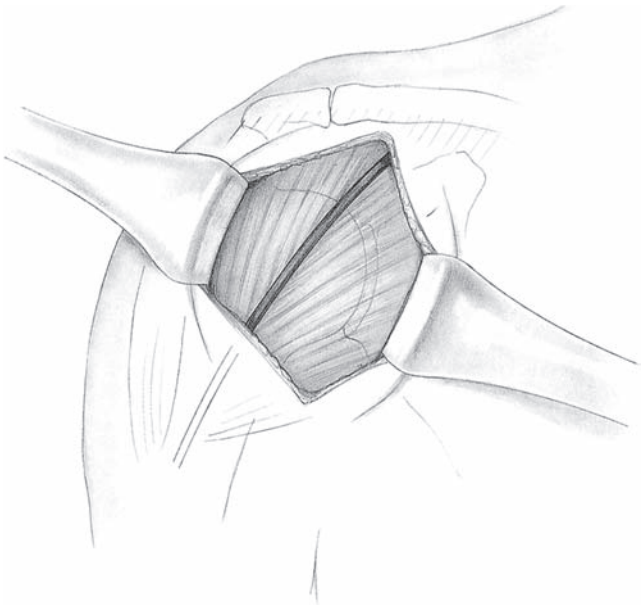

FIGURE 9.9

Exposure of the anterior shoulder. The cephalic vein lies in a small bed of fatty tissue and delineates the interval between the pectoralis major and the deltoid.

with 0.5% lidocaine with epinephrine and the skin is incised. Sharp dissection is taken down to the deltopectoral fascia and superficial retractors are placed in the skin to facilitate exposure.

Once the deltopectoral fascia is exposed, the cephalic vein is identified in the field of the incision (Fig. 9.9). It typically lies within a bed of fatty tissue and can be located by externally rotating the arm. Using curved Metzenbaum scissors, the vein is isolated and taken laterally. Blunt dissection is then used to develop the plane between the deltoid and pectoralis muscle. Deep self-retraining retractors are placed between the deltoid and the pectoralis, above the level of the strap muscles. Although some surgeons prefer placing the rectractors deep to the strap muscles, there is a risk of nerve injury with placement here, and we feel that exposure is adequate with the retractors above the strap muscles.

The clavipectoral fascia is incised and elevated off the surface of the subscapularis muscle. Once the subscapularis muscle is exposed, there are several techniques to gain exposure to the anterior joint capsule. The subscapularis can either be taken off the lesser tuberosity, leaving a small (1 cm) cuff of tissue on the lesser tuberosity for repair at the conclusion of the case. In this case, the subscapularis is cut with an electrocautery device, and the three small vessels at the inferior border of the subscapularis are identified and cauterized to minimize bleeding. The tendon is tagged with heavy 1 fiberwire sutures and carefully elevated off the anterior capsule. Alternatively, the subscapularis can be split in line with its fibers at the junction between the middle one third and distal one third to expose the anterior joint capsule (Fig. 9.10).

The anterior capsule exposure is facilitated with a Homan retractor above and below the humeral head. The capsulotomy can be performed with either a straight transverse incision, or a medial- or lateral-based "T-incision." In cases of isolated Bankart lesions with minimal capsular laxity, a straight transverse incision is probably sufficient. However, if there is significant capsular laxity, a lateral- or humeral-based T-type incision is made (1). The ends of the capsule are tagged with heavy sutures and a ring or Fukuda retractor is slid along anterior margin of the glenoid, exposing the glenoid rim and Bankart lesion.

The steps of the open Bankart repair are similar to the arthroscopic procedure. A small elevator is used to elevate the labrum off the glenoid neck to facilitate reduction of the labrum to its anatomic position. A rasp or small burr is used to create a bleeding surface on the glenoid rim. Two to four suture anchors are placed in the anteroinferior glenoid neck abutting the articular margin, spaced approximately 8 to 10 mm apart (Fig. 9.11). It remains imperative to avoid articular damage with placement of the anchors. The sutures are placed through the labrum and tied, securing the labrum to the glenoid rim.

The arm is placed in 45-degree abduction and 45-degree external rotation and the capsule is repaired. In cases of a straight transverse incision, the capsular flaps are secured in a pants-over-vest fashion with the inferior limb translated superiorly to decrease capsular volume. If a T-type incision was used, the inferior limb is secured superiorly followed by advancement of the superior limb inferiorly. 2 fiberwire or similar heavy nonabsorbable sutures should be used for the capsular repair (Fig. 9.12).

If there is significant inferior laxity preoperatively, a rotator interval closure can be performed at this point in the procedure. This is done with heavy nonabsorbable sutures. However, this step can considerably decrease external rotation and should be done in limited cases to avoid difficulty with range of motion following surgery. The subscapularis is reapproximated with 2 fiberwire with the arm in neutral. The deltopectoral split is closed with absorbable suture and a routine skin closure is performed. A sling with an abduction pillow is applied prior to the patient waking up.

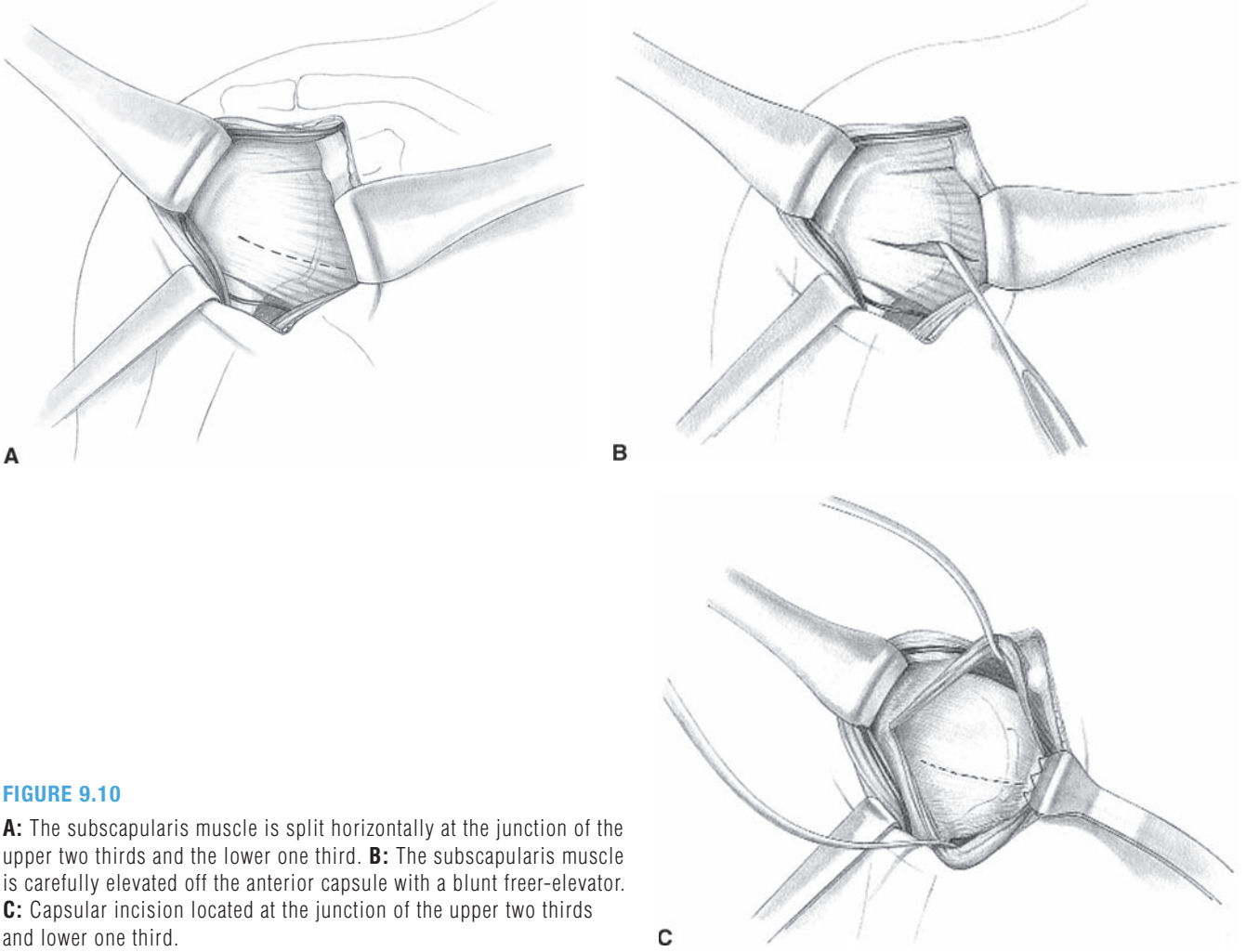

FIGURE 9.10

A: The subscapularis muscle is split horizontally at the junction of the upper two thirds and the lower one third. **B:** The subscapularis muscle is carefully elevated off the anterior capsule with a blunt freer-elevator. **C:** Capsular incision located at the junction of the upper two thirds and lower one third.

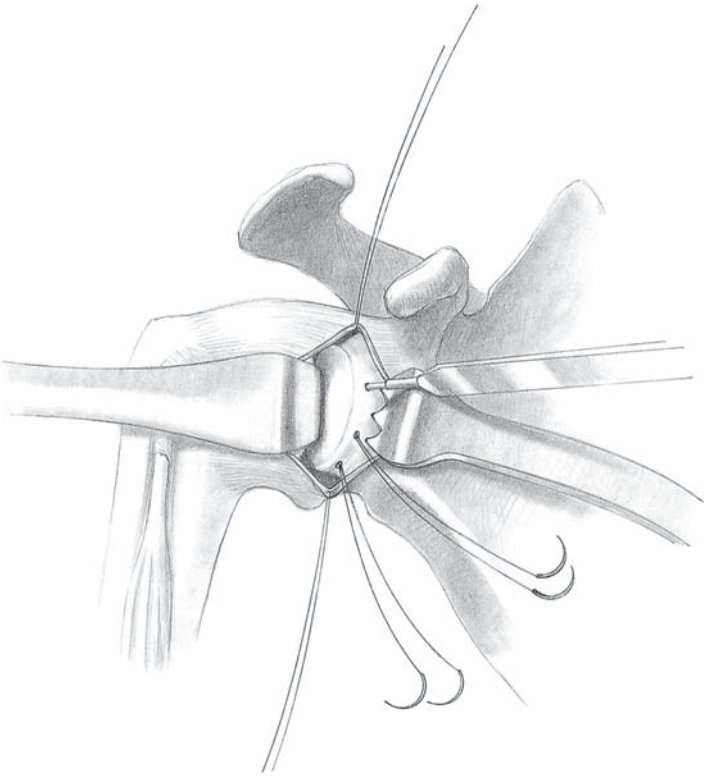

FIGURE 9.11

Placement of anchors into the glenoid rim.

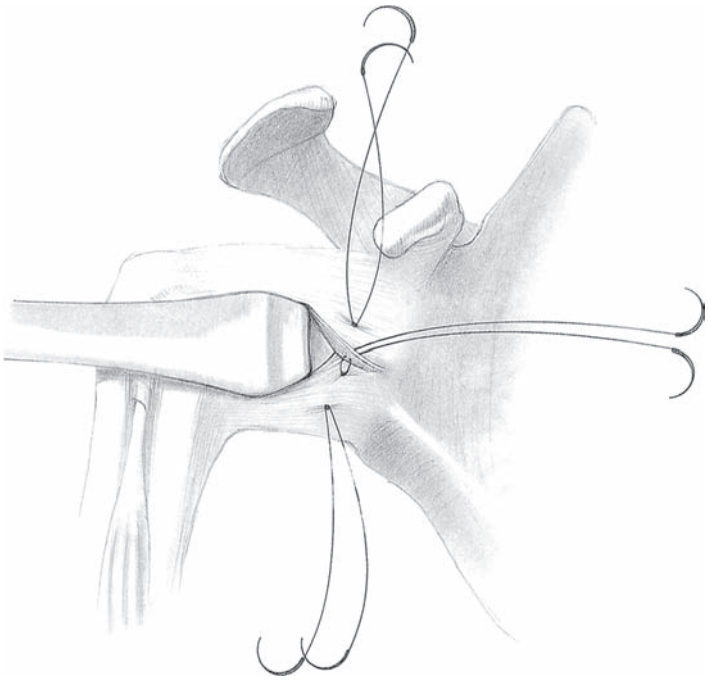

FIGURE 9.12

Capsular closure with the superior capsular flap advanced inferiorly, overlying the inferior capsular flap that has been advanced superiorly.

POSTOPERATIVE CARE

In the early postoperative period (weeks 0–4), the sling is maintained at all times. Pendulum exercises and elbow range of motion exercises are permitted, as are deltoid and scapula isokinetic exercises. At the beginning of week 5, passive and active assisted range of motion exercises are started, with external rotation limited to 45 degrees. Rotator cuff strengthening is started with 130 degrees of abduction, typically at approximately 8 to 10 weeks. At week 12, exercises are advanced to restore full external rotation, and neuromuscular feedback with plyometric exercises are initiated. By week 16 to 18, conventional weight training exercises can be done. When strength and range of motion are equal to the other side, contact sports can resume—typically at 6 to 8 months.

OUTCOMES

The results of open and arthroscopic stabilization have been reported in many studies. Overall, the recurrence rate is quite small (0%–10% in most series). Pagnani and Dome (15) reported on 103 patients with a minimum of 2 years follow-up with an open stabilization and no bony augmentation. The overall recurrence rate was 2%. Two patients lost significant (20 degrees or more) external rotation. Hubbell et al. (12) reported on a small case series (20 patients) with no recurrence (12). With the increasing trend toward arthroscopic shoulder stabilization, there have been many studies reporting on the outcomes of arthroscopic anterior stabilization with suture anchors. The overall recurrence rate ranges from 0% to 16%. Bottoni et al. (4) reviewed 32 shoulders at a mean follow-up of 32 months. There was 1 recurrence, and a mean Rowe score of 89 (out of 100).

Outcomes for stabilization in contact athletes tend to favor an open approach, although a formal comparison is lacking. Pagnani and Dome (15) evaluated the outcome of an open stabilization on 58 American football players with an average age of 18 years. At 2 years' follow-up, all had returned to play at the same level and there were no true dislocations. Similarly, Mazzocca et al. (14) found similar results in 18 patients followed for 37 months. There were two recurrences (11%) and a mean ASES score of 90 (out of 100). Cho et al. (6) compared the results of arthroscopic stabilization in collision and noncollision athletes. At 5 years, there was a significantly higher failure rate in collision (28%) versus noncollision (6%) athletes. Rhee et al. (16) found higher recurrence rates in arthroscopic stabilizations (25%) compared to open stabilizations (12%) in contact athletes.

SUMMARY

The surgical treatment of anterior shoulder instability continues to evolve. Both open and arthroscopic techniques have good to excellent results with acceptable recurrence rates. The careful selection of patients for open or arthroscopic anterior stabilization should result in predictable outcomes. Patients with an isolated recurrent

anterior instability who are noncontact athletes and have no bony loss can likely be successfully managed with an arthroscopic stabilization. Those with significant capsular laxity or bony deficits are better managed with an open stabilization.

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10 Posterior Shoulder Stabilization

Brian T. Feeley and C. Benjamin Ma

INTRODUCTION

Recurrent glenohumeral posterior instability is significantly less common than its anterior counterpart. In most large series, recurrent posterior instability accounts for between 3% and 10% of all patients with glenohumeral instability (6,7). In many cases of posterior instability, there is often a component of inferior laxity or multidirectional instability. The etiology of recurrent posterior instability can be from a single isolated traumatic event, repeated microtrauma (such as occurs with offensive linemen), or atraumatic and associated with ligamentous laxity. Anatomic considerations for posterior instability include soft tissue abnormalities such as a thin or patulous posterior capsule, increased glenoid retroversion, and increased humeral retroversion.

INDICATIONS/CONTRAINDICATIONS

Posterior stabilization is indicated in the younger patient with isolated posterior instability following a trial of physical therapy that has not relieved the feelings of pain and instability. The patient should not have global instability and should have a history of an identifiable traumatic event or recurrent lesser traumatic events. Excessive glenoid retroversion is not a contraindication but should be evaluated properly as it will alter the intraoperative plan considerably. Patients with multidirectional instability are generally not considered candidates for surgery, although those who have failed physical therapy and continue to have primarily posterior-inferior instability may benefit from a posterior capsular shift. The decision on whether to perform an open or arthroscopic posterior stabilization is usually determined based on the need to perform a capsular plication. Those patients who require an isolated labral repair are better managed with an arthroscopic posterior stabilization. Patients who have failed arthroscopic management, patients who have excessive posterior laxity on exam, and those with poor capsular tissue when evaluated arthroscopically should be considered for open posterior stabilization. Patients who voluntarily sublux their shoulder posteriorly with their arm at their side by selective muscle activation should not undergo posterior stabilization. Patients with a psychiatric history, active infection, inability to comply with postoperative immobilization and therapy, and secondary gain are not candidates for surgery.

PREOPERATIVE PLANNING

A thorough history and physical exam is important in the evaluation of suspected posterior instability. Patients typically have a traumatic event where the arm was positioned below shoulder level. There is often a posteriorly directed blow to an arm extended or flexed at the elbow. Other patients report repeated minor traumatic events with the arm positioned in a similar manner. Unlike anterior instability where the primary concern is usually apprehension, patients with posterior instability often present with vague activity-related posterior shoulder pain, clicking, or popping.

Patients often complain of difficulty pushing open heavy doors. The physical exam should document range of motion and must include a complete instability exam. It is vitally important to determine if the posterior instability is isolated or due to a more global instability pattern. Care must be taken to attempt to elucidate signs of multidirectional instability and generalized laxity. Patients with hyperflexibility of the elbows, wrists, and laxity of the contralateral shoulder should raise the possibility of global laxity, and any surgical procedure should commence only after a complete trial of physical therapy has failed.

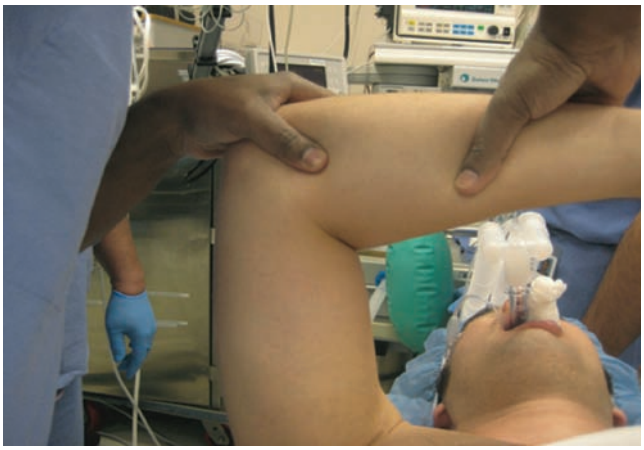

FIGURE 10.1
Jerk test. The "jerk test" is performed with an axial posterior load onto an arm flexed at 90 degrees, adducted, and internally rotated; it is positive with reproduction of the instability sensation.

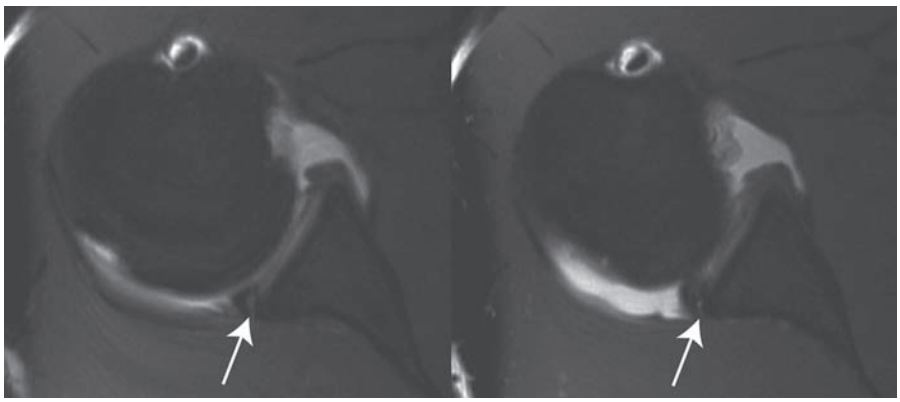

FIGURE 10.2
T1 FSE sequential axial MRI images with contrast of a posterior labral tear (*arrows*) in a patient with recurrent posterior instability.

Isolated posterior instability can be elicited in the office setting. The load and shift test is performed by flexing the arm to 90 degrees, flexing the elbow to 90 degrees, and applying a posterior-directed force while stabilizing the scapula with the other hand. The patient may complain of pain or subluxation may be evident on exam. The "jerk test" is performed with an axial posterior load onto an arm flexed at 90 degrees, adducted, and internally rotated; it is positive with reproduction of the instability sensation (Fig. 10.1). It is important to confirm with the patient that the pain felt during this exam is indeed the same pain that is limiting activities as athletes often have multiple causes of shoulder pain. If the load and shift exam does not reproduce the pain experienced by the patient, alternative sources of pathology should be thoroughly explored.

Imaging of the shoulder begins with radiographs. An instability series should be obtained, including an AP of the glenohumeral joint in internal rotation, a West Point axillary view, and a scapular Y view. Plain radiographs are usually normal, but can identify a reverse Hill Sachs lesion and can identify bone loss in the posterior glenoid. Magnetic resonance imaging (MRI) is routinely performed at our institution with the addition of an arthrogram to better delineate any labral pathology (Fig. 10.2). The MR arthrogram is also helpful to determine the capsular volume and can aid in the diagnosis of multidirectional instability. In cases of suspected bone loss or bony abnormalities, a computerized tomography scan with reconstructions is quite beneficial in surgical planning.

SURGERY

Most of the patients receive an interscalene nerve block and general anesthesia. The interscalene block is helpful in limiting intraoperative narcotics and decreases postoperative pain and nausea. The open approach to the posterior shoulder can be performed in either the lateral decubitus position or the beach chair position, but we generally perform this procedure in the beach chair position.

Anesthesia and Positioning

The patient is anesthetized supine on a full-length bean bag and the operating table is configured into the beach chair position. Once the patient is properly positioned, the bean bag is inflated to secure the patient in the upright position. The bean bag must be properly folded to leave the entire medial border of the scapula free.

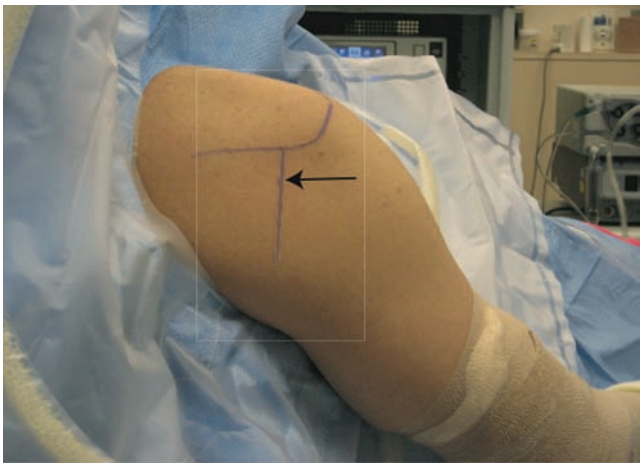

FIGURE 10.3

Patient positioning and surface anatomy. The patient is placed in a beach chair position with the bean bag medial to the medial scapula border. The posterior surface anatomy is marked along with the proper portal position (*arrow*).

This setup allows excellent control of the head and body during the procedure and is easy to adapt for people of any body habitus. Once the beanbag is inflated, the patient and beanbag are brought laterally to the edge of the bed, allowing complete exposure of the shoulder to the medial border of the scapula (Fig. 10.3). The arm is prepped and draped in standard fashion. In cases where an open procedure is performed, we routinely use an Ioban dressing in the axilla in order to decrease the risk of p acnes infection. A McConnell arm holder is used to position the arm in space during the procedure.

Exam Under Anesthesia

Prior to any incision, it is critical to perform an examination of the shoulder under anesthesia. The examination should be performed on both shoulders to assess asymmetry in the exam compared to the contralateral side. Range of motion should be recorded as well. Exam under anesthesia should confirm grade 2 to 3+ posterior instability without any anterior or inferior translation. In some cases of inferior laxity, however, there will be some degree of inferior subluxation, and this should be accounted for in the capsular placation.

Diagnostic Arthroscopy

The surface anatomy is marked, with attention paid to the acromioclavicular (AC) joint and the posterior glenohumeral joint. Even in cases where we suspect that an open procedure is necessary, we routinely perform a diagnostic arthroscopy to evaluate the status of the posterior labrum and determine the need to perform a labral repair as well as a capsulorrhaphy. In addition, arthroscopy allows for identification of other concomitant pathology such as biceps tendon lesions, SLAP tears, and articular cartilage injury (Fig. 10.4). After the glenohumeral joint has been evaluated from the posterior portal, the arthroscope is placed in the rotator interval anterior portal to allow for better visualization of the posterior labrum, capsule, and posterior glenoid.

Arthroscopic Posterior Labral Repair

The first step in performing a posterior labral repair is to mobilize the posterior labrum. The arthroscope is kept in the anterior portal and a small rasp elevator is advanced in through the posterior portal. The margins of the tear are identified and the rasp is used to carefully elevate the posterior labrum off the surface of the glenoid (Fig. 10.5). Any bleeding that is encountered is cauterized with an arthroscopic cauterization device. Once the posterior labrum has been completely elevated, a 4.5-mm shaver is used to decorticate the glenoid rim and achieve a fresh bleeding surface.

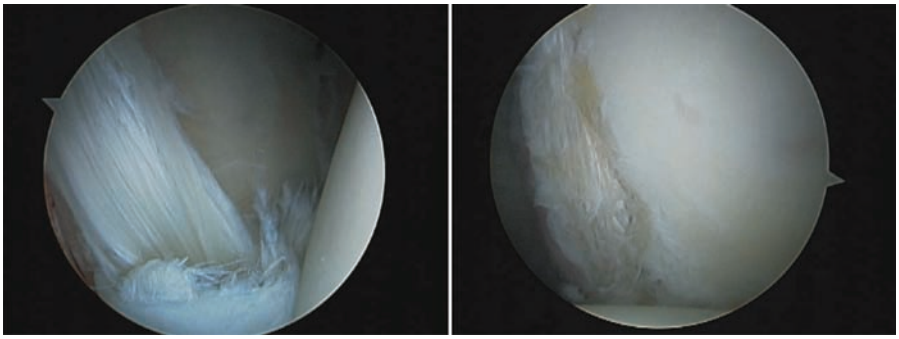

FIGURE 10.4

Arthroscopic images of a patient with recurrent posterior instability and a posterior labral tear.

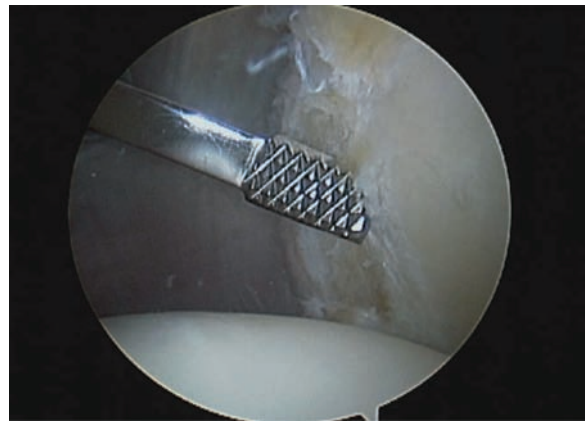

FIGURE 10.5

An arthroscopic rasp is advanced into the joint via the posterior portal. This is used to elevate the posterior labrum off the glenoid neck.

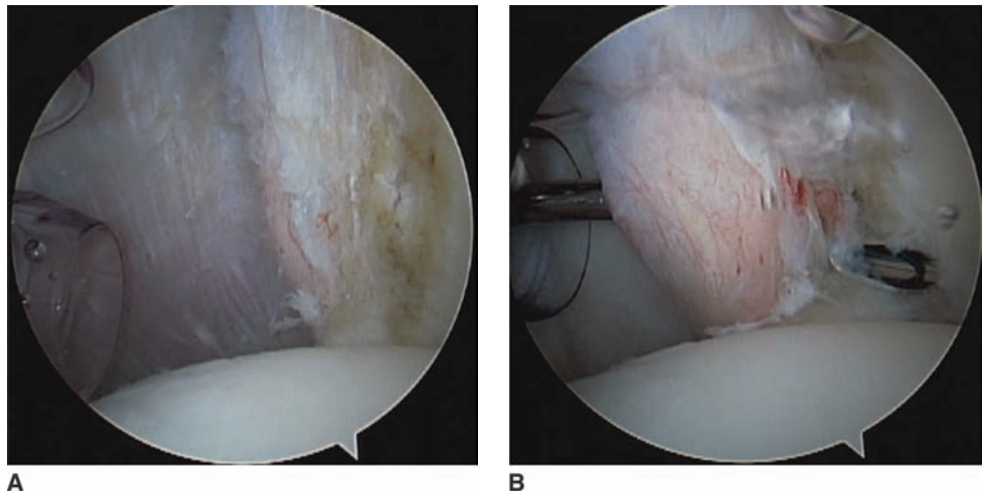

FIGURE 10.6

A: Placement of two posterior cannulas. The inferior cannula is angled in order for proper placement of the anchors on the glenoid rim rather than on the glenoid neck. **B:** A suture lasso is passed through the posterior capsule and labrum to attach the capsulolabral complex to the glenoid rim.

A posterior accessory portal is established in order to facilitate an appropriate angle for placement of suture anchors in the posterior labrum (Fig. 10.6). Larger (7–8 mm) cannulas must be placed in order to facilitate passage of instruments. Through the posterior portal, a 45-degree curved suture lasso suture passer (Arthrex, Naples, Florida) is utilized to penetrate the labrum. For a left shoulder, a left 45-degree suture lasso is used, and for a right shoulder, a right 45-degree suture lasso is used. The suture lasso is advanced through the posterior portal and passed gently through the posterior labrum at the level of, or just inferior to, the anchor. Again, care is taken not to damage the posterior glenoid cartilage surface. In cases with minor posterior capsular laxity, the lasso can be advanced through the posterior capsule approximately 1 cm lateral to the labrum, then underneath the labrum itself (Fig. 10.6). This will effectively reduce the posterior capsular volume. The anchor is advanced through the accessory posterior portal and is placed at the articular margin of the glenoid rim, rather than on the glenoid neck. This allows for a proper anatomic reduction of the glenoid, although care must be taken to drill at approximately 45 degrees to the posterior labrum so as to not damage the articular surface and obtain sufficient bony purchase with the anchor. We typically use a bioabsorbable anchor, although small metal anchors are frequently used as well.

The anchor is placed through the loop in the suture anchor (Fig. 10.7). Once the anchor is drilled, one limb of the suture from the anchor is removed, and the other is pulled through the portal with the lasso. An arthroscopic retriever is used to retrieve the other limb and the knot is tied in standard arthroscopic fashion with the knot advanced posteriorly off the glenoid. This technique allows the knot to be located off the articular surface. These steps are repeated until the entire labrum is reattached to the posterior glenoid (Fig. 10.7C). For most posterior labral tears, we typically use two to three anchors. We typically conclude the repair by closure of the posterior portal incision. This is performed by withdrawing the cannula slightly and passing a PDS suture with a straight Spectrum. The PDS is advanced into the joint, and a straight penetrator is used to grab the PDS. The PDS is then tied down blindly within the cannula.

In cases with a significant component of multidirectional instability, we will typically perform a rotator interval closure as well. The arthroscope is placed back in the posterior portal and the rotator interval is viewed

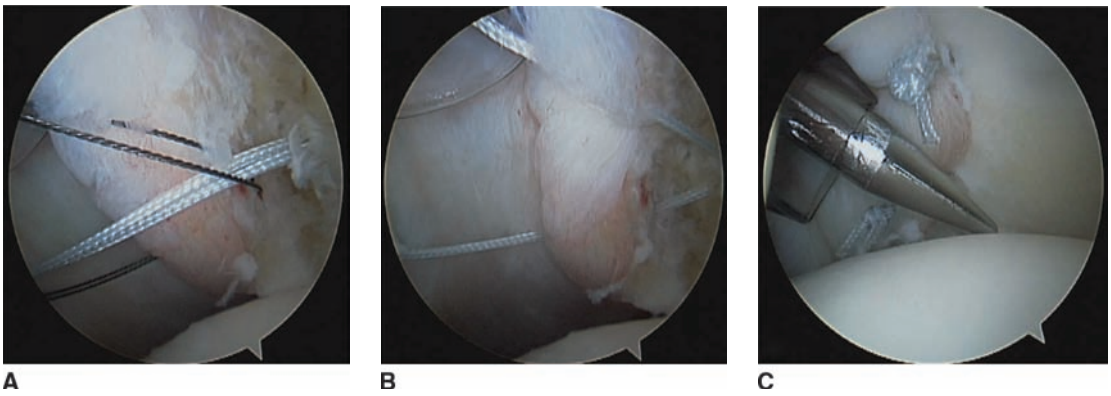

FIGURE 10.7

A: Placement of the anchor through the suture lasso. The anchor is placed on the glenoid rim to properly reduce the labrum to the surface of the glenoid. **B:** Passage of the suture through the posterior labrum. **C:** Final repair of the posterior labrum with two anchors.

anteriorly. A nonabsorbable suture is loading into a penetrator and the penetrator is advanced from the anterior portal through the capsule. This should be placed 1 cm lateral to the glenoid and just above the subscapularis tendon. A suture grasper is used to secure the suture within the joint. The penetrator is advanced again into the joint, this time piercing the superior glenohumeral ligament. The free suture is grasped and transported out the portal. The knot is tied blindly outside the capsule with the arm at 30 degrees of external rotation so as to not overtighten the shoulder. This is repeated with two to three sutures. Shoulder range of motion should be checked to ensure that there has not been excessive loss of external rotation.

Posterior Exposure to the Glenohumeral Joint

In cases where open posterior stabilization is to be performed, the diagnostic arthroscopy is performed quickly, the instruments are removed, and the open procedure is started. A vertical skin incision is planned, parallel to the glenohumeral joint. The line for the glenohumeral joint usually is directly posterior to the AC joint. The incision is started at the level of the scapular spine superiorly, incorporates the posterior arthroscopic portal, and is continued distally for approximately 7 to 9 cm to the axillary crease.

The dissection is sharply taken down to the level of the deltoid fascia and skin flaps are elevated medially and laterally. The deltoid fascia is split in line with its fibers that typically run slightly medial to lateral. This split should be directly posterior to the glenohumeral joint. Once the entire deltoid is spilt, deep retractors are placed, exposing the infraspinatus superiorly and the teres minor inferiorly (Fig. 10.8). Internal rotation of the shoulder generally facilitates identification of the infraspinatus and teres minor. There is typically a heavy layer of fascia covering these muscles, and the infraspinatus is identified as the bipennate muscle with a yellow strip

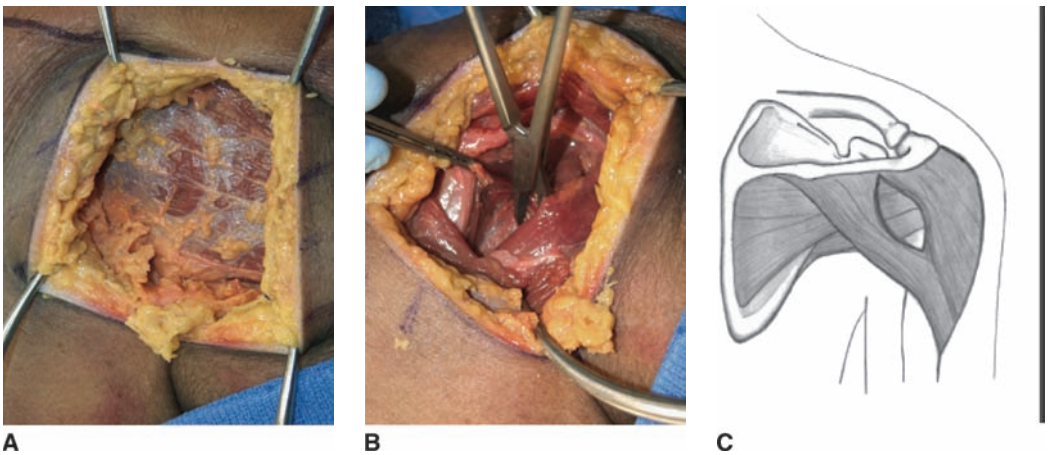

FIGURE 10.8

A: Following the longitudinal incision, the deltoid muscle is identified. Gelpie retractors are placed in the skin to facilitate exposure. **B:** The deltoid is split in line with its fibers, exposing the infraspinatus deep to the deltoid. **C:** Deltoid split demonstrating exposure to the infraspinatus.

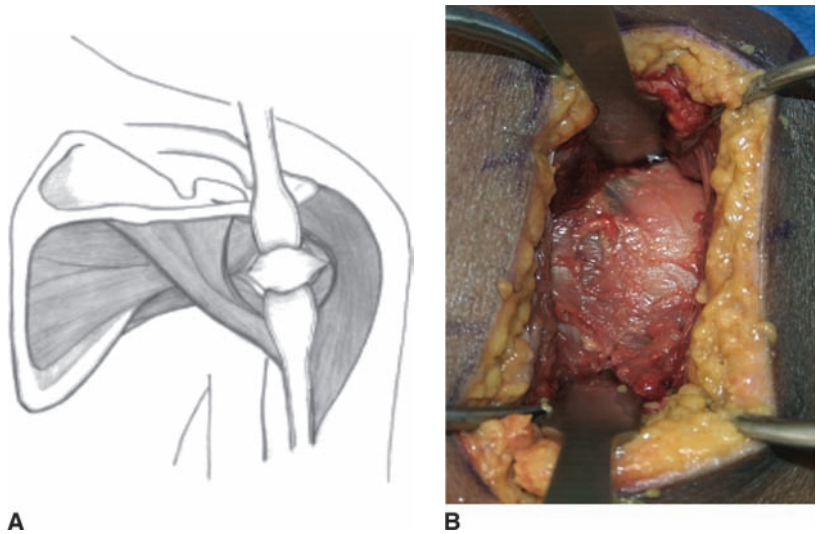

FIGURE 10.9

A: Split of the infraspinatus along the fat strip, exposing the capsule deep to the rotator cuff muscle. **B:** Once the capsule is exposed, deep retractors are placed on either side of the humeral head in order to facilitate exposure of the capsule and labrum.

of fat that runs between its two heads. The fascia is incised longitudinally in this area from the lateral tendinous portion to the medial aspect of the wound. The suprascapular nerve runs medially, approximately 1.5 cm from the glenoid, so dissection should stop short of this point. The infraspinatus is carefully elevated off the capsule with a Cobb elevator and sharp dissection. Care should be taken to preserve the capsule in order to facilitate repair and capsulorrhaphy and the end of the procedure. At this point, it is important to expose the entire posterior capsule. This is most readily facilitated with thorough blunt dissection of the infrapsinatus off the capsule and placement of curved retractors superiorly and inferiorly over the glenohumeral joint (Fig. 10.9).

Capsulotomy

The capsular incision is usually performed with a T-shaped medial incision. A bovie device or marking pen is used to mark the capsulotomy incision site. The vertical incision is placed just lateral to the capsular attachment on the glenoid, and the longitudinal incision is placed at the equator of the glenohumeral joint. The flaps are tagged with suture and retracted superiorly and inferiorly to expose the joint (Fig. 10.10).

Labral Repair

In many cases, the posterior labrum will be intact. However, in some cases, the initial arthroscopy will have determined that a labral repair is necessary in addition to a capsulorrhaphy. We typically use a metal suture anchor so that position of the anchor can be confirmed on postoperative imaging studies. The injured labrum is

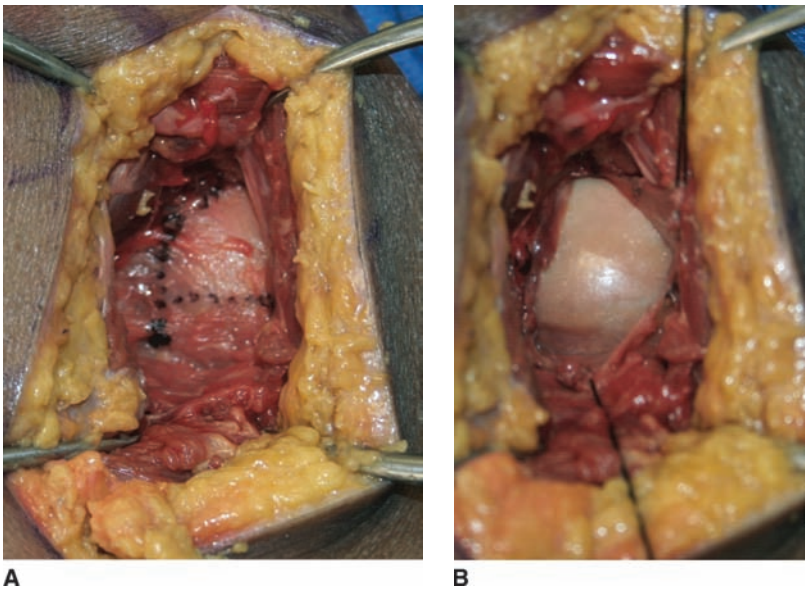

FIGURE 10.10

A: With the capsule exposed, a medial T-shaped incision is planned. The longitudinal incision is just lateral to the glenoid and labral rim, and the transverse incision is planned with the incision along the inferior one third of the humeral head. **B:** Capsulotomy has been performed and the leading edges of the capsule have been tagged.

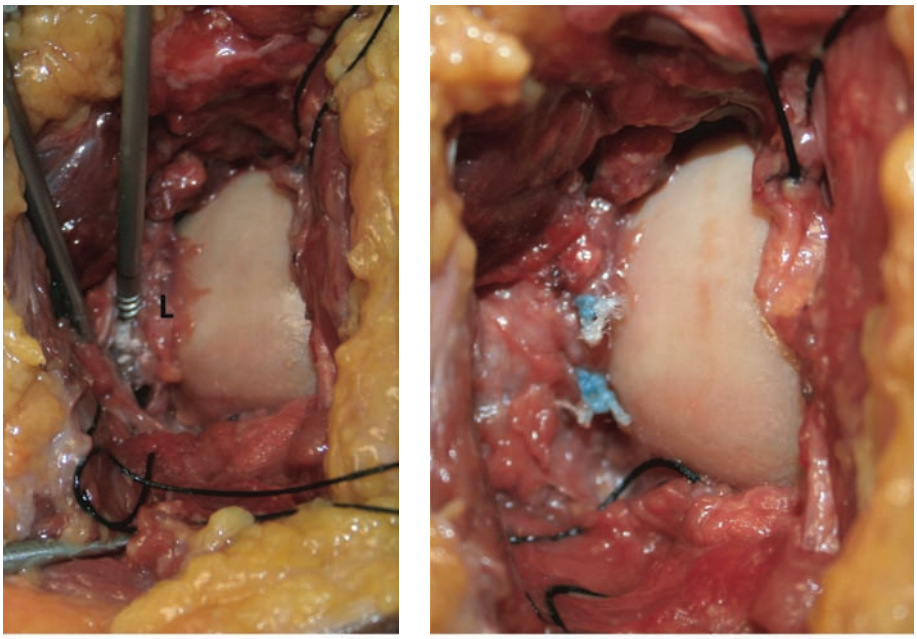

FIGURE 10.11

A: Placement of anchors at the bony insertion of the glenoid after the labrum (L) has been elevated. **B:** Two anchors placed in the labrum, reattaching the labrum to bone.

elevated and mobilized free of the glenoid. The glenoid neck is roughened to provide a bleeding surface. The hole for the anchor is placed at the cartilage border and the anchor is placed. Nonabsorbable suture is placed around the labrum and the labrum is secured to the glenoid rim. The knot is tied so that it does not interfere with the glenohumeral articulation. We typically place two to three anchors for a posterior repair (Fig. 10.11).

Capsulorrhaphy

The arm is placed in 20 degrees of abduction and a medially based capsular shift is performed. The inferior flap is advanced superiorly to the superior border of the glenoid and labrum. It is reapproximated to the capsulolabral complex. The inferior flap is then folded inferiorly, effectively augmenting the superior flap. The longitudinal incision is imbricated with nonabsorbable suture to reinforce the repair (Fig. 10.12).

Augmentation

In rare cases such as revision surgery for posterior instability, a very thin patulous capsule, it may be necessary to augment the capsulorrhaphy. Soft tissue augmentation of the capsular repair can be performed by vertically incising the infraspinatus and securing it to the capsule with use of the capsule repair sutures. Alternatively, an

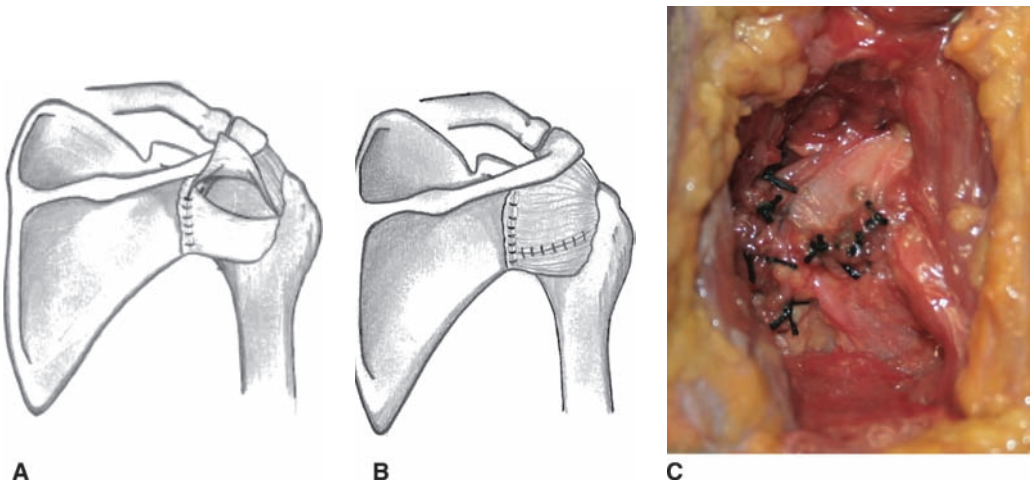

FIGURE 10.12

A: The capsular closure is performed by bringing the inferior limb superiorly and attaching it to the medial capsulotomy with interrupted sutures. **B:** The superior limb is then pulled inferiorly to decrease the space in the capsule. **C:** Completed capsulotomy with the final longitudinal and transverse sutures.

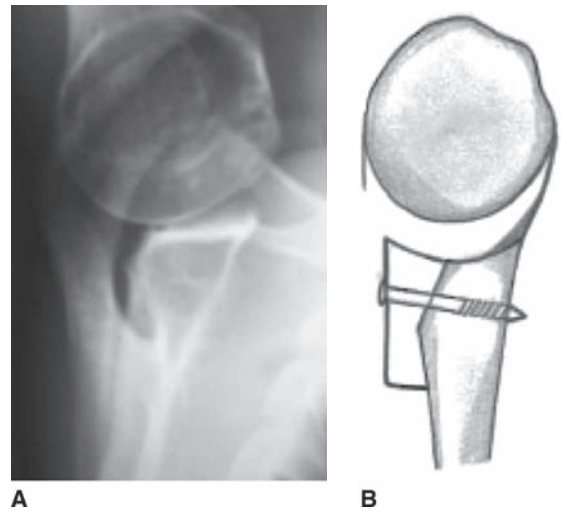

FIGURE 10.13

A: Axillary lateral demonstrating significant bone loss along the posterior rim of the glenoid. **B:** Schematic of iliac crest bone graft used to augment the posterior glenoid. The bone graft is secured with 4.5-mm partially threaded cancellous screws to compress the graft to the posterior glenoid.

Achilles tendon allograft can be used to augment the posterior capsule, although long-term data utilizing this in clinical practice are not available.

Bone Loss/Retroversion

Posterior instability resulting from excessive glenoid retroversion is rare, but is important to identify preoperatively as soft tissue procedures alone may result in continued posterior instability (9). After the posterior glenoid has been exposed, a burr is used to abrade the posterior cortex of the glenoid and provide a fresh bed of bleeding bone. Ipsilateral iliac crest or ipsilateral scapular spine can be harvested. The graft should measure approximately 4 × 2.5 cm. The graft and glenoid neck are predrilled prior to capsule repair, and the capsule is interposed between the bone block and the glenoid rim. The bone block is placed on the posteroinferior quadrant of the glenoid using bicortical screws parallel to the articular surface (Fig. 10.13). Alternatively, a glenoid-opening wedge osteotomy can be performed in those patients with excessive (>10 degrees) glenoid retroversion (4,5).

Closure

The wound is closed in layers, with a running 0-Vicryl used to loosely close the infraspinatus fascia and the deltoid fascia. The skin is closed with 2-0 Vicryl and a subcuticular stitch. Sterile dressings are applied and the patient is placed in an abduction orthosis that maintains slight abduction and neutral rotation. Drains are not typically used.

POSTOPERATIVE REHABILITATION

Physical therapy is initiated in the hospital in order to instruct the patient on the postoperative precautions in order to protect the repair. We typically will place the patient in a gunslinger sling to immobilize the arm in external rotation and avoid internal rotation. Passive abduction and forward flexion is allowed daily out of the sling. The sling is worn for a majority of the time until postoperative week 5 or 6. After week 6, active and passive range of motion is initiated with a goal of 90% of expected range of motion by week 12. Progressive resistance and strengthening to the rotator cuff and scapular stabilizing muscles are added after range of motion improves. Patients can expect return to full activities at 7 to 9 months following surgery in most cases.

OUTCOMES

Arthroscopic posterior shoulder stabilization outcomes have been satisfactory across the literature. Williams et al. followed 26 patients who underwent arthroscopic posterior stabilization with a mean follow-up of 5.1 years (13). The authors found that 24 of 26 patients (92%) had a successful outcome. Similarly, two recent studies reported 88% success at a mean of 40 months (8), and 91% success at a mean of 27 months (2).

The outcomes following open posterior shoulder stabilization in general have been quite good. Most studies report good to excellent results in 75% to 90% of patients, with recurrence rates between 7% and 30% (1,3,10–12,14). Bottoni et al. (1) reported on 31 patients who underwent posterior stabilization, 12 of which were open procedures. All patients suffered a traumatic event causing their posterior instability. At an average follow-up

of 40 months, there was one recurrence each in the open and arthroscopic group. Eleven of the twelve patients (91%) who underwent open posterior stabilization rated their outcome as good or excellent. Wolf et al. (14) described the largest series to date of open posterior shoulder stabilizations. At an average of 7.6 years, 32 of 44 (72%) rated their outcomes as good to excellent, and the recurrence rate was 13%. The outcomes following posterior bone block augmentation are promising as well (9). A recent study retrospectively reviewed 21 shoulders that underwent glenoid augmentation at a mean of 6 years. All patients reported their subjective outcomes as good or excellent, and 15 of the 21 patients returned to their preinjury level of sports. Three patients were considered failures, two with posterior apprehension, and one with recurrent posterior instability.

SUMMARY

Recurrent posterior instability is much less common than anterior shoulder instability. The diagnosis can be elusive, but a thorough history and physical exam combined with the appropriate imaging modalities should lead to an accurate diagnosis in a majority of cases. In those patients who do not improve with a trial of physical therapy, posterior stabilization offers a treatment option with reliable outcomes. Whether to proceed with arthroscopic or open stabilization is based on the patients' symptoms, exam under anesthesia, and diagnostic arthroscopy. Isolated labral tears or labral tears with minimal capsular laxity can be treated arthroscopically. The posterior approach to the shoulder is straightforward and provides excellent access to the posterior glenohumeral joint. Repair of the labrum in combination with a posterior capsulorrhaphy will restore stability to the shoulder. Postoperatively, the patient is placed in a gunslinger sling for 6 weeks. Full activities usually are resumed in 7 to 9 months.

ACKNOWLEDGMENTS

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11 HAGL: Arthroscopic/Open

James Bicos and Robert A. Arciero

INTRODUCTION

Humeral avulsion of the glenohumeral ligament (HAGL) lesions is an important but less common cause of recurrent instability in the shoulder after injury. Typically in the pathology of shoulder instability, either a capsulolabral avulsion of the anteroinferior portion of the inferior glenohumeral ligament (IGHL), the so-called Bankart lesion, or capsular laxity is observed. Most literature emphasizes the importance of avulsion of the IGHL from the glenoid as the essential pathology in a traumatic dislocation of the shoulder, with the Bankart lesion accounting for 80% of posttraumatic shoulder instability (3,36).

Although reports of Bankart lesions accounting for anterior shoulder instability are seen in 45% to 100% of cases, there is evidence that the glenohumeral ligaments can fail at the humeral insertion site (17). HAGL lesions are infrequent as compared to Bankart lesions. HAGL lesions have been reported in 1% to 9% of patients with recurrent shoulder instability (5,34,37). Wolf et al. (37) looked at 64 shoulders with instability and found a 9.3% incidence of HAGL lesions. Bokor et al. (5) reviewed 547 shoulders for the cause of instability and found HAGL lesions in 7.5% of patients. They further found that in looking at their failed recurrent instability procedures, at revision surgery the incidence of a HAGL lesion was 18.2%. In another study, there was a 2% incidence of HAGL lesions in glenohumeral instability patients (7). Of those 2% of patients, 67% reported that they sustained an anterior shoulder dislocation and only 50% were detected on radiologic exam (x-ray or MRI).

In order to diagnose a HAGL lesion, one needs a high suspicion, an understanding of the anatomy of the ligaments, and its forms of injury. Approximately 66% of HAGL lesions in the literature had other associated abnormalities at the time of arthroscopy (6). Failure to diagnose the HAGL lesion could lead to persistent instability and pain. More commonly, HAGL lesions have been associated with rotator cuff tears, Bankart lesions (i.e., a floating IGHL), Hill-Sachs lesions, and labral tears (7). Because of the associated pathology with HAGL lesions, a thorough arthroscopic inspection of the shoulder should include the axillary pouch and the IGHL attachment to the humeral neck to avoid missing the lesions (2,13). Bach et al. (2) state that in the absence of capsular laxity and glenoid pathology, a disruption of the lateral capsule (i.e., HAGL lesion) must be excluded.

ANATOMY

A complete review of the anatomy of the shoulder is beyond the scope of this chapter. The main focus is on the IGHL complex. The IGHL has two bands, the anterior inferior glenohumeral ligament (AIGHL) and the posterior inferior glenohumeral ligament (PIGHL). The IGHL also has an axillary pouch that spans between the AIGHL and the PIGHL (23) (Fig. 11.1)

In the right shoulder, the AIGHL extends from the 2:00 to 4:00 position and the PIGHL extends from the 7:00 to 9:00 position. The IGHL complex attaches to the medial humerus just under the cartilage of the humeral head. Two configurations have been identified. One is a collar-like attachment where the entire IGHL complex inserts just below the anatomical neck of the humerus. The other is a V-shaped attachment, where the AIGHL and PIGHL attach at the margins of the humeral neck cartilage surface and the interposing pouch inserts more distal on the neck of the humerus (2,23).

Numerous studies have shown the functional importance of the IGHL in maintaining shoulder stability with range of motion (23,35). The IGHL is the primary restraint to anterior shoulder dislocation with the arm at

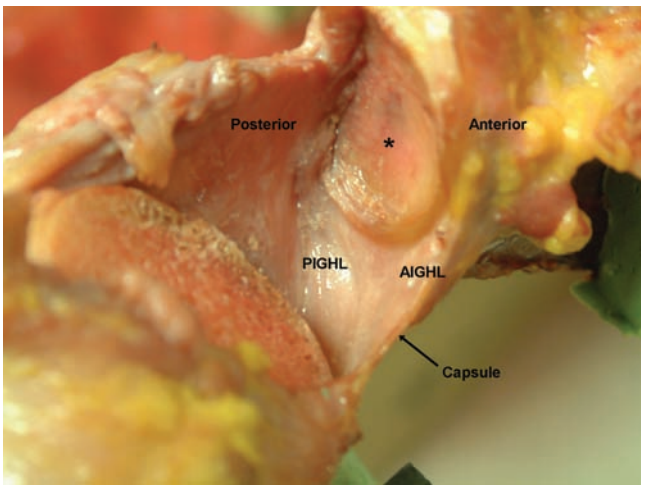


FIGURE 11.1

Anatomic specimen showing the IGHL with a resected part of humeral head (*asterisk* = glenoid).

90 degrees of abduction and external rotation (35). Other stabilizing structures include the labrum as a static stabilizer and the subscapularis muscle as a dynamic stabilizer with the arm at zero degrees of abduction (37).

ETIOLOGY

Nicola has been credited with describing the first known HAGL defect after an anterior shoulder dislocation (22). He reported on four of five acute cases of shoulder dislocations producing HAGL lesions and found HAGL lesions in 6 of 25 recurrent shoulder dislocations. He followed up the study with a cadaver study on 50 shoulders where he reproduced an anterior shoulder dislocation. The results showed that unlike a Bankart defect that occurs with the arm in an hyperabducted position with impaction, the HAGL lesion was most likely to occur with the arm both in the hyperabducted and externally rotated position (5,22).

Fourteen percent of HAGL lesions reported in the literature occurred in shoulders with prior surgeries. The data are unable to support if the prior surgeries placed the patients at an increased risk for future shoulder injury (7). Shoulder dislocations are associated with different structural abnormalities, depending on the age of the patient. Younger patients are more likely to disrupt the anterior labral-ligamentous attachment to the glenoid. Older patients are more likely to disrupt the anterior capsular attachment to the humerus (HAGL lesion) and also may disrupt the subscapularis tendon. In fact, older patients with anterior dislocations may be misdiagnosed with an axillary nerve neuropraxia or a rotator cuff tear if they cannot abduct their arm (20,21). The difference in pathology due to age may be secondary to a weakening of the rotator cuff and weakening of the capsular attachment to the humerus. This results in a higher likelihood that the capsular humeral interface fails rather than the capsular-glenoid interface (18,20). In patients who sustained a documented first-time anterior shoulder dislocation, 33% developed shoulder instability secondary to a HAGL lesion (20).

The reported incidence of HAGL lesions has increased with shoulder arthroscopy. Therefore, it could be a site for ligament failure more commonly than previously believed (5,13). Trauma has been shown to contribute to HAGL lesions in over 94% of reported cases in the literature (12,29), but there has been one reported case of a HAGL lesion after a repetitive microtrauma from overhead throwing (15). Warner first described a combined Bankart and HAGL lesion, the so-called floating AIGHL. He treated it with an open repair and had excellent results (36).

CLASSIFICATION

There are three possible locations of injury to the IGHL—failure at the glenoid, failure at the humerus, or an intrasubstance tear. In addition, one could have an injury to the AIGHL or PIGHL in each of the locations described above. Lastly, when the failure occurs at the humerus, it could either be a pure ligamentous tear or a piece of the medial cortex of the humerus could avulse off with the ligament producing a bony HAGL (BHAGL).

Bigliani et al. (4) in a biomechanical study evaluated the tensile property of the IGHL bone-ligament-bone complex. His results showed IGHL failure at the glenoid in 40% of cases, an intrasubstance tear in 35% of cases, and a HAGL lesion in 25% of cases. Another cadaveric study by Gagey et al. (14) showed a HAGL lesion in 63% of specimens tested for dislocations. They speculated that the higher rate of HAGL lesions in cadavers than in human subjects was the due to the loss of the protective role of the subscapularis muscle in cadaver specimen testing. A much later study by the same author showed that when a HAGL lesion does occur, there needs to be a significant avulsion of that ligament from the humerus before the shoulder would dislocate. Smaller ligament avulsions did not produce shoulder dislocations (26).

TABLE 11.1 Frequency of HAGL Lesions Based on Anatomic Location

AHAGL	55%
Anterior BHAGL	17%
Floating AIGHL	21%
PHAGL	3%
Posterior BHAGL	0%
Floating PIGHL	4%

AIGHL, anterior inferior glenohumeral ligament; BHAGL, bony humeral avulsion of the glenohumeral ligament; PIGHL, posterior inferior glenohumeral ligament.
Source: Taken from Bui-Mansfield LT, Banks KP, Taylor DC. Humeral avulsion of the glenohumeral ligaments: the HAGL lesion. *Am J Sports Med.* 2007;35(11):1960–1966.

A posterior HAGL lesion (PHAGL) has been recognized as a cause of shoulder pain, posterior instability, and discomfort (8,10,30). PHAGL lesions have been associated with other shoulder abnormalities in 67% of cases (17).

In order to try and standardize the nomenclature for tears of the IGHL complex, Bui-Mansfield et al. (6) proposed a classification scheme derived from the terminology in the literature combined with the anatomic sites of rupture of the IGHL. They found six different forms of HAGL lesions based on the involvement of the anterior or posterior band of the IGHL, the presence or absence of a bony avulsion, and whether or not a labral tear was also identified in the injury pattern. The anterior band was involved in 97% of the HAGL lesions. The strict avulsion of the IGHL from the humerus could either be purely ligamentous—anterior HAGL (AHAGL); or with a bony lesion—BHAGL. The last option is a floating HAGL where both the humeral and the glenoid sides of the IGHL complex are torn. The same nomenclature exists for the PIGHL. Table 11.1 lists the frequency of HAGL lesions based on their anatomic locations. In other literature, the frequency of HAGL as compared to a floating AIGHL, and a BHAGL is 59%, 22%, and 20%, respectively (2,5,13,24,31,36,37).

HISTORY AND PHYSICAL EXAM

Although no specific historical feature will indicate the presence of a HAGL lesion, the senior author has observed a higher preponderance of this lesion in wrestlers. In this mechanism, the wrestler almost always reports a combination of hyperabduction and external rotation. No specific clinical test can specifically differentiate a HAGL lesion from a Bankart lesion (25). In addition, the review of a complete shoulder examination is beyond the scope of this chapter, but there are some clinical examinations that should be mentioned.

As with all examinations, inspection of the shoulder should be performed first. One should look for signs of ecchymoses, swelling, or skin deformity that can be associated with acute shoulder dislocations. Range of motion should be evaluated and clearly noted in flexion, external rotation with the arm at the side, external rotation in abduction, and internal rotation. Especially with external rotation in abduction, the point of shoulder apprehension should be carefully noted. The feeling of apprehension at small degrees of external rotation and more so with the arm at the side are clues to the severity of the instability. Test for rotator cuff strength. As previously mentioned, older patients may be misdiagnosed with an axillary nerve neuropraxia or rotator cuff tear if they cannot abduct their arm (20,21). Biceps pathology is evaluated with the Speeds test (biceps tendon issues) and O'Brien test (superior labral tears). The subscapularis muscle, often involved in older patients with anterior shoulder dislocations, is tested using the lift-off test, belly-press test, and bear-hug test.

Specific clinical exams for shoulder stability include the apprehension and relocation tests, assessing anterior shoulder instability, the posterior jerk test assessing posterior shoulder instability, and the load and shift test. The latter gives the examiner a sense for how "loose" the shoulder or capsule is in the anterior and posterior directions. A grade 1, 2, or 3 is given to the load and shift test based on the examiners ability to bring the humeral head to the glenoid rim, over the glenoid rim but with a spontaneous reduction, or over the glenoid rim without a reduction, respectively. The load and shift is tested in the anterior, anterior-inferior, and posterior directions.

IMAGING STUDIES

The imaging diagnosis of HAGL lesions is typically seen on MRI examination, but x-rays are still useful and can be diagnostic. It should be noted that the diagnosis of HAGL lesions is missed in 50% of cases based on imaging studies alone (7). Other associated shoulder injuries (rotator cuff tears, Hill-Sachs defects, labral tears, and OCD injuries) are seen in 68% of patients with HAGL lesions. Therefore, in addition to imaging studies, one needs a high index of suspicion during arthroscopy (7).

The BHAGL lesion was first described by Bach et al. (2). They found a bony fragment avulsed from the medial aspect of the humeral neck that was the cause of recurrent dislocations (Fig. 11.2) Other studies have

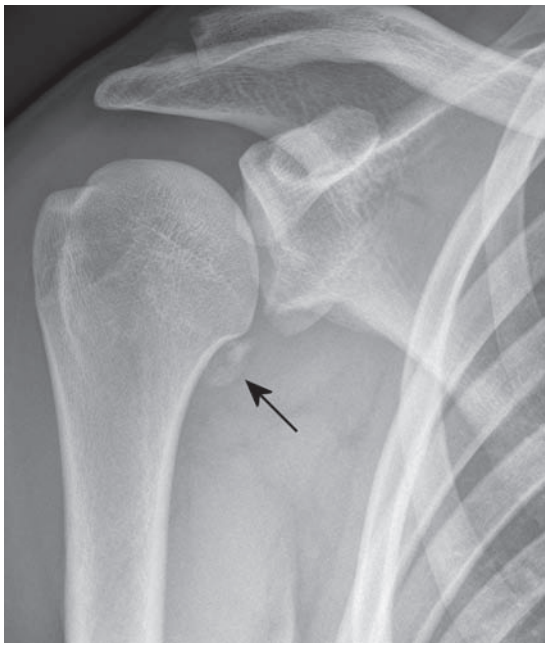


FIGURE 11.2

A calcification is noted inferiorly that represents a BHAGL lesion (*black arrow*).

shown that scalloping of the medial humeral neck on the anterior-posterior x-ray view can be consistent with a HAGL defect, even without seeing any calcification in the soft tissues (5). The bony fragment in a BHAGL lesion is best visualized with a Garth view of the shoulder, which is a 15-degree oblique x-ray in the anterior plane of the shoulder (24). In order to distinguish a BHAGL from a bony Bankart lesion, a West Point axillary lateral view is recommended (7).

CT arthrography can be useful in identifying a BHAGL lesion. Typically, on the CT arthrogram, the linear bony density representing the BHAGL is seen posterior to the MGHL and contrast extravasation is seen anterior to the BHAGL (24).

An MRI arthrogram is typically used in the diagnosis of HAGL lesions and in shoulder instability. The MRI diagnosis of a HAGL lesion is best seen on the fat-suppressed T2-weighted images in the coronal oblique and sagittal oblique planes (7). The MRI arthrogram characteristics of a HAGL lesion include (a) increased signal intensity and increased thickness of the inferior capsule, (b) extravasation of the contrast material or the joint effusion along the medial humeral neck, and (c) conversion of the normal U-shaped axillary pouch to a J-shaped structure (7,33) (Fig. 11.3). Posterior or reverse HAGL lesions ("RHAGL") have also been described (Fig. 11.4).

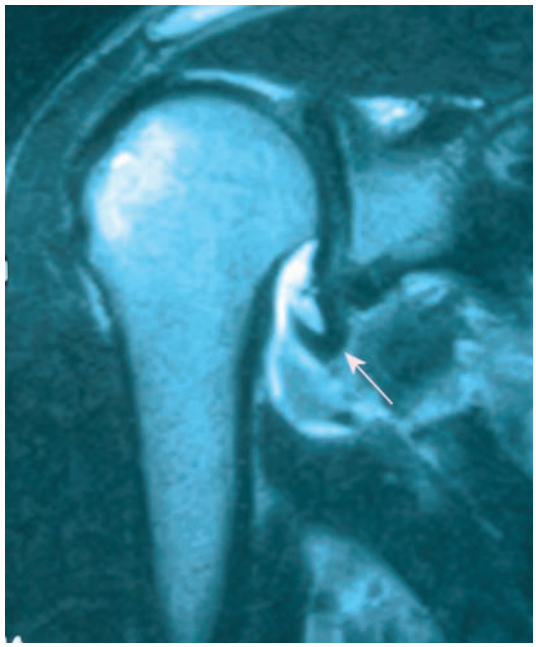


FIGURE 11.3

MRI depicting a HAGL lesion. The *white arrow* shows the avulsed capsule.

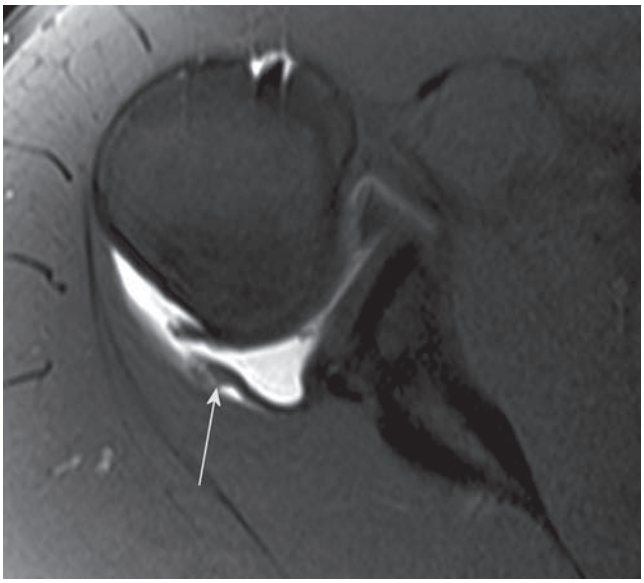


FIGURE 11.4

MRI depicting a posterior lateral avulsion of the IGHL (i.e., reverse HAGL lesion). The *white arrow* points to the avulsed capsule.

Although the MRI arthrogram is considered the best method of detecting HAGL lesions, most studies have correlated the MRI arthrogram with clinical information and not arthroscopic confirmation (7,11). Therefore, the sensitivity and specificity of the MRI diagnosis of a HAGL lesion is really unknown (19). Routine x-ray arthrograms in shoulder dislocations have shown an incidence of capsular ruptures in 10% of cases (27). In a study looking at the MRI diagnosis of HAGL lesions, only 7 of 835 shoulder MRI examinations had HAGL lesions for an incidence of 1% (34). Another series found no lesions reported on pre-op MRI examinations, but PHAGL lesions at arthroscopy (9). Furthermore, 77% of patients with HAGL defects had an MRI arthrogram preoperatively, and only on retrospective review of the preoperative MRI scans was the HAGL defect seen in only 67% of cases.

MRI can also lead to the false-positive diagnosis of HAGL lesions. Therefore, the recommendation from Melvin et al. (19) was that a HAGL diagnosis be reserved for arthroscopy. This also shows the difficulty in distinguishing HAGL lesions from other IGHL abnormalities. Interestingly, when a HAGL lesion is associated with a tear of the subscapularis tendon, MRI is especially useful in making that diagnosis (34).

TREATMENT OPTIONS

The conservative treatment of HAGL lesions depends on the associated pathology found in the shoulder. If it is truly an isolated defect, treatment includes a sling immobilizer for 4 weeks followed by a shoulder-strengthening program (24). The literature has proved that isolated HAGL lesions are rare. Approximately 66% of HAGL lesions have other associated shoulder pathology found at the time of arthroscopy (6). The failure to diagnose not only a HAGL defect but also the other associated pathology could lead to persistent instability and pain. Wolf et al. (37) looked at the incidence of HAGL lesions in anterior shoulder instability. Sixty-four shoulders were prospectively evaluated with arthroscopy. The incidence of a HAGL lesion was 9.3%, a Bankart lesion 73.5%, and generalized capsular laxity was seen in 17.2% of the shoulders. Their recommendation was that in all cases of documented anterior instability, a HAGL lesion should be ruled out at arthroscopy. The reported HAGL cases all had multiple episodes of instability prior to repair with one patient having failed a Bankart repair and another two patients having associated Hill-Sachs defects.

The surgical diagnosis and/or treatment of HAGL lesions can be done either open or arthroscopically. The HAGL lesion as seen on an open dissection is below the level of the subscapularis muscle, in the inferior pouch of the shoulder. It is a thickened, rolled edge in the capsular defect (5). The difficulty with the diagnosis of a HAGL lesion on open shoulder dissection is if the plane between the subscapularis and capsule is inadvertently entered, this may lead to a false-positive diagnosis of a HAGL lesion. Along the same lines, it may also lead to a false-negative diagnosis of a HAGL lesion because the surgeon thinks he or she dissected through the capsule when the capsule was not there to begin with because of the HAGL lesion. The last option with open dissections is if one leaves the deep portion of the subscapularis muscle/tendon over the capsule, this may also hide the presence of a real HAGL lesion (37).

Arthroscopy seems to be the best way of evaluating the IGHL ligaments and documenting a HAGL lesion. The HAGL lesion can be seen at the inferior aspect of the shoulder, in the axillary recess (Fig. 11.5). With the arthroscope in the posterior portal, one may need a 70-degree scope to formally evaluate the IGHL complex. On the other hand, with the arthroscope in the anterior-superior portal, one could use a standard 30-degree scope for the diagnosis (Fig. 11.6). In all cases of shoulder arthroscopy, the capsular attachment of the IGHL to the humerus should be documented (32). The cardinal sign of a HAGL lesion at arthroscopy

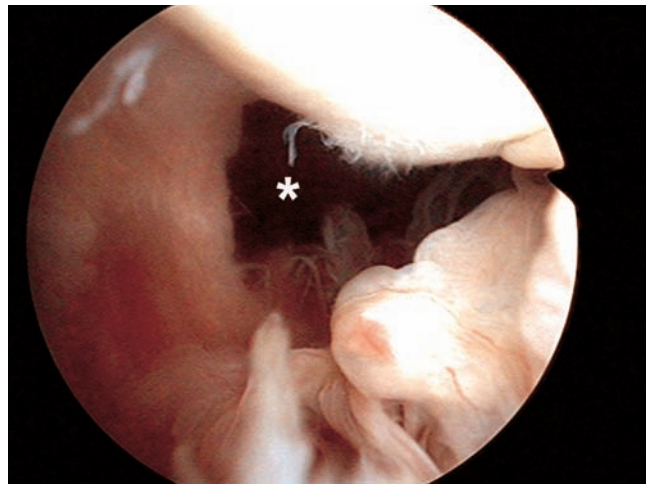


FIGURE 11.5

Arthroscopic inferior axillary view in a left shoulder showing HAGL lesion (*asterisk* = HAGL lesion).

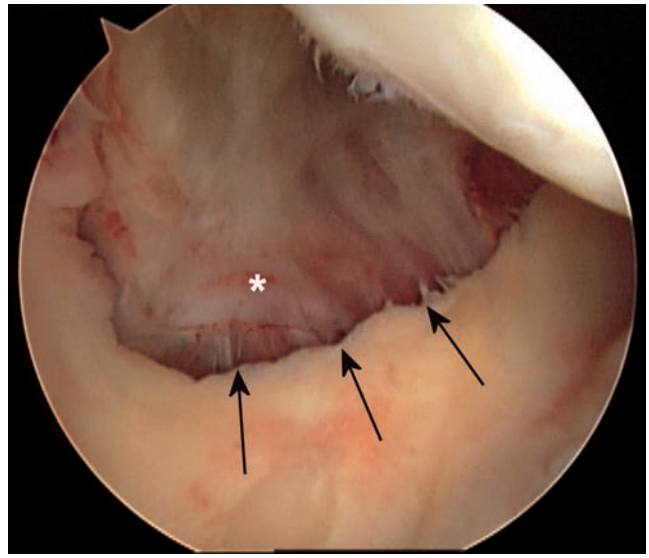


FIGURE 11.6

HAGL lesion with subscapularis exposed. *Black arrows* = avulsed leading edge of IGHL (*asterisk* = subscapularis muscle). Right shoulder viewed with arthroscope in ASP.

is the visualization of the fibers of the subscapularis muscle through the rent in the inferior capsule (32,37) (Fig. 11.6). Another sign of a HAGL lesion at arthroscopy is disruption of the wave formed by the reflection of the inferior capsule onto the humeral neck (5).

The surgical treatment of HAGL defects has been successful using open or arthroscopic techniques (2,5,13,15,31,36,37). The open approaches can be subdivided into traditional subscapularis detachment techniques (2,5,37) or partial detachment techniques (1). Bach et al. (2) were the first persons to describe the operative treatment of the HAGL defect. They reported on two cases treated with open repair. Bokor et al. (5) reported on 41 HAGL defects that were repaired open with suture anchors or drill holes. The advantages of all-arthroscopic technique include easier identification of the lesion, less soft tissue trauma (i.e., less injury to the subscapularis), better surgical visualization, less postoperative pain, and the ability to perform accelerated rehab (25). There are a small number of published articles on arthroscopic HAGL repairs in the literature (16,17,28,32,37). Wolf et al. (37) treated the HAGL defects with plication of the IGHL and tying it over the deltopectoral fascia. Kon et al. (17) reported on three arthroscopic HAGL repairs with no recurrences and documented a return to preinjury activity with 12 to 24 month follow-up. Huberty and Burkhart (16) reported on six HAGL defects treated arthroscopically. At 31.8 months' follow-up, no patients had sustained recurrent dislocations and all were satisfied with their repair.

Arthroscopic HAGL Repair

The patient is placed into the lateral decubitus position with proper padding. An exam under anesthesia is documented in the lateral position. The arm is placed into lateral traction in 50 degrees of abduction and 15 degrees of forward flexion with 5 to 10 lb of weight. A standard posterior arthroscopy portal is made taking care to avoid coming in too medial relative to the glenoid and to inferior along the posterior labrum. Most HAGL lesions can be viewed from this position with the arthroscope in the axillary pouch (Fig. 11.5). A second

portal is made high in the rotator interval (anterosuperior portal—ASP) and a full diagnostic arthroscopy is performed. The arthroscope is then placed into the ASP and the posterior diagnostic arthroscopy is finished. Viewing from the anterior portal during arthroscopy is important in making the diagnosis of an AHAGL or a PHAGL lesion (17,25).

The humeral insertion of the IGHL is best visualized from the ASP portal with a 30-degree scope. If a combined HAGL defect and Bankart defect occur, the HAGL defect is repaired first and the Bankart second to avoid overtensioning the capsule medially on the glenoid and not having enough excursion to repair the lateral HAGL lesion.

From a second midanterior portal that is traditionally placed just superior to the leading edge of the subscapularis tendon, a grasper is used to assess the mobility of the HAGL defect. A burr is used from the midanterior portal to create a bleeding bony bed at the anatomic HAGL insertion site on the humerus, which at this time may be better observed with a 70-degree arthroscope viewing from the ASP (Fig. 11.7). The correct path for suture anchor placement onto the medial humeral neck is made under direct visualization using an 18-gauge spinal needle and may be placed in a percutaneous fashion through the subscapularis. The trochar for the suture anchor is placed through this path and a 3.0-mm bioabsorbable anchor is placed (Fig. 11.8A and B). One limb of the suture is retrieved through the posterior portal and the other limb is left through the insertion trochar. From the midanterior portal, a suture-passing device is used to thread a monofilament suture through the detached lateral capsule of the HAGL lesion. The limb of the monofilament suture is retrieved through the posterior portal, and using proper suture shuttling technique, the suture limb from the anchor is shuttled back

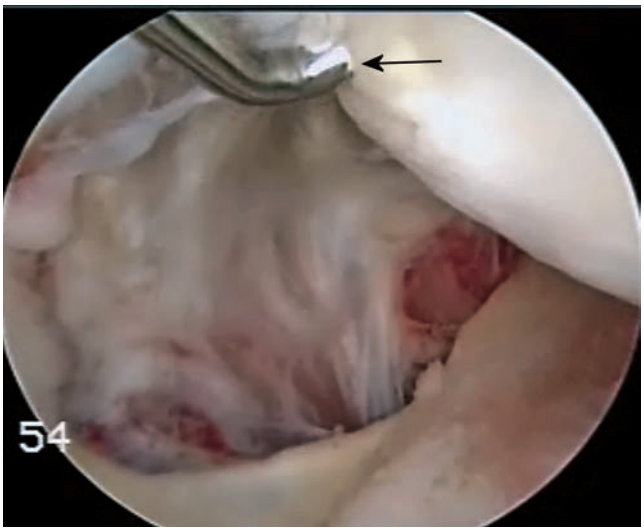
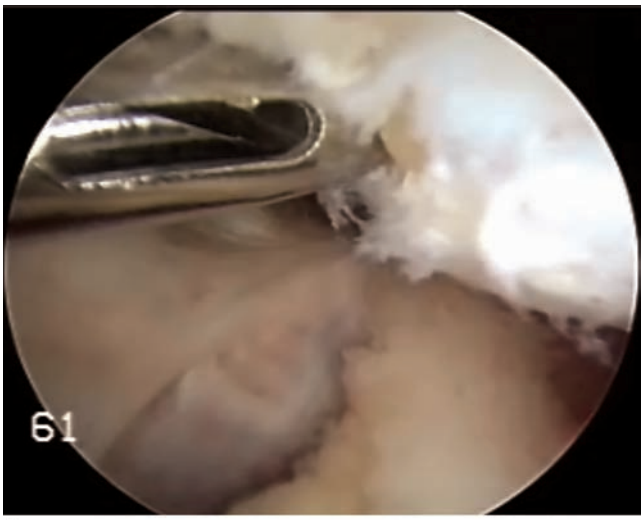
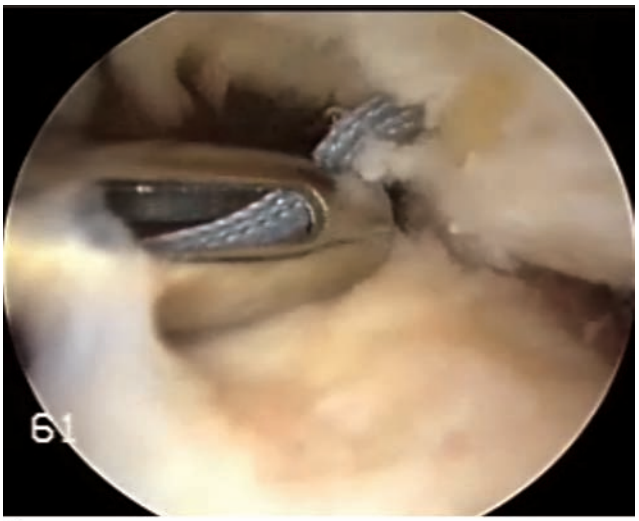


FIGURE 11.7

Arthroscopic probe marking anchor placement (*arrow*). Right shoulder viewed with arthroscope in ASP and the probe is through the midanterior portal.



A



B

FIGURE 11.8

A: Drilling for placement of anchor along neck of humerus. Right shoulder viewed with arthroscope in ASP. **B:** First anchor is placed along neck of humerus. Right shoulder viewed with arthroscope in ASP.

through the IGHL and out the midanterior portal (Fig. 11.9). The same sequence of steps is followed to pass the other limb of the suture anchor through the IGHL to create a mattress suture. The sutures are tied from the midanterior portal (Fig. 11.10).

In order to continue the repair anteriorly, a trans-subscapularis portal is made (accessory low anterior portal, 5:00) for anchor placement. The anchor trochar is inserted into this pathway, and another anchor is placed at the humeral attachment of the IGHL (Fig. 11.11). In order to get the proper angles for anchor placement, rotation of the arm may be necessary. Using a suture-passing device from the accessory posterolateral 7:00 portal similar to above, each limb of the suture anchor is shuttled through the IGHL in a mattress-type fashion and tied through the midanterior portal. (Fig. 12A,B)

Miniopen HAGL Repair

The arthroscopic technique can be challenging due to the limited exposure along the anterior-inferior pouch and humeral neck. If that is the case, a technique has been described by the senior author that spares the superior 50% of the subscapularis tendon with a limited open exposure (1).

The patient is placed into the beach chair position with all bony prominences and head carefully secured. The surgical extremity is draped free and supported by a padded Mayo stand. A 3- to 4-cm skin incision is made from the axillary fold to the coracoid process. The deltopectoral interval is opened and the cephalic vein is retracted laterally. The clavipectoral fascia is then opened up to but not through the coracoacromial ligament.

The subscapularis tendon and anterior humeral circumflex vessels are now exposed. An L-shaped incision is made at the lower half of the subscapularis tendon. The vertical part of the incision is made 1.5 cm medial

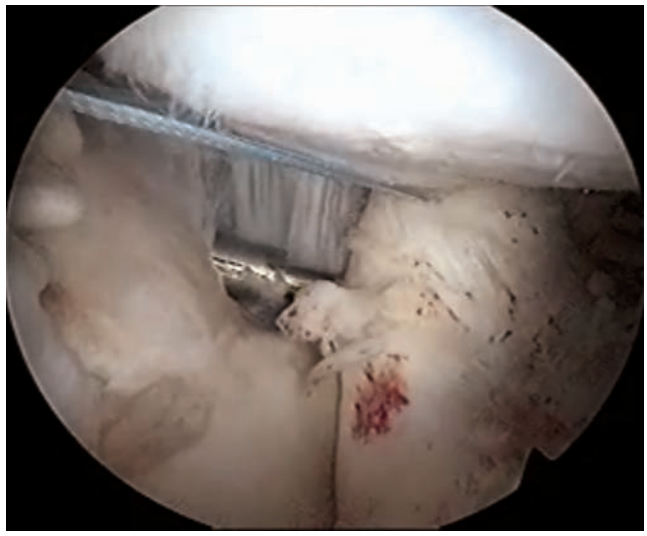


FIGURE 11.9

The suture from the first anchor is shuttled through the HAGL lesion. Right shoulder viewed with arthroscope in ASP.

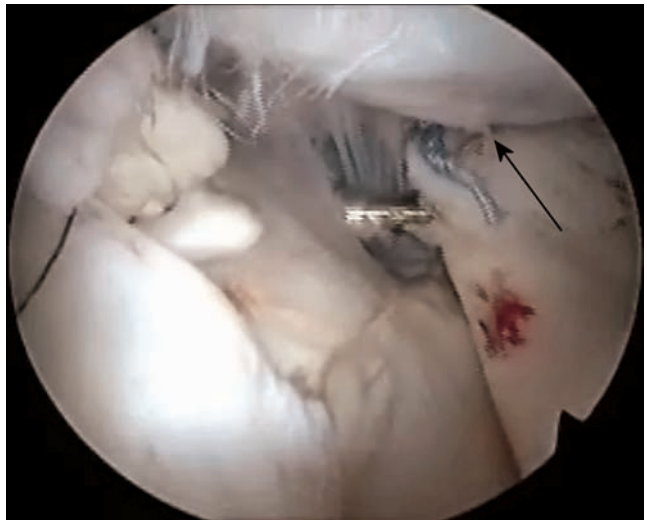


FIGURE 11.10

The first inferior anchor sutures are tied in a mattress-type fashion (*arrow*). Right shoulder viewed with arthroscope in ASP.

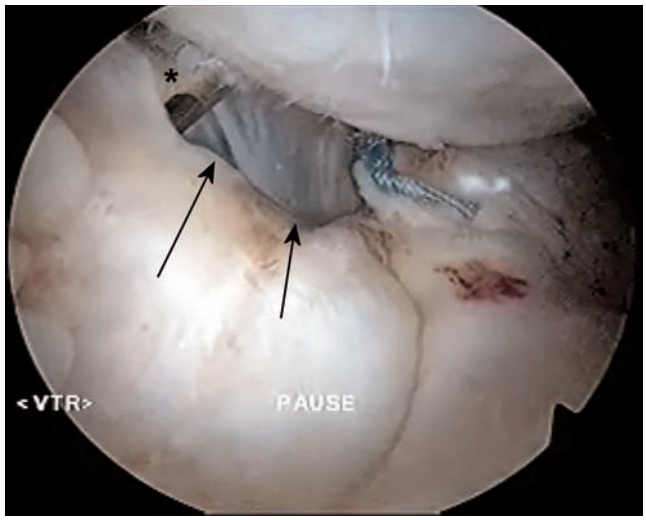


FIGURE 11.11

The second more proximal anchor is being placed. The *black arrows* point to the remaining HAGL defect to be repaired. The *asterisk* shows the anchor trochar.

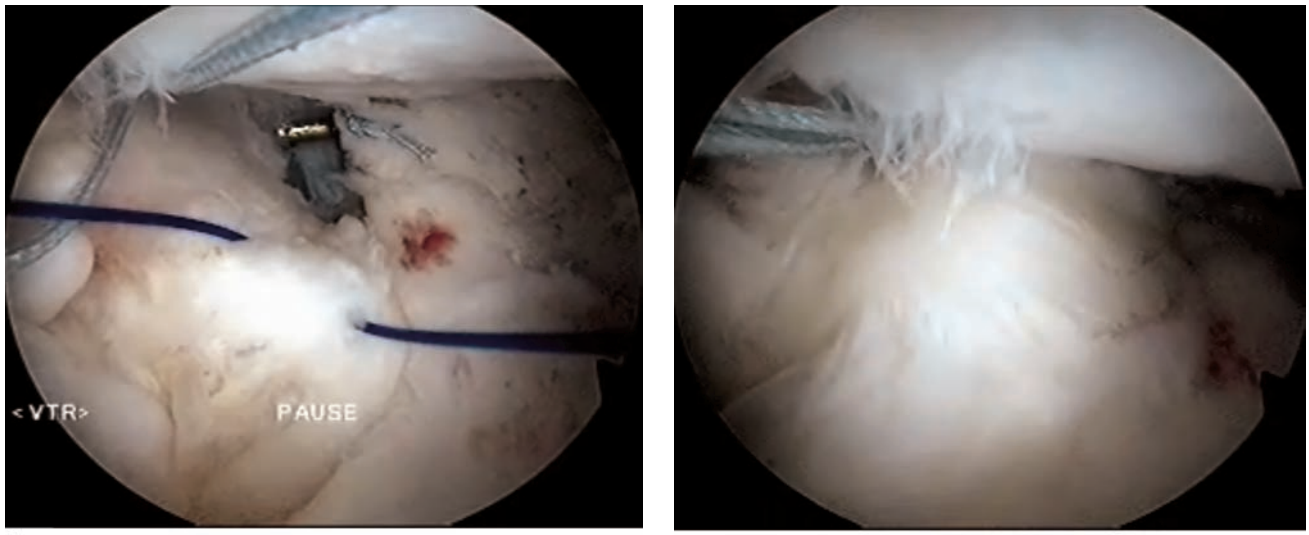


FIGURE 11.12

A: An absorbable suture (*dark blue*) is seen through the HAGL lesion. It is used to shuttle the nonabsorbable suture from the anchor.
B: HAGL lesion repaired.

to the lesser tuberosity and started at the inferior half of the subscapularis tendon (Fig. 11.13). The incision stops just proximal to the circumflex vessels. The axillary nerve is now palpated to ensure its protection. The subscapularis tendon and muscle fibers are then incised medially for 1.5 to 2 cm, thus creating the horizontal portion of the L-shaped subscapularis incision. The fleshy fibers of the inferior subscapularis are gently spread with a cobb elevator or Metzenbaum scissors and the L-shaped incision is lifted proximally (Fig. 11.14). This exposes the HAGL defect (Fig. 11.15)

The lesion is located in the anterior-inferior aspect of the glenohumeral joint from the 8:00 to 6:00 position on a right shoulder. A tag suture is placed into the leading edge of the avulsed IGHL. The cortex of the anatomic attachment site of the IGHL on the humeral neck is gently débrided down to a bleeding bony bed. Suture anchors are placed into the neck of the humerus (Fig. 11.16). The sutures are passed through the HAGL lesion in a mattress-type fashion and tied down (Fig. 11.17). Typically, two anchors are needed. Once this is completed, the inferior half of the subscapularis tendon is repaired anatomically back to its insertion site using nonabsorbable sutures (Fig. 11.18)

The postoperative course includes placing the arm into a sling in neutral or slight internal rotation for 4 weeks. During the first 3 to 4 weeks, the patient is allowed Codman exercises and supine well-arm assisted forward elevation. Isometric exercises are started within 2 to 3 weeks of surgery. At 4 to 6 weeks postoperatively, external rotation exercises are started. Progressive resistance with bands, cords, and weights is started at 6 weeks postoperatively. After 4 months post-op, the patient is returned to full activity and contact sports. The main benefit of the miniopen technique is that patients experience a rapid return of lift-off power and little weakness in subscapularis function.

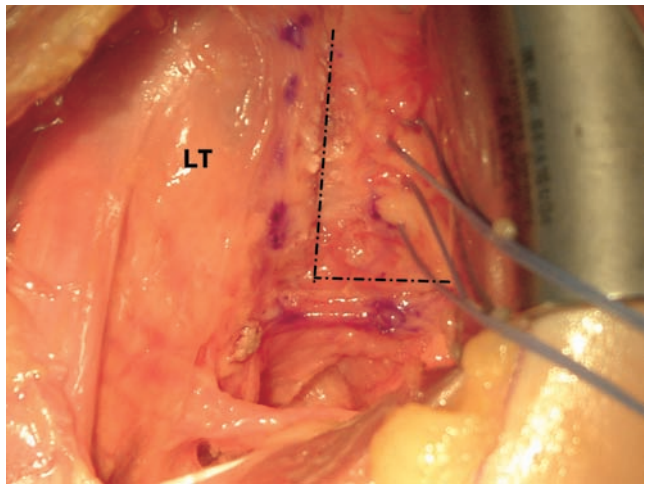


FIGURE 11.13

The open repair incision in the subscapularis muscle. The "L"-shaped incision spares the upper proximal tendinous portion of subscapularis. Tag stitches have been placed in the subscapularis muscle. The dotted line shows the orientation of the incision. LT, lesser tuberosity.

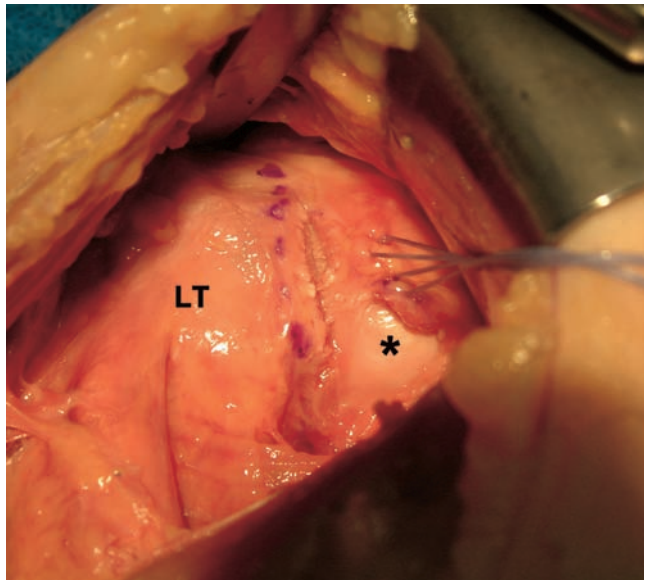


FIGURE 11.14

The lower third of subscapularis is reflected proximally. LT, lesser tuberosity (*asterisk* = "L"-shaped edge of subscapularis).

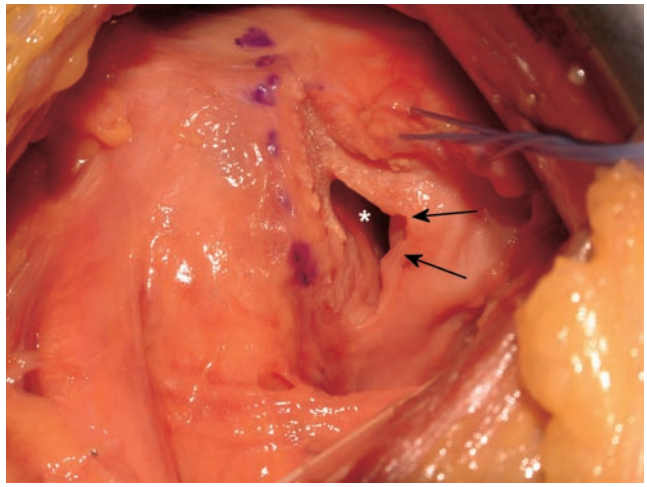


FIGURE 11.15

The HAGL defect is exposed. *Black arrows* show avulsed capsule. *Asterisk* shows defect created by HAGL. Tag stitches are in subscapularis tendon/muscle.

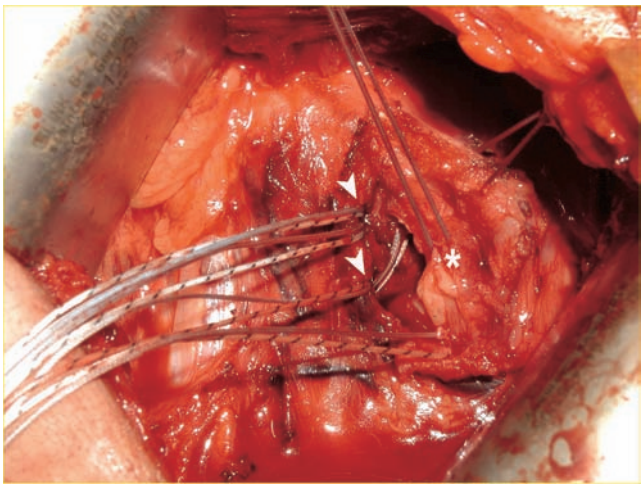


FIGURE 11.16

Suture anchors have been placed in the humeral neck (*white arrowheads*). Note single tag suture in leading edge of HAGL lesion (*white asterisk*).

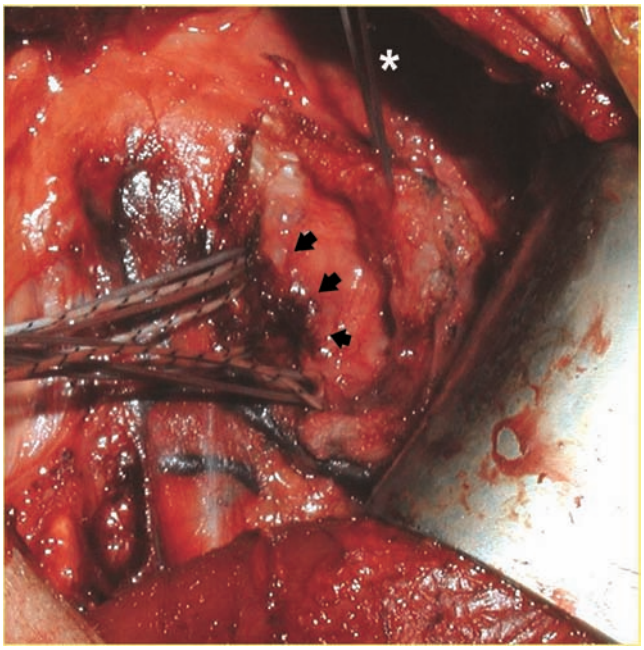


FIGURE 11.17

HAGL defect repaired. *Black arrows* show leading edge of HAGL lesion attached back to humeral neck. *White asterisk* shows tag suture in subscapularis.

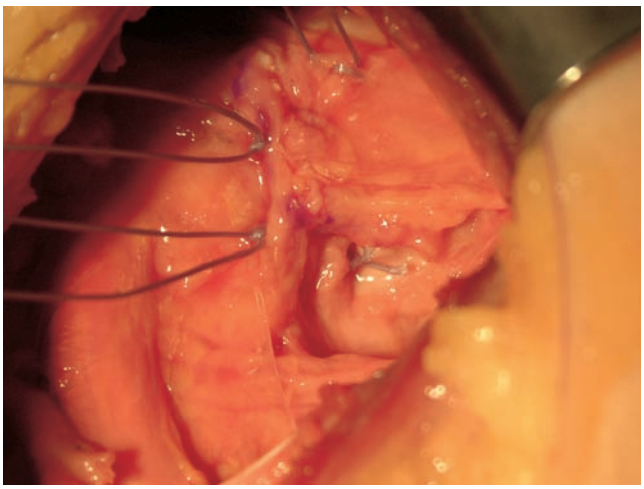


FIGURE 11.18

Lower portion of subscapularis muscle/tendon is repaired.

CONCLUSION

In conclusion, HAGL lesions are an important cause of recurrent instability in the shoulder after injury. The incidence of these lesions as a cause of anterior shoulder instability is seen in 7.5% to 9.3% of cases. As there is no single clinical test that can reliably diagnose a HAGL lesion, one must have a high suspicion. The definitive diagnosis is made at surgery, and in all cases of shoulder arthroscopy, the capsular attachment of IGHL to the humeral should be documented.

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12 Arthroscopic Subacromial Decompression

Susan S. Jordan

SURGICAL INDICATIONS

Arthroscopic subacromial decompression (SAD) has become an increasingly common procedure for orthopaedic surgeons in the United States. From 1999 to 2003, it rose from being the ninth most commonly reported procedure by those taking their American Board of Orthopaedic Surgery Part II to the second most common procedure (2). Recent studies have questioned the need for SAD in the setting of rotator cuff repair (3,7,8). For patients with type 2 acromions and supraspinatus tears, inclusion of SAD with rotator cuff repair did not affect functional outcome in a prospective randomized study (3). In prospective randomized study of patients with full-thickness rotator cuff tears, SAD did not affect outcome at 2 year follow-up (7). In spite of these studies, there still appears to be a role for isolated SAD for the patient with impingement and an intact rotator cuff.

Patients with impingement syndrome typically complain of pain with overhead reaching and abduction motions. They often complain of night pain as well. On examination, there may be limitation of active forward flexion and abduction secondary to pain. Neer and Hawkin impingement signs will be positive. In addition to physical examination, the initial work up of the patient should include shoulder x-rays, with particular attention to the supraspinatus outlet view. This view best demonstrates the shape of the acromion (Fig. 12.1). Patients with large anterolateral hooks or spurs on the acromion may benefit ultimately from surgical decompression if nonoperative treatment fails. MRI may also be obtained to rule out associated rotator cuff, labral, or biceps pathology but is not necessary in every case.

An isolated SAD may be appropriate for the patient with persistent impingement symptoms that fail to improve with nonoperative management for more than 6 months. Prior to considering surgical treatment, patients should undergo an extensive rehabilitation protocol targeted at rotator cuff and scapular stabilizer strengthening. Ice and anti-inflammatory medications also help during initial nonoperative management. Subacromial injections are often helpful in treating impingement pain. Pain relief from the injection with resolution of impingement signs (Neer impingement test) is also informative; a good response to injection is associated with good results from SAD should it be necessary (6,9).

SURGICAL TECHNIQUE

Arthroscopic SAD may be performed in the beach chair or lateral position depending on surgeon preference. An interscalene block may be supplemented with sedation or general anesthesia. Once the patient is positioned, the landmarks of the shoulder are marked including the borders of the acromion, the acromioclavicular joint, and the coracoid. Portal locations are marked. The lateral portal is marked 2 to 3 cm from the anterolateral border of the acromion in line with the anterior edge of the acromion. The arthroscopy is performed by establishing a typical posterior portal 2 to 3 cm inferior and slightly medial to the posterolateral acromial edge. First, the surgeon may insufflate the glenohumeral joint with a spinal needle directed toward the coracoid. Then, the arthroscope is introduced into the joint. An anterior portal just superior to the subscapularis is established to allow insertion of a probe. The joint is thoroughly inspected for any pathology, with close attention to the undersurface of the rotator cuff for partial-thickness tears.

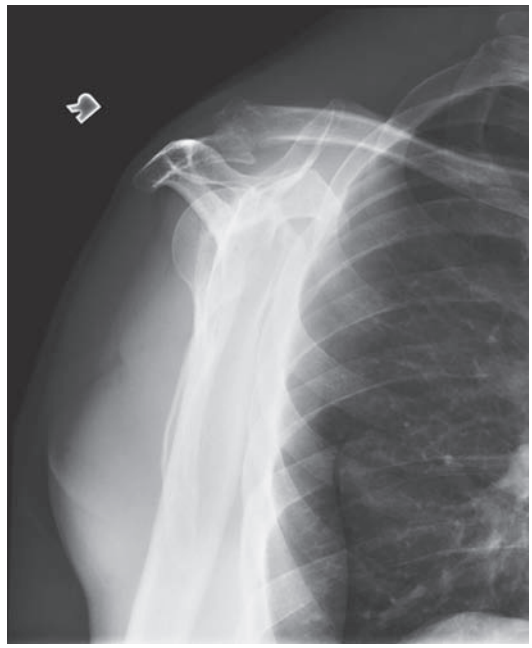

FIGURE 12.1

The supraspinatus outlet view demonstrates the acromial morphology clearly. In this case, the anterior acromion has a large downsloping spur.

Once the joint has been inspected, the arthroscope is removed from the glenohumeral joint. The trocar is then introduced through the posterior portal into the subacromial space. The tip of the trocar can be used to palpate the posterior edge of the acromion, and then the trocar should be inserted directly under the acromion, hugging the undersurface. The trocar can then be swept medially and laterally to establish a viewing space and release any bursal attachments. The trocar is positioned near the anterolateral aspect of the acromion and the arthroscope is introduced. Next, a spinal needle is introduced laterally and triangulation between the arthroscope and the needle is performed. The ideal position for the spinal needle (and eventually the lateral portal) allows the needle's trajectory to parallel the undersurface of the acromion. The needle position is adjusted until this trajectory is achieved. A No. 11-blade is used to incise the skin for the lateral portal. A blunt trocar can be introduced to dilate the portal.

Next, a shaver is introduced. The shaver should be viewed clearly from the posterior portal before it is used, and the blades should face superiorly. Blind activation of the shaver should never be performed. The shaver is swept from anterior to posterior to resect the subacromial bursa and widen the viewing space. An electrocautery device may also be used to clean off the undersurface of the acromion and identify the anterior and lateral borders of the acromion. The presence of inferiorly protruding acromial spurs is confirmed at this time (Fig. 12.2). The coracoacromial ligament will be visualized anteriorly. Some advocate complete release of this structure (1,10). However, if there is a rotator cuff tear, particular attention should be paid to preservation of the coracoacromial ligament. This ligament has a role in preventing superior migration of the humerus and it also contributes to shoulder stability (5). The shaver can be swept back and forth over the rotator cuff to allow exposure of the rotator cuff tendon and viewing of any partial-thickness or full-thickness tears. The shaver blades should be positioned away from the cuff tissue at all times.

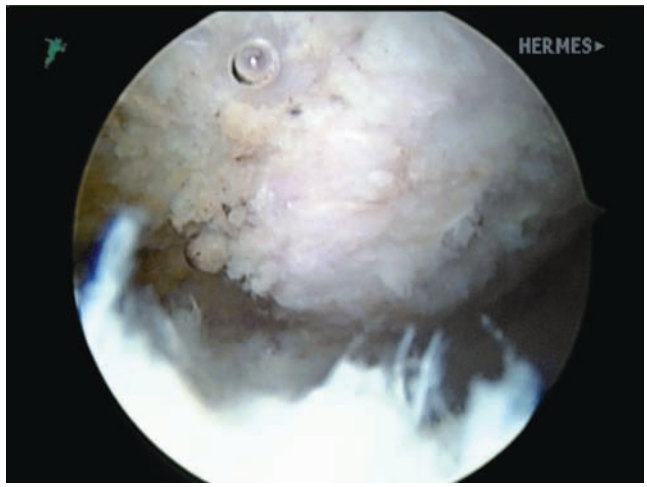

FIGURE 12.2

A shaver has been used to perform a bursectomy, and an electrocautery device to expose the large anterolateral acromial spur.

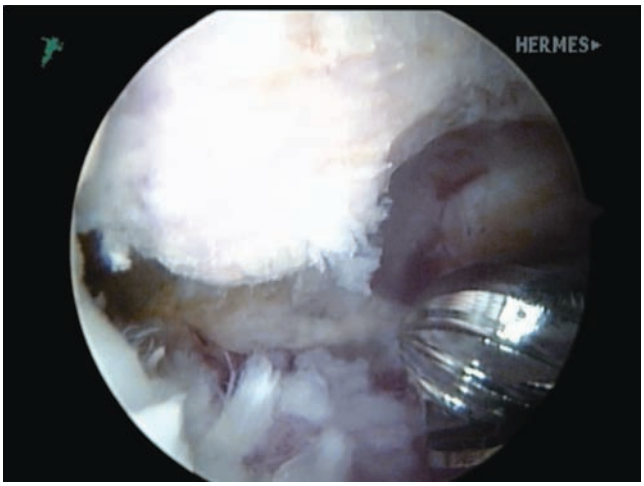

FIGURE 12.3
The burr is introduced laterally and the most anterolateral aspect of the acromion is resected first.

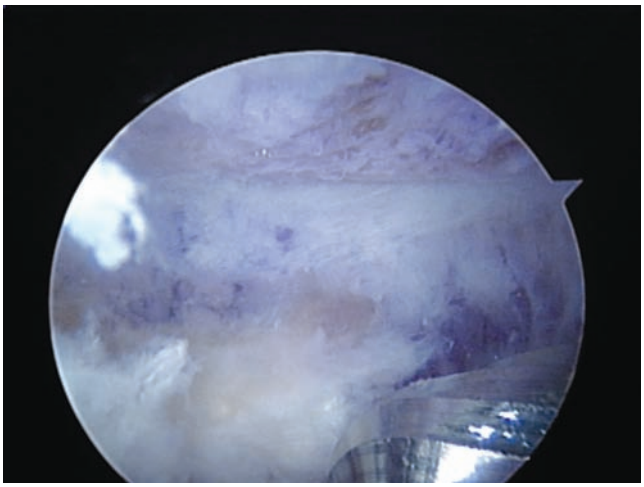

FIGURE 12.4
The undersurface of the acromion is now flat following completion of the SAD (viewing with the arthroscope in the posterior portal).

Once the acromion has been adequately exposed, the decompression may be performed. With the arthroscope in the posterior portal and looking laterally, a burr is introduced through the lateral portal. First, the undersurface of the most anterior and lateral aspect of the protruding acromion is resected (Fig. 12.3). Resection need not be excessive; the goal of the decompression is to make the anterior aspect of the acromion level with the middle aspect. The extent of resection necessary will vary depending on the acromial shape and size of spurs; it may only involve a few millimeters of bone. Next, the burr is moved medially to even out the remaining acromial undersurface. Rotating the lens on the camera to look medially facilitates this step. The acromioclavicular joint is left intact in an isolated SAD. With soft bone, operating the burr on forward may remove bone too aggressively. Using reverse mode will allow more gentle burring and prevent over-resection of the acromion. The scope can be placed in the lateral portal as well as the posterior portal to confirm that the acromion is now flat. Any remaining irregularities should be smoothed out until the acromial undersurface is smooth and flat (Fig. 12.4). Other techniques described for SAD include inserting the "cutting block technique" in which the burr is introduced posteriorly with the arthroscope positioned laterally. The burr is used to resect the undersurface of the anterior acromion in this manner, using the posterior undersurface of the acromion as a guide to the angle of resection (4).

SURGICAL PEARLS

1. Placing the lateral portal in the proper position will facilitate the SAD. When triangulating, the goal is for spinal needle to parallel undersurface of acromion so that when the burr is introduced, the trajectory is appropriate for resecting the anterolateral acromial spur.
2. Careful delineation of anterolateral border of acromion with an electrocautery device is critical to visualization and prevents inadequate resection of anterolateral acromion.

3. Shaver blades should always be directed away from the rotator cuff and visualized prior to activation of the shaver.
4. Preserve the CA ligament in cases of large or massive rotator cuff tears.
5. With soft bone, using the shaver in reverse mode prevents overly aggressive bony resection.
6. Visualization of the subacromial space is often obscured by bleeding. The use of dilute epinephrine in the irrigation bags facilitates visualization. In addition, the use of an outflow portal anteriorly also improves visualization.

POSTOPERATIVE MANAGEMENT

The patient is placed in a sling immediately postoperatively until the interscalene block has resolved. After that, the patient is encouraged to remove the sling and use the shoulder and arm for activities as tolerated. Pendulum exercises, as well as elbow, wrist, and hand range of motion, are started immediately after surgery. Physical therapy may begin within a week after surgery, focusing on regaining full, pain-free shoulder range of motion. Once full motion has been obtained, rotator cuff and scapular stabilizer muscle strengthening begin.

OUTCOMES OF ARTHROSCOPIC SAD

Much of the literature describing outcomes after arthroscopic SAD includes patients with rotator cuff pathology. For isolated SAD in the absence of rotator cuff tear, the retrospective studies in the literature report variable outcomes that range from 40% to 90% satisfactory results depending on the stringency of the outcome criteria, with the majority of authors reporting satisfactory results in 80+% of patients (1). Patel reported on 114 patients after an isolated SAD. At an average of 19-month follow-up, 75% of patients were satisfied with their outcome. The authors observed that patients with prolonged symptoms before SAD fared worse, nondominant shoulders fared better, and those with good response to injection prior to surgery fared better. As a result of their findings from this study, the authors concluded that careful patient selection is key to maximizing outcome after SAD (9).

Complications after arthroscopic SAD are rare, but include infection, acromial fracture, over-resection or under-resection of acromion, and overzealous release of CA ligament. Other possible complications include shoulder stiffness and persistent pain.

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13 Arthroscopic Double-Row Rotator Cuff Repair

Dara Chafik, Robert Z. Tashjian, and Ken Yamaguchi

INTRODUCTION

With the advent of improved techniques and instrumentation, and increased experience, arthroscopic rotator cuff repair has become as effective as traditional open and miniopen approaches for a variety of tear sizes ranging from small to massive (3,26,27,31,34). Arthroscopic techniques also have several distinct advantages over traditional open methods including less soft tissue violation, decreased risks of injury to the axillary nerve and deltoid origin, and a decreased infection rate. By decreasing the amount of dissection with arthroscopic repairs, patients can be immobilized safely postoperatively for a longer period of time with less concern for the development of acquired postoperative stiffness compared to open repairs. Arthroscopic approaches also allow for accurate inspection of the glenohumeral joint and treatment of intra-articular pathology including injuries to the biceps tendon and labrum. Accurate determination of rotator cuff tear anatomy is also facilitated when repairs are performed arthroscopically. Because of these advantages, we now rarely resort to open techniques and repair most rotator cuff tears, including most massive tears, arthroscopically with consistently good results. We present here one of our current double-row techniques for repairing full-thickness medium to large and simple massive rotator cuff tears.

We routinely perform double-row rotator cuff repairs for most medium, large, and massive tears. Several biomechanical studies suggest that double-row repairs are stronger than single-row repairs (19,22,23). Despite these biomechanical advantages, current clinical studies do not clearly indicate the superiority of double-row repairs over single-row repairs with respect to final functional outcomes. There is some clinical evidence supporting the idea that double-row constructs lead to higher healing rates compared to single-row repairs (1,6,20,29). Other authors report no difference between single- and double-row repairs with regard to healing (5,9). Nevertheless, potentially higher healing rates do not necessarily translate into improved clinical outcomes in all cases. We have anecdotally noticed in our own patients that younger patients who fail to heal often have worse function and pain control compared to similar older patients. Since the clinical benefit of a double-row repair has still not been proven with regard to final functional outcomes and because of the added cost, some surgeons choose to perform single-row repairs in all patients, or at least in older patients where a retear may not have as significant of a clinical effect. At this time, we still prefer a double-row construct for most patients and in particular younger ones because of the theoretical improvements in healing.

INDICATIONS

Our main indication for rotator cuff repair is presence of a painful full-thickness tear in a young patient or a tear that is refractory to conservative management in older patients. We will not review the management of partial-thickness tears in this chapter. Three factors have a significant influence on rotator cuff repair healing and therefore the decision-making algorithm for treating full-thickness rotator cuff tears. These include patient age, tear

size, and muscle quality (degree of fatty degeneration and atrophy). Along with taking into consideration these factors, knowledge of the natural history of tears treated nonoperatively will guide surgical indications.

The rotator cuff has limited capabilities for healing without repair, and there is a significant prevalence of tear progression over time with nonoperative treatment of full-thickness tears (33). Older and more sedentary patients tolerate tears and lack of healing after repair better than younger and more physically active patients (11,18). Younger patients heal rotator cuff repairs more reliably than older patients (2,7,11,17,24). Larger and more complex tears have higher retear rates after repair than smaller tears (8,12,25). Fatty degenerative changes of the rotator cuff occur over time as the tendon remains detached (13). These changes can be halted in the setting of a healed repair although they are not reversible (14). In some more advanced cases, rotator cuff repair may not prevent progression of fatty degeneration and muscle atrophy (15,16,28). Finally, preoperative atrophy and fatty infiltration of the rotator cuff muscles negatively influences the ability of a rotator cuff repair to heal (21).

In considering these factors, we tend to be more aggressive in repairing any sized full-thickness tear in patients <60 years of age. In this patient population, negating all other confounding factors such as smoking, we know that the chances of healing are much better than in older patients. We also know that without surgical intervention, there is a 50% chance that the symptomatic tear will increase in size and become more symptomatic (33). Younger patients with a cuff tear, and those who fail to heal a repair, are more often dissatisfied and symptomatic compared to patients older than 60 years (32). This may be in part due to the fact that younger patients are more active and have higher functional demands. We are less aggressive in repairing very large, chronically retracted tears with extensive muscle changes even in a younger age population because of poor healing capabilities of severely affected muscles. We are also less aggressive in repairing tears in patients older than 65 because of the poorer healing capabilities in this older population. However, if prolonged conservative management fails in these older patients or younger patients with very large tears with extensive muscle changes, rotator cuff repair is considered.

CONTRAINDICATIONS AND ALTERNATIVES

Contraindications to arthroscopic rotator cuff repair include ongoing or recent infection, inability to comply with postoperative requirements, advanced glenohumeral joint arthritis, superior migration of the humeral head in the setting of rotator cuff-tear arthropathy, serious life-threatening comorbidities, and some neuromuscular disorders such as advanced Parkinson disease and cerebral palsy. Massive retracted tears with extensive fatty degeneration and scarring is also a relative contraindication. Patients older than 70 with low activity demands and with massive retracted and scarred cuff muscle remnants who present with pain that is refractory to conservative management as the chief complaint may be most reliably treated with either an arthroscopic débridement with biceps tenotomy or a reverse total shoulder arthroplasty dependent on their baseline shoulder function. Younger patients with irreparable massive rotator cuff tears and an intact subscapularis in the absence of glenohumeral arthritis may be candidates for a latissimus dorsi tendon transfer, with or without the teres major. Patients with painless rotator cuff tears, or those with very mild pain, and without any significant functional disability, are usually observed. In this scenario, younger patients are followed more vigilantly with yearly examination and imaging studies (magnetic resonance imaging [MRI] or ultrasound) to ensure that the tear is not progressing. In cases of rotator cuff tear arthropathy with massive irreparable tears and an intact deltoid muscle, the reverse total shoulder arthroplasty is a reliable option for pain relief and optimal recovery of function.

PREOPERATIVE PLANNING

Patients with symptomatic rotator cuff tears often complain of pain with overhead activities and reaching behind their back. Patients usually either report an insidious onset of symptoms or an acute traumatic event. Often, the pain is described as radiating from the shoulder along the lateral aspect of the upper arm, sometimes to the elbow and proximally to the neck. Patients routinely describe pain at night that interrupts sleep. In addition, depending on the tear size and chronicity, there may be variable degrees of functional deficits.

The physical examination includes inspection of the shoulder for supraspinatus and infraspinatus wasting that is present with very large rotator cuff tears. Passive motion is tested in all directions. Limitation of internal rotation is very common with any rotator cuff pathology and reflects a posterior capsular contracture. Inferior contracture can occur with large tears and superior migration of the humeral head, which should be released prior to repair through manipulation. Significantly increased external rotation at the side compared to the opposite shoulder can indicate a very large subscapularis tear. Rotator cuff strength is tested using a variety of maneuvers. The abdominal compression test or lift off test can be used to evaluate subscapularis strength. Resisted thumbs-down abduction in the scapular plane evaluates the supraspinatus, while external rotation strength with the elbows at the side evaluates infraspinatus function. The hornblower's test and resisted external rotation with the shoulder abducted 90 degrees examine teres minor function. Pain with palpation of the acromioclavicular (AC) joint and crossbody adduction can point toward the AC joint as a potential source of pathology. The biceps contour should be evaluated for a Popeye sign seen with rupture of the tendon of the

long head of the biceps. Other biceps provocation test, such as Yergason or Speed maneuver, can be performed although the specificity of these tests to indicate biceps pathology is limited. Pain with direct palpation over the proximal biceps can be indicative of disease.

Diagnostic Imaging

Our routine shoulder radiographic series consists of a standard anteroposterior (AP) view of the shoulder with the humerus in internal rotation, a true AP view of the scapula with the involved shoulder abducted 30 degrees and the humerus in neutral rotation, a scapular Y view, and an axillary lateral view. The true AP view of the scapula is useful for evaluating the glenohumeral joint, viewing the greater tuberosity on profile, and evaluating for superior head migration. As this view is performed with the shoulder abducted to 30 degrees, the pull of the deltoid will accentuate superior head migration in a shoulder with a massive rotator cuff tear. In addition, if there is substantial contracture of the inferior capsule, as in more severe cases of adhesive capsulitis, scapular compensation can also be detected well on this view. The scapular Y view is useful to evaluate subacromial narrowing and spurs and to classify the type of acromial morphology. The axillary view is useful to evaluate the glenohumeral joint for arthritic changes and anteroposterior subluxation.

We routinely use both MRI and ultrasound to evaluate the rotator cuff. We have found that at our institution ultrasound is more accurate at defining rotator cuff tendon tear size and morphology as it can be used in a dynamic fashion that is not possible in the same way with MRI. MRI seems more valuable in evaluating the status of the rotator cuff muscles, labral pathology and paralabral cysts (especially with contrast), cystic and degenerative bone changes, and articular cartilage damage. Acute tears often show fluid collection and edema in the affected muscle that is more easily detected by MRI. The biceps tendon and its location in its groove are equally well defined by either technique. As each technique has its advantages and adds important information, we tend to perform both studies in most patients.

SURGICAL PROCEDURE

Anesthesia/Analgesia Management

We perform routine arthroscopic rotator cuff repairs with an indwelling interscalene catheter and block that is placed by the anesthesiologist in the preoperative holding area. This helps with postoperative pain control and decreases intraoperative systemic pain medication requirements. A 0.5% bupivacaine pump with approximately 2 mL delivered by patient demand every 6 hours is attached to the catheter after the procedure. The patient is placed on oral antibiotics until the catheter is pulled by the patient at home on the third day after surgery. The patient is also given general endotrachial anesthesia in the operating room. If it is medically safe to do so, the patient's systolic blood pressure is kept around 100 mm Hg throughout the case to minimize bleeding and optimize visualization with decreased arthroscopic pump pressure and flow requirements.

Patient Positioning

We use a high (60–70 degree) beach chair position for all of our arthroscopic rotator cuff repairs. Compression stockings and sequential compression devices are placed on bilateral lower extremities. A mechanical arm-holding device is used and has a very important role in positioning and traction for various parts of the case as described below. After positioning the patient, shoulder range of motion is evaluated under anesthesia. If there is tightness with forward elevation, gentle passive forward elevation with a short lever arm is performed in order to lyse adhesions of the anteroinferior capsule. External rotation manipulation is not performed as the torsional forces imparted on the humerus during such maneuvers may lead to fracture. If needed, rotator interval and anteroinferior capsular release can be performed during the intra-articular portion of the case. Prior to prepping and draping of the arm, a 20-mL injection of 0.25% bupivacaine with epinephrine is placed in the subacromial space from a posterior approach. This helps with hemostasis during the subacromial portion of the case.

Time Consideration

Arthroscopic rotator cuff repair duration >2 hours can have serious deleterious effects on the ability to perform the surgery safely. The surgeon must remain aware of elapsed time to avoid complications related to the prolonged use of arthroscopic fluid. These potential problems include postoperative airway compromise and inability to visualize the surgical field properly to perform the surgery secondary to soft tissue swelling. If there is excessive swelling, the surgeon may be forced to convert to an open approach or abort the surgery altogether. To avoid these potential complications, several steps can be taken. We use a fluid pump set at 35 mm Hg. On occasion, we may increase the pressure, but we rarely do so for a prolonged period of time and we rarely increase it beyond 60 mm Hg. In addition, portals and instruments should be placed optimally to accommodate for soft tissue swelling (see below). Finally, the procedure should be performed as expeditiously as possible while maintaining safe technique.

Portal Placement and Preliminary Glenohumeral and Subacromial Arthroscopy

Posterior Portal The placement of our posterior portal depends to some degree on the patient's body habitus. In general, however, for rotator cuff repairs, we place the posterior portal more laterally and inferiorly than the usual standard posterior soft-spot portal. Our preferred posterior portal is placed directly inferior to the posterolateral corner of the acromion in line with the axilla. The distance inferior to the acromion depends on the shoulder girth. In larger patients, all portals are placed more distally to accommodate for the swelling and to avoid impinging cannulae on the acromion. The more lateral placement of the posterior portal helps in posterior viewing during rotator cuff repair and places the cannula further away from the posteromedial subacromial fat. It also provides more space for percutaneous use of suture passing devices. The posterior portal into the joint is established first by placing some anterior and distal traction on the arm using the mechanical armholder. After the skin incision, we use a sharp trochar to penetrate the deltoid fascia and stop short of the capsule. We then switch to a blunt trochar to enter the joint.

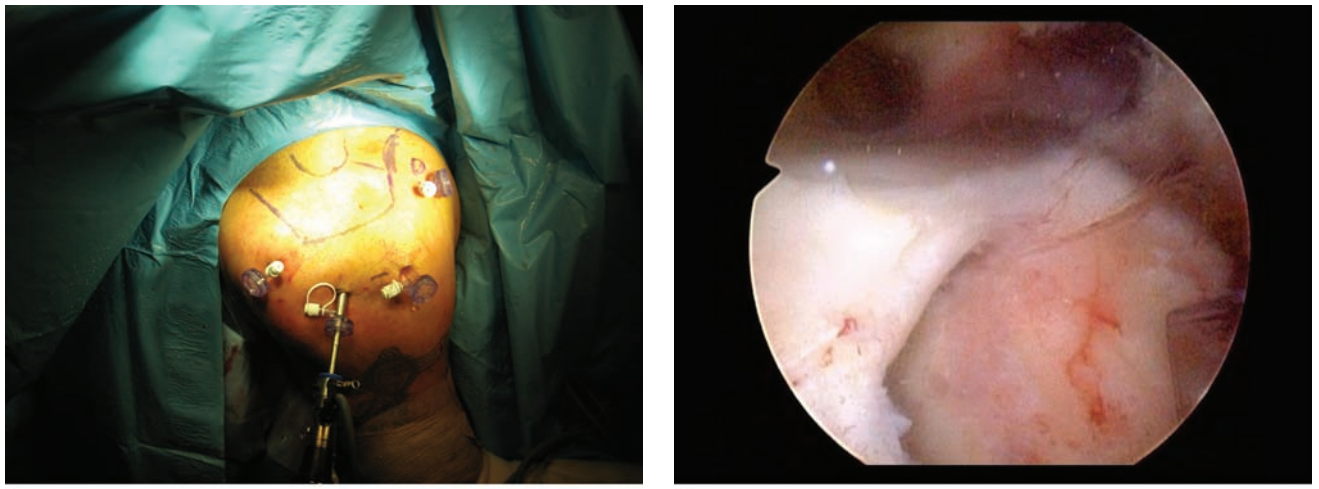
Anterior Portal Once the glenohumeral joint is entered, a spinal needle is used immediately with an outside-in technique to localize placement of the anterior portal within the rotator interval just below the biceps tendon. The skin incision for the anterior portal should be slightly more distal and just lateral to the coracoid tip to accommodate for soft tissue swelling as the case progresses. Placing the portal too high will result in a caudad-angled cannula in the subacromial space later in the case and make suture management and arthroscopic knot tying more difficult.

After the skin incision, a 5 to 6 mm cannula is placed as an anterior rotator cuff interval portal. An arthroscopic shaver is placed through the anterior portal to perform débridement of the labrum and rotator cuff as needed. The shaver or a probe is used as a blunt instrument to examine the glenohumeral joint fully including the biceps tendon by pulling it into the joint and examining its sling and its superior and inferior surface for tears and subluxation. Taking the arm out of the arm holder and forward flexing and slightly abducting the shoulder allows for better visualization of the biceps sling and insertion of the posterior superior rotator cuff tendons on the greater tuberosity.

Lateral portals and Subacromial Preparation After the initial glenohumeral work has been completed, the arthroscope is removed from the posterior portal. Distal traction is placed through a special strap attached to the mechanical arm holder and proximal forearm. This maneuver helps open up the subacromial space. A sharp trochar is then used to enter the subacromial space from the posterior portal sliding just under the acromion. The sharp trochar is then switched to a blunt trochar and the subacromial space is swept systematically starting medially first beneath the AC joint. The trochar is then pulled back and the lateral gutter is swept fully all the way to the posterior aspect of the humerus taking care not to tear into the deltoid fascia. The camera is placed in the posterior portal and a spinal needle is used to localize the placement of the anterolateral portal. As with the posterior and anterior portals, the lateral portals must also be placed sufficiently distal from the lateral acromial border to accommodate for soft tissue swelling and to allow proper visualization of the rotator cuff defect and placement of the lateral row anchors later in the case. After skin incision with a No. 11 blade, the anterolateral portal is dilated using a 5.75-mm cannula and trochar, both of which are then removed. The subacromial space is then débrided with a shaver pulling the camera back slowly to create a working space. Bleeders are encountered as one débrides posteromedially and medially as well as during release of the coracoacromial ligament from the undersurface of the acromion that we perform routinely. To manage these bleeders, we perform the débridement in these areas with a coagulation/ablation device (ArthroCare, Austin, Texas). We also use this device to remove soft tissues from the undersurface of the acromion. The lateral gutter is débrided carefully with a shaver as is the footprint of the torn rotator cuff on the greater tuberosity and the edges of the torn tendon. A bur is then used to perform a conservative acromioplasty and to lightly decorticate the torn rotator cuff footprint until slight bleeding is encountered from the bone. A spinal needle is then used to localize placement of the posterolateral portal. A 7-mm threaded cannula is then placed in all four portals taking care to ensure that the anterolateral and posterolateral portals converge at the rotator cuff tear. The anterolateral portal is positioned near the anterior aspect of the tear and the posterolateral portal is placed close to the posterior aspect of the tear. The anterior portal enters underneath the anterior acromion where the coracoacromial ligament was released. With cannulae in each portal, switching viewing portals and instruments is now made easy (Fig. 13.1A and B).

Rotator Cuff Repair Technique

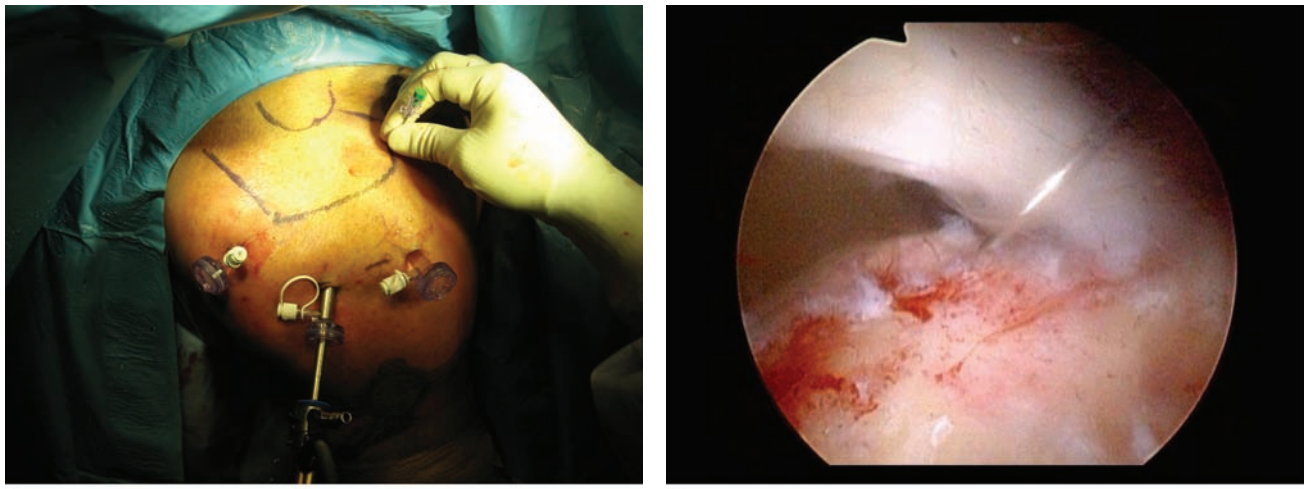
The arthroscope is placed in the one of the two lateral portals that gives the best tear visualization (usually the anterolateral portal). A shaver is used through the other lateral portal as needed to finish preparing the rotator cuff tear and greater tuberosity. An ArthroCare device is used to clear soft tissues as needed for visualization. Coagulation and ablation is never used on the greater tuberosity and rotator cuff tendon to ensure maximal blood supply to the repaired tendon. Also, the soft tissues over the greater tuberosity just lateral to the torn



A B

FIGURE 13.1

Right shoulder cannula placement. **A:** The beach chair position is used with distal traction and four 7-mm threaded cannulae in place. The inferior and converging position of the cannulae in this large patient helps maintain horizontal cannula placement within the subacromial space. The lateral position of the posterior portal facilitates rotator cuff repair. **B:** With the arthroscope viewing from the posterior portal, the three other portals are seen within the subacromial space of this patient with a simple massive rotator cuff tear.



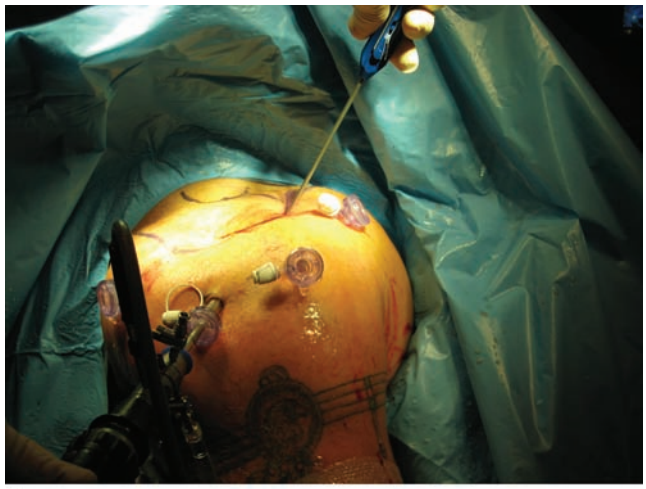
A B

FIGURE 13.2

Right shoulder anchor localization technique. **A:** A spinal needle is placed just anterior to the acromion and used to localize the percutaneous placement of the anterior medial anchor. **B:** Viewing from one of the lateral portals, the spinal needle is used to localize the exact position of the anteromedial anchor just lateral to the articular surface and adjacent to the anterior aspect of the tear. The greater tuberosity has been cleared of soft tissue and abraded slightly to create cortical bleeding and a healthy bed for rotator cuff repair healing onto the footprint.

rotator cuff footprint are not débrided as we believe that this vascular tissue provides an additional blood supply to the rotator cuff repair. While viewing from the anterolateral portal, a spinal needle is used to localize the percutaneous placement of the anterior anchor. The needle is placed just anterior to the anterior border of the acrominon exactly half-way between the anterolateral corner and the AC joint for optimal angular placement of the anterior most medial row anchor (Fig. 2A and B). We use a 5.5-mm metal screw-in type anchor loaded with two 2 Fiberwire sutures (Arthrex, Naples, Florida).

The position of the metal anchors can be visualized by radiograph if needed in the future (Fig. 13.3A–C). In the case of a medium-sized tear requiring two medial anchors, the second anchor is placed using the same technique with a starting point along the lateral border of the acromion. We try to place these medial row



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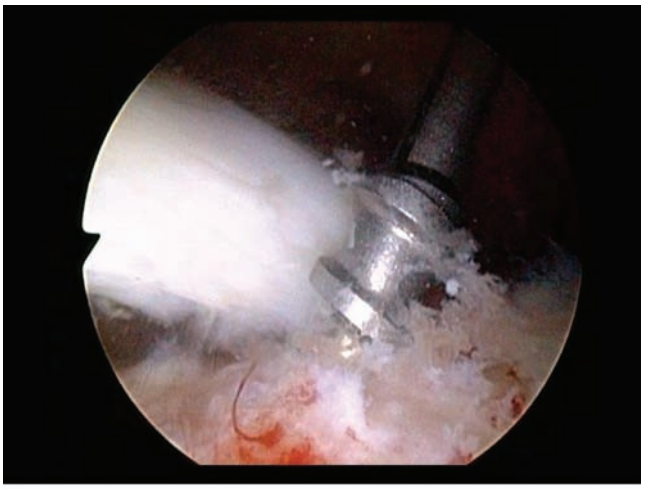

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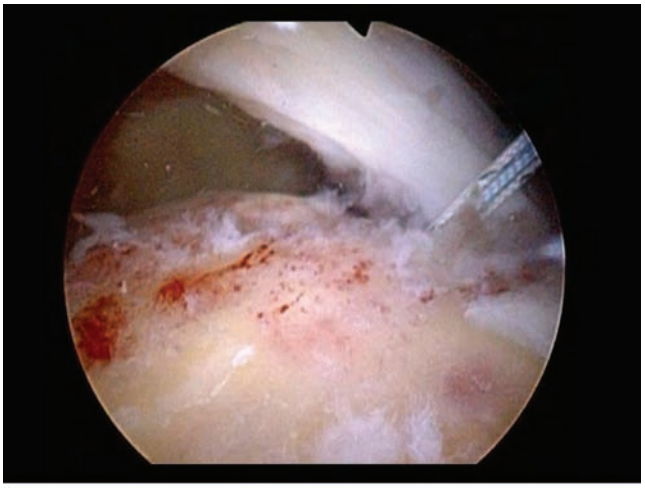

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FIGURE 13.3

Right shoulder anchor placement technique. **A:** After spinal needle localization, a stab incision is made in the skin and an anchor is introduced percutaneously just adjacent to the acromion. **B:** The anchor is placed at a slight angle to increase its strength. **C:** The anchor contains two sutures.

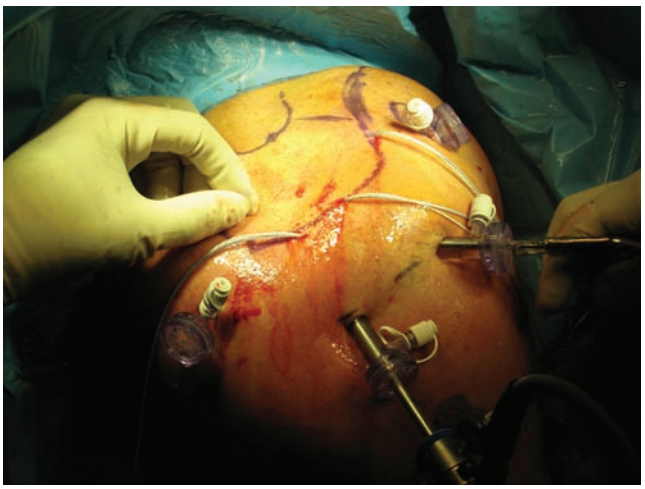


FIGURE 13.4

An antegrade device is used through a lateral portal to pass sutures through the rotator cuff after all of the anchors have been placed percutaneously adjacent to various aspects of the acromion.

percutaneous anchors as close to the edge of the acromion as possible to allow for optimal anchor angle placement. If there is a large or massive tear requiring three anchors, we place another anchor in between the anterior and posterior anchors (Fig. 13.4). The medial row anchors are placed approximately 2 mm lateral to the articular surface and slightly more laterally in the bare area. The bone adjacent to the articular margin tends to be much harder than the bone more laterally on the greater tuberosity. Care should be taken when placing very posterior anchors as the bone quality in the posterior tuberosity is often inferior to that in an anterior location.

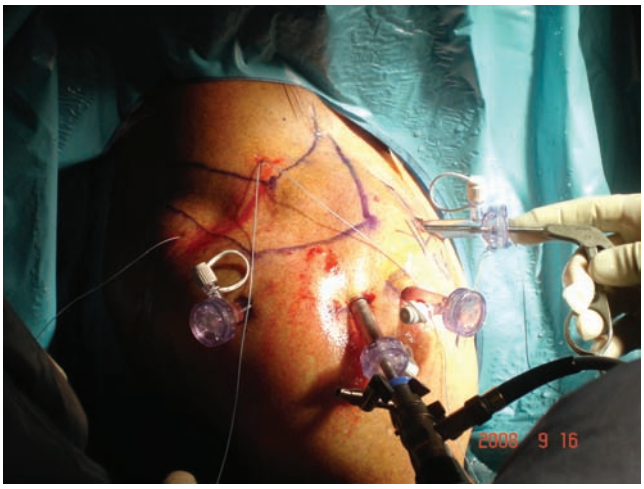


FIGURE 13.5

In a different patient, a percutaneous technique is used and all of the suture limbs from previously placed anchors have been passed through the rotator cuff in a retrograde fashion using a lasso device. The sutures are exiting through the skin at the points where the percutaneous device was introduced forming an arc centered at Neviaser's portal.

Suture Passing Technique The sutures are passed through the rotator cuff tendon in an antegrade fashion using a Scorpion device (Arhrex, Naples, Florida), or other similar device, from the lateral portals (Fig. 13.4), or in a retrograde manner using a Banana Lasso (Arhrex, Naples, Florida) percutaneously in larger or massive tears. In the latter case, we use the Neviaser portal for passing sutures in the middle of the tear. The Banana Lasso is passed percutaneously anterior to the clavicle or posterior to the posterior acromion in an even arc connecting these points to the Neviaser portal (Fig. 13.5).

Two Medial Anchor Mulberry Knot Technique In the case of a two-anchor medial row repair, a mulberry knot is placed using one of the suture limbs from the anterior anchor and one of the limbs from the posterior anchor. The knot is tied outside the shoulder and brought into the shoulder by pulling on the other limb of the same suture. This, in effect, creates a single static limb in the anterior and posterior anchors (Fig. 13.6). The two free-sliding suture limbs from the anterior anchor are then passed through the anterior aspect of the rotator cuff as a horizontal mattress. Next, the single static mulberry suture limb is passed just posterior to the most posterior limb of the anterior horizontal mattress suture. The posterior static mulberry limb is then passed toward the posterior aspect of the tear. Finally, the two limbs of the free-sliding posterior anchor suture are passed in the posterior aspect of the cuff tear as a horizontal mattress. The camera is usually switched to the posterolateral portal with the anterolateral portal as the working portal while passing the posterior sutures. The anterior horizontal mattress suture is then tied arthroscopically from the anterior portal, followed by the posterior mattress from the posterior portal. Lastly, the two middle mattress mulberry knot static sutures are tied through one of the lateral portals, creating three horizontal mattresses from the two medial row anchors with six free suture limbs. The remaining six free limbs may then be used to create a suture-bridge construct with knotless lateral anchors as described below (Fig. 13.7). In the case where remaining suture limbs are used in a suture-bridge construct attached to lateral anchors, we use two half-hitches thrown around the same post in the same direction to allow sliding and tensioning and only one additional half-hitch in the opposite direction on the same post to provide loop security.

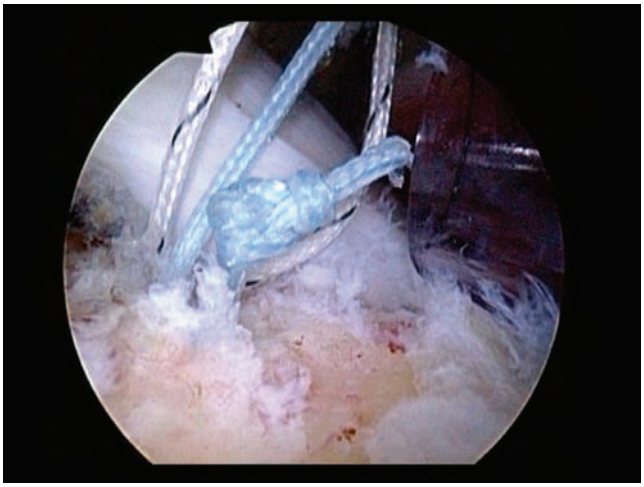


FIGURE 13.6

A mulberry knot has been tied on one limb of one of the two sutures in the anterior anchor converting it to a single static suture limb. The mulberry suture limb can now be passed through the rotator cuff and tied to another such suture from a different anchor in a horizontal mattress.

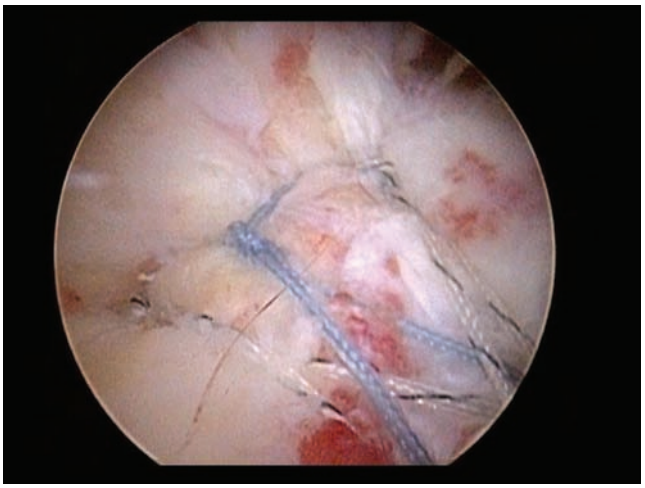


FIGURE 13.7

Final appearance of a two medial and two lateral row anchor suture-bridge construct for repair of a large rotator cuff tear. The anterior and posterior white sutures were tied in horizontal mattresses. The blue suture from each anchor was converted into a single static suture limb using a mulberry knot technique. The two static blue suture limbs, one from each anchor, were then tied to each other in a third, middle horizontal mattress. The resultant six free suture limbs were then used to create a suture-bridge construct through two lateral anchors.

Three Medial Anchor Construct In the case of larger and massive tears, an additional third anchor may be placed percutaneously in between the anterior and posterior anchors as described above. In these cases, we may use one of two constructs depending on the tear size and configuration. One approach is to convert the two sutures from the middle anchor into two static sutures via the mulberry knot technique mentioned above. In this way, four horizontal mattresses may be created from the three medial anchors as follows. After the suture limbs have been passed through the tendon, the anterior and then posterior free-sliding horizontal mattress sutures are tied first. Next the anterior anchor static mulberry suture is tied to one of the middle anchor static mulberry sutures and the same is done for the two posterior static sutures (one from the middle anchor and one from the posterior anchor). This creates four medial row horizontal mattresses that can then be incorporated into a suture bridge construct as described above with two lateral anchors.

Alternately, after the same technique is used as described for the two-medial row anchor construct, one limb from the third middle anchor may be removed and the remaining free-sliding suture tied in a horizontal mattress. This creates a small horizontal mattress in the middle of the tear in addition to the standard three horizontal mattresses as previously described from the anterior and posterior anchors. The tails of one of the middle mattress suture may be cut. A suture bridge technique is then used with knotless lateral row fixation with the remaining six free limbs as described above (Fig. 13.8A–C).

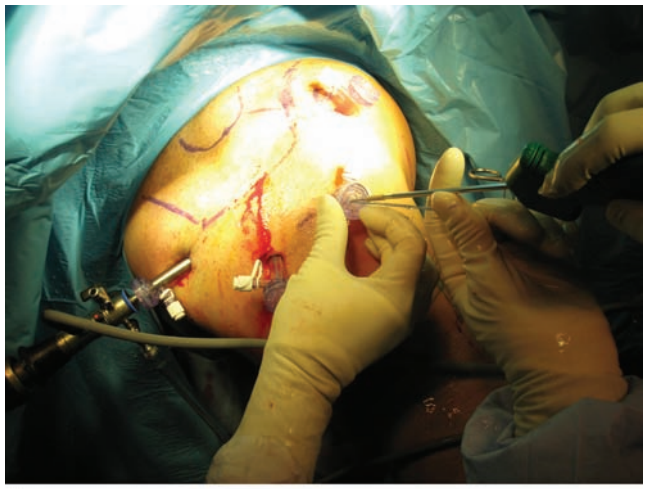
Lateral Row Anchors and Suture Bridge Construct We use a knotless lateral row fixation system (4.5 mm PushLock, metal tipped, Arthrex, Naples, Florida). Before the two lateral row anchors can be placed, visualization must be optimized with two maneuvers. First, the shoulder is abducted and rotated into optimal position using the mechanical arm holder, thereby opening up the lateral gutter and positioning the greater tuberosity correctly in line with the two lateral cannulae. Second, an ablator may be needed to clear off soft tissue through the lateral portals for optimal visualization of anchor placement. One limb from each horizontal mattress is tensioned in each of the two lateral anchors to create a suture bridge construct where the cuff tendon is pressed down onto the footprint (Fig. 13.8A–C). Lateral anchor location depends to some degree on the rotator cuff reduction requirements. Dog-ears are best avoided by proper suture placement. Placing the most anterior and posterior suture limbs slightly more laterally can help in reducing dog-ears.

POSTOPERATIVE MANAGEMENT

The postoperative rehabilitation protocol may be individualized based on surgical findings. However, the following is a guide to our standard postoperative and rehabilitation protocol. We have found that increasing the immobilization period to 6 weeks in certain cases where we are more concerned about tendon healing has not increased the rate of postoperative stiffness.

Phase 1 (Weeks 1–6): Protected range of motion

The patient goes home with an interscalene bupivacaine pain pump that they can administer themselves every 6 hours. Oral antibiotics are given until the pump is discontinued by the patient along with the dressings on the third postoperative day. The patient may shower after the dressings are removed. A cold-flow cuff system is used for at least 1 week four times per day. A sling is worn at all times, even during sleep, and is removed only for hygiene and to perform prescribed exercises.



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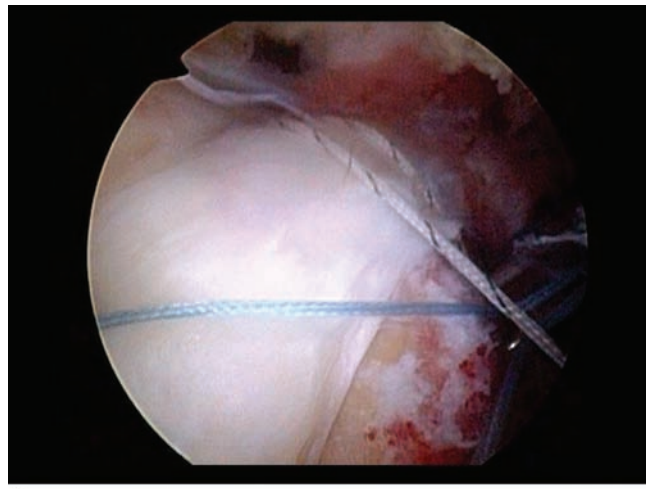

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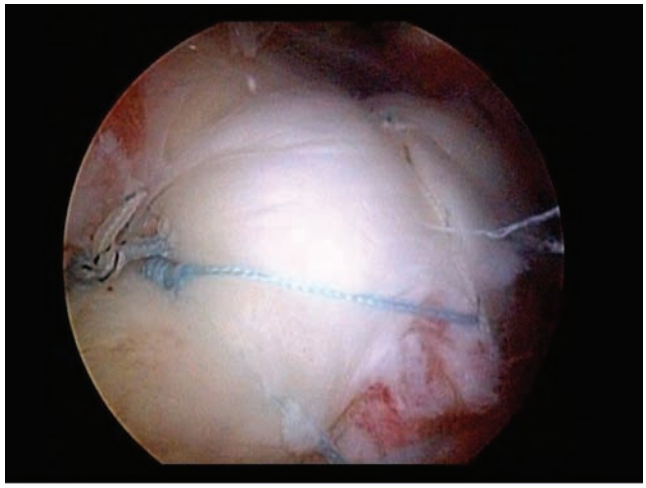

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FIGURE 13.8

Massive right rotator cuff double-row suture-bridge repair with three medial and two lateral anchors. **A:** The lateral row anchors are placed through the lateral portals while viewing from the posterior portal. **B:** Arthroscopic view of anterolateral anchor placement. The posterolateral anchor has not yet been placed. **C:** Final repair construct depicting the anterior (*white*) and middle (*blue*) anchor sutures. The posterior (*blue*) anchor sutures are not visualized. The knot with both a white and blue suture, and excess limbs cut, is composed of two static mulberry knot sutures, one from the anterior anchor (*blue*) and one from the posterior anchor (*white*). The visible blue suture with limbs incorporated into the lateral row anchors and suture-bridge construct is from the middle, third anchor that was placed in a simple horizontal mattress (the white suture from this anchor was removed).

Beginning on the second day after surgery, the sling is removed three times per day for 15 to 20 minutes for gentle elbow, forearm, and wrist range of motion with the arm kept at the side. Patients are instructed not to lift the arm actively away from the body. Pendulum exercises are also begun on the second day after surgery.

Sutures are removed 7 to 10 days following surgery. Physical therapy is started after the first postoperative visit with a home program that enlists family members. An exercise program is initiated three times per day consisting of elbow, hand, wrist range of motion, pendulum exercises, passive external rotation of the shoulder to tolerance, and passive scapular plane elevation as tolerated. Internal rotation stretches are prohibited. At 3 to 4 weeks after surgery, active scapular mobility exercises are started with the therapist's supervision to ensure that the shoulder musculature remains relaxed. All shoulder active and active assisted exercises are avoided.

Phase 2 (Weeks 7–12): Progressive Range of Motion

The sling is discontinued after week 6 and a lifting restriction of 5 lb is reinforced. Active-assisted and active range of motion is begun. This includes pulleys, wand, and supine gravity-assisted exercises. Active range of motion is still avoided in positions of impingement. At 10 to 12 weeks after surgery, all motion is allowed, including internal rotation behind the back. The scapular stabilizers are isolated and strengthened. Passive range of motion and terminal capsular stretching of the shoulder is progressed gradually.

Phase 3 (≥12 weeks)

Formal lifting restrictions are discontinued. Rotator cuff and shoulder strengthening is begun. A home program for rotator cuff and scapular stabilizer strengthening is provided. The goal is to equalize active and passive range of motion and gradually progress into regular work and recreational activities as rotator cuff strength and endurance improves.

COMPLICATIONS

Complications of arthroscopic rotator cuff repair can be classified into several main categories—infection, incorrect diagnosis, technical errors, stiffness, and anesthesia-related problems. Infection after shoulder arthroscopy occurs in about 0.1% of cases. Infections may present in a delayed fashion. Portals that continue to drain should significantly raise the suspicion for infection. In suspected infections, aspiration should be performed prior to antibiotic treatment. Cultures often grow *Propionibacterium acnes*, *Staphylococcus aureus*, and coagulase-negative *S. aureus. Proprionibacterium acnes* is the most common pathogen accounting for postoperative shoulder infections. This pathogen takes 7 to 10 days to grow, and therefore, cultures should be kept and checked for at least 1 week. Treatment consists of irrigation and débridement and intravenous antibiotics for 6 weeks. Several surgical débridements may be necessary along with hardware removal and the use of a drain between débridements. Serial serum c-reactive protein levels can be useful in evaluating the efficacy of treatment. In our experience, we have had reasonable luck with patients healing their repair after the treatment of an infected arthroscopic repair. Therefore, adequate pain control and functional outcomes may be obtained after proper and timely treatment of an infected arthroscopic repair.

Correct preoperative diagnosis is fundamental to good outcomes after arthroscopic rotator cuff repair. Continued pain may be due to a missed concomitant problem such as those related to the cervical spine, suprascapular neuropathy, isolated compression of the branch of the axillary nerve to teres minor, biceps tendinopathy, labral pathology, instability, arthritis, and frozen shoulder. The early phase of frozen shoulder is commonly mistaken for rotator cuff-derived pathology by clinical examination. Pain-free active external rotation at the side indicates the cuff is not likely involved; therefore, frozen shoulder is a more likely diagnosis. Resisted thumb-down abduction in the scapular plain can also be tested within the limits of painless passive arc of motion in these patients.

There are many possible complications related to technical errors such as inadequate portal placement, improper suture tying, faulty anchor placements, and suture shuttling. Excessive pump pressures for prolonged periods of time may cause fluid extravasation into the soft tissues that may hinder or prohibit completion of the case arthroscopically. In severe cases, excessive fluid extravasation can cause neurologic symptoms and airway compromise. We routinely use a pump pressure of 35 mm Hg and may increase it as needed to a maximum of 60 mm Hg for short time periods. We request that the blood pressure be lowered as much as possible within safe measures as determined by the anesthesiologist. The procedure should not take much in excess of 2 hours. During patient positioning, care should be taken to pad all bony prominences and to release all traction devices as soon as possible. We routinely use the beach chair position with compression stockings and sequential compression devices to bilateral lower extremities to avoid the development of a deep venous thrombus. Kidney posts should be used to avoid unrecognized patient leaning, which could cause cervical spine and brachial plexus injuries. The lap belt should also be placed snuggly but not excessively tight as to injure the lateral femoral cutaneous nerve or limit lower extremity blood circulation. Excessive hip flexion for a prolonged time may also injure the lateral femoral cutaneous nerve and care should be taken to avoid such positions.

Postoperative stiffness is less common after an arthroscopic rotator cuff repair compared to open and mini-open techniques. However, we routinely check for stiffness on postoperative office visits and adjust our postoperative physical therapy routine accordingly. In rare cases, if stiffness persists after healing is complete and physical therapy and conservative management have failed to increase motion, we will consider arthroscopic subacromial lysis of adhesions and capsular release.

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14 Multidirectional Instability

Clifford G. Rios and Robert A. Arciero

INTRODUCTION

A discussion about the diagnosis and management of multidirectional instability (MDI) requires a review of the distinction between glenohumeral joint laxity and instability. Laxity is asymptomatic, passive translation of the humeral head as determined on clinical examination. Instability is a pathologic condition whereby pain or discomfort is attributable to excessive translation of the humeral head during active motion. These terms are not synonymous, as a patient may have laxity in more than one direction without any symptoms or experience symptoms (i.e., instability) only in one direction.

The concept of MDI was first described in 1980 by Neer and Foster (1). In this classic report, a cohort of patients with either failed surgery for instability or uncertainty in diagnosis was identified. All patients had pathologic inferior glenohumeral joint laxity combined with anterior or posterior instability, or both. These patients were treated successfully with an open inferior capsular shift, which eliminated capsular redundancy by selective capsular release and imbrication. Since this original report, there have been multiple permutations of the definition of MDI. Open and arthroscopic techniques have emerged that are designed to eliminate pathologic laxity of the glenohumeral joint without sacrificing motion. This chapter reviews our approach to the clinical evaluation and treatment of patients with MDI. To make the diagnosis of MDI, the patient must have symptomatic, involuntary subluxation, or dislocation in more than one direction.

CLINICAL EVALUATION

The diagnosis and management of MDI is challenging. Part of the difficulty in diagnosing patients with MDI comes from the inconsistent definitions in the literature (2,3). Instability can be defined as subluxation or dislocation and voluntary or involuntary. Matsen popularized the acronyms TUBS (traumatic, unilateral, Bankart, surgery) and AMBRII (atraumatic, multidirectional, bilateral, rehabilitation, inferior capsular shift interval closure) to divide instability patterns into two groups (4). This segregation represents two ends of a spectrum of pathology, but it is evident that patients may experience characteristics of both of these patterns of instability. For example, a patient with multidirectional laxity may experience a traumatic anterior dislocation with a Bankart lesion.

The classification of MDI has also divided patients into groups based on whether they have voluntary or involuntary instability. It is essential to ascertain whether the patient can subluxate or dislocate his or her shoulder voluntarily. Voluntary dislocators may have a psychiatric disorder or secondary gain at the root of their instability. Habitual dislocators have instability episodes attributable to muscular imbalance. These patients often do poorly with surgical intervention. Positional dislocators are aware of activities or arm positions that will reproduce their symptoms, but will avoid these positions because the feeling is uncomfortable or painful. Involuntary subluxators are not able to reproduce their symptoms and may represent the best indication for surgical intervention if nonoperative treatment fails.

The diagnosis of MDI relies heavily upon a precise patient history and clinical examination. MDI patients are often athletic and may participate in sports that involve strenuous shoulder activity, such as swimming, gymnastics, weightlifting, or overhead sports. These patients may be aware of instability as a cause of their symptoms, or they may complain of pain or mechanical symptoms (grinding, popping, clicking) with activities. These symptoms are often experienced in the midrange positions of glenohumeral motion, such as those that occur with activities of daily living. We have seen patients who have pain anteriorly over the coracoid with secondary impingement, scapular dyskinesia, and pectoralis minor contracture, so-called SICK Scapula syndrome (5). The condition is bilateral in approximately 20% of cases, but symptoms in both shoulders may

not occur simultaneously. Thus, it is important to inquire about a history of similar symptoms in either shoulder in the past. The position of the shoulder at the time of symptom onset provides clues as to the pattern of instability that is present. Pain that occurs with the arm in a forward flexed, adducted, and internally rotated position (such as during push-ups, bench pressing, etc.) suggests posterior instability. Competitive athletes may not report pain with these maneuvers, but we have observed some patients who describe the affected arm lagging behind the well arm with bench pressing. Pain with the arm overhead is usually indicative of anterior pathology. Patients with inferior instability may notice pain or paresthesias when carrying heavy objects with the arm at the side, as the unstable shoulder allows downward traction on the brachial plexus.

The physical examination of the shoulder begins with a general cervical spine evaluation. Proper examination of the shoulder requires that the entire shoulder and periscapular muscles be exposed. We start our examination of the shoulder from the back, inspecting for any evidence of atrophy or asymmetry in scapular position and motion. Many patients will exhibit pseudowinging of the scapula or will have malpositioning of the scapula with a protracted appearance when viewed from posterior as they go through a full arc of motion. Active and passive ranges of motion are evaluated. Anterior and posterior load-shift tests determine laxity in their respective directions. They are graded as 1+, to glenoid rim; 2+, over glenoid rim with spontaneous reduction; 3+, glenohumeral dislocation requiring manipulation to reduce. To perform this test, the arm is abducted to 90 degrees and a gentle axial load is applied to center the humeral head within the glenoid. The scapula is stabilized and anterior and posterior translation is assessed. Anterior laxity becomes more apparent if and when the examiner attempts to translate the humeral head in an anterior-inferior direction. Provocative tests such as the apprehension-relocation tests also assess anterior instability. Posterior laxity is also evaluated by positioning the arm in forward flexion, adduction, and internal rotation and applying a force directed posteriorly. It is important to flex the arm enough so that the humeral head does not impinge against the spine of the scapula because this can mask posterior translation. Inferior instability is determined by the sulcus sign. With the arm at the patient's side, downward traction is applied to the arm. In the presence of inferior capsular laxity, a dimple will form in the region between the humeral head and the lateral acromion. In a normal shoulder, this dimple disappears with maximal external rotation of the arm. A pathologic sulcus sign is one that does not diminish with humeral external rotation and signifies an incompetent rotator interval. The literature has shown a wide range of normal variants of shoulder laxity. It is not uncommon to be able to subluxate a shoulder over the glenoid rim, particularly with the examination under anesthesia. Thus, it is crucial that these clinical examination findings correlate with the patients' symptoms. Lastly, the examiner should look for other signs of generalized ligamentous laxity. These include passive elbow hyperextension, thumb to forearm apposition, metacarpophalangeal joint extension beyond 90 degrees, and the ability to flex from the standing position and place the palms on the floor.

Plain radiographs should be inspected for evidence of bony defects in the glenoid or humeral head. In many instances for the patient with MDI, these studies are normal. If there is any suspicion for bone loss from the history, physical examination, or plain radiographs, then a CT scan will define the anatomy of these lesions best. Our current indications for CT scanning include a history of dislocation requiring reduction, recurrent dislocation, apprehension at low abduction angles, recurrent dislocation following minimal provocation (e.g., washing hair), and instability at low abduction angles (e.g., reaching in front of body). Magnetic resonance imaging with intra-articular gadolinium in a patient with MDI will show a capacious inferior capsular pouch. An abduction external rotation MRI will show laxity of the inferior glenohumeral ligament. Injuries to the glenoid labrum are less common in MDI than in cases of unidirectional instability.

TREATMENT OPTIONS

Nonoperative

Treatment of MDI may utilize nonoperative, open surgical, or arthroscopic techniques. First-line treatment involves physical therapy rehabilitation and patient education always. It is important for patients to understand that deconditioning of a shoulder with laxity can lead to instability, and focused rehabilitation can help return their lax shoulder to an asymptomatic, functional state. Anti-inflammatory medications can diminish symptoms. The goal of rehabilitation is to restore dynamic stability to the glenohumeral joint through improved function of the rotator cuff musculature. To achieve an adequate contraction of the rotator cuff musculature, the scapula must be stabilized on the thorax. Once a stable base has been established, exercise to the rotator musculature can be initiated (5–7). Initial treatment consists of improving scapular motion and control through combinations of movements to facilitate scapular retraction. These movements include trunk extension and rotation and used in conjunction with other kinetic chain exercises (5). Provided the patient is able to maintain a retracted position of the scapula strengthening of the rotator cuff muscles is initiated. A closed- to open-chain approach is taken to improve strength of function of the scapular and rotator cuff muscles. Closed-chain exercises are favored early in the rehab process as they reduce joint sheer and encourage coordinated muscle activation patterns followed by open-chain exercises to maximize muscle strength, endurance, and function (7,8). As strength and control improve, proprioceptive and functional sport-specific training are incorporated in preparation for return to sport or work activity. Many patients with MDI (65%–90% in current studies) will improve following an appropriate trial of conservative modalities, but improvement may take up to 3 months (9–11).

Operative

Patients who have persistent pain and disability after a minimum of 3 to 6 months of appropriate nonoperative management are considered for surgery. A capsular shift procedure is considered the surgical treatment of choice in MDI, and this intervention can either be arthroscopic, open, or a combination of the two. The goals of surgery are to repair any labral tears, tighten the capsule/ligaments, and possibly close the rotator interval. The decision to perform open or arthroscopic stabilization is surgeon dependent and will vary depending on certain patient characteristics. If open surgery is chosen, the approach may either be from anterior or posterior. Neer and Foster first popularized the open inferior capsular shift. In this technique, the shoulder is approached through the deltopectoral interval (1). The capsule is identified after tenotomy of the subscapularis tendon. Next, a laterally based T-shaped capsulotomy is performed and the inferior leaflet is shifted cephalad, tightening the inferior pouch. This shift has been shown in cadaver models to reduce glenohumeral joint volume by as much as 66% (12).

The anterior approach has the advantages of surgeon familiarity as well as preservation of the infraspinatus. Moreover, the anterior capsule is more robust than the posterior capsule and this allows for a more secure repair. The primary disadvantage of this approach is that it requires violation of the subscapularis muscle. Ultimately, the surgical approach is dictated by the presence and location of a labral tear. A posterior labral tear requires a posterior approach. An alternative technique is to address the posterior labrum arthroscopically and perform the open capsular shift from the front.

Current arthroscopic techniques have been shown to reduce capsular volume as well as open techniques (13–15). Arthroscopy allows an unparalleled evaluation of the intra-articular pathology, preserves critical muscle attachments, and requires smaller incisions as compared to open stabilization.

Thermal capsulorrhaphy was used extensively for this problem and was used to augment other techniques (16). Although there are reports of surgeons obtaining good results with this technique, others identify the risks of capsular ablation, inconsistent capsular tightening, chondrolysis, and the potential risk of nerve injury as reasons to avoid this technique (17). In addition, patients who have had previous thermal capsulorrhaphy can have capsular tissue that is more friable and preclude a secure arthroscopic repair.

AUTHORS' PREFERRED TREATMENT

The authors' preferred technique for the patient with MDI who fails nonoperative treatment is arthroscopic capsulorrhaphy. An interscalene block is administered in the preoperative holding area. After administration of a general anesthetic in the operating room, the patient is placed in the lateral decubitus position with a vacuum bean bag. An examination under anesthesia is performed to reinforce the clinical findings identified on preoperative examination and imaging. The arm is then prepared and draped in a usual sterile fashion. The operative extremity is placed in a traction sleeve in 70 degrees of abduction and 10 to 20 degrees of forward flexion with 10 to 12 lb of traction. A sterile bump is placed to in the axilla to facilitate exposure. It is important to avoid an extended position of the arm as this is associated with a higher risk of neurologic injury. A posterior portal is created and a diagnostic arthroscopy is performed. For arthroscopic stabilization cases, this portal is created 2 cm inferior to the posterolateral corner of the acromion, as this will provide a better angle of approach to the posterior and inferior labrum.

Anterosuperior (ASP) and anteroinferior (AIP) portals are established within the rotator interval by an outside-in technique (Fig. 14.1). A spinal needle is inserted high within the rotator interval and once its position is confirmed a pointed switching stick is inserted immediately adjacent to this needle. We then "park" this

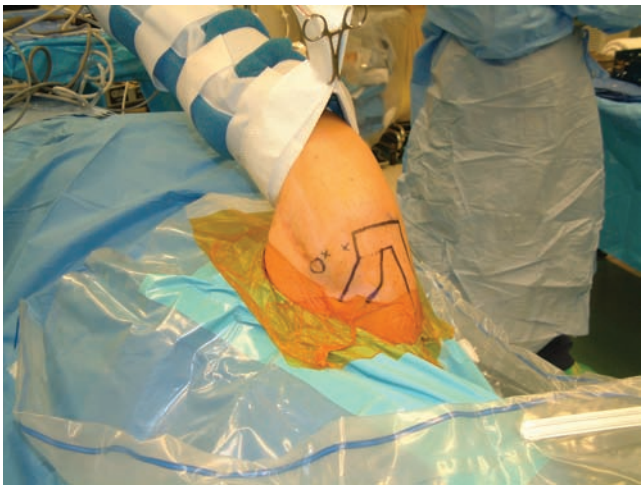


FIGURE 14.1

Lateral decubitus positioning for arthroscopic stabilization of a right shoulder. The "X's" mark the estimated positions of the ASP and AIP portals within the rotator interval.

switching rod superior to the biceps. The AIP is created just superior to the rolled edge of the subscapularis tendon and cannulated with an 8-mm cannula. The arthroscope is brought to the ASP, placed over the switching rod. A cannula is then inserted in the posterior portal. The majority of the surgery is performed viewing with the arthroscope in the anterior-superior portal. There is no "essential lesion" that produces MDI, although redundancy of the axillary pouch is present always (Fig. 14.2). This produces the so-called arthroscopic drive-through sign whereby the arthroscope is maneuvered easily between the humeral head and the glenoid at the level of the anterior band of the inferior glenohumeral ligament.

A shaver or rasp is brought through the posterior cannula to lightly debride the labrum and synovium to create a healing bed of tissue. Initially, two mattress sutures of 2 Orthocord (Depuy, Mitek) are passed postero-inferiorly. To achieve this, a 45-degree suture hook (Spectrum Suture Hook, Linvatex, Inc, Largo, Florida) is inserted through the posterior portal and pierces the capsule at the 6 o'clock position, taking 1 to 1.5 cm of capsule (Fig. 14.3) and then penetrating through the labrum (Fig. 14.4). Posteriorly, it is common to use a curve-to-the-left device for right shoulders and a curve-to-the-right for right shoulders. A 0-PDS is advanced and retrieved through the AIP (Fig. 14.5A and B). One limb of the 2 Orthocord is shuttled from the AIP and back out the posterior portal (Fig. 14.6). These steps are repeated a second time, placating a portion of the capsule more anteriorly and using the PDS shuttling the second limb of the Orthocord posteriorly (Fig. 14.7A and B). The limbs of Orthocord are now tied from the posterior portal to create a horizontal mattress suture with the knot away from the articular surface (Fig. 14.8A and B). A second posterior-inferior capsular plication is made at about the 5 o'clock or 4:30 position (left shoulder). For this plication, the curved suture hook can be used in either the AIP or the posterior portal, depending on which is easier. This effectively eliminates the posterior-inferior pouch. Knots may be tied after each plication or they may be tied after passing multiple plication sutures. If the latter is chosen, some authors recommend using a Suture Saver (Linvatex, Inc, Largo, Florida) to assist with suture management.

Next, attention is turned to the anterior-inferior capsule. Anteriorly, we use a curve-to-the-left device for left shoulders and curve-to-the-right for right shoulders. Again, the capsule is excoriated with the shaver and an angled left Spectrum (left shoulder) is used to pass a 0-PDS as a shuttle and then this maneuver is repeated for

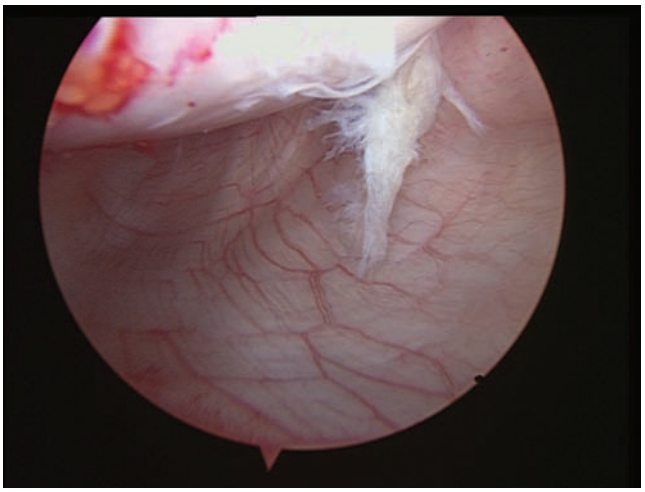


FIGURE 14.2
Inferior capsular redundancy is a hallmark of MDI.

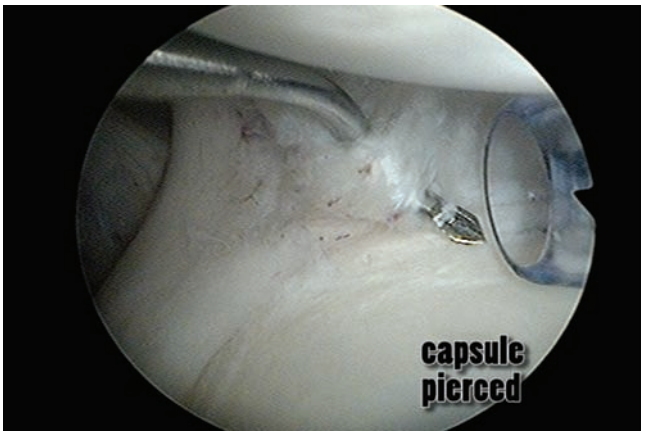


FIGURE 14.3
Spectrum suture hook penetrates capsule.

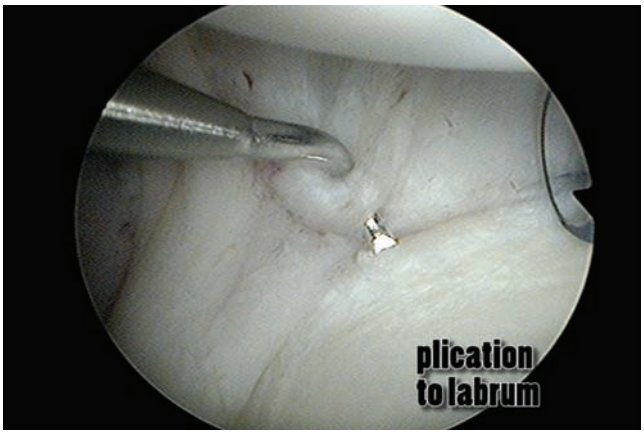
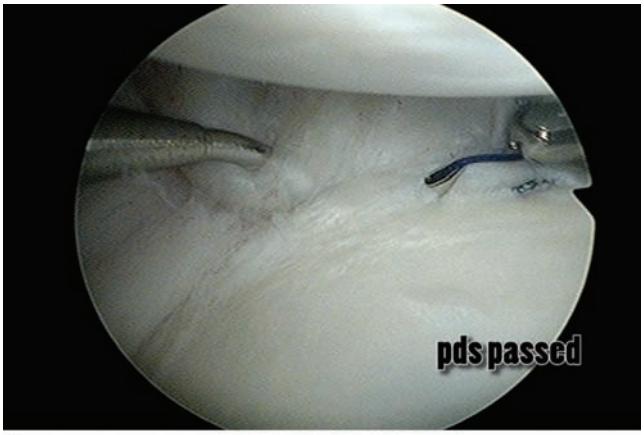
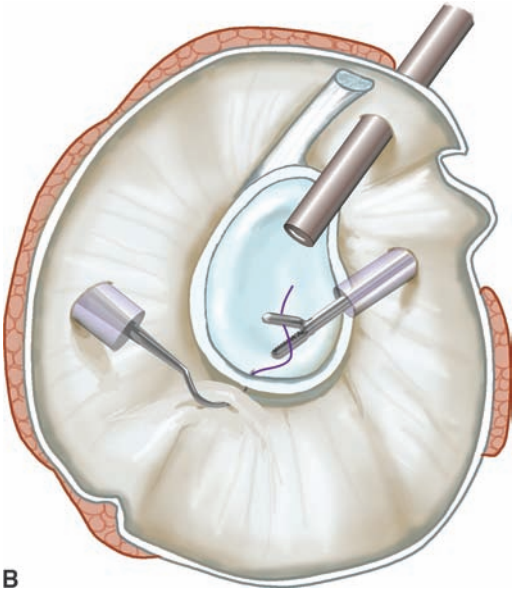


FIGURE 14.4

Suture hook is then passed through glenolabral junction to plicate with capsule. This eliminates capsular redundancy.



A



B

FIGURE 14.5

View from ASP looking at posterior cannula **(A)** and illustration **(B)** show PDS suture being passed from posterior cannula to plicate posterior-inferior capsule. This will be used to shuttle nonabsorbable suture.

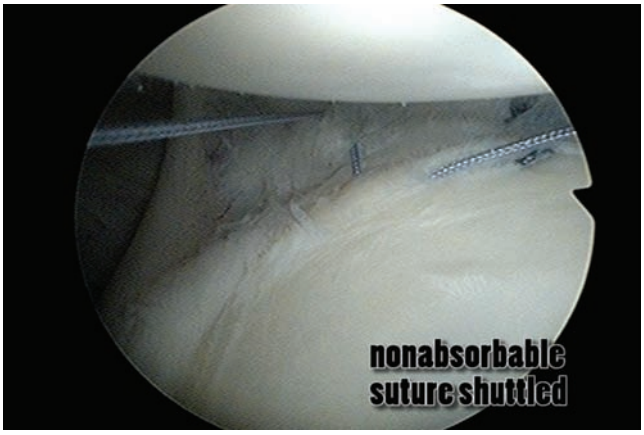
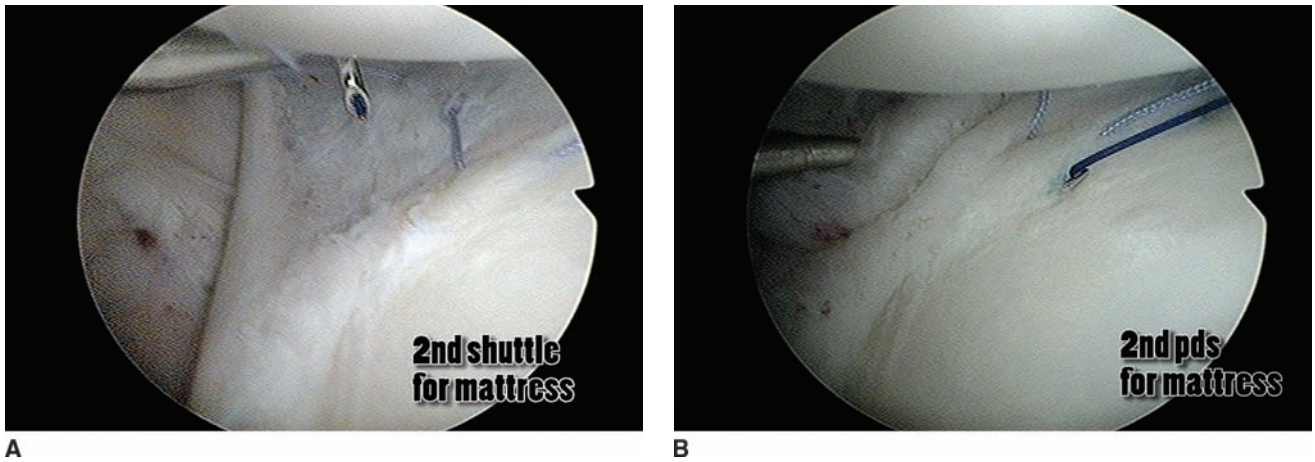


FIGURE 14.6

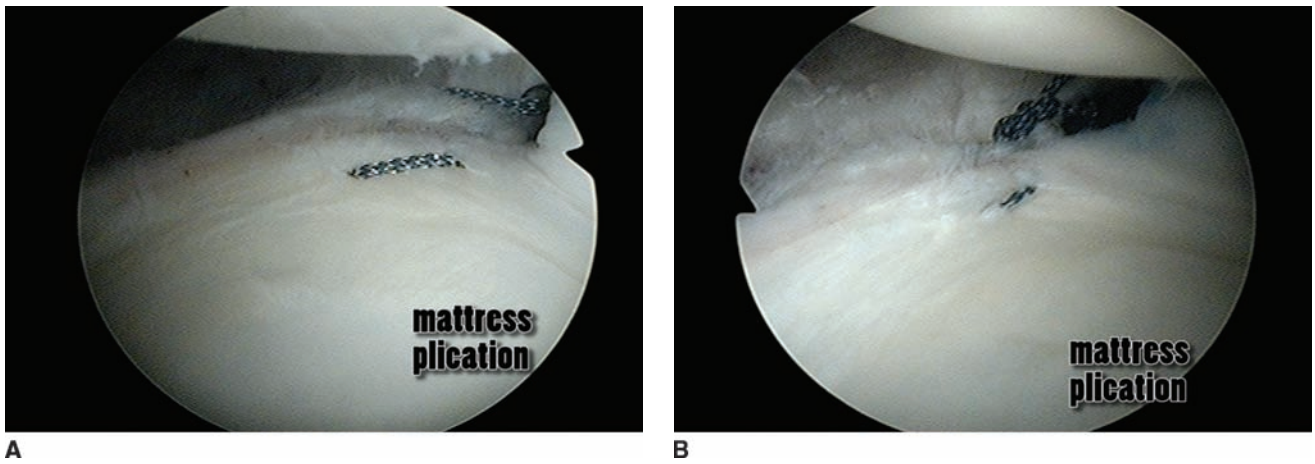
Nonabsorbable suture has been shuttled to create first limb of a horizontal mattress suture.



A B

FIGURE 14.7

The suture hook is passed a second time through the inferior capsule **(A)** and labrum **(B).**



A B

FIGURE 14.8

A: The second limb of nonabsorbable suture is shuttled and retrieved from the posterior portal. **B:** The mattress suture is tied, reducing capsular redundancy. The knot is away from the articular surface.

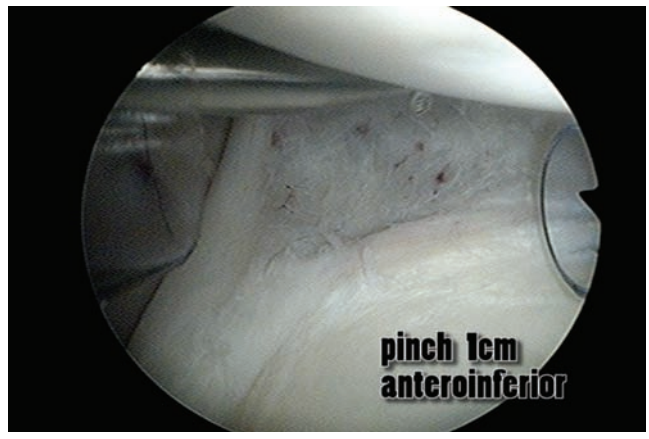


FIGURE 14.9

The plication steps are continued along the AIP glenoid. The suture hook (curve to the right for right shoulder) is inserted from the AIP portal.

a mattress configuration at about the 6:30 position (Figs. 14.9 and 14.10). Subsequent knot tying rebolsters the labrum and allows capsular plication. The maneuver is repeated two additional times coming more cephalad to almost the 9 to 10 o'clock position (Fig. 14.11). The humeral head should be centered on the glenoid after accomplishing this part of the procedure.

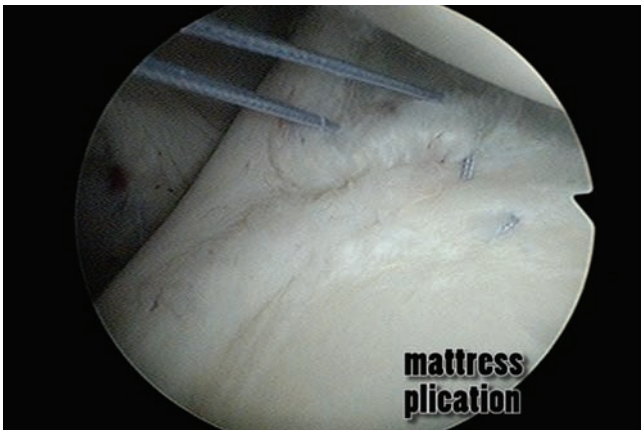


FIGURE 14.10

Another mattress suture is prepared and tied from the AIP portal. Typically, we will place a total of two to three plication sutures posteriorly and three to four sutures anteriorly.

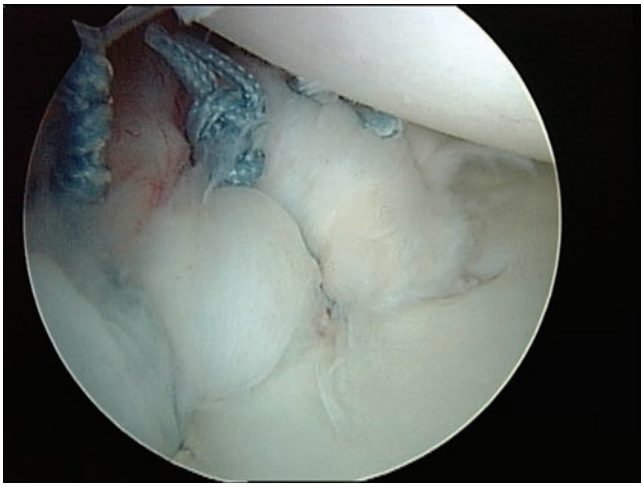
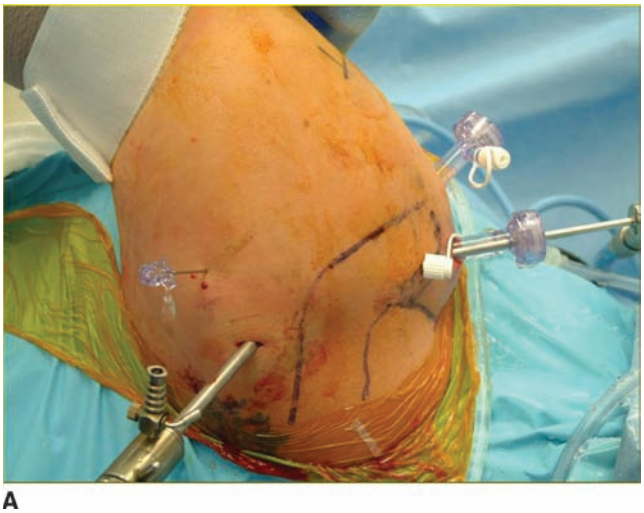
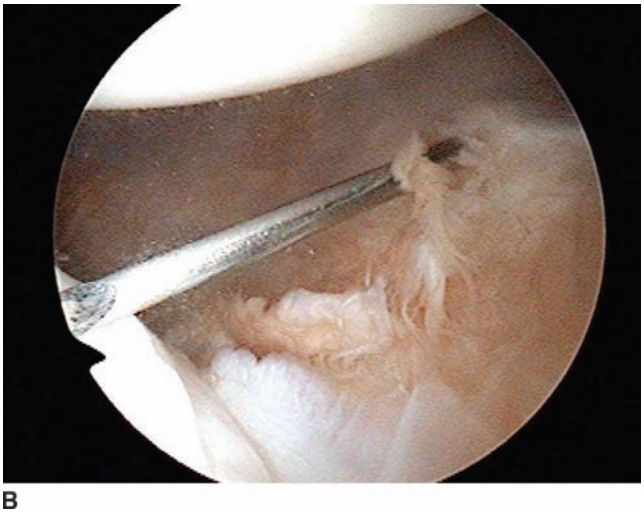


FIGURE 14.11

Sequential plication of the anterior capsule and labrum produces a robust anterior bumper.



A



B

FIGURE 14.12

A: Percutaneous technique allows precise anchor placement for posterior and inferior glenoid. **B:** A spinal needle localizes the exact trajectory of for anchor placement.

Our decision on whether or not to use suture anchors depends on the apparent quality of the labrum and its attachment to the glenoid. If the labrum is robust and has a secure attachment, we favor plication of the capsule to the labrum without suture anchors. We will use suture anchors if the labral tissue is deficient, detached, or degenerative with splitting. Anchor placement frequently requires the use of percutaneous portals. Posteriorly, an 18-gauge spinal needle is used to identify the appropriate trajectory of this portal (Fig. 14.12A and B). Our

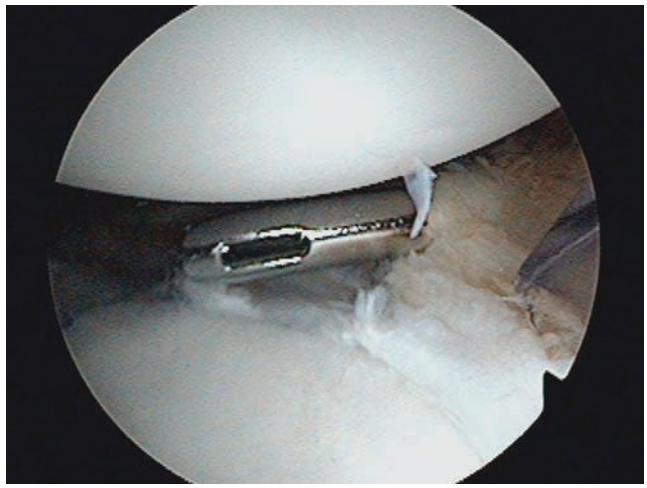


FIGURE 14.13

The drill guide for the 3-mm BioSutureTak (Arthrex, Inc., Naples, Florida) is inserted percutaneously after localization with a spinal needle. It is possible to place two anchors through a well-positioned portal.

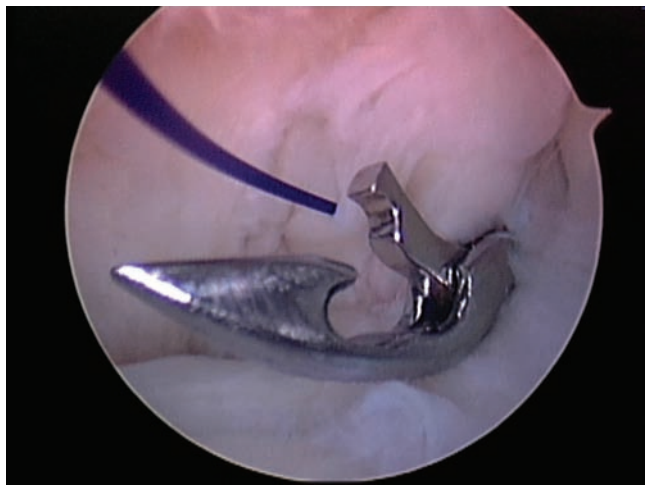


FIGURE 14.14

Rotator interval closure is performed by advancing an absorbable suture through the ASP. Next, the cannula in the AIP is backed out just superficial to the capsule in the rotator interval, and a penetrator is inserted through this cannula to retrieve the suture. The knot is tied extra-articularly, closing the rotator interval.

goal is to position this portal such that it allows an appropriate angle of insertion for more than one anchor (3-mm BioSutureTak, Arthrex, Inc., Naples, Florida) if needed (Fig. 14.13). Anteriorly, a percutaneous portal (5 o'clock portal) may be created from an outside-in technique, through the subscapularis tendon. The space available to view and work within the shoulder will diminish as the capsulorrhaphy continues. If suture anchors are used anteriorly, it is helpful to perform a pinch-tuck with the 0-PDS suture prior to anchor insertion. This creates a less obstructed view of the plication. Once the PDS is retrieved from the posterior portal, a suture anchor (3-mm BioSutureTak, Arthrex, Inc., Naples, Florida) is inserted through a percutaneous "5 o'clock" portal. A limb of suture from this anchor can then be retrieved from the posterior portal and shuttled retrograde with the PDS out the AIP.

The arthroscope is then returned to the posterior viewing portal and a 0-PDS suture is used to grasp the middle glenohumeral ligament from the AIP. The cannula is backed out of the capsule and a BirdBeak (Arthrex, Inc., Naples, Florida) penetrator is used, coming just anterior to the supraspinatus tendon edge to grasp the PDS (Fig. 14.14). A knot is tied outside the capsule to close the rotator interval. Figure 14.15 illustrates the finished repair. All weights are removed and the portals are closed in a standard fashion.

COMPLICATIONS

Risks of primary arthroscopic stabilization for MDI are generally rare. Loss of motion is infrequent in these patients. Arthroscopic stabilization for MDI yields similar recurrence rates as open stabilization (2%–12% in current reports) with less morbidity (18,19). Arthroscopic surgery minimizes the potential for subscapularis insufficiency that can occur after open anterior techniques. Infection is extremely rare with appropriate antibiotic prophylaxis. Neurologic injury has been reported to occur in up to 30% of shoulder arthroscopies and these injuries are more common with lateral decubitus positioning. Although the vast majority of these injuries are neuropraxias that resolve over time, a number of steps should be taken to minimize direct or indirect neurologic trauma. These include careful attention to positioning and padding with neutral position of the cervical spine, use of an axillary roll, a pad under the proximal and distal fibula, avoiding excess traction, and edema control.

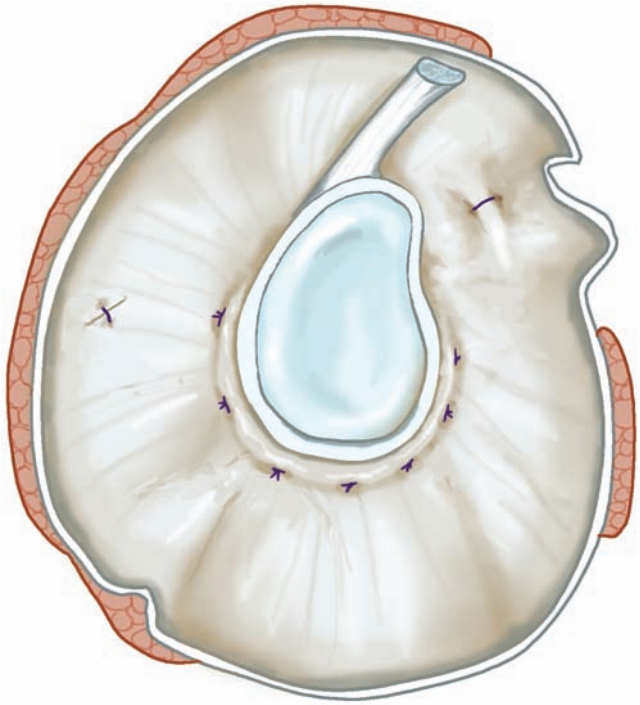


FIGURE 14.15

Illustration demonstrates finished repair. Generally, two to three plication sutures are placed posterior to the 6 o'clock position (right shoulder) and three to four are placed anterior to this position. The rotator interval is closed in a medial to lateral direction and the posterior portal has been closed as well.

When performing an inferior capsular plication, there is concern about iatrogenic injury to the axillary nerve as it traverses the quadrangular space inferior to the glenoid. Cadaveric studies have shown the nerve to pass between 2.5 and 3.2 mm from the inferior glenohumeral capsule, and this distance is smallest at the 6 o'clock position (20,21). Of the branches of the axillary nerve, the motor branch to the teres minor and the sensory branch to the lateral arm are closest to the inferior capsule. The authors are not aware of any reports documenting iatrogenic axillary nerve directly attributable to suture passing instruments. Nonetheless, care must be taken when penetrating the inferior capsule with curved suture hooks.

REHABILITATION

We immobilize our MDI patients in a sling with an abduction pillow for 4 to 6 weeks postoperatively. Active hand, wrist, and elbow motion is permitted immediately. Patients with MDI tend to have more generalized ligamentous laxity than patients with unidirectional instability and postoperative stiffness is less of a problem. Pendulum shoulder range of motion is initiated at 3 weeks. A formal range of motion program is initiated at 4 weeks. Sport-specific exercises are initiated at 3 to 4 months postoperative. Patients can return to noncontact sports at 6 months. Collision and contact athletics is permitted after 6 to 9 months provided the patient has full range of motion and full strength.

PEARLS AND PITFALLS

A precise diagnosis of MDI is critical when developing a treatment plan. Inaccurate diagnosis of inferior instability with subsequent inferior capsular shift with or without rotator interval closure can lead to significant loss of motion and poor clinical outcomes. The diagnosis of MDI must be made clinically and *confirmed* with examination under anesthesia and with arthroscopy. The greatest pitfalls in the management of MDI occur either from "stabilizing" something that is not pathologic, or failing to diagnose and treat all components of the pathology. For example, a large sulcus sign is not an independent indicator of inferior instability. The sulcus sign should only be considered pathologic if it does not diminish when the arm is externally rotated or if downward displacement of the arm reproduces the patient's symptoms. Either of these findings represents an indication for rotator interval closure. Recent studies have demonstrated that rotator interval closure does not affect posterior laxity (22,23). Routine rotator interval closure can diminish external rotation of the adducted arm without improving posterior stability.

It is also possible to overtighten the anterior shoulder and insufficiently address the inferior pouch, which produces a shoulder with restricted external rotation and persistent inferior instability. The senior author (RAA) refers to this as the "Erlenmeyer flask phenomenon" where the humeral head translates inferiorly into the axillary pouch with range of motion. This can be avoided by starting the plication posteroinferiorly and then working systematically from AIP and to the anterior aspect of the glenoid and rotator interval.

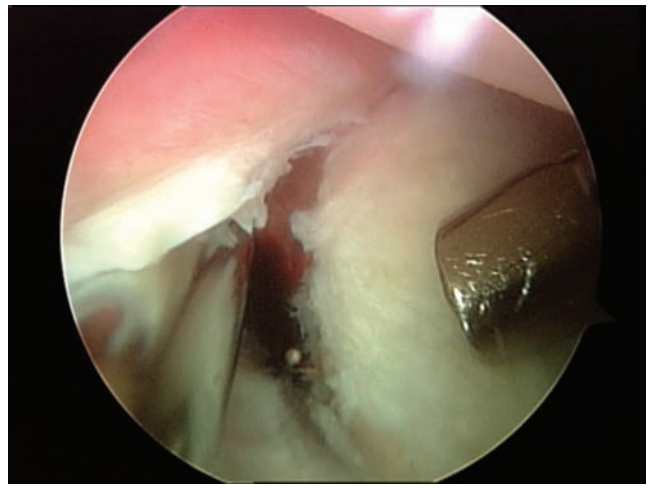


FIGURE 14.16

Anterior labrum of right shoulder viewed from ASP. The probe is directed toward the muscle fibers of the subscapularis. This indicates that the labrum has been elevated and mobilized from the glenoid sufficiently.

Although the majority of patients with MDI will report an insidious onset of symptoms, some will sustain a traumatic anterior-inferior dislocation with a resultant Bankart lesion. The evaluation of patients with traumatic anterior dislocations requires the same clinical history and physical examination to establish whether the patient has underlying MDI. In this scenario, the posterior capsular plication is performed as described above. It is critical to mobilize the anterior labrum sufficiently prior to performing a capsulorrhaphy. The indication that the anterior-inferior labrum has been mobilized sufficiently is that subscapularis muscle fibers are visualized in the window created between the labrum and the glenoid (Fig. 14.16). Special attention should be given to addressing the capsular redundancy as well as the labral repair in these instances.

CONCLUSIONS

It has been nearly 30 years since Neer and Foster's original description of MDI, and there has been a multitude of biomechanical and clinical studies that have contributed to our understanding of glenohumeral joint anatomy and the etiology of glenohumeral instability. MDI patients are generally young and present with an insidious onset of symptoms, although trauma of variable severity is occasionally reported. To diagnose MDI, the patient must have symptoms attributable to glenohumeral laxity in more than one direction. Nonoperative treatment is initiated for all patients who present with signs and symptoms of MDI. If this fails, capsulorrhaphy for MDI requires symmetric tightening of the capsule so that the humeral head is concentrically reduced on the glenoid, yet normal range of motion is still permissible. Arthroscopic equipment continues to evolve and this will facilitate capsular plication techniques. Multiple options are available to the surgeon performing arthroscopic shoulder stabilization. These include the type of suture (absorbable or nonabsorbable), the use of suture anchors, and the technique/instruments used to perform capsulorrhaphy. We are not aware of clinical outcomes in the literature that demonstrate superiority of one technique over another for MDI. Unfortunately, there are still no discrete guidelines to predict the amount of tightening that occurs following a particular degree of capsular shift. This may be defined through future biomechanical studies.

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15 Subscapularis Repair

Florian Elser and Peter J. Millett

INTRODUCTION

Historically, the incidences of subscapularis tendon tears have been underreported, despite its importance as a major muscle of the rotator cuff and its important role in shoulder function and stability. Codman found a 3.5% involvement of the subscapularis tendon in 200 rotator cuff tears (1). More recent studies found a higher incidence of 5.8% (8/139 patients) for isolated subscapularis tears and 29.4% to 33.8% (47/139) overall involvement of the subscapularis in rotator cuff tears (2,3). The reason for the higher incidence may be that many of these tears started as partial thickness articular sided tears that were easily missed clinically and with traditional open surgical approaches.

Anatomy

The subscapularis muscle originates from the medial two thirds of the anterior scapula. It courses laterally underneath the coracoid process and inserts onto the lesser tuberosity. The muscle becomes tendinous at the level of the joint line. It is innervated by the upper and lower subscapular nerves.

The subscapularis has the largest muscle tendon unit of all rotator cuff tendons (4) and the largest footprint (5). There are several papers published in the literature on the anatomy of how the subscapularis tendon inserts on the humerus. The footprint has been described as ear shaped (6) or comma shaped (4,7). Its superior insertion is wide in the uppermost margin of the lesser tuberosity, while the superior two thirds have a tendinous insertion (8). The inferior portion inserts into the anteromedial bony anatomy of the lesser tuberosity. In this area, the tendon is shortened and the muscle almost inserts directly onto the humerus (8).

The superior glenohumeral ligament has been described as inserting proximal to the subscapularis insertion on the lesser tuberosity. More recent arthroscopic (9,10) and histologic studies (11) have shown that the humeral insertions of the subscapularis, superior glenohumeral ligament, and coracohumeral ligament appear to be attached through interdigitating fibers.

Function

The subscapularis is an internal rotator and stabilizer to the glenohumeral joint.

Subscapularis injuries can cause considerable changes in shoulder mechanics (12,13). Untreated subscapularis tears may lead to pain, loss of function, weakness (14,15), and anterior instability (12,13,16,17). Many studies have been published on subscapularis function. Burkhart et al. (18) showed that the subscapularis and its moment balance the transverse force couple, which is important to provide a stable fulcrum for glenohumeral motion. Neviaser et al. (19) highlighted the role of subscapularis tears in shoulders with recurrent instability after traumatic dislocations.

Therefore, it is important to surgically address repairable subscapularis tears.

Etiology

The mechanism of subscapularis tendon injury has been reported to be mainly traumatic in nature. Traumatic injury usually occurs with the arm with hyperextension or external rotation of the abducted arm (20).

This is in contrast to the history of microtrauma and early nonspecific onset of symptoms that are frequently seen with degenerative rotator cuff tears involving the supraspinatus or infraspinatus tendons.

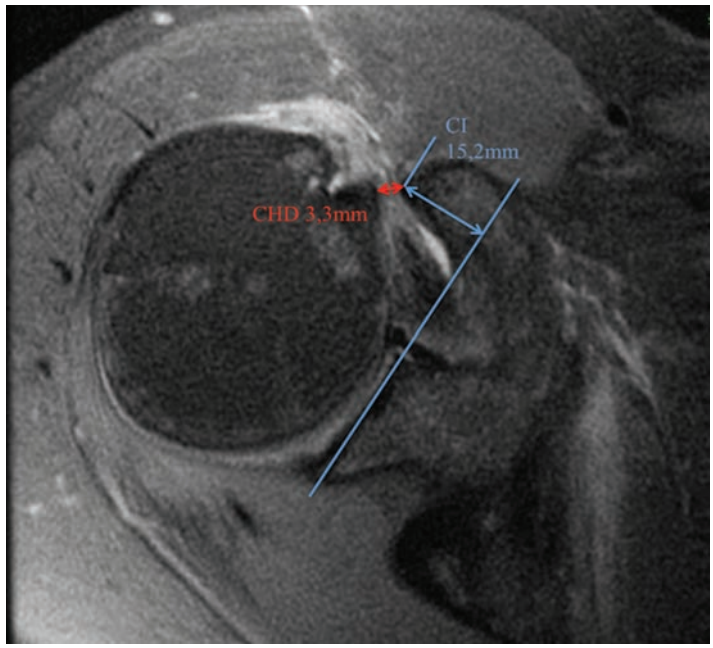

FIGURE 15.1
Measurement of CHD (*red arrow*) and CI (*blue lines* and *arrow*).

It has been suggested that a narrowed coracohumeral interval (21) and conditions that allow the biceps tendon to subluxate anteriorly (9,22) may be a cause for subscapularis tendon tears.

The coracohumeral interval is the distance between the tip of the coracoid and the nearest cortex of the lesser tuberosity (Fig. 15.1). There is no evidence in the literature how humeral head rotation influences these distances.

Richards et al. (21) found a significant relationship between a narrowed coracohumeral distance (CHD) and subscapularis pathology (10 ± 1.3 mm vs. 5 ± 1.7 mm).

A study recently by Millett et al. presented at arthroscopy association of north america (AANA) showed significant correlations between subcoracoid space narrowing and rotator cuff tears, including supraspinatus (p = 0.008) in 94 patients. Complete rotator cuff tears had smaller CHDs (9.6 mm) compared to partial tears (11.2 mm) and no tears (12.3 mm).

DIAGNOSIS

History

Subscapularis pathology diagnosis can often be difficult. However subscapularis tears, especially traumatic tears, can be evident from the history alone. Sudden onset of symptoms (weakness, pain) after a hyperextension or external rotation trauma of the abducted arm indicates subscapularis pathology. Traumatic glenohumeral dislocations in individuals older than 40 years of age also have a strong association with rotator cuff tears, especially subscapularis tendon tears. Further recurrent anterior instability can be caused by rupture of the subscapularis and anterior capsule. Patients with prior open surgical history, where the subscapularis has been taken down, are also at higher risk for subscapularis pathology.

Patients with intrinsic degeneration of the tendon and degenerative tears typically present with limited shoulder function due to pain and weakness. Recurrent anterior shoulder dislocations can also be associated with subscapularis tears (19).

Clinical Examination

Patients with full thickness subscapularis tears may present with an increased external rotation on the affected side and no defined end-point on external rotation.

Clinical tests for detecting tears or dysfunction of the subscapularis are the lift-off test (20) and the belly-press test (23), both described by Gerber and coworkers. The Napoleon test described by Schwamborn and Imhoff (24), the belly-off sign described by Scheibel and Habermeyer (25), and the Bear-Hug test described by Barth et al. (2) are also useful.

Clinical examination should include more than one test to optimize the chance of detecting subscapularis tears. The authors prefer to perform both the belly-press and the lift-off test because they are reliable clinical tests. Performing a lift-off test, the patient's hand of the affected side is placed on the back. The test is

considered positive, if the patient is unable to lift the arm posteriorly off the back. For the belly-press test, the arm is positioned at the side with the elbow flexed at 90 degrees. The patient is asked to press the palm onto the abdomen by internally rotating the shoulder. The test is considered positive if the patient shows a weakness in comparison to the opposite shoulder or if the force is not achieved by active internal rotation but elbow or shoulder extension.

Positive bear-hug and belly-press tests suggest that the tear size is at least 30%, a positive Napoleon test suggests that the size is at least 50%, and a positive lift-off test suggests that the tear size is at least 75% of the subscapularis (2).

Imaging

As a first step, plain radiographs in three planes are recommended to rule out bony alterations, degenerative changes, or calcification of the rotator cuff tendons. Patients with isolated subscapularis tears usually have a normal bony radiographic anatomy, but an anterior subluxation might be present in the axillary view. In rare instances, coracoid abnormalities such as subchondral sclerosis or a positive coracoid index (CI) might be present. The CI (26) is measured on axial cross section images (CT, magnetic resonance imaging [MRI]). It describes the lateral projection of the tip of the coracoid beyond a tangential line to the articular surface of the glenoid (Fig. 15.1). The average index in 67 nonsymptomatic shoulders was 8.2 mm (26).

The gold standard for imaging of soft tissue pathologies of the shoulder girdle is MRI. Studies have proven a high sensitivity and specificity of MRI in detecting the presence or absence of full-thickness rotator cuff tears, ranging from 84% to 100% and 93% to 99%, respectively (27–35). Newer studies have shown that high-quality MRI scans are even able to predict tear patterns (36), which enables the surgeon to better plan the procedure.

In every MRI, the muscle quality should be evaluated. Flury et al. (37) found that advanced fatty degeneration stages 3 and 4 (Goutallier Grading System of Fatty Degeneration of Muscle, 38) are associated with a significant increase in rerupture rate after subscapularis repair.

In a postoperative setting, the diagnosis and imaging of subscapularis retears are more difficult. Especially the differential diagnosis to subscapularis dysfunction due to denervation or nerve injuries can be challenging. When in doubt, additional neurologic examinations have to be performed before revision surgery.

TREATMENT

Surgical Indications

Early operative management with primary tendon repair has been shown to yield reproducible results (23), whereas chronic tears lead to muscle atrophy and retraction of the tendons. Ticker and Warner (39) found that tears repaired more than 1 year after the injury have frequent repair failures because of severe muscle degeneration. Other studies also showed that a delay from the time of injury to the time of operative repair may cause decreased quality of results (23,37). An increased rerupture rate was noticed in patients who were treated more than 1 year after tendon rupture (37).

Therefore, in subscapularis tears, early operative management is recommended. Especially in chronic cases, the muscle quality has to be evaluated before surgical treatment. As mentioned before, Flury et al. (37) found that advanced fatty degeneration stages 3 and 4 (Goutallier Grading System of Fatty Degeneration of Muscle, 38) are associated with a significant increase in rerupture rate after subscapularis repair. Subscapularis repair is therefore debatable in stage 2 and not recommended in stage 3 and 4 fatty degeneration of the muscle.

Contraindications for direct reinsertion of the subscapularis tendon are patients with

1. fatty degeneration stages 3 and 4
2. tendon injuries that are more than 1 year old

In these patients, alternative procedures such as pectoralis major muscle transfer may be used to augment or substitute for the subscapularis. Originally, a transfer of the whole muscle was described. Warner et al. modified the original pectoralis tendon transfer by rerouting its sternal head underneath the clavicular head before fixation to the lesser tuberosity (40).

Transfer of the pectoralis muscle is an effective method for patients with irreparable subscapularis tears. The results are reasonable, but not great (15,40–42). The transfer is especially problematic with a high failure rate in patients with irreparable ruptures of subscapularis after shoulder replacement, particularly if there is preoperative anterior subluxation of the humeral head (42).

Surgical Treatment Options

Both open and arthroscopic techniques are described in the literature for direct subscapularis reinsertion. An all-arthroscopic subscapularis tendon repair is a technically challenging procedure, but the results are equal or even better than after open repair (43–47).

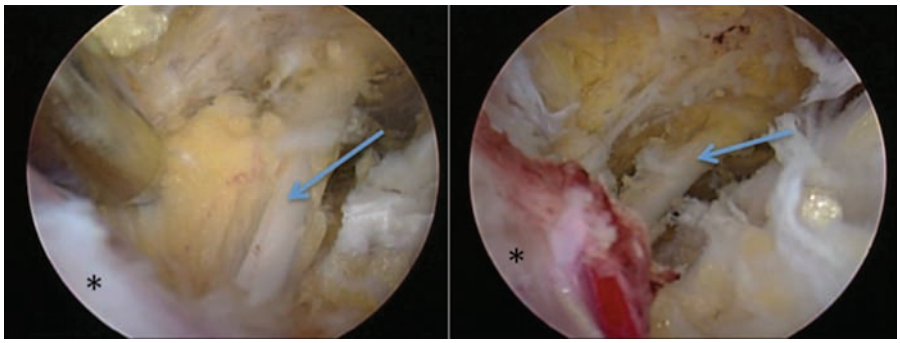

FIGURE 15.2

Neuroanatomy, left side blunt dissection of the axillary nerve (*blue arrow*) at the inferior border of the subscapularis (*asterisk*); right side subscapularis muscle (*asterisk*) and axillary nerve (*blue arrow*).

Arthroscopic Subscapularis Repair Advancements in arthroscopic surgery have not only improved repair techniques, but also enabled surgeons to understand more about intra-articular shoulder pathology.

But identifying the subscapularis tendon stump can be difficult. Therefore, particular attention has to be paid to the subscapularis insertion in order not to miss the so-called hidden lesions (9,46,48). In order to get a good arthroscopic view on the subscapularis insertion, one should put the arm in forward flexion and internal rotation.

In chronic isolated and combined complete tears, the subscapularis footprint at the lesser tuberosity will appear bare. In these cases, the tendon will usually be retracted medially and scarred against the deltoid fascia and coracoid. Identifying the subscapularis tendon stump can be challenging. The comma sign, an arc formed by a portion of the superior glenohumeral ligament/coracohumeral ligament complex, which is attached to the superolateral corner of the subscapularis tendon, can be helpful (46).

Arthroscopic subscapularis repair can be challenging. The subacromial space is tightly constricted, which makes visualization and manipulation of arthroscopic instruments more difficult.

Chronic subscapularis tears, as stated above, have a tendency to retract more and tend to scar against the coracoid process, close to important neurovascular structures. Therefore, it is very important to know exactly the arthroscopic anatomy around the coracoid (Fig. 15.2), which will avoid injuries of the axillary nerve and artery, the musculocutaneous nerve, and the lateral cord of the brachial plexus. Anatomic cadaveric dissections revealed a minimum distance of these structures of 24 mm from the anteromedial aspect of the coracoid (49). The axillary nerve was closest to the anteromedial aspect of the coracoid with a mean distance of 29.3 mm (49).

ARTHROSCOPIC TECHNIQUE

The procedure can be performed both under general and interscalene block anesthesia. Bilateral examination under anesthesia is recommended to get a feel for what is normal for the patient. Patients with complete subscapularis tears often have significantly increased external rotation.

The authors prefer to use the beach-chair position, which frees up the medial border of the scapula so that there is room to pass instruments and position the arm at the necessary angles. In order to position the arm appropriately during different parts of the surgery, the use of a mechanical arm holder is recommended, such as the Spider limb positioner (Tenet Medical Engineering; Calgary, Canada) or the McConnell arm holder (McConnell Orthopaedic Manufacturing Company; Greenville, Texas). The arm holder allows the surgeon to apply traction to the arm, which opens the subacromial space or coracohumeral interval and thus improves visualization.

Alternatively, the patient might also be positioned in a lateral decubitus position. However, in the authors' opinion, this does not allow dynamic joint inspection and arm movement as readily as the beach chair with an arm holder.

The basic instruments used for arthroscopic subscapularis reconstruction include a 30-degree arthroscope, a motorized shaver, a radiofrequency tissue ablation device, and various perforation instruments and graspers. A 70-degree arthroscope can be additionally helpful.

In order to decrease bleeding, epinephrine can be used in the saline. For better fluid management, an arthroscopic pump is recommended, as this allows the surgeon to control the pressure as needed. It is helpful to keep the pump pressure as low as possible; therefore, start shoulder cases with a pump pressure of 40 mm Hg.

Portals

Diagnostic arthroscopy is performed via a standard posterior portal (Fig. 15.3). Once subscapularis pathology is recognized, an anterior and anterosuperolateral portal is established (Fig. 15.3). Proper portal placement is essential. First the anterosuperolateral portal is established: an 18-gauge spinal needle is inserted into the

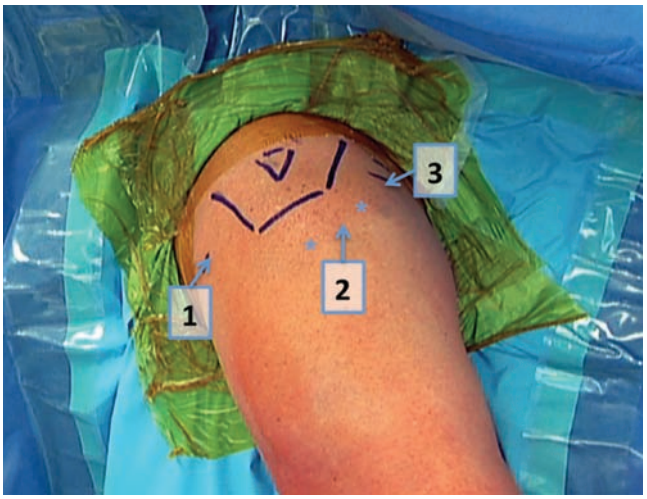

FIGURE 15.3
Right shoulder, posterior viewing portal (*1*), anterolateral (*2*), and anterior (*3*) working portals. Accessory antero- and anterolateral portals may be needed for large tears (*asterisk*).

glenohumeral joint off the anterolateral tip of the acromion at an angle that allows appropriate preparation of the lesser tuberosity. This portal also allows relative parallel access to the subscapularis tendon for mobilization of adhesions or suture passage. It is helpful to place a cannula in this portal; the authors use a 5.0-mm threaded clear cannula (Arthrex, Naples, Florida).

The anterior portal is primarily used for anchor placement and suture management. It is placed lateral to the coracoid tip and approaches the lesser tuberosity in an angle of approximately 45 degrees (Fig. 15.3). For proper placement of the portal, an 18-gauge needle is inserted into the glenohumeral joint before a cannula is introduced.

Long Head Biceps Tendon and Pulley Lesions

A tear of the upper subscapularis is usually associated with medial subluxation of the long head biceps tendon, since the footprint of the medial sling of the bicipital sheath is directly adjacent to the footprint of the upper subscapularis. The biceps tendon has to be carefully examined and addressed with tenodesis or tenotomy if there is a pulley lesion present; otherwise, force of the persistently subluxated biceps will stress the subscapularis repair and cause it to fail. Biceps tenotomy, also in preparation for tenodesis, should be performed before repairing the subscapularis, since visualization will be much easier. The authors' preference is to perform a subpectoral tenodesis at the end of the procedure, which reliably relieves pain and improves function (50).

Coracoid Process and Coracohumeral Interval

Both in partial tears and full-thickness tears with retraction, we recommend identifying the coracoid tip: in partial tears, it allows to assess the coracohumeral interval and possibly perform a possible coracoidplasty. In retracted full-thickness tears, it allows a safe lysis of the retracted tendon.

The coracoid tip can be found both from an intra-articular approach and from extra-articular through the subacromial space. The authors prefer the intra-articular approach for isolated subscapularis tears. A window is made into the rotator interval just above the superior border of the subscapularis, preserving the medial sling of the biceps sheath and the superior glenohumeral ligament (Fig. 15.4). In complete tears, the diagonal fibers from the coracoacromial ligament can be followed to the coracoid tip. The ligament originates from the anterolateral aspect of the acromion and heads in an inferomedial direction toward the coracoid tip.

In exposing the coracoid, one must preserve the attachments of the conjoined tendons. The preparation is performed through the anterior portal with electrocautery, arthroscopic elevators, or a motorized shaver (Fig. 15.4). If the viewing portal is from posterior, visualization can be easier with a 70-degree arthroscope. Careful blunt preparation medial to the coracoid with a trocar is strongly recommended until the neurovascular structures are identified.

Subscapularis Mobilization

In the case of a retracted subscapularis tendon, an anterior, superior, and posterior release has to be performed to mobilize the tendon. A suture at the superior border of the subscapularis tendon is placed to provide traction during the release. The release should be performed in a systematic fashion, starting anterior at the previously identified coracoid tip dissecting medially to the level of the coracoid base and neck. Next, release superior adhesions above the superior border of the subscapularis. Dissection should not be performed medially to the base of the coracoid to protect neurovascular structures.

Finally, adhesions between the subscapularis and glenoid neck are released.

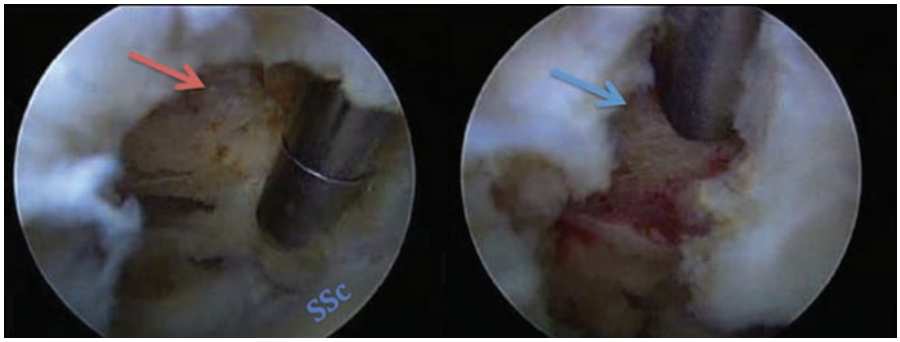

FIGURE 15.4

Preparation of the coracoid tip (*red arrow*) by opening up the rotator interval on the superior border of the subscapularis tendon (SSc). Coracoid plasty via anterior portal (*blue arrow*).

Arthroscopic Repair

The arthroscopic repair of the subscapularis can be performed intra-articularly or extra-articularly from the subacromial space. We use the intra-articular approach for small upper one third tears that are completely visible from within the joint. The lower border of the tendon is covered by the inferior glenohumeral ligament (IGHL), and this makes it more difficult to repair larger tears using this approach (51). For larger more retracted tears, it is easier to work from an anterosuperior portal and visualize the subscapularis fossa directly. The axillary nerve can be safely visualized and protected from this approach. Before the repair, the bone bed on the lesser tuberosity is prepared using an arthroscopic shaver or burr. It is important that the bone bed is prepared down to a bleeding base without decorticating the bone. If mobilization of the tendon is not possible, to obtain good coverage of the footprint on the lesser tuberosity, medialization of the footprint is possible up to 5 mm.

In partial tears up to 50% of the subscapularis, we recommend the use of one or two doubly loaded suture anchors. In complete tears, the inferior anchor is placed first and the sutures are passed and tied before the superior anchor is placed. Double-row fixation is performed by the authors for larger, complete tears if there is enough lateral excursion of the tendon.

Intra-articular Repair

The anchors are placed through the anterior portal at an appropriate angle to the lesser tuberosity (Fig. 15.5). Afterward, one suture strand is pulled out of the anterosuperolateral portal. There are several techniques to shuttle the sutures using different kinds of perforation instruments. The authors preferred technique is to perforate the tensioned subscapularis tendon (using a traction suture or rotator cuff grasper) with a percutaneously introduced 18-gauge spinal needle, which is armed with a 1 PDS suture (Fig. 15.6). The intra-articular strand of the PDS suture is pulled out of the anterosuperolateral portal and used to shuttle the previously pulled out

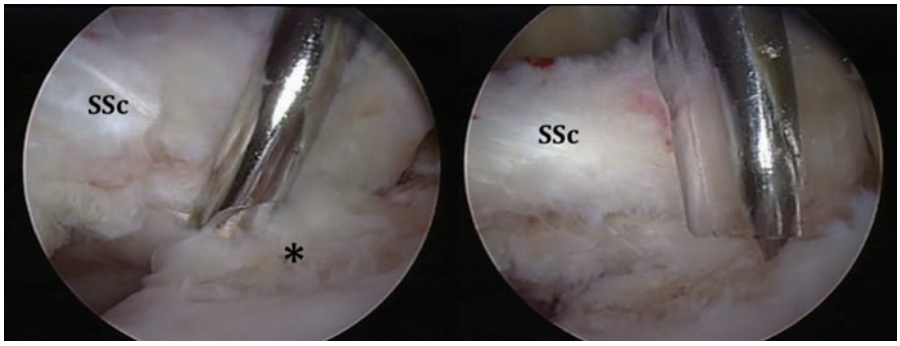

FIGURE 15.5

Preparation of the bone bed on the lesser tuberosity (*asterisk*) by use of an arthroscopic shaver (*left side*). Anchor placement in an appropriate angle to the lesser tuberosity (*right side*). SSc, subscapularis tendon.

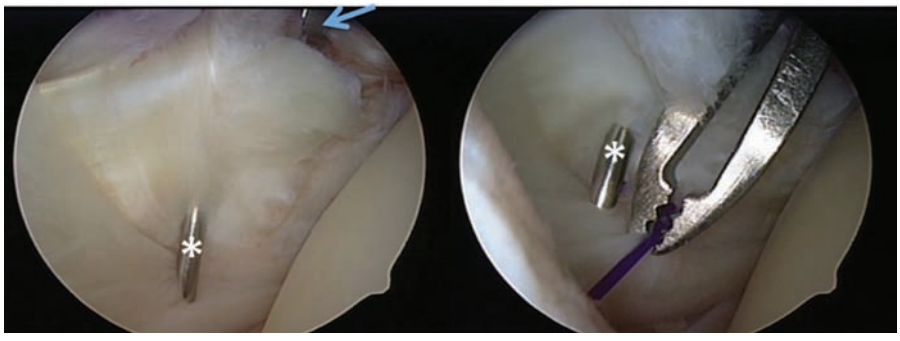

FIGURE 15.6

Perforation of the subscapularis tendon with an 18-gauge needle (*asterisk*) while tensioning the subscapularis tendon with a rotator cuff grasper (*blue arrow*). Introducing a PDS shuttle suture (*right side*).

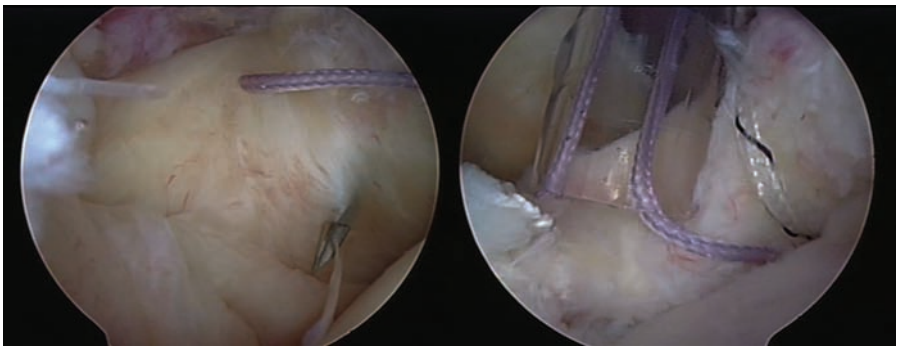

FIGURE 15.7
Shuttling of both sutures of the doubly loaded suture anchor.

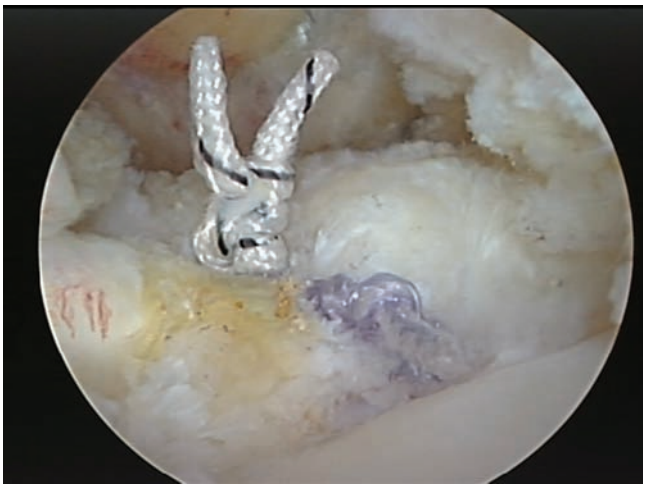

FIGURE 15.8
Finished repair.

suture strand of the anchor with a simple eyelet. This technique is repeated with the other suture strand of the anchor (Fig. 15.7).

Afterward the sutures are tied, typically through the anterosuperolateral portal and the repair is completed (Fig. 15.8).

Extra-articular Repair

In combined anterosuperior rotator cuff tears, the authors recommend an extra-articular approach (Fig. 15.9). The repair technique and portals are basically the same, but the repair is performed from the subacromial and anterior subdeltoid space. We typically use three anterior and anterolateral portals to obtain appropriate visualization and to allow the repair to be performed. Additional portals for supraspinatus repairs can be placed as needed. We prefer to address the subscapularis tear first, if more than one tendon is torn.

Results

Buess et al. (45) compared their results of a series of 96 patients treated with an arthroscopic versus open subscapularis repair. They found that even at the beginning of the learning curve arthroscopic cuff repair yielded equal or better results than open repair.

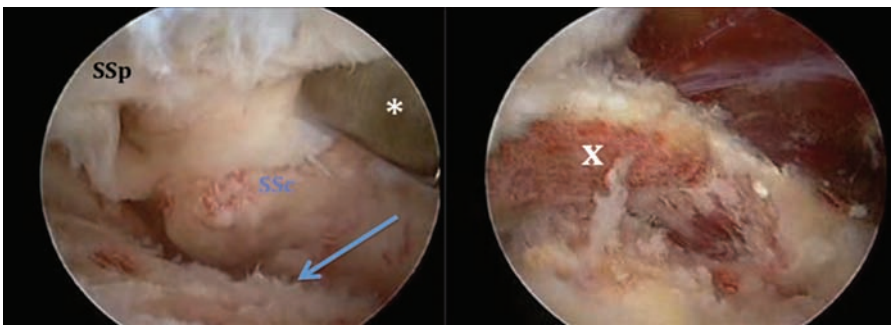

FIGURE 15.9
Left side: extra-articular view on torn supraspinatus (SSp) and SSc retracted by grasper (*asterisk*). Subscapularis footprint (*blue arrow*) on lesser tuberosity. Right side: extra-articular view on coracoid plasty.

A prospective study on arthroscopic isolated subscapularis repair on 17 patients published by Lafosse et al. (44) found an improvement of the average relative Constant score from 58% to 96% at a mean follow-up of 27 months. Twelve patients were very satisfied, four satisfied, one not satisfied.

In a study by Adams et al. (43), the authors evaluated 40 patients with arthroscopic subscapularis repairs and a mean follow-up of 5 years. There were significant improvements in all outcome scores. Eighteen patients had excellent, fourteen good, six fair, and two poor results.

OPEN SUBSCAPULARIS REPAIR

An open approach is favored for larger or more chronic tears and for tears with significant scarring. It can be used for all subscapularis tears as the deltopectoral approach adds very little morbidity. The procedure is performed with the patient in the beach chair position. The subscapularis tendon is exposed via a standard deltopectoral approach. The rotator interval is opened. In complete, retracted tears, the axillary nerve has to be identified before mobilization of the tendon. The motor branches to the subscapularis should be preserved as these enter laterally into the muscle. Mobilization of the tendon around the coracoid should be performed carefully in order to avoid neurovascular damage to these branches and to some of the larger nerves such as the axillary and musculocutaneous nerves. A traction suture is placed in the superior aspect of the tendon and the mobility of the tendon is tested (Fig. 15.10). If necessary, the tendon can be released until adequate mobility has been achieved. Before reinsertion of the subscapularis tendon, the biceps tendon and pulley system should be inspected to confirm that it is pristine. In the vast majority of cases, there will be changes in the long head of biceps (LHB) or pulley lesions, and in such instances, a tenodesis should be performed.

The insertion footprint on the lesser tuberosity is prepared. It is important that the subscapularis tendon is reinserted at its natural anatomic insertion with a wide contact area to restore the natural footprint. For large tears, the authors prefer to perform a double-row technique (Speed Bridge, Arthrex, Naples, Florida) to restore the surface area on the footprint. The medial row of the anchors is placed and the sutures (Fibertape) are passed through the tendon, medial enough to restore a good footprint. Afterward, the lateral row of anchors, which are preloaded with respectively one strand of the medial row anchors, is placed and the reconstruction is completed (Fig. 15.10).

Results

Gerber et al. (23) evaluated 16 patients with traumatic isolated subscapularis tendon tears treated with an open surgical technique. After a mean follow-up of 3.6 years, eight patients had excellent, five good, one fair, and two poor results.

Warner et al. (52) evaluated 19 patients with anterosuperior rotator cuff tears repaired with an open surgical technique. At a mean follow-up of 40 months, five had excellent, three good, four fair, and seven poor results. A significant correlation was found between a lower Constant score and duration of symptoms longer than 6 months as well as an appearance of severe fatty degeneration and atrophy of the subscapularis muscle on magnetic resonance imaging. Nine of the patients included in this study had unsuccessful prior surgery, which failed to recognize the extent of the subscapularis tear component.

Edwards et al. (53) evaluated their results of isolated open repair of the subscapularis tendon in 84 shoulders at a mean follow-up of 45 months. They found a mean Constant score improvement from 55 to 79.5 points and a high satisfaction rate.

Open repair is important to know in case an arthroscopic repair needs to be converted.

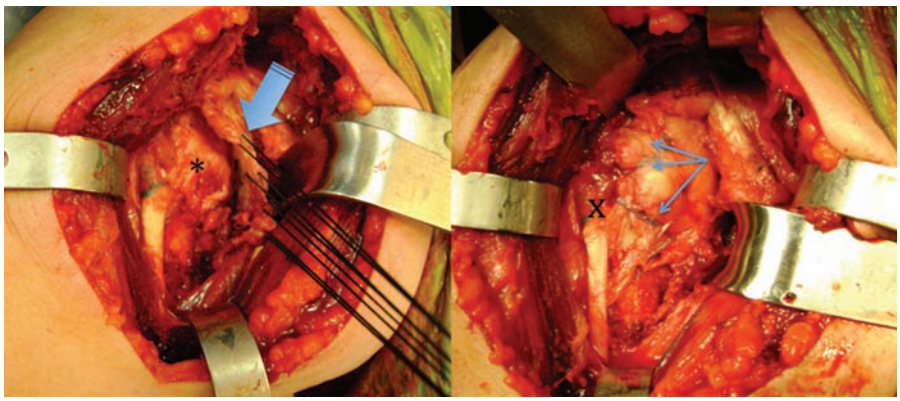

FIGURE 15.10

Right shoulder, left side subscapularis tendon augmented with traction sutures (*arrow*); lesser tuberosity (*asterisk*). Right side completed repair with sutures (*blue arrows*); tenodesis of the long head biceps tendon (*X*).

COMPLICATIONS

Complications after subscapularis tendon repair include

- Persistent weakness of the subscapularis
- Retear
- Neurovascular injuries, especially axillary nerve injury
- Stiffness and scarring
- Infection

Adams et al. (43) reported on a series of 40 patients with subscapularis repair treated arthroscopically with no surgical complications or revision surgeries.

In a comparative study published by Buess et al. (45), the overall reoperation rate was 7.6%. There was no statistical difference between open versus arthroscopic technique. There was 1 infection in this series after open treatment. Otherwise, complications that lead to revision surgery were arthrofibrosis and rerupture of the tendon.

REHABILITATION

The rehabilitation should progress in four phases (54):

- Phase 1 (0–6 weeks): passive range of motion (ROM) starting day 1 post op
- Phase 2 (7–12 weeks): active ROM
- Phase 3 (13–16 weeks): strengthening
- Phase 4 (17–22 weeks): strengthening, conditioning, and translation to full activity.

We recommend adjusting rehabilitation protocols to account for size of the tear, tissue, and bone quality age of patient, degree of tissue atrophy, concomitant procedures, and tendons involved.

Our standard protocol for isolated complete subscapularis tendon tears is as follows:

Phase 1: Abduction brace at 30 degrees for 6 weeks. The patient is allowed to come out of the device for passive ROM exercises. Exercises start with pendulums and low load passive mid-ROM exercises. External rotation is limited to 30 degrees for 6 weeks if the repair is solid and good quality tissue is present. Subscapularis rehabilitation programs can carefully address early scapular strengthening with side lying active ROM exercises in scapular retraction and protraction.

In partial tears or complete tears with good tissue quality and excellent repairs, the phase 1 protocol can be modified as follows:

Abduction brace at 30 degree for 6 weeks. The patient is allowed to come out of the device for passive ROM exercises. Exercises start with pendulums and low load passive mid-ROM exercises. External rotation is limited to 30 at 45 degrees of abduction for 4 weeks, and then slowly progress to full ROM. Early scapular strengthening can be started with side lying active ROM exercises in scapular retraction and protraction. Submaximal (light) internal rotation isometrics can begin at 4 weeks.

Phase 2: Exercises progress from active assisted ROM to full active ROM (from gravity assisted to gravity resisted). The patient is weaned from the sling and pain should be well controlled. End range stretching at progressively higher intensities and joint mobilization techniques may be initiated without limitations in ROM.

Phase 3: It is important to start with the initial strengthening phase only when sufficient glenohumeral and scapulothoracic kinematics have been demonstrated in phase 2. Only exercises that do not put the repair at risk of excessive loads should be performed. With the presence of joint or ROM limitations, continued passive and active assisted ROM exercises, stretching, and manual therapy are indicated.

Phase 4: When sufficient rotator cuff strength is demonstrated, patients may start with strengthening of larger prime mover muscles of the shoulder (pectoralis major, latissimus dorsi, deltoid muscles). Overhead activity is advanced as tolerated and more sport-specific type exercises may be initiated.

SUMMARY

The subscapularis is an important structure for shoulder function. Untreated subscapularis tears may lead to pain, loss of function, weakness, and anterior instability. The diagnosis of subscapularis pathology can be challenging, but tears should not be missed. In subscapularis tears, early operative management is recommended.

Outcomes after subscapularis repair are significantly worse in patients with advanced fatty degeneration. Therefore, the muscle quality has to be evaluated before surgical treatment.

Both open and arthroscopic techniques are described. Arthroscopic subscapularis repair is technically demanding but seems to be associated with a higher satisfaction rate.

An open approach is favored for larger or more chronic tears and for tears with significant scarring. It can be used for all subscapularis tears as the deltopectoral approach adds very little morbidity.

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PART THREE
KNEE

16 Medial Patellofemoral Ligament Reconstruction

Miho J. Tanaka and Andrew J. Cosgarea

Medial patellofemoral ligament (MPFL) reconstruction is indicated for patients with recurrent lateral patellar instability; the goal of this procedure is to restore the primary medial restraint of the patella. However, patellofemoral instability is a complex entity. Although the MPFL is disrupted in 94% of patients after acute patellar dislocations (15), there are a multitude of factors that can contribute to patellofemoral instability, including bony deficiencies, malalignment, ligamentous laxity, and muscle imbalance. Successful outcomes after MPFL reconstruction require the recognition of both the function and limitations of this procedure in the setting of those other factors. An understanding of patellofemoral kinematics combined with thorough preoperative assessment and planning will allow one to provide the appropriate treatment for patients with lateral patellofemoral instability.

INDICATIONS/CONTRAINDICATIONS

Patients with recurrent episodes of lateral patellar instability typically present in adolescence, often after an acute inciting event. They may describe symptoms of anterior knee pain that accompany the episodes of instability. As with most conditions, the first line of treatment for patellar instability is nonoperative interventions, including activity modification, brace protection, and physical therapy. A brace with a lateral buttress, along with oral analgesics and icing, can help minimize the initial symptoms. Physical therapy is useful in helping the patient regain strength and function. The goals of rehabilitation are to minimize the lateral forces on the patellofemoral

joint by strengthening the vastus medialis obliquus (the dynamic medial stabilizer of the patella) and by stretching the lateral extensor mechanism and retinaculum. Activity modification, which is generally not well accepted in a young, active patient, includes avoidance of activities involving planting and twisting motions.

In the event that nonoperative treatment fails, choosing the appropriate operative intervention by correctly understanding the source of the patient's symptoms is key in attaining successful outcomes. First, because MPFL reconstruction recreates the primary medial stabilizer of the patella, patellofemoral *pain* alone must be carefully differentiated from patellofemoral *instability* in the history and physical examination. MPFL reconstruction is reserved for lateral instability of the patella and should be regarded as a stabilization procedure. In contrast, symptoms of maltracking, arthrosis, and excessive lateral patellar pressure are better addressed by tuberosity osteotomy procedures that realign the extensor mechanism and unload the lateral patellofemoral cartilage.

Second, a thorough assessment of the factors contributing to the patient's patellofemoral instability must be considered before proceeding with MPFL reconstruction. Numerous factors can contribute to patellar instability, most of which involve a combination of hyperlaxity, malalignment, and bony abnormalities. Trochlear dysplasia and insufficiency of the medial retinaculum and MPFL can reduce the medial restraint of the patella and facilitate lateral instability. Such cases without concomitant malalignment can be treated with MPFL reconstruction. In contrast, instability secondary to substantial malalignment indicated by excessive lateralization of the tibial tuberosity (tibial tuberosity trochlear groove distance >15 mm), with or without patella alta, is better treated with tuberosity osteotomy procedures. MPFL reconstruction can be used to supplement these procedures in the event that adequate patellar stability is not attained after distal bony realignment.

Third, medial patellofemoral instability, although rare, should be distinguished from lateral instability because the former is a contraindication to MPFL reconstruction. Medial instability is usually an iatrogenic problem that occurs after an overly aggressive lateral retinacular release. MPFL reconstruction restores lateral patellar instability only and does not address medial instability. Other contraindications include active infection and inability to comply with postoperative instructions. Skeletal immaturity is not an absolute contraindication to MPFL reconstruction, but it necessitates an alternative procedure that avoids drilling a tunnel through the distal femoral physis (6).

PREOPERATIVE PLANNING

History

A thorough preoperative history and physical examination is required to evaluate each individual's causes of patellar instability. The obtained history should include the duration of symptoms and the number of episodes of instability. Patients may present after the first acute episode, describing it as a sense of giving way during a planting and twisting motion. Less commonly, direct trauma to the medial knee can also cause patellar instability. Patients may note an initial hemarthrosis and tenderness along the course of the MPFL. Those with recurrent instability after the initial trauma may have associated anterior knee pain or mechanical symptoms from chondral injuries and loose bodies. Any previous treatment or procedure for their symptoms should be noted. Instability after a previous lateral retinacular release may indicate medial patellar instability, which should be noted in the examination.

Physical Examination

Physical examination begins with the patient in a standing position as the clinician notes any abnormalities in alignment, including genu varum or valgum, increased femoral anteversion, and excessive pronation of the foot. The examination continues with the patient sitting on the edge of the examination table: observation of patellar tracking in active extension may reveal a positive J sign, made apparent by lateral translation of the patella as it exits the trochlear sulcus while the knee approaches full extension. With the patient in the supine position, the patient's Q angle is noted by measuring the angle between two lines: one from the anterior superior iliac spine to the center of the patella and one from the tibial tubercle to the center of the patella. The Q angle is usually difficult to measure and is typically greatest at 90 degrees of knee flexion. Angles of more than 15 degrees in males and 20 degrees in females suggest malalignment. Any hypoplasia of the vastus medialis obliquus or quadriceps should be noted. As always, a thorough ligamentous examination is obtained, with care taken to rule out concomitant injury. In particular, the knee should be assessed for injuries to the medial collateral and anterior cruciate ligaments because they may have a similar mechanism of injury.

Several tests are used specifically to assess patellar instability. With the knee in extension, the glide test is used to assess patellar mobility and medial structure laxity. This test is performed by manually displacing the patella laterally (Fig. 16.1). Excursion is measured in patellar quadrants, which are described as one quarter of the width of the patella. Normal lateral translation is quantified by comparing the test to the normal contralateral patella. In patients with bilateral patellar instability, it may be difficult to assess what degree of translation is pathological or normal. The apprehension sign is assessed by displacing the patella laterally with the knee at 20 to 30 degrees of flexion. A sense of apprehension in the patient with this motion is often

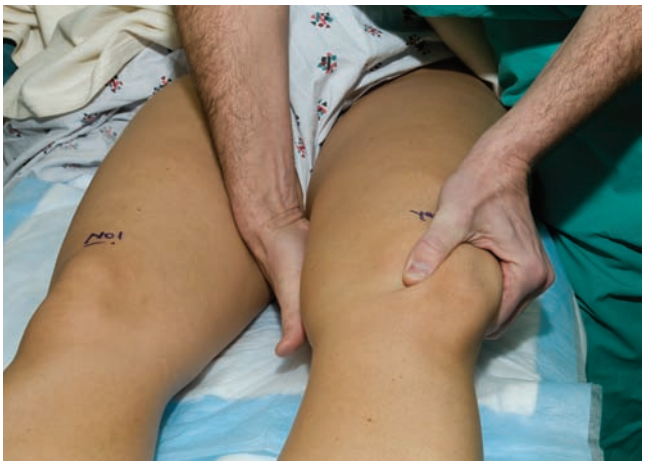

FIGURE 16.1
The glide test. In this patient, the patella can be easily dislocated laterally.

indicative of patellar instability. Finally, the tilt test is used to assess for tightness of the lateral structures. This examination involves lifting the lateral border of the patella. If the clinician is unable to elevate the lateral border of the patella above the horizontal plane, this test is considered positive and may be an indication for lateral retinacular release. Any medial patellar instability and associated medial apprehension should be ruled out during the physical examination.

Radiographic Imaging

Adequate imaging studies are critical in detecting anatomic abnormalities that may contribute to patellar instability. They may also help in identifying any associated injuries. Standard radiographs include anteroposterior, lateral, and sunrise views of the knee at 30 to 45 degrees of flexion. The lateral radiograph should be noted for any signs of patella alta or trochlear dysplasia. The crossing sign, seen on the lateral view of the knee, is present when the line of the anterior femoral condyles crosses that of the trochlear groove, indicating a dysplastic trochlea. Radiographs may also show the presence of loose bodies from chondral injury or calcification along the medial border of the patella, indicative of MPFL injury.

Computed Tomographic Imaging

Computed tomography can also be used to assess the bony abnormalities associated with patellar instability. Precise measurements of the degree of patellar tilt, the height of the lateral trochlear ridge, and the degree of patellar subluxation are possible with computed tomographic imaging. The degree of subluxation is assessed by the congruence angle on the axial view, which is measured by the difference in angle between the line bisecting the femoral sulcus and the line drawn from the center of the sulcus to the patellar apex. Angles lateral to the bisecting line are considered positive, and medial angles are considered negative. Tubercle malalignment can also be measured on axial views with the tibial tuberosity trochlear groove distance; measurements of more than 15 mm are considered to be abnormal and indicate malalignment.

Magnetic Resonance Imaging

Magnetic resonance imaging can provide information regarding anatomic alignment, but it is most valuable in visualizing soft tissue and cartilage injuries. Magnetic resonance imaging can show the details of MPFL injury with regard to the type and location of the tear (11). It is also used to identify the presence of chondral lesions or concomitant ligamentous injury, which is particularly helpful in planning for concurrent procedures.

Potential Intraoperative Findings

When planning for MPFL reconstruction, the clinician should anticipate that additional or alternative intervention(s) may be required based on the intraoperative evaluation. For example, contractures of the lateral patellar soft tissues may require a lateral release, and the presence of chondral lesions found during diagnostic arthroscopy may necessitate débridement and possible microfracture. On the other hand, high-grade chondral lesions that require unloading may prompt the need for a distal realignment procedure instead of MPFL reconstruction. The potential need for these procedures should be adequately addressed in the preoperative consent and planning process.

SURGICAL PROCEDURE

Preparation

The patient is placed in a supine position on the operating room table. Anesthesia is administered using general or regional techniques. Prophylactic intravenous antibiotics are given before the incision is made. A thorough examination of the operative and contralateral knees is performed. Standard evaluations include range of motion (ROM) testing and the Lachman test, posterior drawer test, and assessments of varus and valgus stability. The patellofemoral examination involves the assessment of patellar stability with the glide test and the tilt test to determine lateral retinacular tightness (Fig. 16.1).

A thromboembolic deterrent stocking is applied to the nonoperative leg. A tourniquet is then applied to the operative proximal thigh, and a vertical post is placed distal to the tourniquet. The leg is then prepped and draped with sterile, impervious drapes.

Diagnostic Arthroscopy

Diagnostic arthroscopy is performed via the standard superolateral, inferomedial, and inferolateral portals. The suprapatellar pouch and medial and lateral parapatellar gutters are closely observed for loose bodies. Evaluation of the patellofemoral joint should include the visualization of patellar tracking during ROM of the knee, with special attention directed to observing the shape of the trochlea and condition of the patellar facets and trochlear ridges. Any chondral damage is noted, with débridement and microfracture performed as needed. If a high-grade chondral lesion involving the inferior pole or lateral facet of the patella is found, the surgeon may, at this time, choose to proceed with a tuberosity osteotomy instead. The complete diagnostic evaluation includes assessment of the anterior and posterior cruciate ligaments, medial and lateral compartments, as well as the posteromedial and posterolateral compartments through the femoral notch.

Landmarks and Graft Harvest

The leg is exsanguinated with an Esmarch bandage, and the tourniquet is inflated. The bony landmarks of the patella and patellar tendon, the medial femoral epicondyle and adductor tubercle, as well as the site of the pes insertion (Fig. 16.2) are marked on the skin surface. A short oblique incision is made over the pes anserine insertion to expose the subcutaneous tissue. Blunt dissection is used to expose and identify the sartorial fascia, and any vessels that cross the field are cauterized. The sartorial fascia is incised and everted, exposing the gracilis and semitendinosus tendons (Fig. 16.3). The semitendinosus tendon is released distally and tagged for harvesting. The fascial band from the semitendinosus to the medial head of the gastrocnemius (~7 cm proximal to the pes insertion) is released, and the graft is harvested using an open-ended pig-tail tendon stripper. The gracilis tendon may also be used in place of the semitendinosus tendon as an alternative graft for this procedure.

Graft Preparation

The semitendinosus tendon graft is prepared by removing the muscle and soft tissue debris from the graft. The tendon is then doubled and measured in length (Fig. 16.4). Alternatively, with a large semitendinosus graft, a single strand may also be used here. A 2 FiberLoop (Arthrex, Inc., Naples, Florida) is woven through the semitendinosus tendon graft (Fig. 16.5), with the sutures exiting the midportion of the graft (Fig. 16.6).

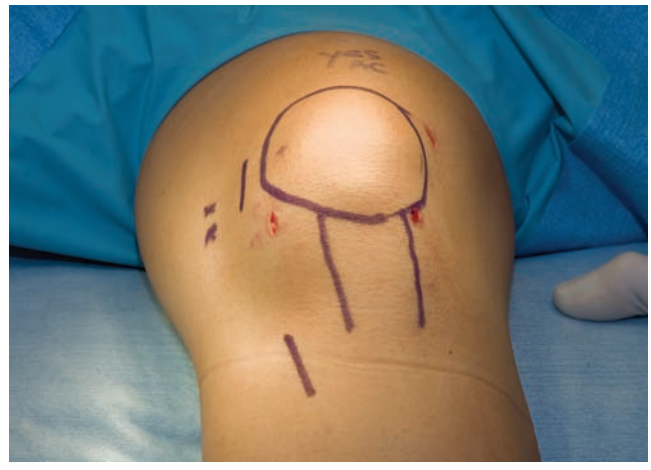

FIGURE 16.2

The patella, the edges of the patellar tendon, the adductor tubercle (proximal "x"), and medial epicondyle (distal "x"), as well as the incision over the pes tendons and the MPFL, are marked on the skin.

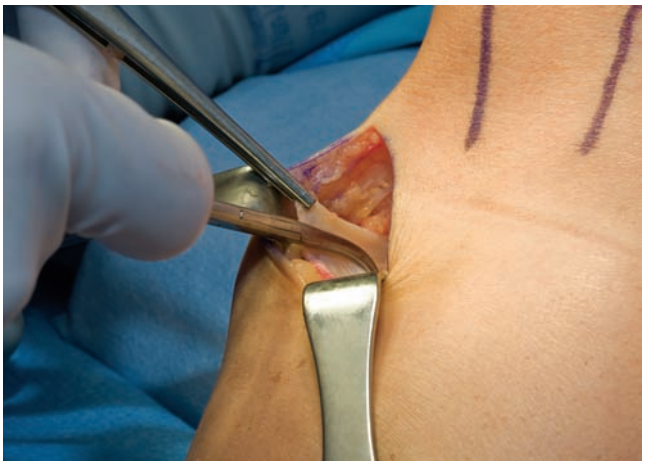

FIGURE 16.3

The sartorial fascia is incised and everted, exposing the gracilis and semitendinosus tendons.

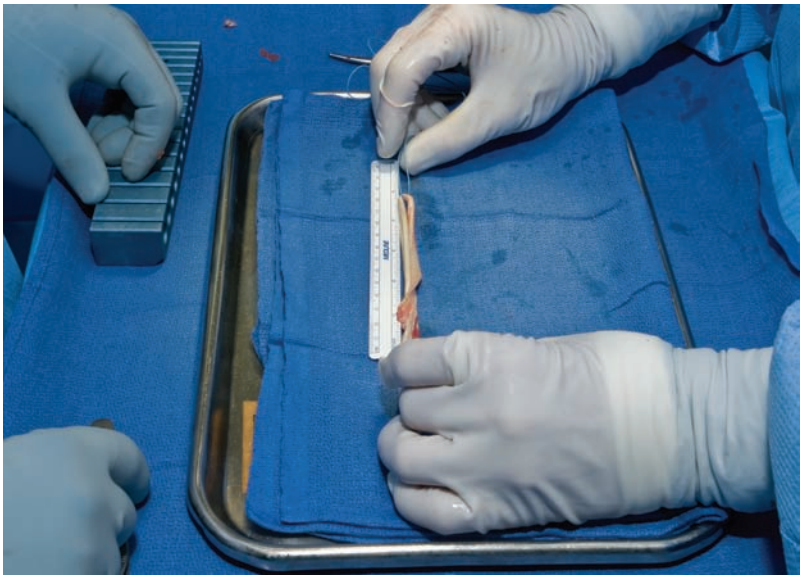

FIGURE 16.4

After removing the soft tissue debris from the graft, the tendon is doubled and measured in length.

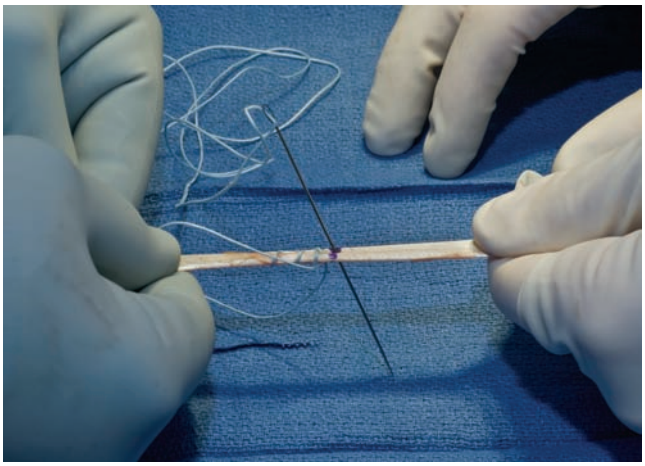

FIGURE 16.5

Preparation of the graft. A 2 FiberLoop suture is woven through the midportion of the doubled semitendinosus tendon graft.

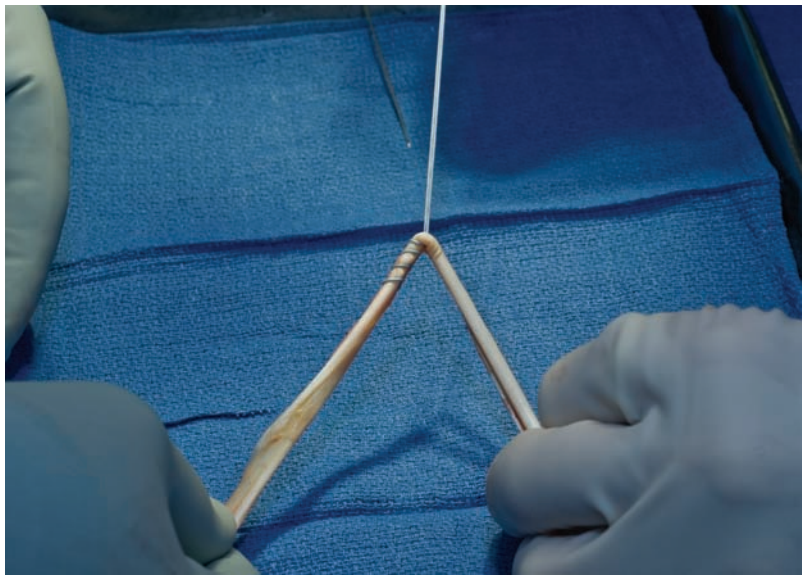

FIGURE 16.6
The 2 FiberLoop sutures exit the graft at its midportion.

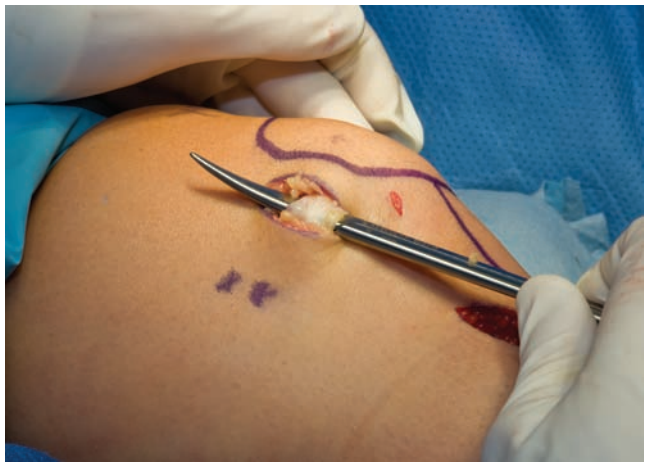

FIGURE 16.7
An incision is made directly over the MPFL, equidistant from the medial border of the patella and the saddle between the adductor tubercle and the medial femoral epicondyle. The MPFL can be identified as a thickening of the medial retinaculum just distal and inferior to the vastus medialis obliquus muscle.

Patellar Tunnel

An incision is made directly over the MPFL, equidistant from the medial border of the patella and the femoral insertion of the MPFL, at the saddle between the adductor tubercle and medial femoral epicondyle. The MPFL can be identified as a thickening of the medial retinaculum just distal and inferior to the vastus medialis obliquus muscle (Fig. 16.7). The medial border of the patella is exposed at the level of the equator. A small incision is made in the medial capsule to allow digital palpation of the articular surface. A 2.5-mm eyelet Kirschner ("K") wire is drilled from the medial border of the patella just proximal to the equator, using digital palpation as a guide to avoid violating the articular surface. Extreme care must be taken to protect both the articular surface and the anterior cortex. The K-wire should be directed in an oblique direction laterally and slightly proximally across the patella. The K-wire then exits through the superolateral portal site.

With a mini C-arm, the position of the K-wire is confirmed to be in the appropriate location. A second short 2.5-mm K-wire is drilled approximately 5 mm proximal and parallel to the first K-wire. Appropriate positioning is again confirmed via fluoroscopy, as is maintenance of an appropriate bone bridge between the two K-wires on the lateral border of the patella (Fig. 16.8). The K-wires are overdrilled with a 4.5-mm cannulated drill bit to a depth of approximately 15 mm and then are advanced laterally. With a rongeur, a blind tunneled trough is created in the medial patella approximately 7 mm wide and 15 mm deep. The K-wires are then passed medially back into the blind tunnel, and the eyelet ends of the K-wires are left protruding from the medial patella at this point (Fig. 16.9).

One end of each suture is passed through each of the two K-wires (Fig. 16.10). The K-wires are advanced across the patella and out through the superolateral portal. After confirmation that the graft is docked well in

FIGURE 16.8

Fluoroscopy is used to confirm the position of the K-wires. It is important that the K-wires do not violate the articular cartilage and that an adequate bone bridge is maintained.

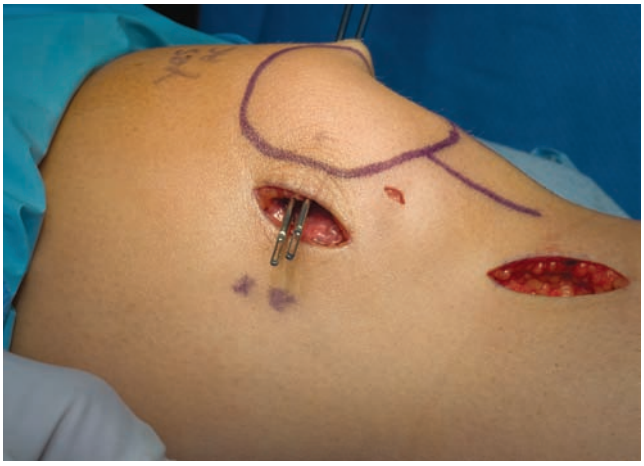

FIGURE 16.9

After the tunnel is created, the K-wires are passed medially back into the blind tunnel, and the eyelet ends of the wires are left protruding from the medial patella.

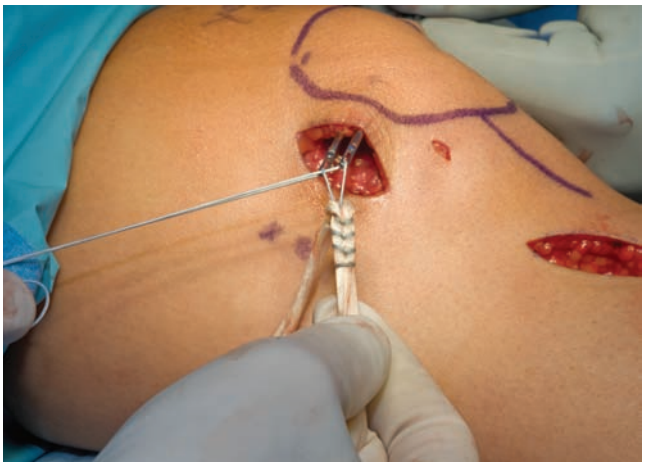

FIGURE 16.10

One end of each suture is passed through the eyelet of each of the two K-wires.

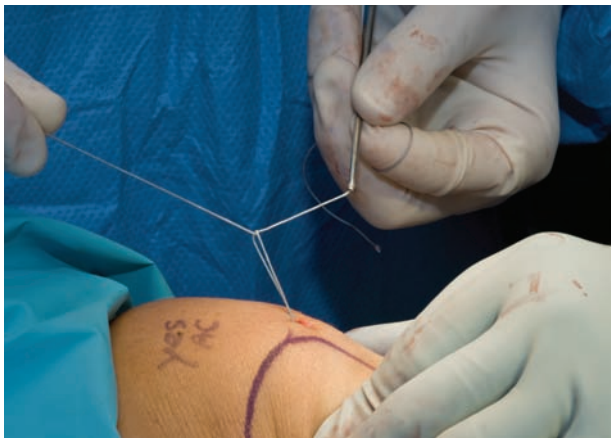

FIGURE 16.11
After passing the graft through the patella, the sutures are tied directly over the patella through the superolateral portal.

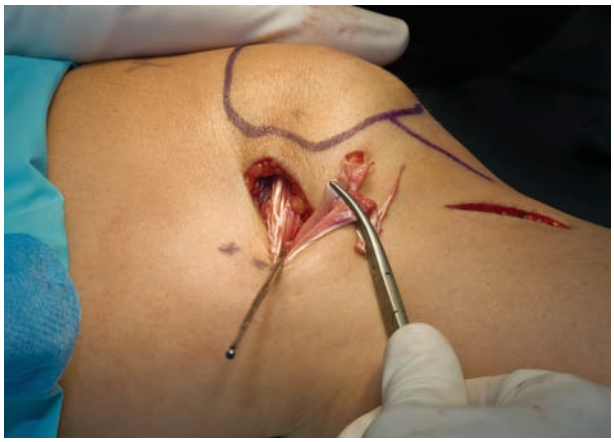

FIGURE 16.12
The two ends of the doubled semitendinosus graft are then wrapped around the K-wire. To assess for isometry, the knee is flexed, and the position of the patella and tension on the graft are palpated and visualized.

the blind tunnel, the soft tissue is cleared from the superolateral portal to the corner of the patella. The sutures are tied directly over the patella (Fig. 16.11), and fixation is confirmed by tugging on the graft.

Femoral Tunnel

At the medial incision, the soft tissue is retracted posteriorly to expose the medial femoral epicondyle and the adductor tubercle. A short 2.5-mm eyelet K-wire is positioned immediately anterior to the medial epicondyle and distal to the adductor tubercle. The K-wire is directed slightly anteriorly and proximally to avoid the posterolateral neurovascular structures. The appropriate positioning is confirmed on fluoroscopy, with minor position adjustments made as necessary. The two ends of the doubled semitendinosus graft are then wrapped around the K-wire (Fig. 16.12). Isometry of the graft is confirmed by ranging the knee through full flexion and extension and assessing graft tension manually. If the isometry of the graft remains appropriate throughout the full ROM of the knee, the femoral tunnel is in the appropriate position. The ends of the graft are cut 2 cm longer than the distance to the opening of the femoral tunnel. A 2 FiberWire (Arthrex, Inc., Naples, Florida) is used to weave together the two ends of the graft, and a loop is left at the distal end. A 5 Tricron suture is then passed through this loop as a pull-through suture, and this suture is removed at the conclusion of the procedure (Fig. 16.13).

A 7-mm drill bit is used to drill the blind femoral tunnel to a depth of 25 mm. The graft should be passed through the soft tissue interval between the MPFL and the capsule and into the blind femoral tunnel (Fig. 16.14). The two ends of the pull-through suture are threaded through the end of the K-wire, and the K-wire is passed laterally through the femur (Fig. 16.15). Tension is placed on the graft sutures exiting the lateral side of the thigh, and the knee is again taken through ROM. Appropriate isometry is confirmed. The knee is then fully extended, and the patella is displaced laterally. The graft is tensioned to recreate the normal lateral patellar translation equal to that of the contralateral patella.

While the desired graft tension is maintained, the knee is flexed to the angle that creates the greatest amount of tension in the graft, typically 70 to 90 degrees. A bioabsorbable cannulated interference screw (8 × 23 mm, Arthrex, Inc., Naples, Florida) is placed for femoral fixation. Once the screw is flush with the cortex, the knee is again extended and the lateral patellar translation is assessed. Care should be taken to avoid overtightening the graft. The patella should have lateral translation symmetric to the normal contralateral knee, or two to three

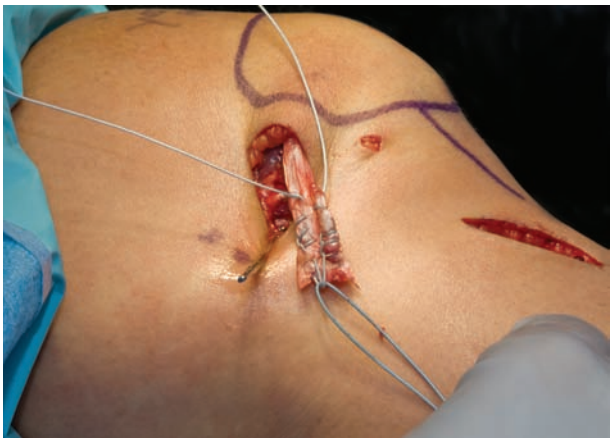

FIGURE 16.13

Once the graft is cut at the appropriate length, the two ends of the graft are sutured together, leaving a loop at the distal end. A pull-through suture is then passed through this loop for removal at the conclusion of the procedure.

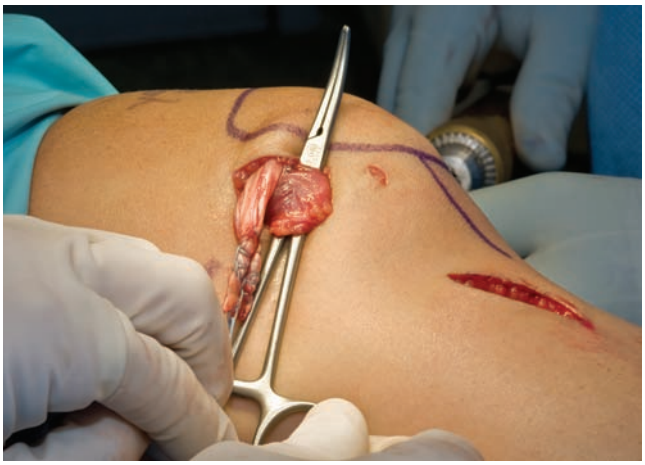

FIGURE 16.14

The semitendinosus graft is passed through the soft tissue interval between the MPFL and the capsule, into the femoral tunnel.

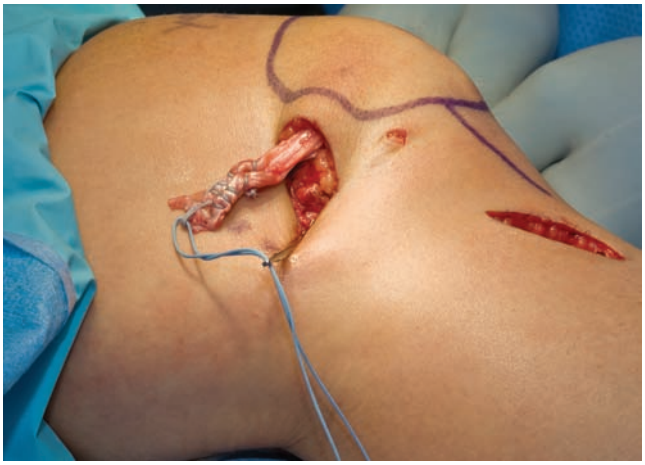

FIGURE 16.15

After drilling the femoral tunnel, the two ends of the pull-through suture are threaded through the end of the K-wire, and the wire is passed laterally through the femur.

quadrants in patients with bilateral instability. The knee must flex fully without capture of the patella. If patellar translation is less than the normal contralateral side, or the patella is felt to be overconstrained, the screw should be removed and the graft should be retensioned.

Closure

At the site of the graft harvest, the sartorial fascia and gracilis tendons are reattached to their insertion sites with 0 absorbable, braided sutures. The subcutaneous layer is closed with inverted 2-0 absorbable, braided sutures.

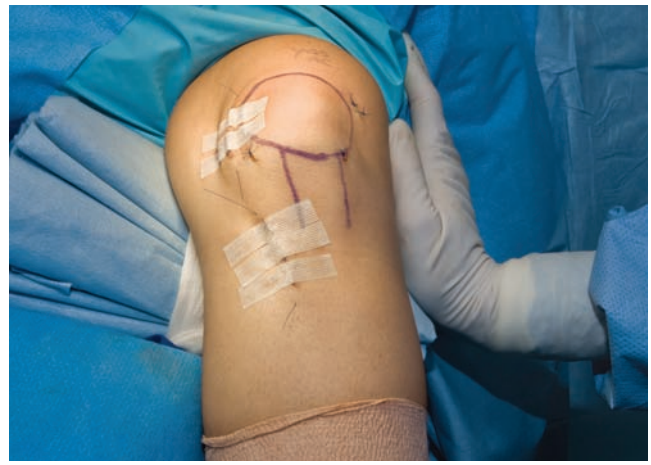

FIGURE 16.16
Final closure.

The skin is closed with a running subcuticular 3-0 nylon suture and covered with Steri-Strips (3M, St. Paul, Minnesota). The medial incision is closed in a similar fashion.

The portal sites are closed with 3-0 nylon sutures (Fig. 16.16). For pain control, a total of 10 mL of 0.25% bupivacaine is injected in and around the incisions, with another 20 mL injected intra-articularly. Sterile dressings are then applied, followed by a cryotherapy cooling unit, a loosely applied elastic bandage, a thromboembolic deterrent stocking, and a hinged brace locked in full extension. The tourniquet is then released.

POSTOPERATIVE MANAGEMENT

- Postoperatively, the patients are kept in a brace for at least 6 weeks, with gradual progression of weightbearing and physical activities.
- Immediately after surgery, the patients are maintained in the brace, which is locked in full extension. Weightbearing is restricted to 5 lb. The patients are instructed to do quadriceps sets and ankle pumps every hour and to ice and elevate as needed.
- Postoperative week 1: The portal sutures are removed, and the patients are advanced to 25% weightbearing in the brace (which is still locked in extension during ambulation). They begin flexion exercises with physical therapy, three times per week for 12 weeks.
- Postoperative week 2: The patients are reevaluated, and the incisional sutures are removed. The patients are progressed to full weightbearing in the brace and begin doing straight-leg raises with 1-lb weights. Activities are then increased as follows:
- Postoperative week 3: Patients are started on the stationary bike to increase ROM, and extension exercises are reemphasized.
- Postoperative week 4: Patients are encouraged to do 100 repetitions of straight-leg raises daily and are expected to have obtained 120 degrees of knee flexion.
- Postoperative week 6: Typically, the brace is discontinued at this time. ROM should be near normal. Recommendations at this point include single-leg stance, step-up exercises of several inches, and water exercises.
- Postoperative week 8: Treadmill walks, elliptical exercises, and isotonic exercises, including leg presses, toe presses, and leg curls are allowed.
- Postoperative week 12: Patients are evaluated in the office and begun on a progressive treadmill jogging program, which is then transitioned to outdoor running.
- Postoperative week 16: Patients advance to cutting and sport-specific drills and may begin returning to regular sports if progress is satisfactory at this time.

COMPLICATIONS

Appropriate positioning and tensioning of the graft is critical to the success of this procedure. Overtightening or malpositioning of the graft can result in iatrogenic medial instability, medial facet arthropathy, and stiffness (1,2,8,21,22). Elias and Cosgarea (8) showed that malpositioning of the femoral tunnel proximally by 5 mm can cause significantly increased pressures on the medial patellar cartilage. Additionally, overtightening of the graft by as little as 3 mm can increase graft and patellofemoral joint reactive forces. The authors theorized that either scenario could lead to degeneration of the medial patellofemoral cartilage. As a result of overtightening, subsequent graft failure and recurrence of instability may also occur. Adequate tensioning of the graft is necessary to avoid continued instability.

Other potential complications after MPFL reconstruction are patellar fractures through the tunnel sites (22), hemarthrosis (12), minor wound complications (12), graft loosening after trauma (20), implant pain (4,20), arthrofibrosis (7), anterior knee pain, and injury to the saphenous vein or nerve.

RESULTS

Overall, MPFL reconstructions appear to provide long-term functional improvement with low rates of redislocation, improvement in Kujala scores, and decreases in apprehension and patellofemoral pain (4,5,7,9,20). However, in a meta-analysis studying outcomes of MPFL reconstruction, Smith et al. (18) showed that there were "substantial methodological limitations" in the current literature, including small sample sizes and limited follow-up times. The techniques for MPFL reconstructions are varied and evolving, and there are few studies that report similar techniques to allow for valid comparison. Despite the diversity of procedures, however, the results are generally favorable. Panagopoulos et al. (14) reviewed several techniques using hamstring autografts, which showed low recurrence and symptomatic improvement in 85% to 93% of the cases. Using a technique similar to that described in this chapter, Christiansen et al. (4) showed good postoperative stability after MPFL reconstruction in 44 patients; they reported only one case of recurrent instability. LeGrand et al. (10) also reported good results with no dislocations using a similar technique. Standardizing the technique and implementing an adequate sample size and follow-up will be necessary for future outcomes studies.

PEARLS AND PITFALLS

- MPFL reconstruction is indicated for recurrent patellar instability and never for isolated patellofemoral pain.
- Patients with recurrent instability and substantial bony malalignment may be better treated with a distal realignment procedure.
- Concomitant injuries should be identified and addressed appropriately.
- When drilling the patellar tunnels, extreme care should be taken to avoid violating the articular surface. Placing one finger on the articular surface while drilling will help to direct the wire appropriately.
- Placing the femoral attachment too proximally will cause the graft to be overly tight in flexion. The femoral attachment should not be proximal to the native origin of the MPFL because it can cause excessive graft tension with subsequent medial facet overload and arthrosis (1,2,8).
- In contrast, placing the femoral attachment too distally may cause the graft to be tight in extension, but it is less likely to cause patellofemoral degeneration. It is thus safer to err more distally if necessary (21).
- The graft should be tensioned so as to match the patellar excursion of the normal contralateral knee—usually two to three patellar quadrants of lateral translation.

ALTERNATIVE PROCEDURES

There are numerous techniques described in the reconstruction of the MPFL. What we have described is one way to approach this procedure with a semitendinosus autograft, femoral interference fixation, and a patellar tunnel with modified docking technique (3). For the femoral attachment of the graft, we prefer fixation with an interference screw, although this procedure has been described using sutures (9), washers (16), and blind- and through-tunnel grafts. A variety of graft types have also been used in addition to the semitendinosus tendon, including the adductor muscle (20), gracilis tendon (4,17), quadriceps tendon (19), synthetic graft (13), and allograft. For patellar fixation, we use a modification of the docking technique, first described by Brown and Ahmad (3). Others recommend the use of single versus double patellar tunnels or the Endobutton (Smith and Nephew, Memphis, TN) (16). Multiple different methods have shown excellent results in reducing lateral patellar instability.

CONCLUSION

Patellofemoral instability is multifactorial and complex, and numerous procedures have been purported to address this issue. Although MPFL reconstruction is a relatively new procedure, the limited results thus far have been favorable when it is used for the appropriate indications. The key to MPFL reconstruction is understanding that its purpose is a stabilization procedure for medial soft tissue insufficiency, not a solution to arthropathy or marked malalignment. Understanding the indications and limitations of the procedure, as well as the importance of graft positioning and tensioning, will help the surgeon attain successful results in the treatment of patellofemoral instability.

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17 Tibial Tubercle Transfer

Robin Vereeke West

INTRODUCTION

This chapter addresses the surgical technique of a tibial tubercle transfer for the treatment of patellar instability and isolated patellofemoral arthritis.

Causes of patellofemoral joint instability and isolated patellofemoral arthritis are multifactorial and can be related to problems with limb alignment, the osseous architecture of the patella and trochlea, and the integrity of the surrounding soft tissues. The incidence of patellar dislocation is 5.8 per 100,000, and this increases to 29 per 100,000 in the 10 to 17-year old age group. The recurrence rate averages 15% to 44% after nonoperative treatment of an acute injury. If there is a subsequent dislocation after the primary injury, the recurrence rate increases to 50%. Many patients continue to have mechanical symptoms and pain after a patellar dislocation. Atkin et al. reported that up to 55% of patients fail to return to sports activity after a primary patellar dislocation. He also showed that 58% of people have limitations with strenuous activity at 6 months after a primary dislocation.

The operative treatment of patellofemoral arthritis is variable depending on the degree and the location of the chondral damage, the age of the patient, and associated chondral injury to the tibialfemoral joint. Arthroscopic débridement can be used for isolated, superficial chondral flaps in the patellofemoral joint. Anteromedialization of the tibial tubercle can be used for the treatment of isolated lateral patellar facet arthritis. Patellofemoral replacement is used in patients with normal limb alignment and osseous anatomy who have diffuse patellofemoral arthritis. Total knee replacement offers the best clinical results in older patients or patients with associated tibiofemoral arthritis.

SIGNS AND SYMPTOMS

Patients with patellofemoral arthritis and recurrent patellar instability have similar symptoms. They may present with a sense of instability, pain, mechanical symptoms, and/or recurrent effusions. Most patients have tried a course of physical therapy to work on flexibility, proprioception, and strengthening around the knee and the hip. Bracing occasionally relieves some of the pain and instability. Hyaluronic acid injections can help relieve some of the swelling, pain, and mechanical symptoms.

PHYSICAL EXAM

A thorough examination of the entire lower limb should be performed and should be compared to the contralateral side. The following findings should be documented: limb rotation (femoral anteversion, external tibial torsion), muscle atrophy, core strength, crepitation, effusion, local or diffuse tenderness, patellar glide, patellar tracking throughout range of motion, patellar tilt, tuberosity position in relation to the center of the trochlea, apprehension (medial and lateral), and the Fulkerson medial instability test.

IMAGING

Radiographs (Both Knees)

Standard radiographs include 45-degree flexion weight-bearing posteroanterior and lateral view, and Merchant view. The flexion weight-bearing radiographs show the degree of tibiofemoral joint space narrowing.

The Merchant view is used to assess patellar tilt, subluxation, and trochlear dysplasia. The lateral view is used to evaluate the patellar height and trochlear dysplasia.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is useful in evaluating injury to the medial patellofemoral ligament (MPFL) and the articular cartilage, bone bruise patterns, and other associated ligamentous or meniscal injuries. When MRI findings were correlated with surgical findings, MRI was found to be 85% sensitive and 70% accurate in detecting disruption of the MPFL.

Computed Tomography

Cross section imaging with computed tomography (CT) slices at different positions along the lower limb can provide a three-dimensional view of the patellofemoral joint. These CT cuts can be used to assess the lateral offset of the tibial tuberosity from the deepest point in the trochlear groove (TT-TG distance). A distance of >20 mm is nearly always associated with patellar instability and can be addressed with a tibial tubercle realignment.

INDICATIONS

Tibial tubercle transfer can be done for patellofemoral arthritis or instability. Indications for medialization of the tubercle include symptoms of patellofemoral instability along with an increased TT-TG distance (>20 mm). Indications for anteromedialization of the tibial tubercle include symptoms of patellofemoral instability and pain along with an increased TT-TG distance and/or distal/lateral patellar facet chondrosis or lateral trochlear chondrosis.

CONTRAINDICATIONS

Contraindications of tibial tubercle transfer include medial and/or proximal patellofemoral chondrosis that would be subjected to increased loading with a transfer of the tubercle. Standard contraindications to any osteotomy around the knee include osteoporosis, nicotine use, nonspecific pain, complex regional pain syndrome, inflammatory arthropathy, infection, patella baja, or arthrofibrosis.

ANESTHESIA

The type of anesthesia used for the case is decided by the surgeon, patient, and anesthesiologist. Options include general anesthesia, sedation along with local anesthesia, regional nerve blocks, or spinal anesthesia. Nerve blocks, including femoral and sciatic, are very popular at our institution. These can be "one-shot" blocks that provide anesthesia for about 18 hours or an indwelling catheter can be left in place. These catheters are routinely removed 3 days postoperatively and are done to provide sensory but not motor block. A narcotic prescription is sent home with all patients, and prophylactic antibiotics are given before the skin incision but not postoperatively.

POSITIONING

The patient is place supine on the operating room table. All bony prominences are well padded. An egg-crate cushion is placed under the nonoperative leg. A tourniquet is applied and is insufflated to 250 mm Hg during the osteotomy portion of the case only.

SURGICAL LANDMARKS, INCISIONS, PORTAL PLACEMENT

Landmarks

- Patella
- Patellar tendon attachment on the tibial tubercle
- Gerdy tubercle
- Tibial crest

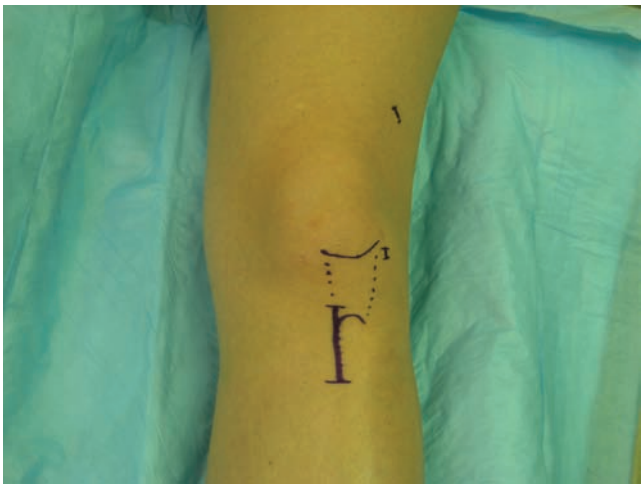


FIGURE 17.1

The landmarks of the inferior pole of the patella, the patellar tendon, the superolateral portal site, the inferior lateral portal site, and the osteotomy site are marked on the skin.

Portals and Incisions

- The landmarks and arthroscopic portal sites and skin incisions are marked on the skin (Fig. 17.1).
- The best viewing portal for the patellofemoral joint is the superolateral portal. A 70-degree arthroscope is used to assess the articular cartilage in the patellofemoral joint and is used to evaluate patellofemoral tracking/glide/tilt.
- A 5 to 7 cm skin incision is made medial to the tibial tubercle, starting 1 cm proximal to the patellar tendon attachment and extending distally.

EXAMINATION UNDER ANESTHESIA

Under anesthesia, both knees are examined and compared. The range of motion, presence of effusion, generalized ligamentous exam, patellar tracking/tilt/crepitation/glide are all documented. The patellar exam should be checked in full extension and then again at 20 to 30 degree knee flexion (when the patella is engaged in the trochlea).

DIAGNOSTIC ARTHROSCOPY

The diagnostic arthroscopy typically involves two portals. The standard anterolateral portal with the 30 degree-arthroscope is used for the full diagnostic examination of the knee. The superolateral portal with the 70 degree-arthroscope is used for evaluation of the patellofemoral joint (Fig. 17.2). This portal gives excellent visualization of the articular cartilage throughout the patellafemoral (PF) joint. Patellar tracking and glide can be examined from this portal.

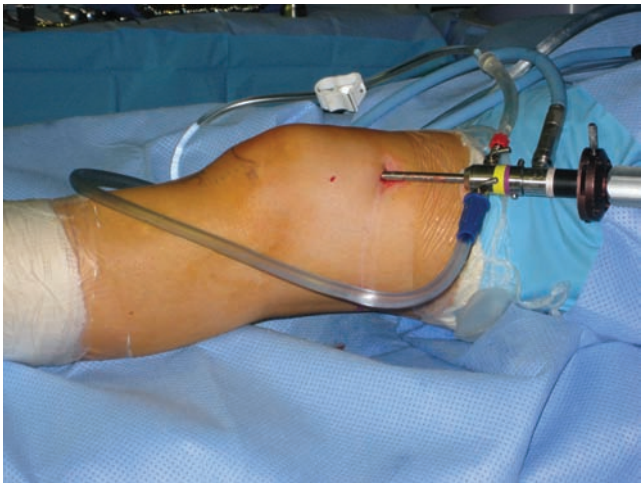


FIGURE 17.2

The superolateral portal site is used with a 70-degree arthroscope to assess the patellofemoral articular cartilage and patellar tracking.

PROCEDURE

Initially, the diagnostic arthroscopy is performed to assess the articular cartilage status and confirm that there is no contraindication to the realignment of the tubercle. An open lateral release is performed through a small 2 to 3 cm incision only if the retinaculum is exceptionally taught (negative patellar tilt). The release confirms that the retinaculum will not tether the patella after the tibial tubercle transfer. The release is not too extensive and only extends from the inferior pole to the superior pole, taking care not to injure the insertion of the vastus lateralis obliquus. A tourniquet set at 250 mm Hg is only used for the osteotomy portion of the case and released prior to wound closure.

The incision is made just medial to the tibial tubercle and is 5 to 7 cm in length, extending from just proximal to the patellar tendon insertion distally. The fascia is exposed and then elevated off of the tibia to expose the anterolateral tibial crest and Gerdy tubercle. The edges of the patellar tendon are identified. The osteotomy site is marked with a Bovie on the anteromedial tibial crest, starting at the medial edge of the patellar tendon insertion and extending distally about 5 cm.

The osteotomy is performed "free hand." With the tibial tubercle pointing directly at the ceiling (the foot is usually internally rotated), a Steinman pin is placed from the medial tibial crest at the proximal portion of the osteotomy. The slope of the pin placement accounts for the slope of the osteotomy (Fig 17.3). The slope is adjusted according to the amount of patellofemoral chondrosis. Once the slope of the osteotomy is determined, a microsagittal saw is used to perform the osteotomy (Fig 17.4).

The osteotomy is completed with a ¼ in curved curette proximally at the patellar tendon insertion in a transverse fashion (Fig 17.5). The osteotomy is hinged distally and is only completed if patella alta is identified on the preoperative radiographs, using the Modified Insall-Salvati and Caton-Deschamps ratios.

The tibial tubercle is then shifted medially or anteromedially about 1 cm. Care is taken to make sure the tubercle has at least 50% contact with the underlying tibia to ensure good healing potential. The tuberosity is temporarily fixed with Kirschner wire and then permanently fixed with two 4.5-mm fully threaded screws,

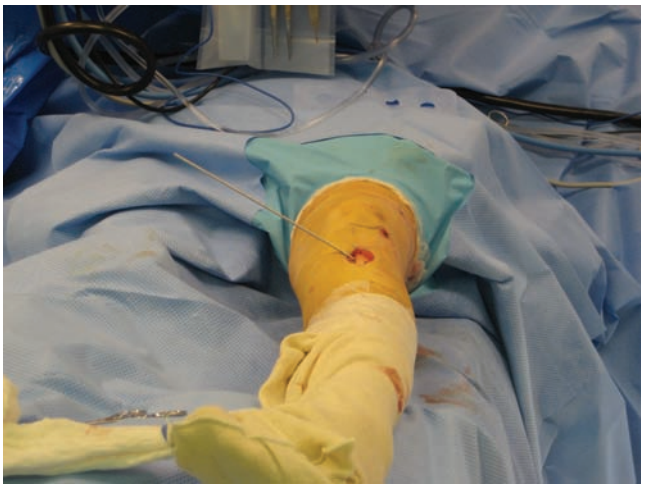


FIGURE 17.3

The Steinman pin is placed from medial to lateral at the proximal portion of the tibial tubercle to mark the angle of the osteotomy slope. The slope is varied depending on the amount of medialization and anteriorization that is desired. This slope is determined by the amount of patellofemoral arthritis that is present.

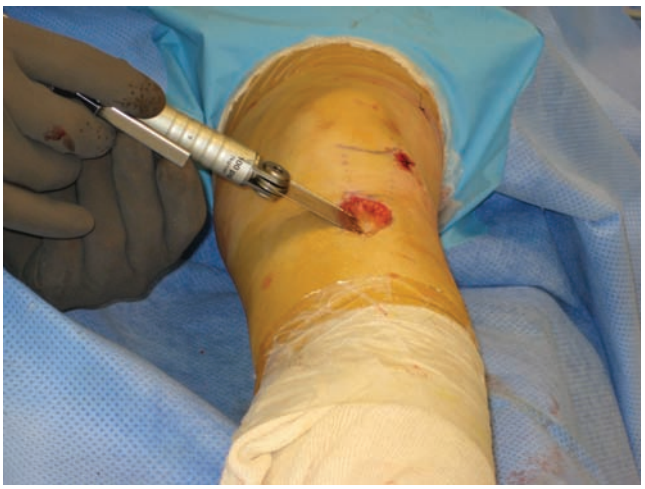


FIGURE 17.4

The osteotomy is performed with a microsagittal saw.

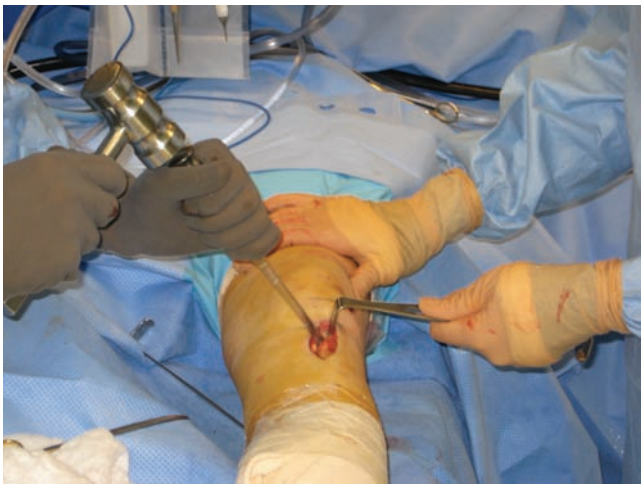


FIGURE 17.5

The osteotomy is completed proximally with a ¼ in curved osteotome. This cut is made transversally just proximal to the patellar tendon insertion.

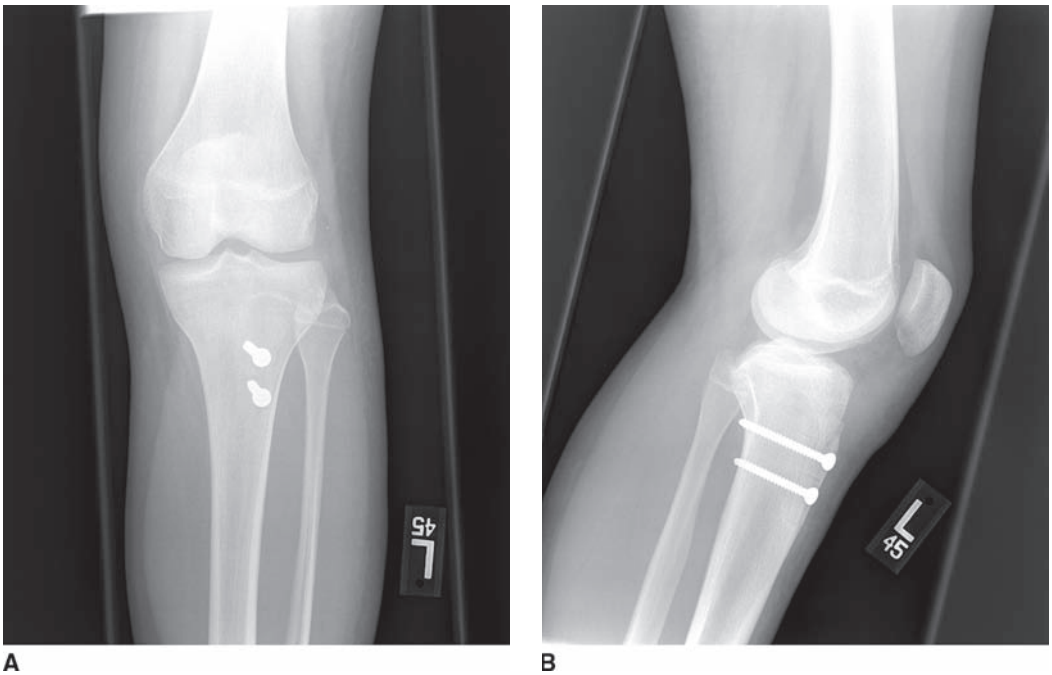
using the AO compression technique. A mini C-arm is used to confirm good position and length of the two screws before wound closure.

The fascial layer is closed in an interrupted fashion, followed by a subcutaneous closure, then a subcuticular closure. Care is taken to provide hemostasis after releasing the tourniquet and prior to wound closure. A drain is not routinely used.

POSTOPERATIVE REHABILITATION AND RETURN TO PLAY

The patient is allowed immediate full weight bearing with crutches and a brace locked in full extension. The brace is unlocked at 6 weeks or when the osteotomy is radiographically healed and is discontinued when the patient has excellent quadriceps control. A CPM is started within a few days after surgery, and heel slides are allowed to 90 degrees of knee flexion until the osteotomy is healed. Physical therapy is started immediately to help regain quadriceps control, patellar mobility, control swelling, and begin a comprehensive core stabilization program.

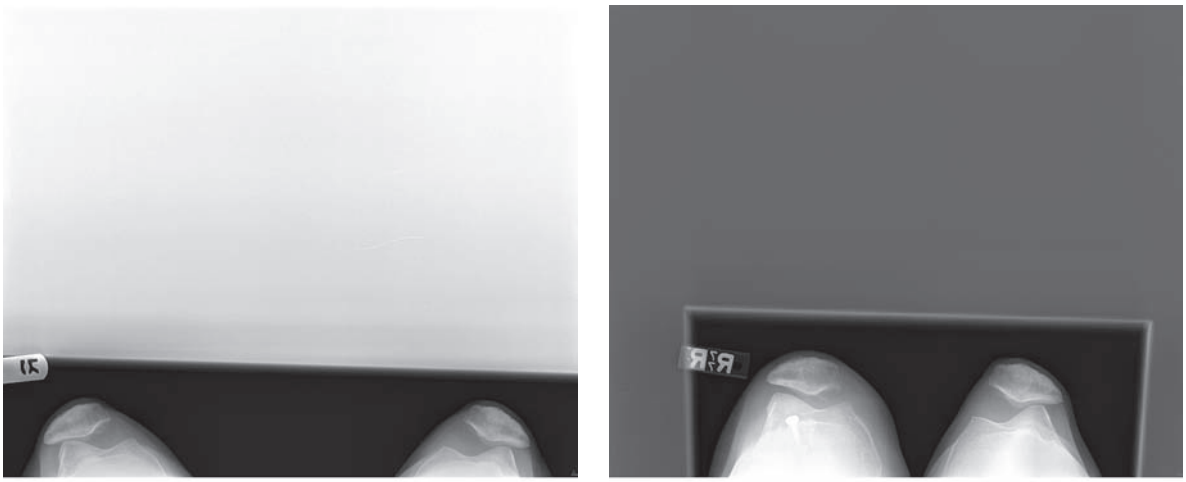
Once the osteotomy is healed, progressive activity is initiated from strengthening, functional training, jogging and then return to sports without restrictions at 4 to 5 months postoperatively (Figs. 17.6 and 17.7).



A B

FIGURE 17.6

A,B: Preoperative and postoperative radiographs after a tibial tubercle realignment for patellar instability and a lateral patellar facet defect in a 15-year-old female.



A B

FIGURE 17.7

A,B: Preoperative and postoperative radiographs after a tibial tubercle realignment for severe bilateral patellofemoral arthritis in a 36-year-old woman.

COMPLICATIONS

Complications are similar to all bony procedures around the knee: infection, malunion, nonunion, compartment syndrome, arthrofibrosis, patella baja, worsening, or no improvement in symptoms.

PITFALLS AND PEARLS

Pitfalls/Pearls

- The lateral release is done in conjunction with tibial tubercle transfer to help "balance" the soft tissues. Overzealous lateral release can lead to poor quadriceps function, medial patellar instability, and increased lateral laxity. Be sure to preserve the vastus lateralis oblique (VLO) insertion.
- Fracture at the osteotomy site can occur in patients who have osteoporosis or use nicotine.
- Complete the osteotomy proximally with a ¼ in curved curette to avoid fracture extension into the lateral plateau.
- "Countersink" the screws to avoid prominent, painful hardware.
- To aid in healing, maintain 50% contact between the tubercle and the tibia after the tubercle transfer.
- Full weight bearing is allowed postoperatively only with the brace locked in full extension to avoid too much force across the osteotomy site.

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18 Acute Quadriceps Tendon Rupture

Christopher S. Proctor and Brooke S. Prather

INDICATIONS/CONTRAINDICATIONS

Quadriceps tendon rupture is an uncommon injury that requires early diagnosis and surgical correction. Clinical findings for quadriceps tendon rupture include immediate suprapatellar pain, inability to obtain full knee extension, and a suprapatellar gap. Imaging useful for diagnosis includes bilateral radiographs demonstrating patella baja, ultrasound, and magnetic resonance imaging (MRI). Nonsurgical treatment may be appropriate to consider in cases of partial quadriceps tendon tears. Unrepaired complete rupture of the quadriceps tendon results in a poorly functioning lower extremity extensor mechanism. Acute surgical repair is indicated in all cases of complete quadriceps tendon rupture except for the medically unstable or previously nonambulatory patients.

Risk Factors

Middle-aged individuals are more likely to suffer from nontraumatic ruptures of the quadriceps tendon with the greatest incidence in the sixth decade (3–5). The incidence is higher in males than females (4,5). Medical conditions such as gout, diabetes mellitus, obesity, and end-stage renal disease are associated with spontaneous quadriceps tendon rupture (1–3). An additional risk factor for spontaneous tendon rupture is hyperparathyroidism, particularly after quinolone antibiotics and steroid use (6). Young athletes are also at risk for quadriceps tendon rupture when they have a history of chronic extensor mechanism inflammation. Sports that increase risk are basketball, volleyball, soccer, high jump, bodybuilding, and weight lifting. Systemic use of anabolic steroids and steroid injections for "body enhancement" should also be considered as a risk factor (2). The common mechanism of injury for quadriceps tendon rupture is contraction of the quadriceps muscle apposed by forced knee flexion (7).

Tendon Vascularity

Decreased quadriceps tendon vascularity plays an important role in tendon rupture and can explain the most common tear pattern. The most frequent pathological finding in ruptured quadriceps tendons is hypoxic degenerative change (8,9). This hypoxic degeneration may be influenced by an unequal distribution of blood supply within the tendon. Recent studies demonstrate a hypovascular zone within the tendon 1 to 2 cm proximal to the superior pole of the patella (3). This region of the tendon, with a relative decrease in blood supply, is associated with an increase in tendon degeneration and has the greatest risk for tendon rupture (3). In light of this, it is best to avoid tendon-to-tendon repair in the hypovascular zone.

PREOPERATIVE PLANNING

A full history and physical examination are important elements of preoperative planning. Radiographs should be taken of the knee. Anteroposterior and lateral views are necessary. In an acute quadriceps tendon rupture, the lateral view will show patella baja. The low-riding patella occurs as a result of unopposed tension from the patellar tendon. Ultrasound examination is also useful to evaluate quadriceps tendon tears (10). Despite ultrasound being an accurate and less expensive option, MRI is the most common imaging technique used to evaluate suspected tendon tears.

SURGERY

Patient Positioning

The patient is positioned supine on the operative table with the leg in full extension. We prefer general anesthesia supplemented with a femoral block. With a tourniquet fitted high on the upper thigh, the lower extremity is prepped with Hibiclens solution and draped in the usual fashion exposing the leg from the tibial tubercle up to the midthigh. The tourniquet is not routinely inflated.

Technique

A midline longitudinal incision is made starting above the proximal patella and extending to the inferior pole of the patella. Blunt dissection is used to elevate the medial and lateral full-thickness skin flaps so that the extensor mechanism is exposed. Most often the retinaculum is ruptured; however, it is split longitudinally if intact. Irrigation is used to dislodge hemotoma and visualize the tear. The most common site of quadriceps tendon rupture is 1 to 2 cm from the superior pole of the patella (3). The tendon ends are débrided of all necrotic and frayed tissue and mobilized so that tendon length is maximized.

The superior pole of the patella is then débrided down to its bony surface. The patella is then roughened, but not decorticated, to provide an optimal healing bed for the tendon. Two 5.5-mm suture anchors double loaded with 2 high strength nonabsorbable suture are inserted into the proximal pole of the patella, approximately dividing the patella into thirds. One suture from each anchor is then sutured proximally along the respective medial and lateral border of the quadriceps tendon using the Krackow technique, and then returned distally to the patella using the same technique (Fig. 18.1). The second suture from each anchor is sutured in the midportion of the tendon using the Bunnell technique (Fig. 18.2). The suture is interlocked with the Krackow stitches that are already in place forming a Krackow-Bunnell weave (Fig. 18.3). The retinaculum is then repaired with 2-0 absorbable sutures.

An alternative to the Krackow-Bunnell technique is the modified Mason-Allen technique.

The knee is then placed through range of motion, making note of the degree of flexion that can be obtained without overly stressing the repair. The patella alignment is then assessed and a lateral release is performed if necessary (11).

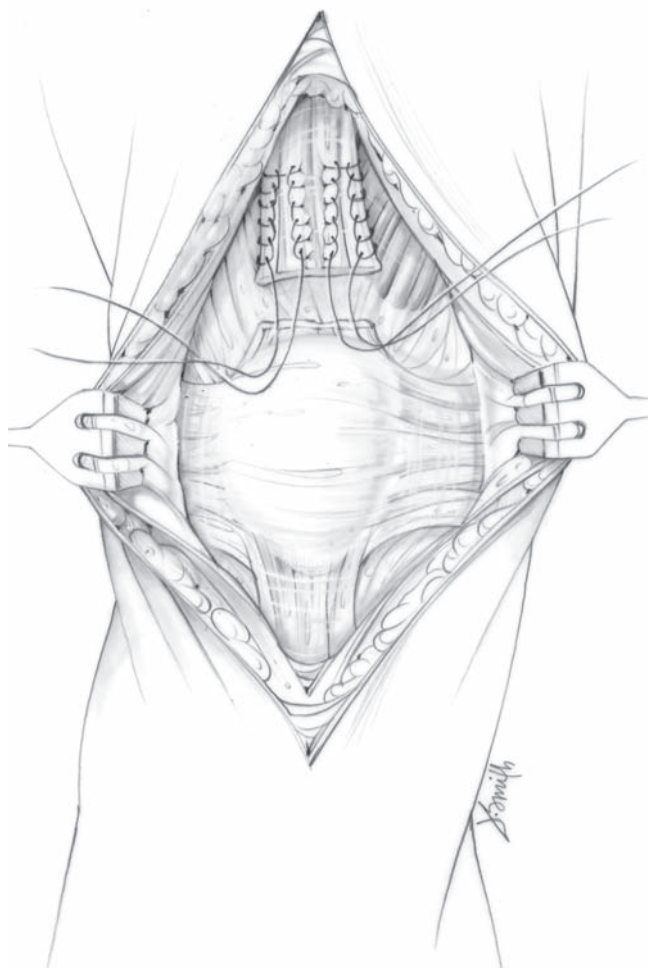

FIGURE 18.1

Suture anchors buried in the patella are made visible for clarity. Two suture anchors double loaded with 2 high strength nonabsorbable suture are inserted into the proximal pole of the patella. Completion of Krackow sutures is shown down the border of the quadriceps tendon.

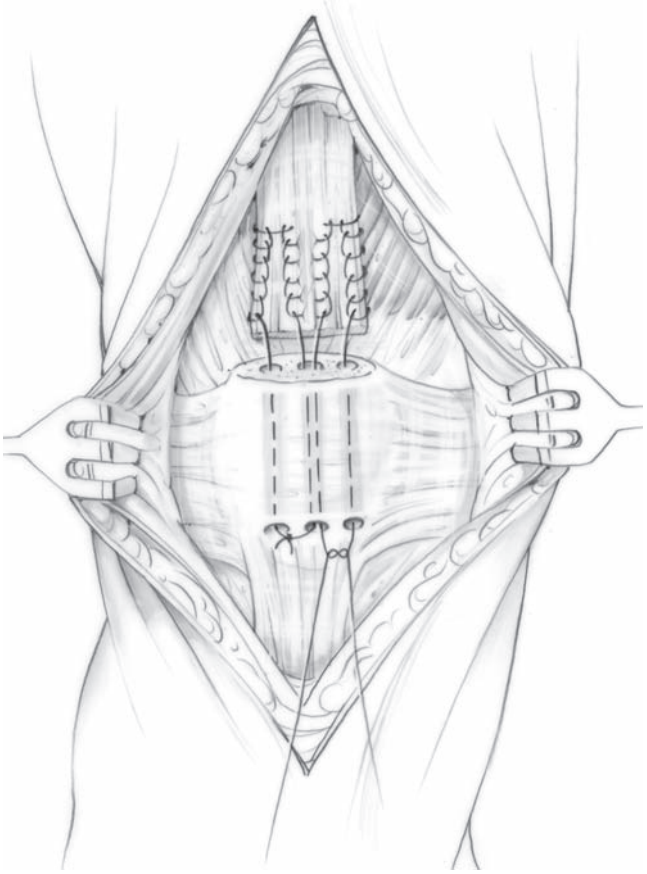

FIGURE 18.2

Bunnell suture technique is shown alone in the midportion of the quadriceps tendon.

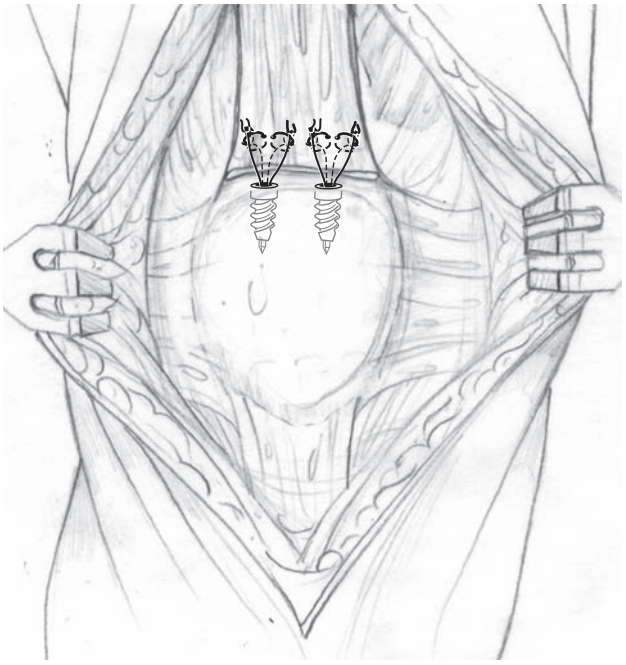

FIGURE 18.3

The final appearance of the Krackow-Bunnell weave technique before the sutures are tied.

Pearls and Pitfalls

Using the Krackow and Bunnell technique together adds strength to the repair. Using combined suture techniques also alleviates potential shortening that is a risk with the Bunnell suture technique alone. It should also be noted that débridement of the proximal pole of the patella and visualization of the patellar surface, particularly the intra-articular and extra-articular cortices, are a key element of this technique because it allows for

greater accuracy in anchor placement. It is important to ensure that the anchors hold firmly within the patella by pulling proximally on all sutures before the stitches are placed in the tendon. Another key point is to drill toward the dorsal cortex of the patella so that potential cartilage damage is avoided if an anchor were to pull out of the bone (11).

Tension across the repair is minimized by first obtaining full extension of the knee, deflating the tourniquet, and pulling the tendon distally prior to tying the final sutures to the patella. It is also important to evaluate anatomic alignment of the quadriceps tendon and patella to help prevent future patellofemoral complications. Repair of the lateral retinaculum can be omitted and a more extensive lateral release performed, if there is a need to restore patellar alignment.

POSTOPERATIVE MANAGEMENT

Rehabilitation

A good rehabilitation program is important after quadriceps tendon repair. It is beneficial for patients to take an early and active role in their recovery. Postoperatively, the leg is kept locked in extension with a long leg brace and the patient allowed partial weight bearing with crutches. The patient is expected to begin straight leg raises and isometric quadriceps strengthening as part of their home exercise program. At 2 weeks, the patient starts physical therapy with gentle passive range of motion exercises to the flexion limits noted in surgery. At 3 weeks, the patient is allowed full weight bearing with the brace locked in full extension. When at rest, the patient is encouraged to unlock the brace and work on passive range of motion exercises. At 6 weeks postoperatively, active range of motion exercises are introduced. The patient is now allowed to ambulate with the brace unlocked up to their maximum active flexion range. If progressive increases of 10 to 15 degrees/wk are obtained, the patient should obtain full range of motion by 12 to 16 weeks. At this time, patients may begin full resistance exercise and move on to light jogging. At 20 weeks, patients may return to full running.

COMPLICATIONS

After quadriceps tendon repair, most patients gain full range of motion; however, extension lag may occur (5). Prolonged atrophy of the quadriceps muscle is not uncommon and patients should not be discouraged as it is usually not associated with overt weakness compared to the nonoperative leg.

RESULTS

Following quadriceps tendon repair, most patients return to preinjury level of activity (5). Results are favorable after quadriceps tendon repair, but some degree in loss of strength and muscle mass is inevitable. Loss of motion is not a common complication (5). Although most patients return to previous activities of daily living and occupational activities, return to competitive sports after quadriceps tendon repair is rare (2) Rigorous, extended physical therapy is necessary for complete recovery after quadriceps tendon repair. Delayed diagnoses and surgical repair may lead to increased weakness and disability postoperatively.

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19 Patellar Tendon Repair

Albert M. Tsai

INDICATIONS/CONTRAINDICATIONS

Isolated rupture of the patellar tendon is a rare injury occurring primarily in patients <40 years old. Most ruptures occur as the result of a rapid forceful contraction of the quadriceps muscle with a flexed knee, and a history of stumbling or giving way of the knee can often be elicited along with a sudden pop and acute onset of pain. It has been demonstrated that normal tendons usually do not rupture without significant trauma (4). A certain degree of tendon degeneration is often present, the result of cumulative microtrauma or the degenerative changes associated with aging. The injury can also be associated with systemic diseases such as chronic renal failure, rheumatoid arthritis, systemic lupus erythematosus, or diabetes mellitus and occurs with little or no trauma in these patients. Rarely, iatrogenic patellar tendon rupture has been reported after harvesting the middle third of the tendon for anterior cruciate ligament reconstruction (1,6).

Surgical repair of an acutely ruptured patellar tendon is the standard of care and is necessary to reestablish continuity of the extensor mechanism of the knee. Neglected injuries can lead to proximal retraction of the quadriceps and patella with resultant adhesions and extensor mechanism insufficiency. Contraindications to acute surgical repair include acute infection, medical comorbidities that make the surgical risk prohibitive, and soft tissue loss that makes primary repair impossible.

PREOPERATIVE PLANNING

The first step in assessing the injured knee is a thorough history and physical examination. There is generally swelling and ecchymosis about the knee as well as tenderness along the patellar tendon or at the inferior aspect of the patella. There may also be a palpable defect in the tendon. Occasionally, the patient will be able to perform a straight leg raise maneuver through an intact extensor retinaculum. However, the diagnosis should still be apparent as there will usually be an extensor lag and weakness when compared to the uninjured extremity.

Imaging of the knee should include routine roentgenograms to rule out fractures. On a lateral view of the knee, patella alta can be seen (Fig. 19.1). Magnetic resonance imaging (MRI) is not usually necessary in acute injuries but may be helpful in chronic neglected ruptures, in those few acute cases where the diagnosis is unclear, or to diagnose suspected concomitant intra-articular pathology (Fig. 19.2).

SURGERY

Patient Positioning

The patient is placed in the supine position, and a small bump is placed under the ipsilateral hip to keep the patella pointing toward the ceiling. A tourniquet is placed on the proximal thigh but is usually not inflated during the procedure. The entire extremity is then sterilely prepped and draped free.

Technique

A midline skin incision is made centered over the defect in the patellar tendon. If the disruption is an avulsion off the inferior pole of the patella, the incision may extend more proximally; in the case of a midsubstance tear or tibial tubercle avulsion, the incision may extend more distally. Routine dissection is carried sharply down

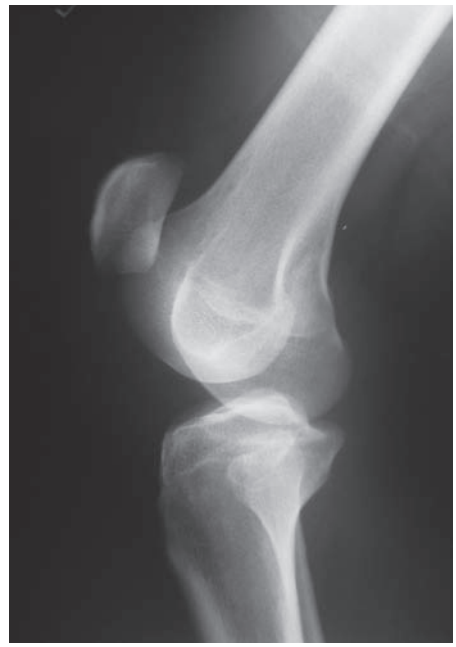

FIGURE 19.1

Lateral roentgenogram of patellar tendon rupture demonstrating patella alta.

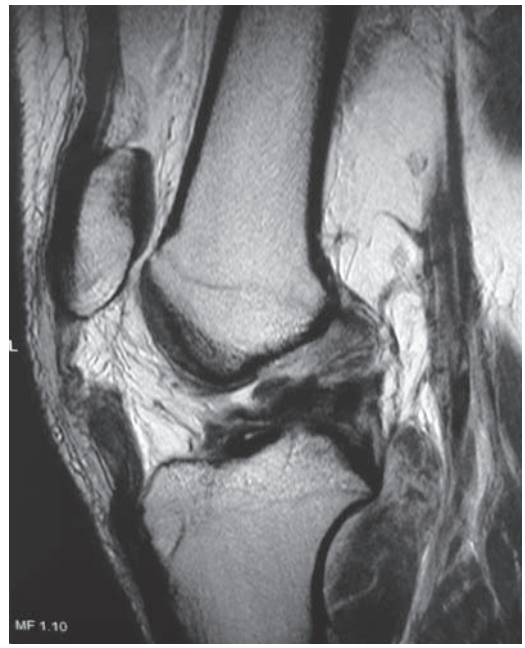

FIGURE 19.2

MRI clearly shows disruption of the patellar tendon. MRI was performed in this patient because of associated injuries to the anterior cruciate ligament, posterior cruciate ligament, and posterolateral corner.

through skin and subcutaneous tissue. At this point, the knee joint is frequently visualized through the ruptured tendon. The joint is thoroughly irrigated to remove old hematoma and soft tissue debris, and the articular surfaces can be examined for any injury. If possible, the paratenon should be identified and incised in order to further dissect out the patellar tendon in preparation for repair.

Most commonly, the patellar tendon is avulsed from the inferior aspect of the patella, along with tears of the medial and lateral retinaculum (Fig. 19.3). The frayed, tattered stump of patellar tendon is sharply débrided with dissecting scissors or a sharp scalpel in order to freshen up the tendon and remove any nonviable tissue. Next a Rongeur is used to débride the inferior pole of the patella, removing soft tissue remnants and providing a healthy bleeding bone surface for the repaired tendon. A total of two 2 FiberWire sutures are woven into the end of the tendon, using a Krackow-type locking stitch. One suture is woven into the medial half of the tendon, working from proximal to distal and then back up in the medial central portion of the tendon. The second suture is similarly woven down the lateral half of the tendon and back up the lateral central portion of the tendon, leaving four suture strands exiting the tendon (Fig. 19.4). These sutures are marked with hemostats so that they can

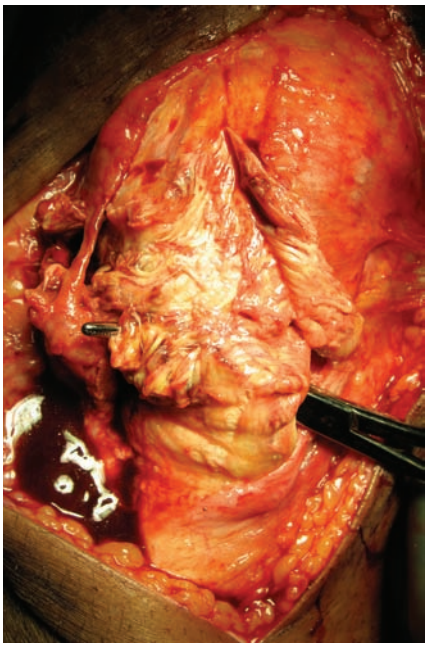

FIGURE 19.3

In this patient, there is a near complete avulsion of the patellar tendon from the inferior aspect of the patella. The clamp lies behind the proximal patellar tendon.

later be passed through drill holes in the patella. For ease of identification, the central sutures can be cut shorter than the peripheral ones and clamped together (Fig. 19.5).

Next, a total of three parallel drill holes are made in the patella from distal to proximal, using a 2-mm drill bit. When drilling, the flat end of an Army-Navy retractor can be used to locate the drill bit as it exits the superior border of the patella and the quadriceps tendon (Fig. 19.6). After withdrawing the drill bit, often it is difficult to locate the hole in the superior aspect of the patella in order to place a suture passer from proximal to distal. Instead, a suture passer is used from distal to proximal in order to pass a loop of 0 PDS suture. This loop of PDS can then be used to pass the FiberWire sutures through their appropriate drill holes (Fig. 19.7). The lateral suture is passed through the lateral drill hole, the medial suture through the medial drill hole, and the two shorter central sutures through the central drill hole. After passing these sutures, they can be tied with the knee in extension, the medial suture to the medial central suture and the lateral suture to the lateral central suture (Fig. 19.8). The tendon should contact the previously prepared inferior pole of the patella, but care should be taken not to overtighten the repair and cause patella baja. If there is any question, an intraoperative lateral roentgenogram can be taken and compared to the contralateral knee.

The medial and lateral retinacular defects are then closed with 1 absorbable suture. 2-0 absorbable suture, as well as the subcutaneous layer, is used for the paratenon if possible, and surgical staples or a running subcuticular stitch is used to approximate the skin. A routine sterile dressing is placed and the patient is placed into a range of motion brace, which is locked in extension.

A similar surgical technique is used for patellar tendon disruption from the tibial tubercle, except the sutures are passed through transosseous tunnels in the tubercle and tied over medial and lateral bony bridges. For a midsubstance tendon rupture, direct tendon-to-tendon repair is performed with a total of four 2 FiberWire sutures—medial and lateral Krackow-type locking stitches in both the proximal and distal tendon stumps (Fig. 19.9). The patellar tendon suture line is oversewn with interrupted 2-0 absorbable suture. Retinacular repair and closure are the same as for proximal avulsion injuries.

Pearls and Pitfalls

- When drilling the three parallel drill holes, take care to start the holes closer to the articular surface rather than the dorsal surface of the patella. This will prevent inward tilting of the distal pole of the patella when the repair is tightened, which could lead to increased contact pressure in the patellofemoral joint.
- After drilling holes through the patella, it is difficult to pass a suture passer from proximal to distal. Use a suture passer from distal to proximal in order to pass a loop of 0 PDS. The loop can then be used to pass the FiberWire from distal to proximal.
- Overtightening the repair can lead to patella baja and a poor result. If in doubt, obtain an intraoperative lateral roentgenogram and compare to the contralateral knee.
- A good repair of the medial and lateral retinacular tissue is a key portion of the procedure. This relieves much of the stress on the central repair and allows for aggressive postoperative range of motion and strengthening.

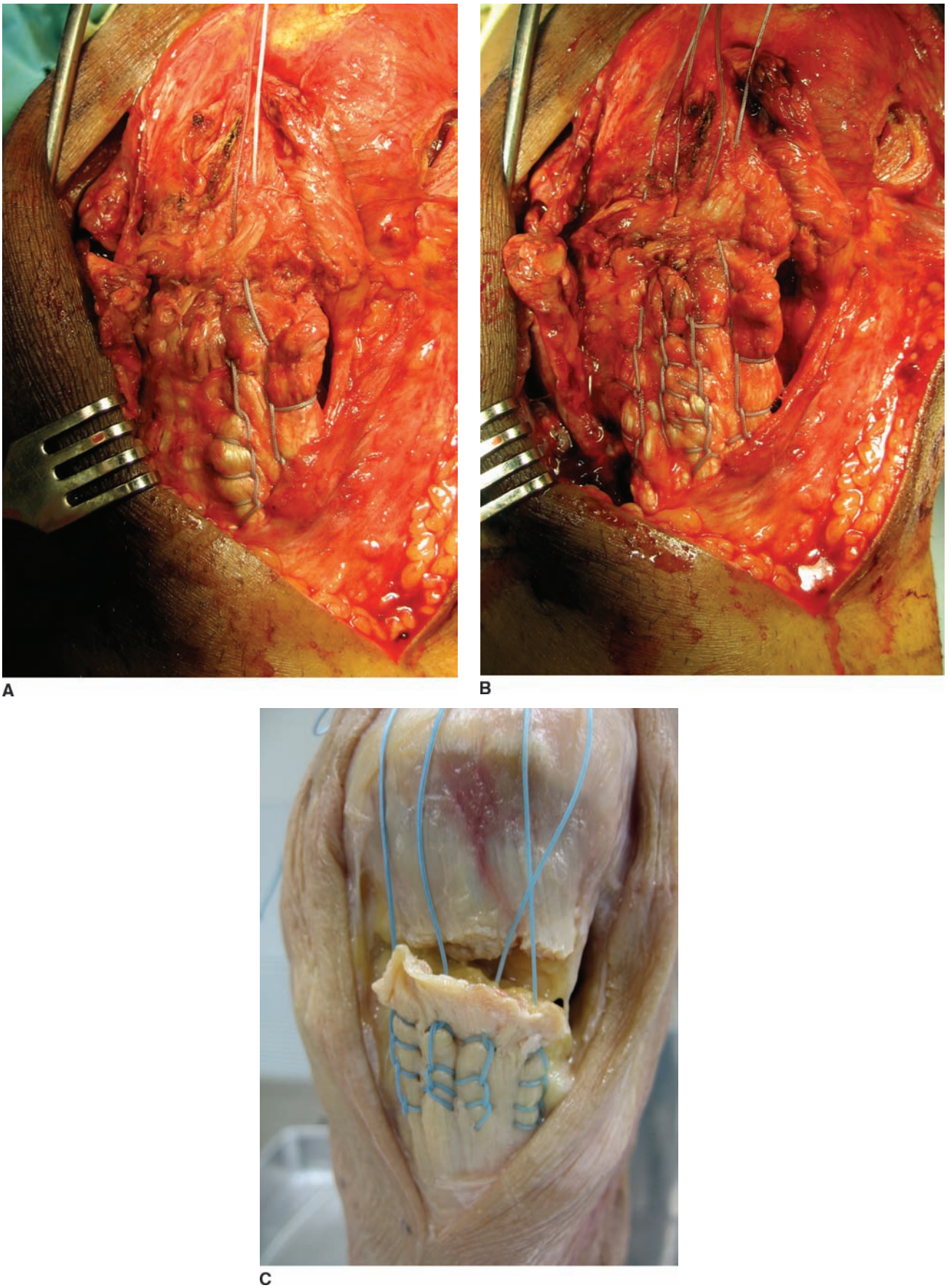

FIGURE 19.4

A,B: A 2 FiberWire suture is woven into the stump of patellar tendon using medial and lateral Krackow locking stitches. **C:** Cadaver specimen demonstrating medial and lateral Krackow locking stitches for patellar tendon rupture.

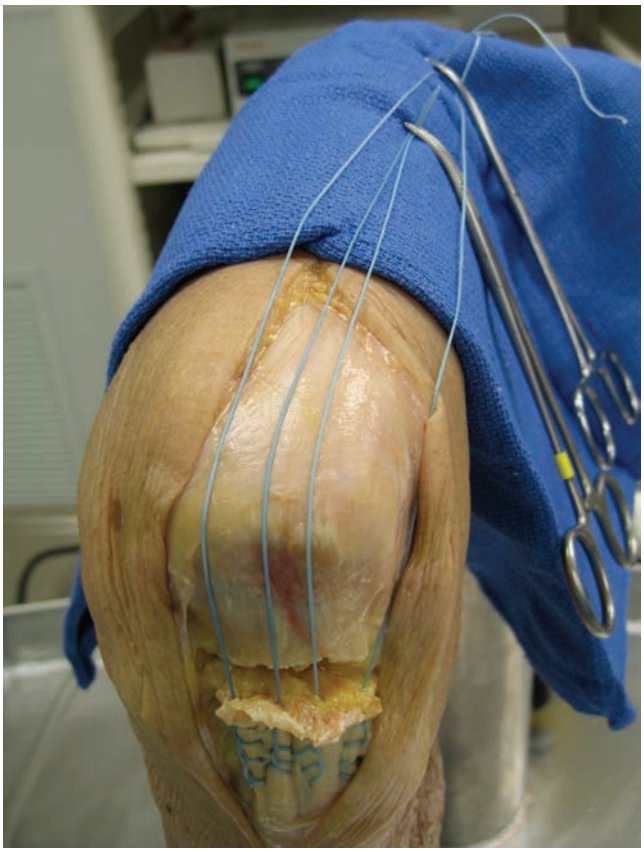

FIGURE 19.5

The central strands of the medial and lateral Krackow stitches can be cut short and clamped together for ease of identification.

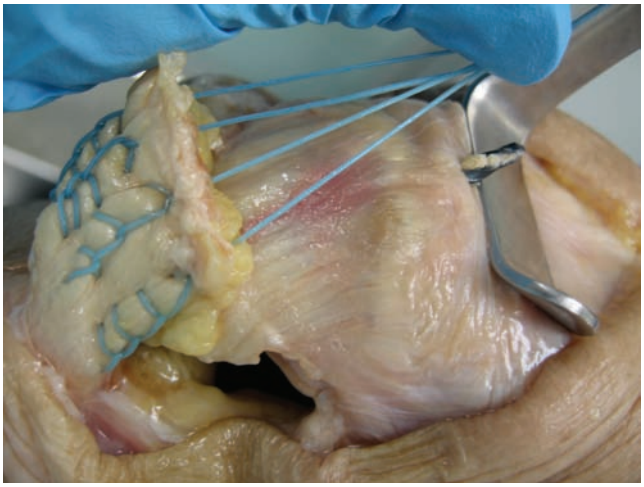

FIGURE 19.6

An Army-Navy retractor helps locate the exiting drill bit.

POSTOPERATIVE MANAGEMENT

Immediate full weight bearing is initiated after surgery with crutches and the range of motion brace locked in extension. Isometric quadriceps and hamstring exercises are also initiated on the first day after surgery. Surgical staples are removed in the office at 10 to 14 days after surgery at which time supervised physical therapy is begun with active flexion and passive extension of the knee. The range of motion is started at 0 to 30 degrees and advanced 30 degrees every 2 weeks with the goal of 90 degrees at 6 weeks. The range of motion brace is gradually unlocked to coincide with the increases in flexion allowed and is discontinued when 90 degrees of flexion is achieved at 6 weeks. A supervised strengthening program is then started, with full return to sports activity prohibited until 6 months after surgery or until the patient demonstrates full range of motion of the knee and at least 80% of the strength of the contralateral knee with isokinetic testing.

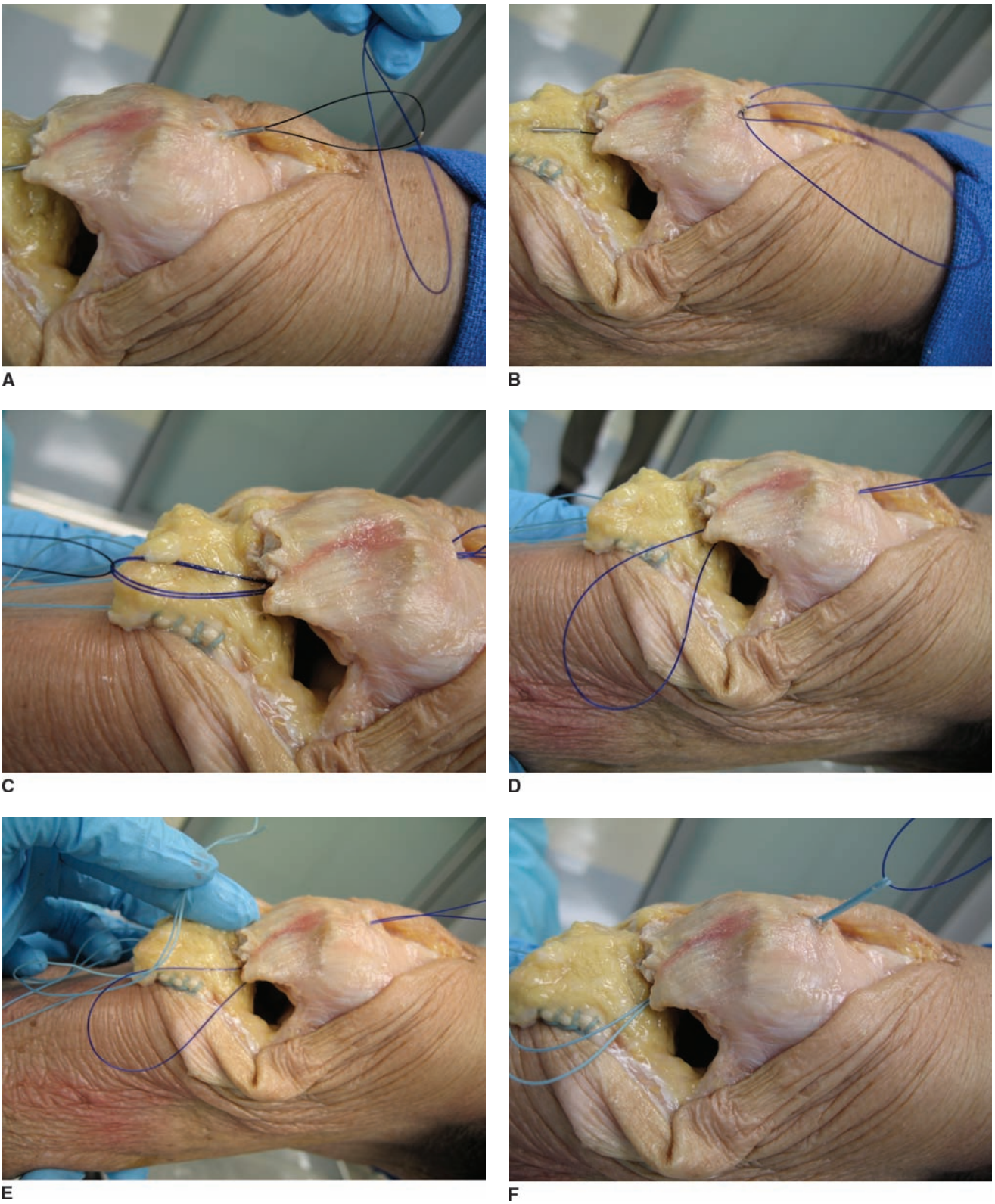

FIGURE 19.7

A: Hewson suture passer used from distal to proximal. **B–D:** Loop of 0 PDS suture passed from proximal to distal. **E,F:** FiberWire suture passed through drill hole using PDS loop.

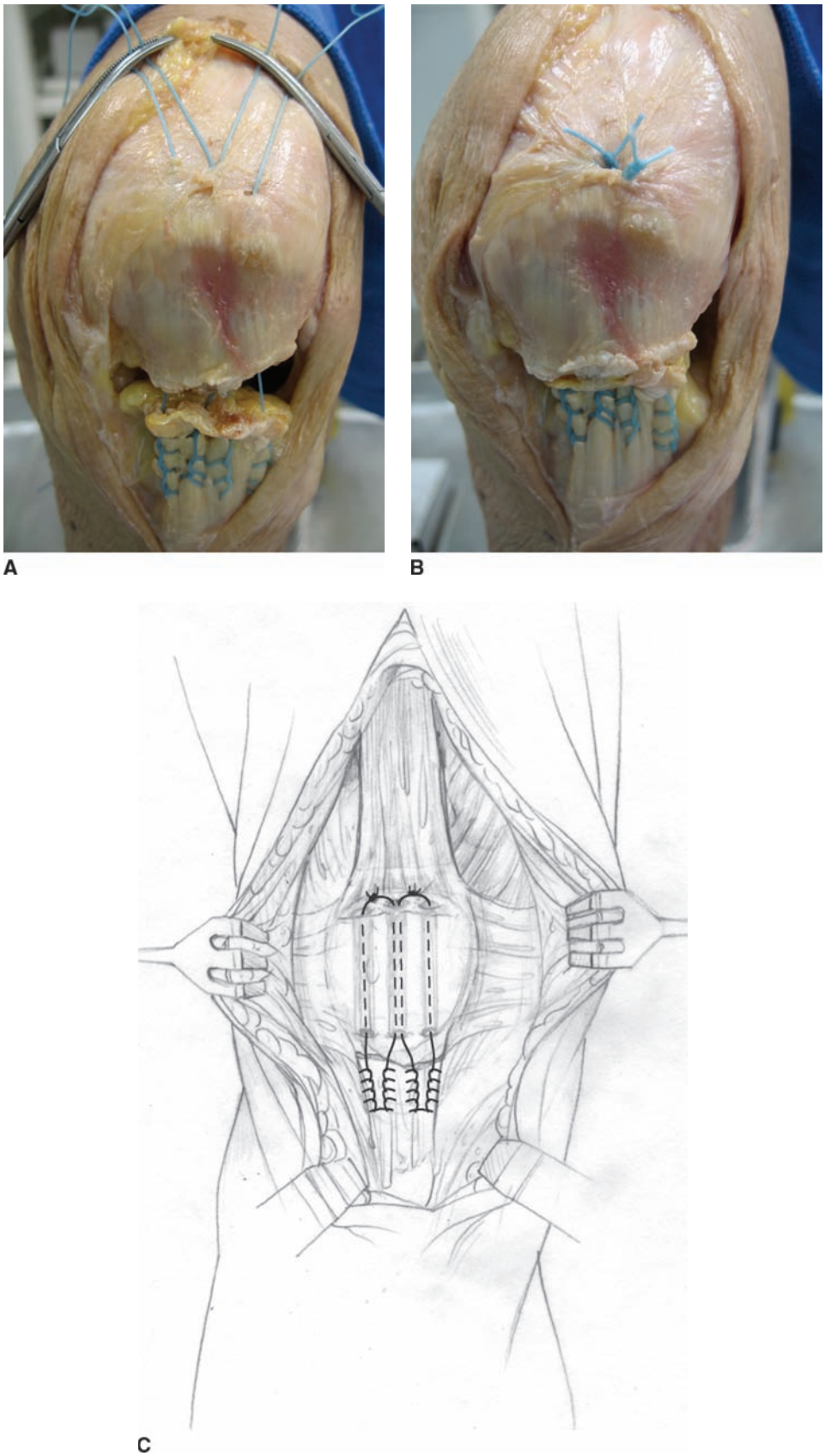

FIGURE 19.8

A,B: Cadaver specimen demonstrating patellar tendon repair with sutures passed through patellar drill holes. **C:** Schematic illustrating patellar tendon repair.

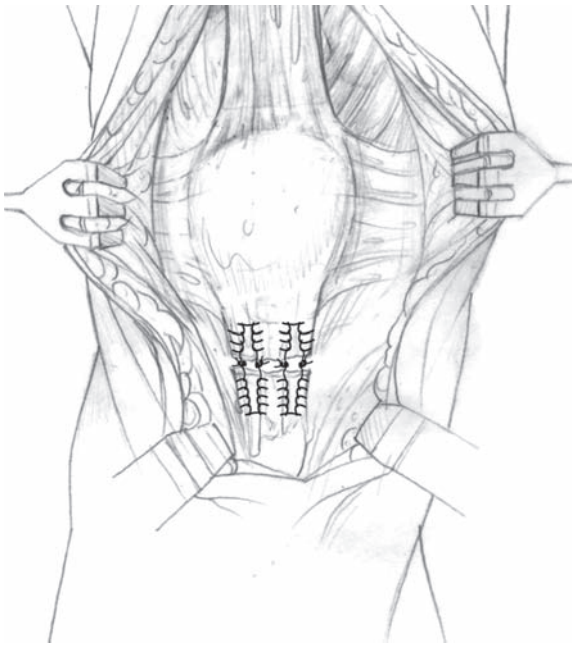

FIGURE 19.9
Schematic of midsubstance patellar tendon repair with sutures.

COMPLICATIONS

Decreased Motion

Decreased range of motion is most likely a result of the initial injury itself, rather than any technical problems related to the surgical procedure. To overcome this, a secure repair allows an aggressive postoperative therapy program emphasizing early range of motion and strengthening. Significant lack of motion at 2 to 3 months is uncommon with acute primary repair but can be treated with manipulation under anesthesia to improve flexion or arthroscopic lysis of adhesions for loss of passive extension.

Wound Problems

Wound dehiscence or infection is uncommon, but may occur distally, where skin coverage is the thinnest. Local wound care and appropriate antibiotics if necessary are usually sufficient to resolve these problems.

Hemarthrosis

Postoperative bleeding may cause an uncomfortable hemarthrosis, which usually resolves spontaneously but can limit mobility and progress with postoperative physical therapy. Meticulous hemostasis during surgery can help prevent this problem. If a tourniquet is used, this should be deflated and hemostasis achieved prior to wound closure.

Missed Diagnosis

Delayed treatment of a neglected patellar tendon rupture will often necessitate reconstruction of the extensor mechanism. Lack of adequate soft tissue and native tendon often precludes primary repair, and quadriceps muscle contracture and adhesions often prevent the patella from being brought distally to an acceptable position. During the preoperative evaluation, a lateral roentgenogram should be obtained of the contralateral knee to be used in estimating patellar height during the reconstruction.

Patient positioning is the same as for acute repair cases. A generous midline incision is used in order to fully delineate the anatomy and address the quadriceps contracture. If significant patella alta is present, the quadriceps mechanism may need fractional lengthening with a pie-crusting technique or formal V-Y advancement. Either Achilles or patellar tendon allograft can be used to reconstruct the extensor mechanism in the absence of acceptable native tissue.

When using Achilles tendon allograft, a rectangular plug of calcaneus with attached Achilles tendon is press fit into a matching rectangular trough made in the tibial tubercle. This bone plug is fixed with 4.5-mm bicortical screws. The soft tissue of the Achilles tendon is then split into two grafts and brought through two transosseous patellar tunnels and sewn into the quadriceps mechanism (Fig. 19.10).

Alternatively, patellar tendon allograft allows bony fixation on both the tibial and the patellar sides. A large rectangular plug from the allograft tibia is inserted into a matching trough in the patient's tibial tubercle and

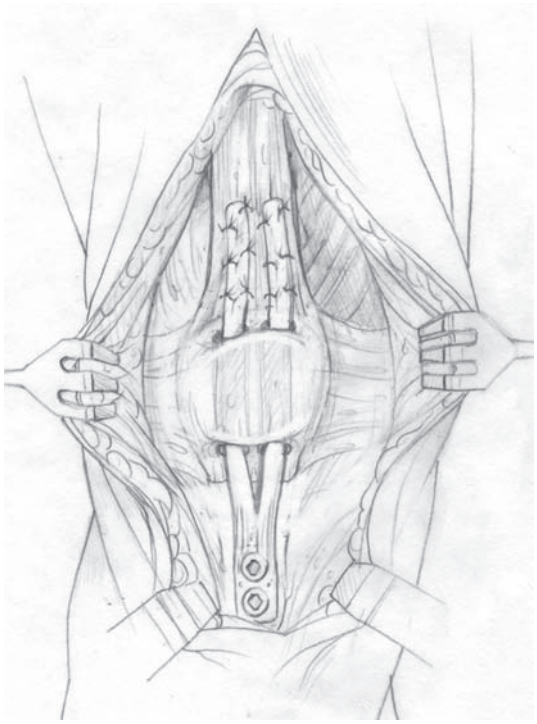

FIGURE 19.10

Achilles tendon allograft for patellar tendon reconstruction. The calcaneal bone plug is fixed with 4.5-mm screws. The soft tissue is passed through 7-mm transosseous tunnels and sutured to the quadriceps mechanism.

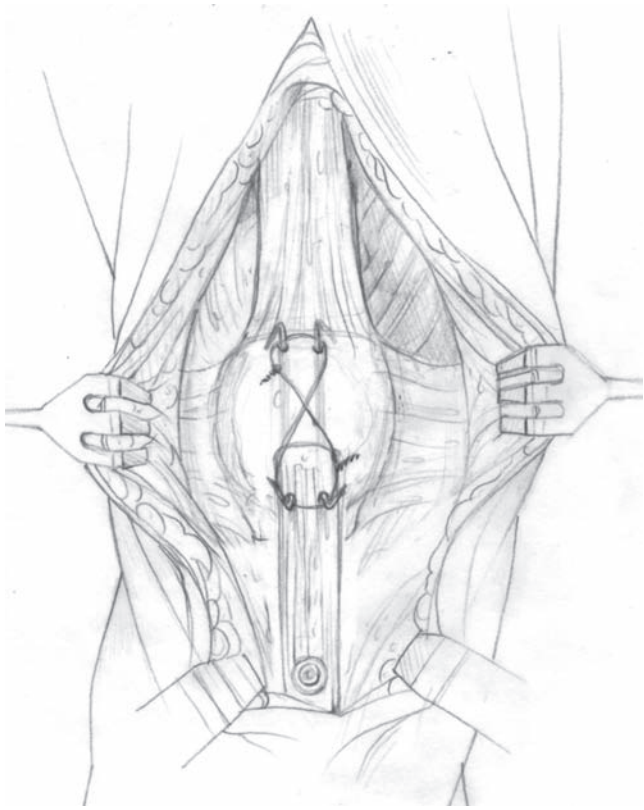

FIGURE 19.11

Schematic of patellar tendon reconstruction using patellar tendon allograft.

fixed with 4.5-mm bicortical screws. On the patellar side, the inferior pole of the patient's patella is removed to match a large portion of the inferior pole of the allograft patella that has been left with the graft. Naturally, the appropriate size and length patellar tendon allograft must be selected during the preoperative planning, which can be facilitated with a lateral roentgenogram of the contralateral knee. Patellar fixation is achieved with Kirschner wires or cannulated 4.0 mm screws and a figure-of-eight tension band wire or 5 nonabsorbable suture (Fig. 19.11).

With reconstruction of chronic tears, a 5 nonabsorbable suture or 5-mm Mersilene tape placed through a transosseous drill hole in the tibial tubercle and then up and over the patella through the quadriceps mechanism will help relieve stress on the repair. A cerclage wire accomplishes the same task but frequently breaks when range of motion is initiated, occasionally necessitating removal.

RESULTS

Results after patellar tendon repair are most closely correlated with the amount of time that has passed between injury and surgical treatment. The overwhelming majority of patients who undergo timely primary repair of an acute patellar tendon rupture will have excellent results, with full range of motion and normal quadriceps strength. Mild quadriceps atrophy may persist but should not affect the return of strength. The results for patients that undergo delayed reconstruction are less satisfactory, with loss of full knee flexion and a decrease in quadriceps strength more likely. However, a functional extensor mechanism can still be reestablished.

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20 Meniscal Débridement

Michael Shin and Geoffrey S. Baer

INTRODUCTION

Much has been learned about the anatomy and function of the meniscus since 1897 when Bland-Sutton described the meniscus as "functionless remnants of intra-articular leg muscles" (6). Since that time, there has been a significantly better understanding of the meniscus's multiple important roles in load bearing, joint stability, shock absorption, proprioception, and lubrication (22).

Meniscal tears can occur from both acute injuries and from chronic degeneration. The exact incidence of meniscal tears is difficult to ascertain due to the high number of asymptomatic tears and the high rate of degenerative tears in patients with advanced degenerative joint disease. It is estimated that the incidence of acute meniscal tears in the United States is approximately 61/100,000 persons per year. An epidemiologic study from Europe estimated the incidence of meniscal tears to be about 60 to 70/100,000 persons (24,44). Meniscal tears are found more commonly in males, a ratio of 2.5:1 to 4:1, and up to one third of tears are associated with anterior cruciate ligament (ACL) injuries (16,49).

The classification of meniscal tears can be based on tear location, blood supply, or by tear pattern (Fig. 20.1). The classification of the tear, in addition to other patient and tear characteristics, assists in the process of deciding the appropriate treatment. Meniscal tears can also be found in meniscal variants, the most common of which is a lateral discoid meniscus. Arthroscopic studies have shown a prevalence of discoid menisci ranging from 0.4% to 16.6% and most are typically discovered incidentally, as they are usually asymptomatic. Discoid menisci are more common in patients of Japanese or Korean descent and can be bilateral in up to 20% of patients (5,30).

With an increased understanding in the importance of the meniscus and in preserving as much functional meniscal tissue as possible, meniscal repair has become an increasingly important option for the treatment of meniscal tears. The possibility of meniscal repair should be considered when evaluating meniscal injuries, especially in young, active patients with or without concomitant ACL reconstructions. However, some meniscal tears are not amendable to meniscal repair due to meniscal degeneration, tear location and pattern, limited vascular supply, or patient age. In these settings, meniscal repair can be impossible or unlikely to heal, and meniscal débridement is the treatment of choice for these patients with symptomatic meniscal tears. Arthroscopic meniscal débridement has become one of the most common orthopedic procedures performed in the United States today, and the AAOS estimates that over 636,000 arthroscopic knee procedures are performed each year (50).

INDICATIONS/CONTRAINDICATIONS

Arthroscopic intervention for meniscal tears are typically for patients who have failed nonoperative management that includes activity modification, physical therapy, and pain medication. Patients will typically have joint line pain and mechanical symptoms such as locking, catching, and giving way that affect activities of daily living, participation in sports, and work.

Meniscal tears in young patients and tears associated with ACL reconstructions should have a meniscal repair if possible. However, many tears found during surgery are not amendable to repair, in which case, a partial meniscectomy that removes unstable fragments and creates a smooth transition, while maintaining as much functional meniscus, should be undertaken (41).

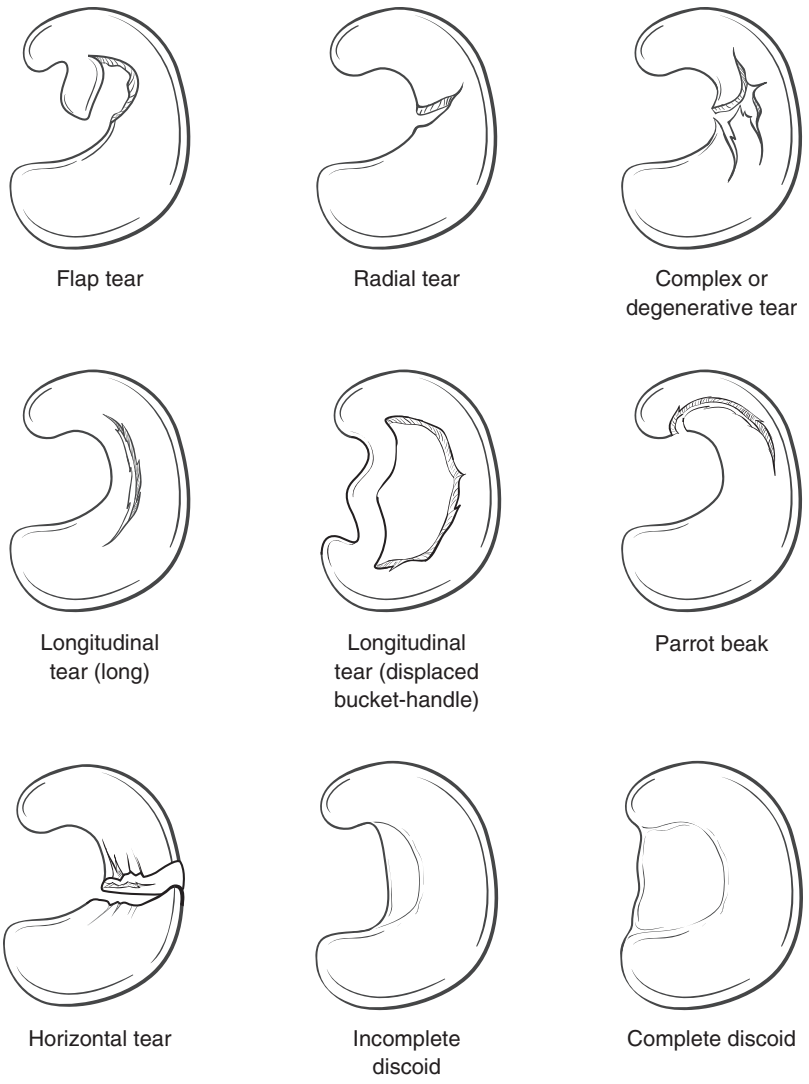


FIGURE 20.1
Common types of meniscal tears and meniscal variants.

Meniscal tears, especially degenerative tears, increase with increasing age and surgical intervention is contraindicated for asymptomatic patients with tears on imaging studies. A study evaluating one hundred patients with an average age of 43 years with a magnetic resonance imaging (MRI) of asymptomatic knees showed a 37% prevalence of meniscal tears (64). Also, patients with degenerative meniscal tears in the setting of significant degenerative joint disease may obtain minimal benefit from arthroscopic meniscal débridement, and arthroscopic intervention should be undertaken only after exhausting nonoperative management. Degenerative changes and damage to the articular cartilage found at the time of arthroscopic partial meniscectomy had the greatest impact on long-term outcome and correlated with significantly worse functional outcomes at 12 year follow-up (26,54).

Another advancement in the current management and treatment of meniscal tears is demonstrated by the further understanding of the importance of preserving as much functional meniscal tissue as possible, without leaving unstable flaps or abrupt transitions. This evolution in philosophy is demonstrated by our current management when contrasted to past treatment of meniscal tears evidenced by McMurray, who in 1942 stated, "a far too common error is shown in the incomplete removal of the injured meniscus" (38). The effects of this type of treatment for meniscal tears were described a short time later by Fairbank who in 1948 described the radiographic "changes in the knee joint after meniscectomy" including "ridge formation, narrowing of the joint space, and flattening of the femoral condyle" (19). Other studies have further delineated the importance of preserving the meniscus through demonstration of decreased contact areas and increased peak contact stresses after partial and total meniscectomies and by showing worsening radiographic progression of osteoarthrosis in patients with <50% meniscal rim remaining compared to patients with >50% meniscal rim remaining after arthroscopic partial meniscectomy (4,26). Another study demonstrated the importance of maintaining the peripheral circumferential meniscal fibers in order to preserve the ability of the meniscus to resist hoop stresses. By retaining the periphery of the meniscus, there was a decrease in mean contact pressures, while loss of this peripheral meniscus, resulting in a segmental meniscectomy, was functionally equivalent to a total meniscectomy. This cadaveric study demonstrated that this peripheral portion of the medial meniscus had a greater

contribution to increasing contact area and decreasing mean contact stresses than the central portions (36). Clinically, Northmore-Ball et al. (45) reported significantly worse outcomes in patients who had undergone open total meniscectomies compared to the arthroscopic partial meniscectomy group with 68% versus 90% good to excellent results.

PATIENT EVALUATION (HISTORY, PHYSICAL EXAMINATION, AND RADIOGRAPHIC EVALUATION)

A complete history and physical exam is essential when evaluating any patient with knee pain and possible meniscal pathology. Patients with meniscal tears typically complain of pain localizing to the joint line, swelling, locking, catching, giving way, and loss of motion. The mechanism of injury often is a twisting or hyperflexion injury that presents with acute pain and swelling. In a study of patients with normal radiographs and a meniscal tear at arthroscopy, Drosos and Pozo (16) reported that approximately 32% of the tears occurred during a sporting activity, 39% were sustained during nonsporting activities, the majority of which were during activities of daily living most commonly squatting, and 29% had no identifiable mechanism.

Physical exam usually demonstrates a patient with a joint effusion, pain in deep flexion, or pain with squatting. With a flipped bucket-handle meniscus tear, patients may have a mechanical block to motion, typically full extension. Specialized tests for meniscal tears include joint line palpation, McMurray test, and the Apley grind test; however, these tests have been reported to have poor sensitivity, specificity, and positive predictive values, especially in isolation (17,39,62). Joint line tenderness with palpation is the most sensitive of the physical examination tests and has 74% sensitivity. A positive McMurray test with a palpable "clunk" at the joint line is very specific for a meniscal tear with 98% specificity but is only 15% sensitive, and pain alone with a McMurray test makes the test more sensitive but less specific. A positive Apley grind test has a sensitivity of 60% and a specificity of 70% (25,40,59). Patients with discoid menisci may present with the classic presentation of a "snapping knee," but this is the least common presentation. It usually presents as lateral sided joint pain of insidious onset in a child or young adolescent (30). Physical examination should also include a ligamentous examination to assess for ligamentous damage and instability and an examination for degenerative joint disease.

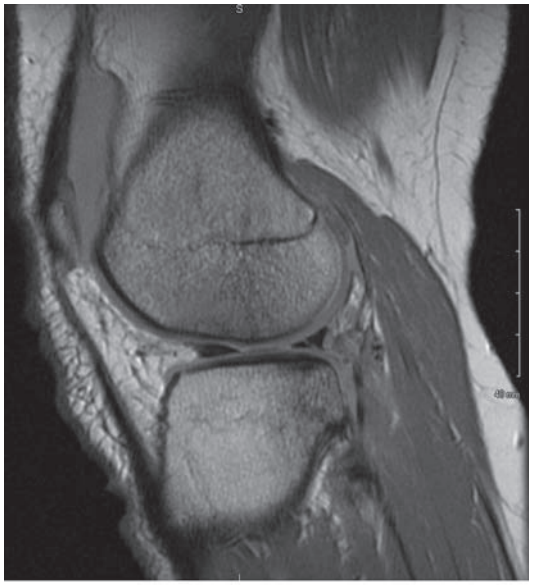
Diagnostic studies are used to supplement and confirm diagnosis made through history and physical exam. Standard radiographs do not confirm a diagnosis of meniscal tears but are very important in evaluating the knee for joint space narrowing, calcification of the meniscus, and degenerative changes. The 45-degree posteroanterior flexion, standing weight-bearing radiograph is more sensitive for evaluating joint space narrowing, and full-length standing radiographs may also be utilized to evaluate overall limb alignment (51). Radiographs of a patient with a discoid meniscus are frequently normal but may have subtle findings of a widened lateral joint space, cupping of the lateral tibial plateau, or flattening/squaring of the lateral femoral condyle (30).

MRI may be utilized to accurately evaluate tear location, tear pattern, and associated ligamentous and chondral pathology (Fig. 20.2). The limitations of MRI include its high cost and potential for misinterpretation, especially due to normal increased signal in the meniscus found in children and with increasing age in adults. Despite this potential for error, advances in technology and experience have increased the accuracy of MRI in diagnosing meniscal tears to 95% or better (43). Another consideration when evaluating MRI includes the high rate of positive readings in asymptomatic individuals (7,35). Therefore, MRI should be used as a diagnostic tool to supplement the clinical diagnosis. Discoid menisci are often found incidentally on MRI, and there are characteristic findings on both the sagittal and the coronal planes. In the sagittal plane, three or greater contiguous 5-mm sections that show the classic "bow-tie" appearance representing continuity of the anterior and posterior horns are diagnostic for a discoid meniscus. In the coronal plane, when viewing a image from the midpoint from anterior to posterior, revealing the free edge of the lateral meniscus to extend past the midpoint of the femoral condyle or further toward the intercondylar notch is suggestive of a discoid meniscus (30).

SURGICAL TECHNIQUE (GENERAL, POSITIONING, TECHNIQUE)

Meniscal débridements have transitioned from total meniscectomies performed open to the current treatment of arthroscopic partial meniscectomies. Open total meniscectomies were originally thought to be benign procedures and were commonly performed for all types of meniscal pathology. However, as more has been learned about the long-term sequelae of open total meniscectomies and with the improvement of arthroscopic techniques, this procedure has fallen out of favor.

Arthroscopy can be performed under many forms of anesthesia including general, regional, and local based on multiple factors including length and type of procedure, patient's medical conditions, and the preferences of the patient, surgeon, and anesthesiologist (11,12,55,63). After adequate anesthesia has been achieved, the



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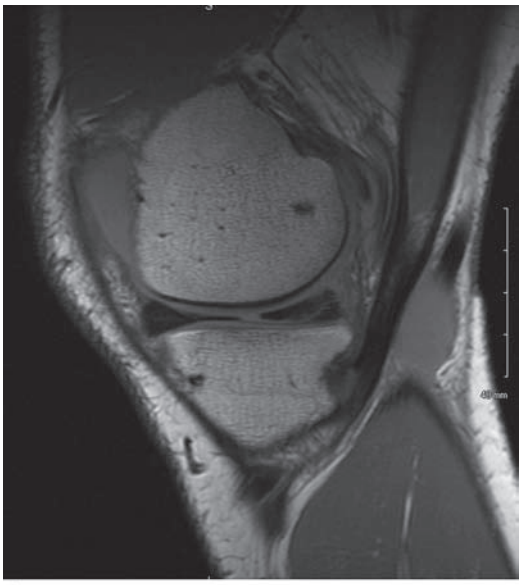

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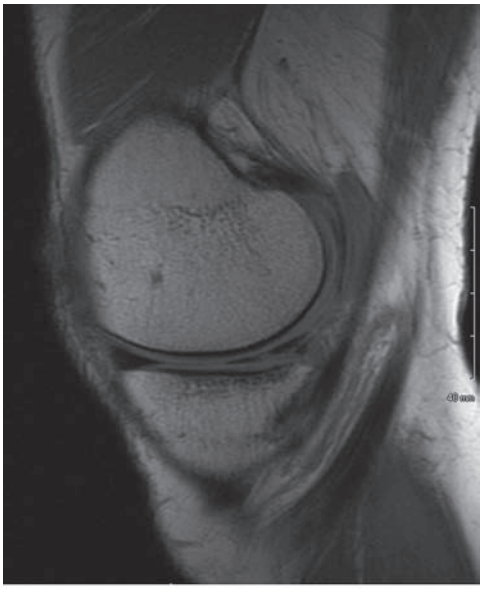

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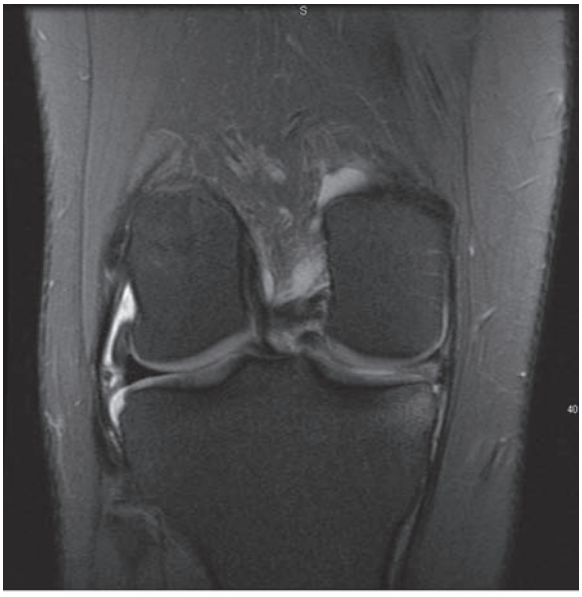

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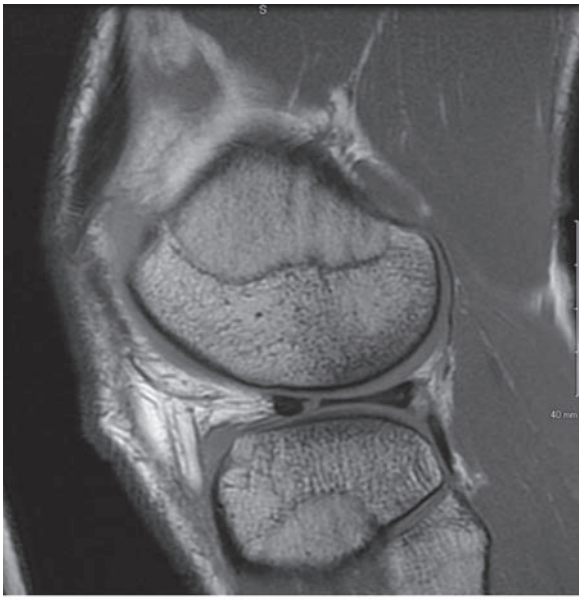

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FIGURE 20.2

MRI images demonstrating meniscal tears **A:** Tear of the posterior horn of the lateral meniscus. **B:** Horizontal tear of the posterior horn of the medial meniscus. **C:** Complex tear of the posterior horn of the medial meniscus. **D:** Displaced bucket-handle tear of the medial meniscus. **E:** Radial tear of the posterior horn of the lateral meniscus.

procedure begins with an examination under anesthesia (EUA). This exam utilizes the ability to get a thorough examination with the patient relaxed and without causing patient discomfort. The examination should evaluate for the presence of an effusion, passive range of motion (ROM), a Lachman test, anterior and posterior drawer tests, a pivot shift, varus and valgus testing at full extension and at 30 degrees of flexion, a Dial test, and examinations for patellar instability. Upon completion of the EUA, the patient is then positioned for the arthroscopic portion of the case. The patient is positioned supine on the operating room table, and care is taken to adequately pad the contralateral peroneal nerve and all bony prominences. A well-padded tourniquet is placed on the upper thigh of the operative leg but is typically not required unless necessary for visualization (34). Two common methods of setup include the use of a lateral post or leg holder, which help to assist the surgeon in positioning and manipulating the leg intraoperatively.

If the lateral post technique is used, the patient is positioned supine on the operating room table and the post is placed at the level of the tourniquet at approximately the level of the mid to upper thigh. A footrest can be secured to the bed and allows the leg to rest at 70 to 90 degrees of flexion and can be used with or without a bump under the ipsilateral hip. The lateral post assists in placing a valgus force through the knee, and advantages include better access to both posterior and superior accessory portals and the ability to rest the leg on the table when the knee is in full extension. A foot rest or hanging the leg off the side of the operative table assists with holding the leg when the knee is in flexion. The lateral post also has the advantages of not acting as a venous tourniquet and not fixing the thigh in place and therefore allowing more flexibility in positioning the leg, including in the figure-four position (Fig. 20.3).

When using the leg holder technique, the patient is positioned supine on the operating room table and the patient's thigh is placed so that the knee is past the break of the table so that the bed does not block the ability of the knee to flex. The leg holder stabilizes the thigh while the foot of the table is dropped and the operative leg hangs free (Fig. 20.4). The nonoperative leg is then placed into a padded well-leg holder. The foot of the patient's operative leg can be placed on the surgeon's hip and then be manipulated into varus and valgus. Exsanguinating the leg by elevating the tourniquet prior to placement of the leg holder can help prevent venous bleeding. Proponents of the leg holder remark that it allows for greater valgus stress to be placed across the knee and therefore provides better visualization and access to the posteromedial joint. However, extra attention must be taken during patient positioning to assure that the leg holder is proximal on the thigh to not block access to accessory portals and to allow the knee to maximally flex. Proper positioning can be especially difficult in heavy patients with short thighs. The leg holder should also not be overtightened to avoid it acting as a venous tourniquet, which can be a significant concern during longer procedures.

Once the patient has been properly positioned, the leg is prepped and draped, and a diagnostic arthroscopy is performed to identify all areas of intra-articular pathology. Joint expansion with arthroscopy fluid can be achieved through different methods, and the inflow and outflow can be brought into the joint in different locations. Some surgeons prefer water pressure through gravity flow while others choose a pump device. Also, both inflow and outflow can be placed on the arthroscope cannula or an accessory superolateral or superomedial portal can be utilized (3,47).

The standard portals for knee arthroscopy are utilized for meniscal débridement. The standard anterolateral viewing portal and anteromedial working portal are placed in the soft spots approximately 1 cm above the corresponding medial or lateral joint line and roughly 1 cm medial or lateral to the corresponding border of the patellar tendon. These portals are usually made as an approximately 1-cm vertical incision with the blade of the scalpel turned upward away from the meniscus. Some surgeons use horizontal anterolateral and anteromedial portals, and these should also be approximately 1 cm in length with the blade turned away from the patellar tendon to decrease the risk of iatrogenic injury. Proponents of horizontal anterior portal placement cite studies that suggest less iatrogenic nerve injury due to the anatomic route of the infrapatellar branches of the saphenous nerve as it traverses the knee (42,61). However, transverse portals have the disadvantage that they cannot be made extensile. Regardless of the type of incision, the portals should be made aiming toward the femoral notch to avoid iatrogenic articular cartilage damage. The anteromedial portal is made under direct visualization with the arthroscope in the anterolateral portal and portal position should be localized using an 18-gauge spinal needle, observing the path of the needle such that optimal access to pathology may be achieved. Superomedial or superolateral portals placed with the knee in full extension approximately 25 mm above superior pole of patella and far enough from the midline to avoid the quadriceps tendon. These portals can be used for inflow, outflow, or as a viewing or working portal. Both the posteromedial and the posterolateral accessory portals should be placed under direct visualization, again with a localizing 18-gauge spinal needle that allows optimal portal placement for accessing pathology. The posteromedial portal should be above the joint line and posterior to the medial collateral ligament, and the posterolateral should be posterior to the lateral collateral ligament, anterior to the biceps femoris tendon and above the joint line. These posteromedial and posterolateral portals can be used during meniscal débridement as both viewing and working portals and are especially useful for loose bodies and some posterior horn and root tears. Risks to placing the posterior accessory portals include risk to the saphenous nerve and vein with the posteromedial portal and the peroneal nerve with the posterolateral portal (33). Care must be taken when positioning the patient, especially with the use of a leg holder, because poor patient positioning can make access to these posterior and superior accessory portals difficult.

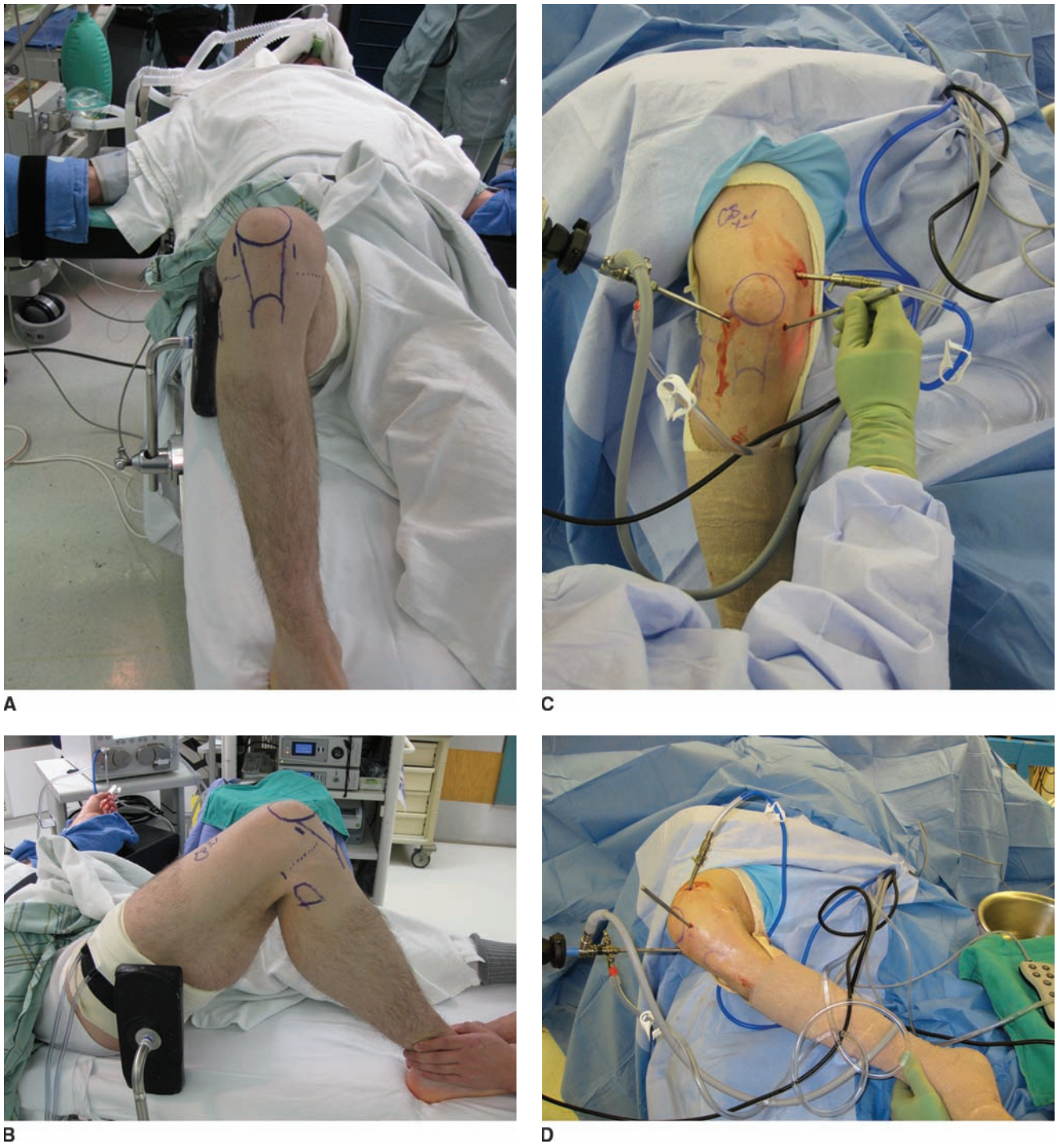
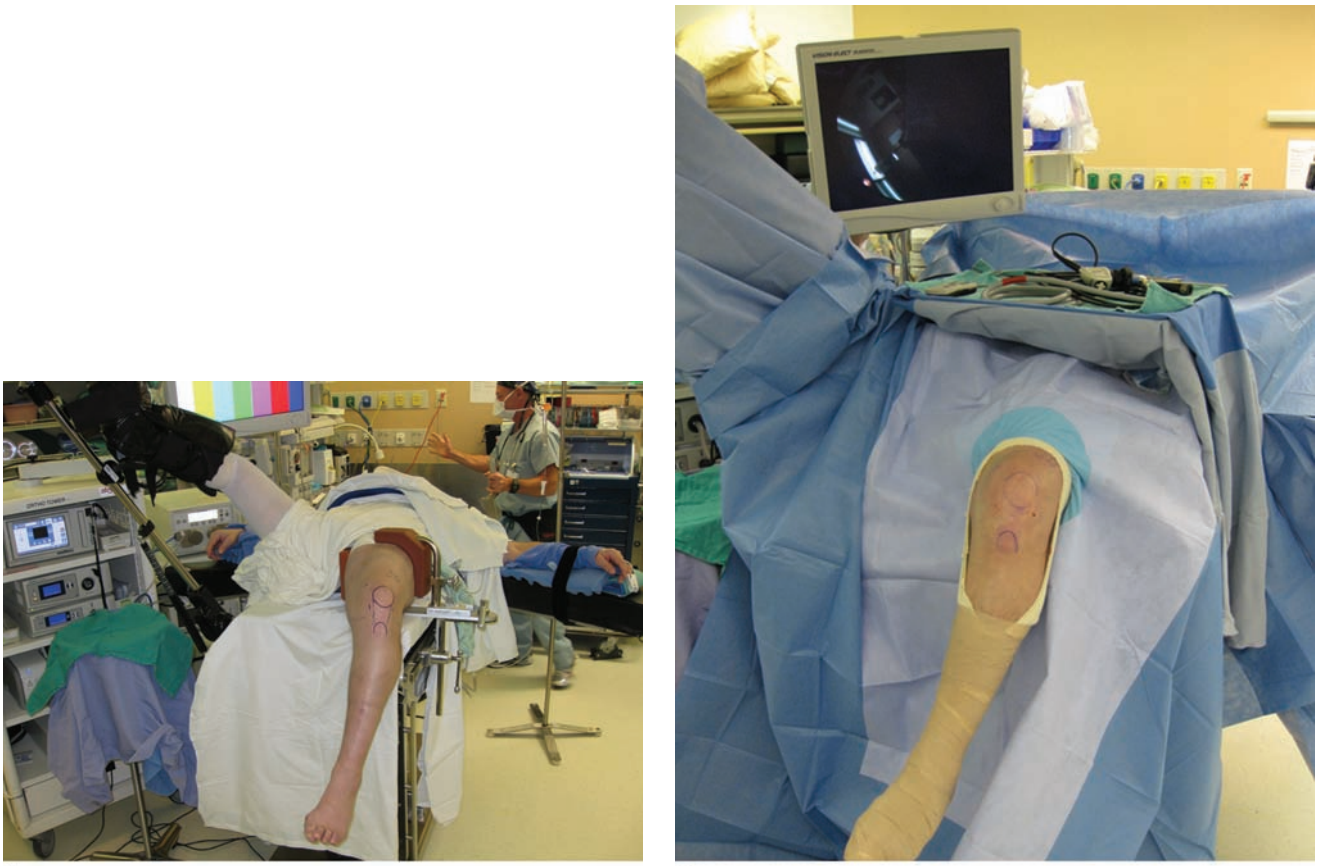


FIGURE 20.3

Lateral post technique. **A:** Anterior view. **B:** Lateral view with the post positioned at the upper thigh. **C:** Operating with knee in flexion **D:** Operative leg placed in figure four position.

Before any arthroscopic knee procedure, including meniscal débridement, a thorough diagnostic arthroscopy should be completed to identify all areas of pathology. The procedure begins by establishing the anterolateral portal and then inserting the cannula with a blunt introducer through the portal while the knee is at 90 degrees of flexion. After the cannula passes into the joint capsule, the knee is extended and the arthroscope is placed into the suprapatellar pouch. Some surgeons who use either a superolateral or a superomedial accessory portal for either inflow or outflow may establish this portal first. The blunt trochar is then removed and a 30-degree arthroscope is placed, and a systematic evaluation is undertaken viewing the undersurface of the patella, the trochlea, and the patellofemoral articulation. The suprapatellar pouch is also thoroughly visualized looking for



A B

FIGURE 20.4

Leg holder technique. **A:** Patient positioned utilizing the leg holder. **B:** After draping, the operative leg is able to hang free.

synovitis, adhesions, and loose bodies. The lateral trochlear ridge and lateral gutter should be examined starting from the patellofemoral joint to the lateral compartment by bringing the knee from full extension into flexion. The popliteal tendon and peripheral aspect of the lateral meniscus can be evaluated as well as examined for the presence of loose bodies, adhesions, and osteophytes. After viewing the lateral gutter, the arthroscope is brought back into the patellofemoral joint and the medial ridge of the patella and the medial trochlear groove are evaluated. The medial gutter is evaluated from the suprapatellar pouch to the medial compartment while the knee is slowly brought from full extension to 90 degrees of flexion. The presence of pathologic plica, osteophytes, loose bodies, and synovitis should all be evaluated and noted. The anteromedial portal should now be established under direct visualization with the help of an 18-gauge localizing needle for optimal placement. The No. 11 blade is then used to make the anteromedial portal and should be visualized to assure that the joint capsule is incised and that the blade does not cause iatrogenic injury to the anterior horn of the meniscus or the articular cartilage. A straight hemostat can be used to help clear and expand the portal. The medial compartment is then examined from anterior horn to posterior horn and root. The knee can be placed into valgus and external rotation to improve visualization of the medial compartment and to allow space for the arthroscope. The meniscus should be probed for tears of the superior and inferior surface, for abnormal translation, and for root avulsions (60). If a meniscal tear is present, it should be thoroughly examined with the use of a probe to determine the type, location, size, and stability of the tear. The femoral and tibial articular surfaces should be evaluated and examined from full flexion to full extension to evaluate the entire chondral surface. If chondral defects are present, the probe should be used to test for flaps and stability and to determine the size of the defects.

The intercondylar notch is evaluated next and the probe is used to examine the ACL, posterior cruciate ligament (PCL), intermeniscal ligament, and meniscofemoral ligaments. In some patients, an enlarged ligamentum mucosum may need to be débrided to allow access through the intercondylar notch and into the lateral compartment.

The lateral compartment is typically viewed with the arthroscope viewing through the anterolateral portal and the knee placed into flexion and a varus stress in the figure-four position. For greater varus stress, an assistant can lift the lateral aspect of the ankle off the table while the leg is in the figure-four position and/or place a hand on the medial aspect of the patient's operative knee or thigh and direct a force toward the lateral aspect of the patient's operative knee. After the knee has been positioned to optimally open the lateral compartment,

the arthroscope is brought from the intercondylar notch into the compartment. It is sometimes necessary to débride parts of a hypertrophic fat pad or an enlarged ligamentous mucosum in order to visualize the lateral compartment. Once in the compartment, the joint surfaces, meniscus, and popliteal tendon should be carefully examined. Any articular pathology or meniscal tears should be probed to define the extent and characteristics of tears and flaps in the same fashion as on the medial side. The articular surfaces should be examined through a full ROM to examine the entire surface for pathology (15).

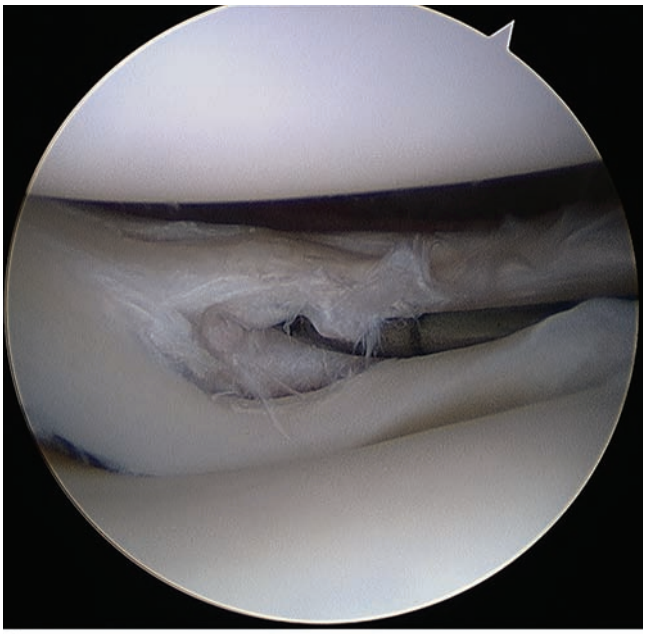
If posterior compartment pathology is suspected, the posteromedial and posterolateral compartments should be examined. To visualize the posteromedial compartment for loose bodies and to view the posteromedial meniscus, the arthroscope can be passed through the intercondylar notch between the PCL and the medial wall of the intercondylar notch against the medial femoral condyle using the modified Gillquist maneuver (21). The arthroscope is replaced by the blunt trochar to facilitate passage of the cannula into the posteromedial compartment with the knee in 90 degrees of knee flexion and valgus stress to the knee. Once the cannula has been passed into the compartment, the blunt trochar is exchanged for the 30- or 70-degree scope for visualization. If needed, an accessory posteromedial portal can be established under direct visualization using a localizing 18-gauge needle. Once the localizing needle is in optimal position, an incision is made through just the skin to decrease the risk of injury to the saphenous nerve and vein, and the portal is completed with the use of a straight hemostat to penetrate the joint capsule and expand the portal. The established posteromedial portal can be used for both visualization and as a working portal.

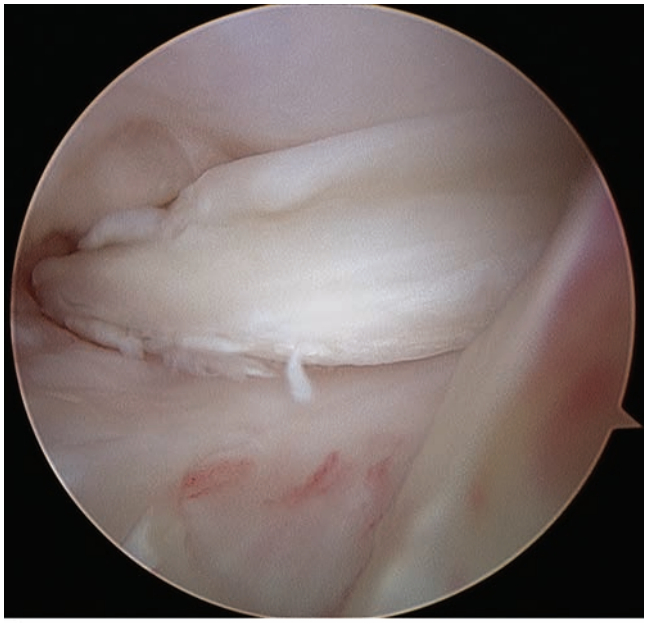
The examination of the posterolateral compartment is through a similar maneuver where the arthroscope is brought into the knee through the anteromedial portal and directed into the intercondylar notch inferior to the ACL, and along the lateral wall of the notch. The arthroscope is replaced by a blunt trochar and with the knee in 90 degrees of flexion and a varus stress onto the knee is advanced into the posterolateral compartment. The blunt trochar is then exchanged for a 30- or 70-degree scope. An accessory posterolateral portal can be created, if necessary, under direct visualization using a localizing 18-gauge needle for proper portal placement. The No. 11 blade is used for skin incision and the straight hemostat is used to penetrate the joint capsule and expand the portal. This accessory portal can be used as both a working and a visualization portal.

Once the diagnostic arthroscopy has been completed and a tear has been identified, the tear should be more carefully evaluated to determine if the tear is repairable and if the meniscal tissue has a high probability to heal (Fig. 20.5). This evaluation should take into account, not only the characteristics of the tear: type, location, size, and stability, but also the age and activity level of the patient, degeneration of the chondral surfaces or the meniscal tissue, the alignment and stability of the joint, and any concurrent procedures that may improve meniscal healing, such as an ACL reconstruction (23). The patient's desires regarding postoperative recovery and return to work should also be determined prior to surgery. Meniscal débridement should be undertaken if the determination is made that meniscal repair is not possible. For most tears, meniscal baskets and arthroscopic shavers should be used to resect all mobile fragments while preserving as much functional meniscus as possible (Fig. 20.6). A wide array of instruments are available for meniscal débridements that assist in accessing the various locations where tears of the meniscus can occur. The typical instruments used for meniscal tears are an up-angled basket for tears of the posterior horn of the medial meniscus and a straight basket for tears of the lateral meniscus. For tears of the midbody and anterior horn of the medial meniscus, one technique is to switch to the anteromedial portal as the viewing portal and use the straight basket through the anterolateral portal to access the tear. Other specialized baskets include back biters, narrow, 45-degree angled, and right angle baskets, available in left and right (Fig. 20.7). The angled baskets and back-biting baskets may also be particularly useful for tears in the midbody of the medial meniscus and tears to the medial or lateral anterior horns. Shavers of various sizes are also available for meniscal débridements and should be selected based on the space available for the instrument (Fig. 20.8). Angled shavers may also be appropriate to optimize the ability to reach some meniscal tears. The remaining meniscal tissue should be contoured to leave a stable meniscal rim with smooth transitions to decrease the risk of retearing the meniscal remnants. The meniscal rim should be retained to maintain circumferential collagen fibers that preserve the meniscus's ability to absorb hoop stresses. After the partial meniscectomy is thought to be complete, the remaining meniscus should be reassessed and probed to confirm that the tear has been completely removed and that the remaining meniscus is stable (2,52,57).

For bucket-handle tears that cannot be repaired, a strategy frequently employed is to reduce the displaced tear back into normal position using a probe or blunt trochar. The posterior attachment is first resected to near completion, and then the anterior attachment is completely resected. The anterior tip of the meniscal fragment is then grasped and the remaining posterior attachment is then avulsed free; a twisting or rolling maneuver may assist in completing the transection. The remaining meniscus is then evaluated and smoothed. This method for resecting bucket-handle tears prevents the fragment from becoming a loose body and decreases the chance that the tear will displace into the posterior aspect of the knee on a posterior hinge if the anterior attachment is transected first (57) (Fig. 20.9).

Horizontal meniscal tears may be treated in two ways and its management is somewhat controversial as no good study was delineated which of the two methods is more advantageous. One method is a complete resection of both leaflets of the horizontal tear leaving a stable edge with the theoretic advantage of having a decreased risk of retearing. The other technique is to assess both the upper and the lower leaflets of the tear and





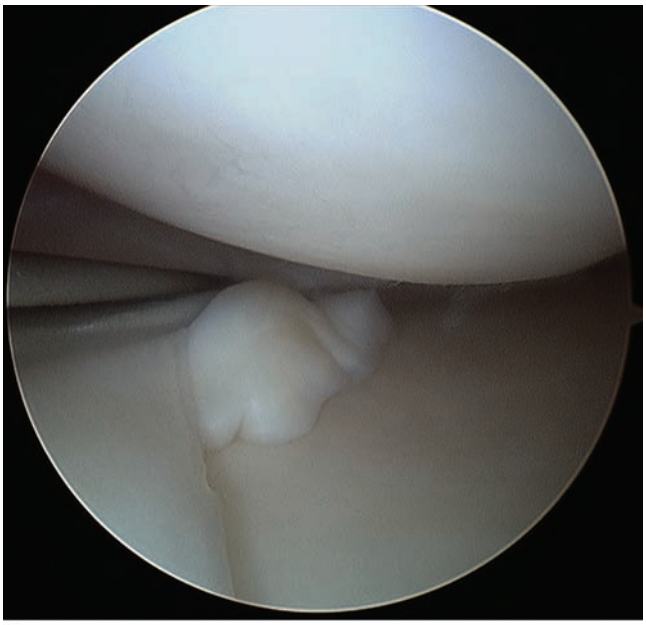


FIGURE 20.5

Arthroscopic images of meniscal tears. **A:** Complex meniscal tear. **B:** Displaced bucket-handle meniscal tear within the notch. **C:** An undersurface tear discovered upon inspection of the inferior meniscal surface.

then determining which leaf to preserve in order to retain as much meniscus as possible. Our preferred method is to attempt to preserve the more stable leaflet if possible, especially in younger patients.

The treatment for an asymptomatic discoid meniscus is observation. For a symptomatic tear in a patient with a discoid meniscus, the tear is resected and the meniscus is saucerized to a more "normal" shape (Fig. 20.10). For the patient with an unstable discoid meniscus, the unstable portion may need to be reattached, in addition to saucerization (30).

POST-OP MANAGEMENT

Postoperative management after arthroscopic meniscal débridement focuses on ROM, pain and effusion control, strengthening, and finally return to full activity. Weight bearing as tolerated can be started immediately postoperatively, and physical therapy and home exercise programs can be initiated within the first few days after surgery as soon as the patient is able to participate. Early therapy focuses on joint effusion control, ROM exercises especially achieving full extension, and quadriceps strengthening exercises. The judicious use of anti-inflammatory medications and use of icing can be very beneficial, especially in the early postoperative

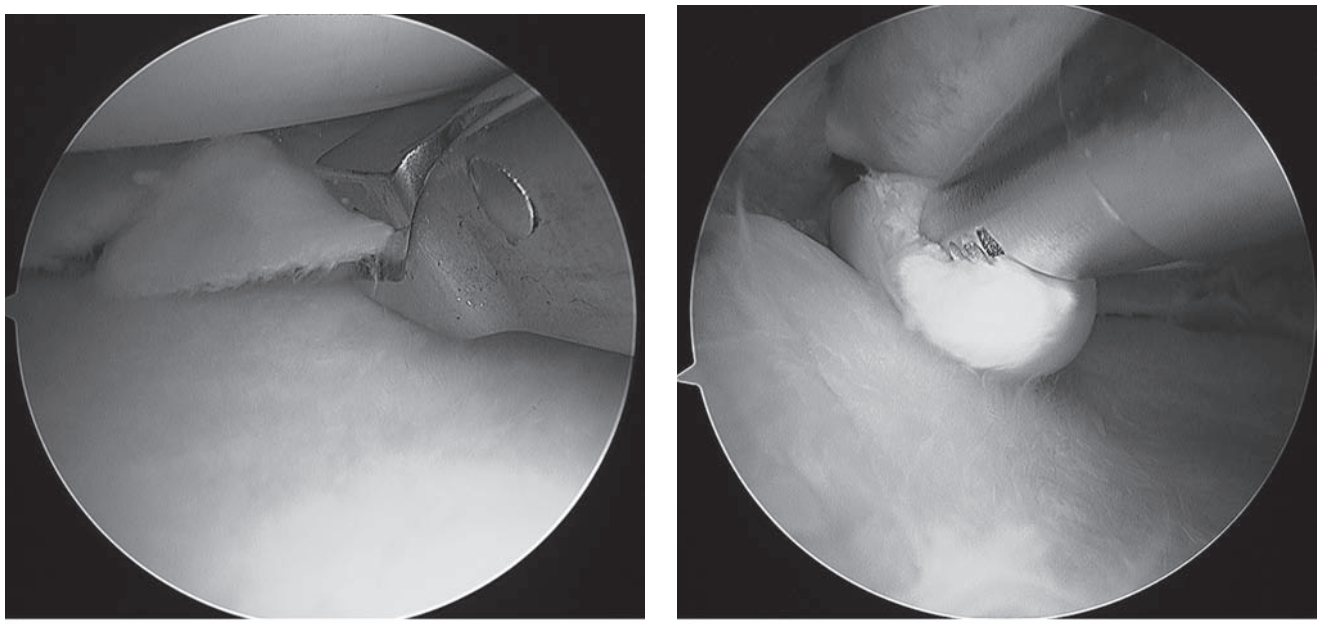


FIGURE 20.6

Arthroscopic instruments. **A:** Utilization of the biter during meniscal débridement. **B:** Use of a shaver during meniscal débridement.

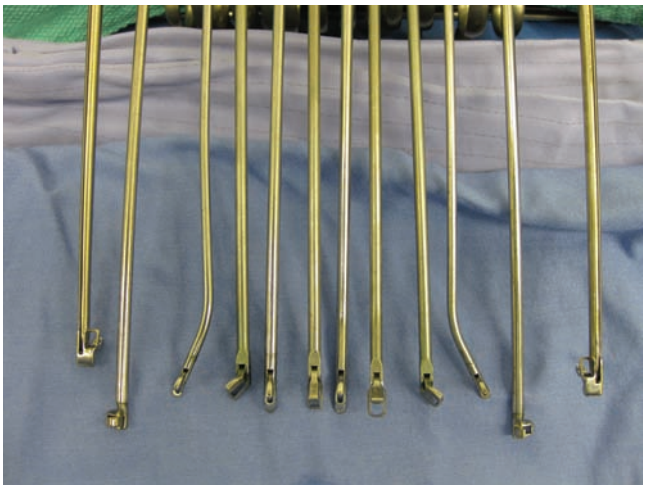


FIGURE 20.7

A variety of biters are available for resecting meniscal tears based upon tear location.

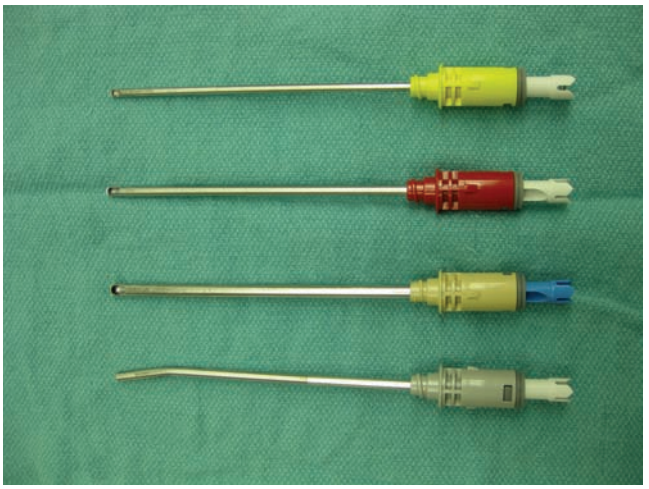


FIGURE 20.8

Shavers of various size and angle are available.

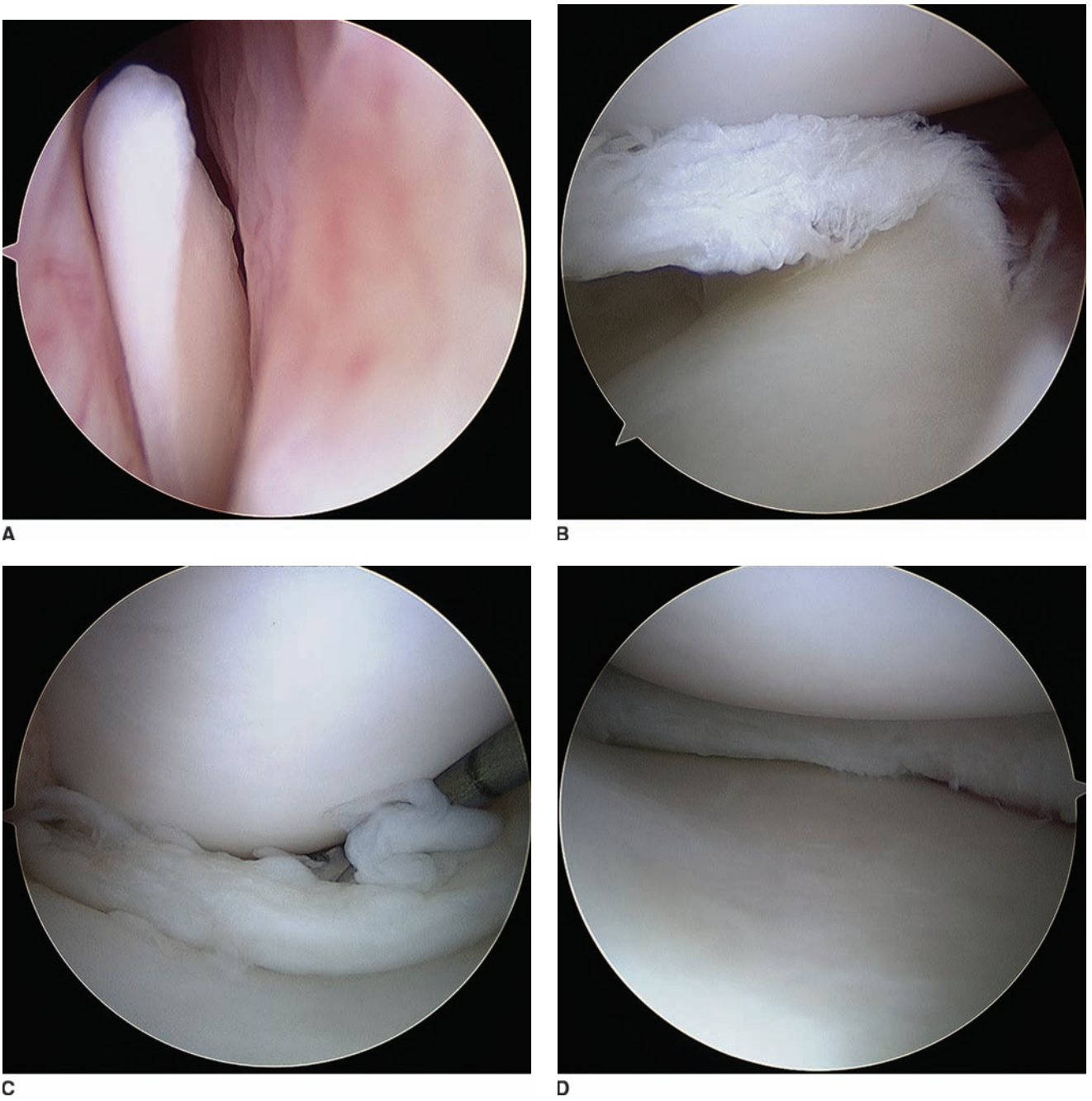


FIGURE 20.9

Partial meniscectomy of a displaced bucket-handle medial meniscus tear. **A:** Flipped fragment of meniscus in the medial gutter. **B:** Meniscal flap brought into medial joint. **C:** Posterior aspect of the complex tear **D:** Post partial meniscectomy.

period. Some surgeons will also provide crutches in the early postoperative period and/or cryotherapy, but both can be discontinued as soon as the patient is comfortable. The patient can advance therapy as the patient's symptoms and tolerance allow and with close monitoring of joint pain and effusions. The initiation of low-impact exercises and advancement to increasing impact and slow jogging can be accomplished with careful attention to the patient's symptoms and intra-articular effusions. The final step is to incorporate running, cutting, and sport-specific activities into the rehabilitation program. Once this final step is tolerated by the patient without pain or joint effusion, along with normal ROM and muscle strength, full return to sports and activity is permitted. The typical time frame for this return to full activity is typically 4 to 6 weeks but in our experience, can frequently be expected to take longer in patients with degenerative joint changes evident at time of arthroscopy and in patients treated for lateral meniscal tears (48).

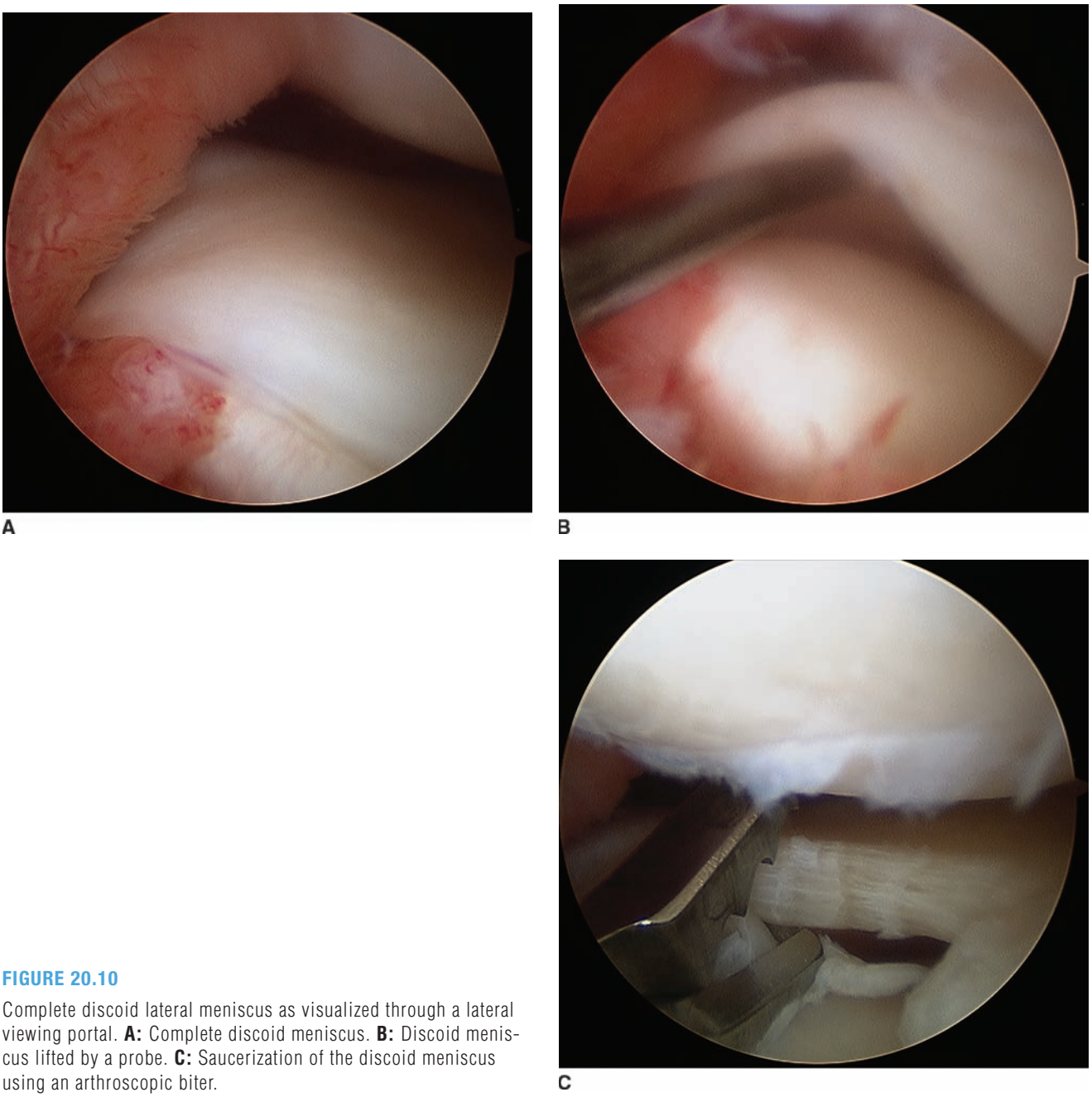


FIGURE 20.10

Complete discoid lateral meniscus as visualized through a lateral viewing portal. **A:** Complete discoid meniscus. **B:** Discoid meniscus lifted by a probe. **C:** Saucerization of the discoid meniscus using an arthroscopic biter.

RESULTS

Arthroscopic meniscectomies have significantly better clinical and radiographic results than their open counterparts, and partial meniscectomies performed arthroscopically have significantly better results than arthroscopic total meniscectomies. Patients with an arthroscopic partial meniscectomy had 90% good to excellent results compared to 68% good to excellent results in the open total meniscectomy group (1,45). The results of arthroscopic partial meniscectomies are generally very favorable with reported satisfactory and good to excellent results in the 80% to 100% range with short-term follow-up (1,28,37). Some studies have demonstrated worse results and higher rates of radiographic degenerative changes with partial lateral meniscectomies when compared to partial medial meniscectomies with rates of radiographic degeneration as high as 84% at 12.3 year follow-up after partial lateral meniscectomy (27,29,53). Long-term results following partial meniscectomies generally decline with time but are still favorable with reported satisfactory and good to excellent results in the 78% to 95% range (8,13,28,54). Two factors that have been shown to be prognostic for worse outcomes after partial meniscectomies are chondral injury evident at the time of meniscectomy and meniscectomies performed in ACL-deficient knees (8,26,37,46,54). Age and gender have not been proven to significantly

alter outcomes after partial meniscectomies, especially when age was separated from age-related degenerative joint disease (8,18,26).

COMPLICATIONS

Complications from meniscal débridement are similar to those of other arthroscopic knee surgeries and include iatrogenic cartilage injury, anesthetic complication, infection, deep venous thrombosis, and neurovascular injury. Postoperative stiffness, joint effusions/hemarthrosis, and residual pain can also be adverse outcomes post meniscal débridement. Overall, knee arthroscopy is a well-tolerated procedure with very low complication rates. In one study, the overall complication rate following an arthroscopic meniscectomy was 1.69%. The most common complications were hemarthrosis, infection, deep venous thrombosis, and anesthetic complications (14,32,56).

SPECIAL CONSIDERATIONS

Special considerations should be given when evaluating meniscal tears and determining the proper surgical intervention in certain patient populations, particularly younger patients, athletic patients, and patients with concomitant ACL tears. In these younger, more active patients, we preserve as much meniscal tissue as possible by attempting to remove the least amount of meniscus, while still resecting the tear. Athletes as a specific subgroup have not been extensively studied, but one longitudinal study showed significantly worse long-term results in this group of patients compared to most other long-term results in the general population with 89% of the athletes demonstrating radiographic degeneration at 14.5 years post meniscectomy. Athletes who had partial lateral meniscectomies did even worse than those who had partial medial meniscectomies (31). An ACL-deficient knee is a poor prognostic factor for outcomes in a postpartial menisectomy knee. However, due to increased healing rates with meniscal repairs with concurrent ACL reconstructions, reported as high as 93%, some meniscal tears that would normally be débrided should be considered for repair (9,10,58). Patients with certain types of tears including radial tears, flap tears, horizontal tears, and lateral meniscus tears also deserve extra attention. It can be more difficult in radial meniscal tears to assess tear depth and resect to the proper level to create a smooth transition. Flap tears were shown in one study to have a significantly longer time to return to sports, 20.1 weeks compared to 5.1 weeks, and a higher rate of repeat arthroscopy, 29% to 13%, when compared with bucket-handle tears (20). There is some controversy in the management of horizontal tears of the meniscus and whether a complete resection of the tear to a stable edge is preferable over assessing both the upper and the lower leaflets and retaining the larger or more normal appearing leaf in an attempt to retain meniscal tissue. No studies have compared these two techniques. Lateral meniscal tears have demonstrated in some studies to have slower return, higher rates of developing osteoarthrosis, and possibly worse clinical results (27,29,53). Finally, patients with degenerative articular changes are a special category due to worse outcomes in patients with articular changes at time of meniscectomy and slower recovery times.

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21 All-Inside Meniscal Repair

Brian Reiter and Steven B. Cohen

INTRODUCTION

Over the past decade, we have developed a more complete understanding of meniscus pathophysiology, mechanical properties and functions, repair site healing, and performance and limitations of the evolving all-inside repair techniques (1,10). Arthroscopic meniscal repair technology continues to improve as does our knowledge of the meniscus itself. As new advances are made and research is continued, indications for repair will expand. Over the past few decades, research has stressed the importance of retaining as much functional meniscal tissue as possible in order to maintain normal contact stresses at the articular surface. The importance of a clear and thorough understanding of the indications as well as the technology and techniques involved in treating this subset of meniscus tears is paramount in decreasing the number of patients who develop significant life-long morbidity as a result of these injuries.

Historically, the inside-out method of suture fixation had been the treatment of choice for a repairable meniscus and remains the gold standard by which all new devices are measured. All inside approaches have become more common over the past decade because of their decreased associated risks, shorter operating time, decreased morbidity associated with a larger incision, less need for trained assistants, and often ability to repair tears in anatomic locations difficult to reach by open techniques. However, most studies continue to find that all-inside devices perform inferiorly to traditional suture repair techniques in biomechanical studies (2,4,11,15). The clinical relevance of this is still undetermined and all-inside devices are increasing in popularity.

INDICATIONS

Indications for meniscal repair are similar regardless of technique. It is generally agreed upon that factors that are favorable for fixation include acute symptomatic tears, longitudinal orientation, peripheral red-red/red-white tears, tears >7 to 10 mm in length, unstable tears with >3 mm excursion, concomitant reconstructive surgery (anterior cruciate ligament (ACL) or articular cartilage), and patients who prefer this procedure over continued nonoperative treatment. Contraindications may include degenerative tears in older patients, chronic tears >3 months, avascular tears in the white-white zone, complex tear patterns, stable/incomplete tears, patients unable to comply with weight-bearing and motion restrictions, and associated infectious/rheumatologic/collagen vascular diseases.

Many find that tears of the anterior one third are still most easily and predictably repaired with outside-in or open techniques with all-inside techniques being reserved for more posterior tears and those involving the body. Posterior one third tears are more difficult to reach using an inside-out technique, which also places the neurovascular structures, such as the saphenous nerve medially or peroneal nerve laterally, at risk. Also, all-inside devices are designed to be inserted perpendicular to the tear. An anterior anatomic location may make this difficult even by switching or using an additional accessory portal. In the case of bucket-handle tears displaced into the notch, some feel that traditional inside-out sutures placed in variable configurations are more preferable. It had been thought that the inside-out technique allows more reliable tensioning of the suture into a meniscus that has been torn. However, with the advent of suture-based fixators, bucket-handle tears may also be secured more reliably using the all-inside devices.

Some surgeons will allow immediate weight bearing in extension following repair with the thought that hoop stresses placed through the meniscus will not harm and in fact may aid in healing. However, many still maintain the traditional protocol of nonweight or partial weight bearing for up to 6 weeks. This conversation with the patient and their ability to comply with these restrictions is necessary prior to every planned arthroscopy with

the potential for repair. The patient must understand that a tear may be found irreparable at the time of surgery and a final decision may be made at that time.

DEVICES

First Generation

Since their introduction over a decade ago, fixator devices have undergone an evolution. The initial most commonly used "first-generation" fixators were

Meniscus Arrow (Bionx, Blue Bell, Pennsylvania, 1996)
T-Fix (Acufex/Smith and Nephew, Andover, Massachusetts)
SD Sorb Staple (Surgical Dynamics, Norwalk, Connecticut, 1997)
Biostinger (Linvatec, Largo, Florida, 1998)
Fastener (Mitek, Westwood, Massachusetts, 1998)
Clearfix Screw (Mitek, Westwood, Massachusetts, 1998)
Dart (Arthrex, Naples, Florida, 1999)

These devices were similar in that they were somewhat rigid devices made up of varying amounts of polymerized levorotatory polylactic acid (PLLA) and polyglactic acid. Two devices, the Arrow and the Dart, changed the composition of their implant around 2000 to include polylactic acid dextrorotatory "D" stereoisomer configuration. This configuration is more amorphous and possesses different degradation properties (7).

Meniscus Arrow

The first popular fixation device, the "Arrow," was "T" shaped with a 4-mm-long cross bar and a shaft of varying lengths to be used at the surgeons discretion. The shafts had reverse barbs projecting 90 degrees from each other. Each could be inserted manually or via a device known as the "crossbow" that held multiple arrows and facilitated multiple implant insertions. The disadvantages included chondral damage from retained PLLA fragments as well as suboptimal fixation strength. A recent systematic review showed that the meniscus arrow was by far the most studied device and had a failure rate between 5% and 43.5% with higher rates occurring, as expected, in studies with longer follow-up (13).

T-Fix

Originally, this device was designed in 1984 but was made usable by the advent of the arthroscopic knot pusher by Joe Sklar, M.D. The device consisted of a 17-guage needle preloaded with blue nonabsorbable suture tied to a polyacetal absorbable bar or "T." A small obturator slid down the needle and pushed the "T" out and clear of the needle tip. A second T-Fix was then inserted 3 to 4 mm from the first, and arthroscopic knots were tied external to the knee and were tensioned using the knot pusher. Much research has been done on the T-Fix, mostly case series and retrospective reviews with failure rates from 1.8% to 43% (13). Again, the studies with longer follow-up tended to reveal higher failure rates.

SD Sorb Staple

This device consisted of two barbed 7-mm fixation posts linked by a 4-mm braided nonabsorbable suture providing two points of fixation. It could be inserted using a manual device or a multifire gun and reportedly resorbed in 15 months. Newer modifications of this device include a lower profile insertion system and longer fixation posts.

Biostinger

Linvatec's Biostinger was the first cannulated device with a lower profile head allowing insertion over a needle trocar. The violet-colored fixator was easily visualized in the joint and the newly developed "Hornet" insertion device allowed for easy one-handed placement. The implant contained four rows of barbs that decreased pull-out strength and came in three sizes each with its own disposable insertion device. Two studies by Barber et al. showed failure rates of 4.9% to 9.0% in 88 patients over a 2 to 3 year follow-up (3,5).

Fastener

Mitek's "Fastener" was part of their Meniscal Repair System introduced in 1998. The "T"- or "J"-shaped fixator device came in two sizes (6 and 8 mm) with two suture materials, a nonabsorbable Prolene (Ethicon: Cincinnati, Ohio) and absorbable PDS (Ethicon). The insertion device also came in three angled tips. The reported advantage of the "Fastener" was that it was one of the few devices that could be used for a peripheral meniscus tear and that the crosslimb of the device could be placed beyond the capsule. In a study of 37 patients at 1 year follow-up, there were 5 retears (12). The results were similar to other techniques at that time.

Clearfix Screw

A 2 mm-diameter by 10-mm-long headless screw with a 0.3-mm variable pitch was designed to allow for countersinking and compression across the tear site. Insertion was similar to other techniques via a cannulated needle-guided system. Multiple studies have reported a 10% to 25% failure rate (13).

Dart

The meniscus repair Dart released in 1999 was low profile and headless with a barb configuration of a double-reverse design. This improved both pull-out strength and pull-through strength, thereby limiting migration of the implant. It could be inserted manually or using a spring-loaded delivery system and curved cannulae. Updates have included a preloaded insertion device called the "Dart Stick." Although lacking in clinical studies, the Dart showed inferior biomechanical properties of ultimate tensile load and stiffness as compared to other first-generation devices and traditional inside-out techniques (6).

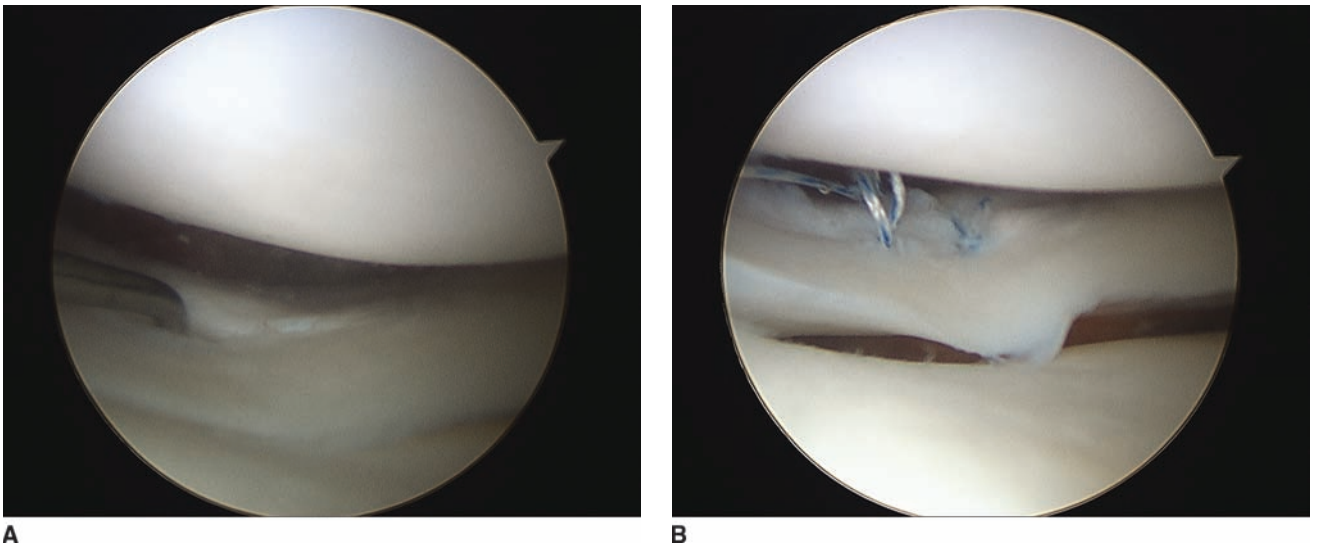
SECOND-GENERATION DEVICES

There is no clear consensus as to which devices definitively belong to the first, second, or later generations. Many improvements and advances have been made on the original instrumentation described above making them second generation for that particular device. However, several newly designed devices have incorporated recent advancements and can truly be termed "second generation."

Case series and long-term studies found an increasing amount of foreign body reaction and chondral damage secondary to implant prominence in first-generation devices. They were less suitable for peripheral meniscus tears and in biomechanical studies continued to be inferior to more traditional techniques. New implants were designed to improve the surgeon's ability to repair a peripheral tear and increase the fixation strength using absorbable, permanent, or hybrid bioabsorbable fixator/anchor and suture constructs.

FasT-Fix

Designed in 2001 by Smith and Nephew, the FasT-Fix meniscal repair system uses the same 5-mm anchor bar as the T-Fix, but the new needle delivery system includes two anchors attached to a braided suture that can be deployed and tightened in series using a preloaded, pretied self-sliding knot. Advancements include the anchors that attach extracapsularly and the sequentially fired implants that allow for both a vertical or a horizontal mattress configuration and the ability to tension across the repair site (Fig. 21.1). The needle delivery system is supplied with three angles: 0, +22, and −22 degrees. The −22 degree needle can be used to place the implant on the undersurface of the meniscus.



A **B**

FIGURE 21.1

A: Arthroscopic view of a longitudinal tear of the lateral meniscus in a left knee from the lateral portal. **B:** Arthroscopic view of an all-inside meniscus repair of the lateral meniscus using 2 FasT Fix devices.

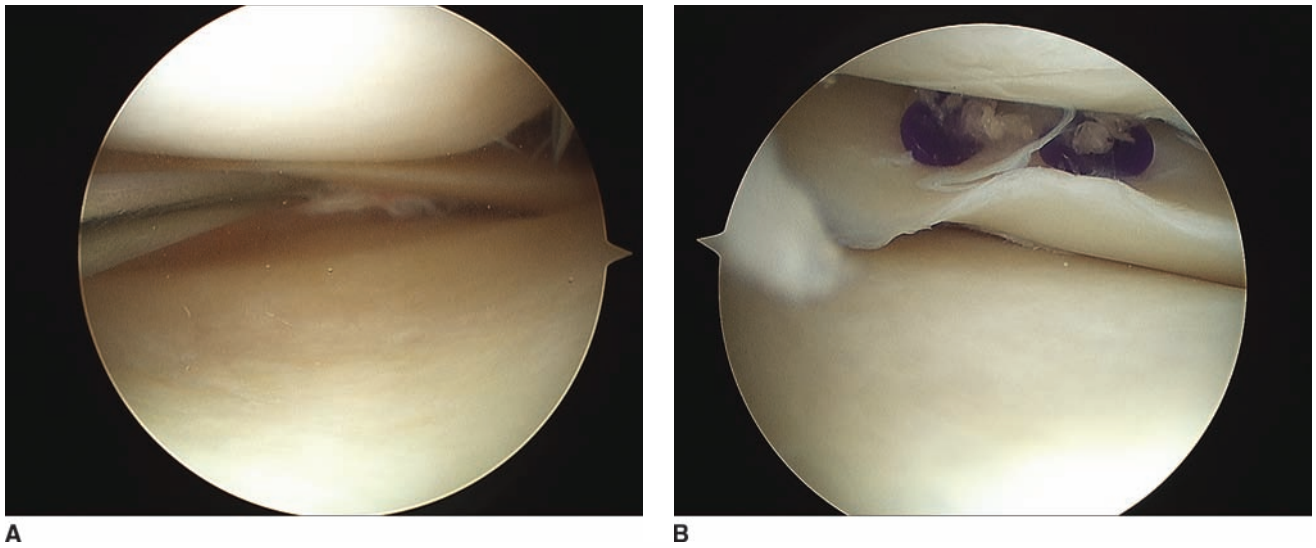


FIGURE 21.2

A: Arthroscopic view of an undersurface longitudinal medial meniscus tear in a left knee from the lateral portal. **B:** Arthroscopic view of an all-inside meniscus repair of the medial meniscus using 2 RapidLoc devices.

RapidLoc

Mitek released a similar device in 2001 also utilizing a similar "backstop" anchor that crosses the tear site and attaches extracapsularly. Only one device is deployed and tensioned at a time using a sequentially loaded second anchor known as a "top hat," which then slides down the suture via an overlying preloaded, pretied, self-sliding knot and compresses the tear. An arthroscopic knot pusher may then be utilized to "cinch" the top hat down even further just until it "dimples" the meniscus (Fig. 21.2). The delivery needle systems are also available in multiple angles.

The FasT-Fix and Rapidloc are currently two of the most widely used all-inside devices. Their techniques for use were well described in Chapter 9 of the latest edition of *Master Techniques in Orthopaedic Surgery: Reconstructive Knee Surgery*.

THIRD/FOURTH-GENERATION DEVICES

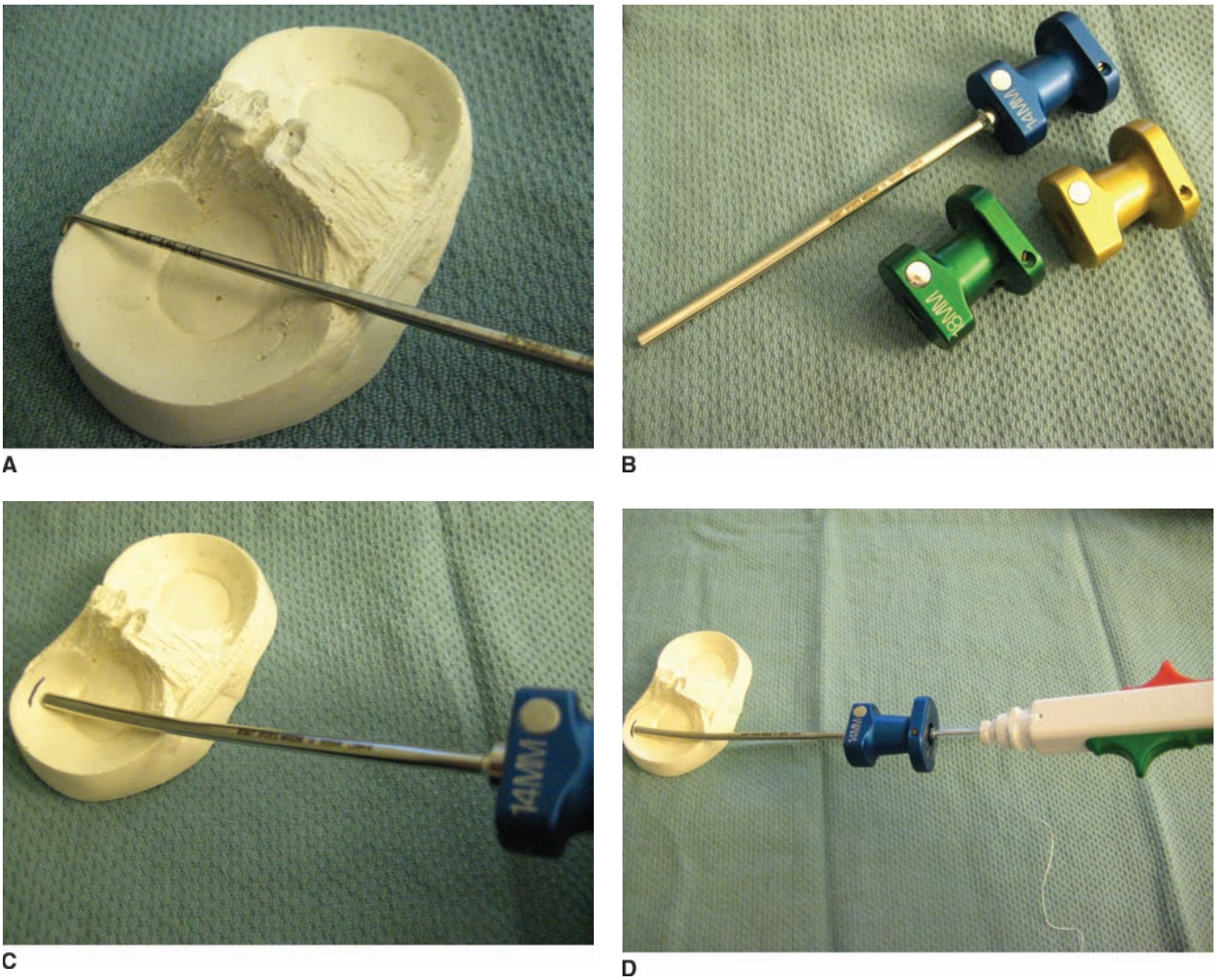
Two of the newer devices recently on the market are the Biomet (Warsaw, Indiana) Maxfire and the Arthrex Cinch. Depending on the source, these may be regarded as third or even fourth generation.

Maxfire

The Biomet Maxfire introduced in March 2007 is a suture-only system and utilizes "Ziploop" technology. "Ziploop" is a unique weave in which a single strand of braided polyethylene is woven through itself twice in opposing directions, thus allowing the surgeon to customize the length and tension of the suture. It is a knotless system, yet has been found to be incredibly strong and resistant to slippage. Similar to other systems, the Maxfire has two sequentially loaded "anchors" that allow the surgeon to place either a horizontal or a vertical mattress configuration (Figs. 21.3–21.5)

Cinch

The Arthrex Cinch approved in March 2008 uses a pistol-grip handle and slotted curved cannula to deploy its double-loaded PEEK anchors. A pretied sliding knot of 2 Fiberwire can then be tensioned to compress across the repair site (Figs. 21.6–21.8). According to their studies, the ultimate load to failure is approximately 100 N, which exceeds that of comparable devices.



A B C D

FIGURE 21.3

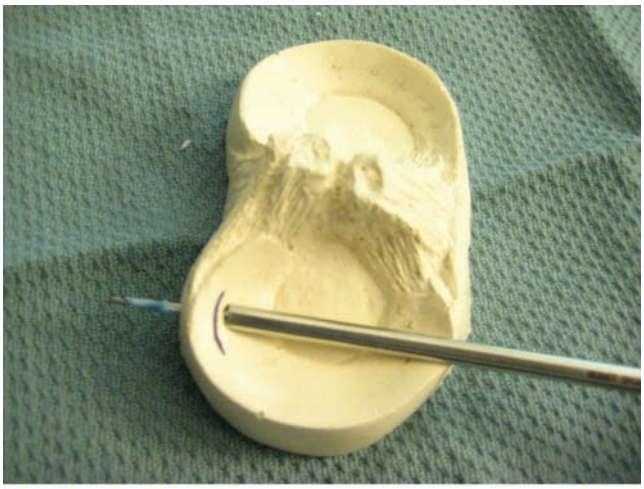
A: Once the location of the tear and optimal portal placement had been determined, measure the width of the tear using a meniscal depth gauge. **B:** After the correct measurement is determined, the appropriate color-coded barrel is attached to the cannula. **C:** An obturator is inserted into the cannula until desired position at the tear site is achieved at which point the obturator is removed. **D:** The MaxFire Meniscal Repair device is inserted into the cannula/barrel assembly by aligning the flats of the barrel with either flat on the tip of the MaxFire inserter handle.

SURGERY/TECHNIQUE

Meniscal Preparation

Once a tear is identified and indicated for repair, preparation of the site prior to introduction of the implant is crucial. Using a motorized shaver and/or rasp, both sides of the tear are débrided of fibrous tissue that may have formed during an attempt at healing. A peripheral tear near the meniscal/synovial junction may show signs of bleeding if the inflow is momentarily stopped and the intra-articular pressure is decreased. Also, a large bore needle may be used often "outside-in" to trephinate the meniscus and allow for vascular access channels.

Regardless of the device chosen for implantation, basic principles apply. Reduction of the meniscus is essential prior to fixation. Some recommend temporary k-wire or needle fixation to hold the reduction while the implant is placed. Fixators should be inserted perpendicular to the tear and often require accessory or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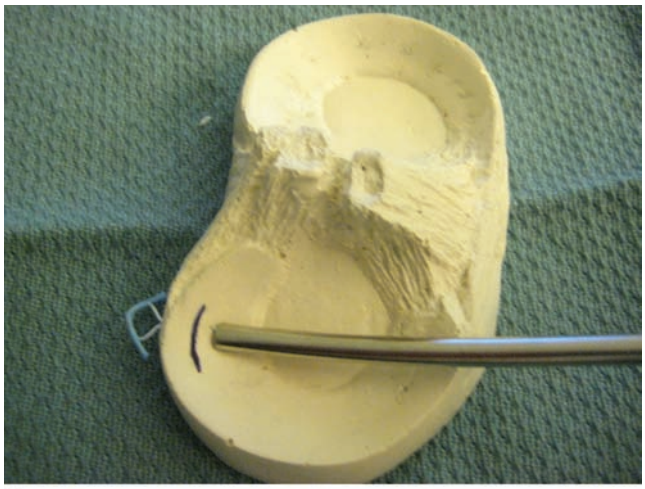
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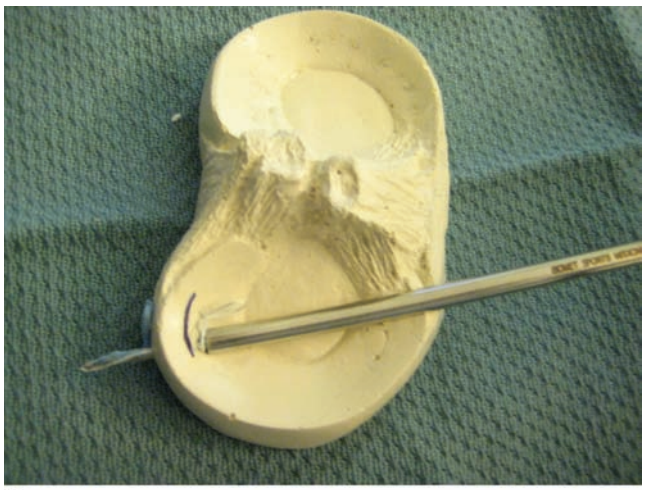
C

FIGURE 21.4

A: While maintaining gentle but firm pressure on the meniscus, the first all-suture anchor is passed by advancing the green trigger to its forward mechanical stop. **B:** Once the green lever has reached its forward mechanical stop, the green trigger is pulled back to its endpoint. **C:** The cannula is repositioned 5 to 10 mm away from the first anchor and toward the side corresponding with the red trigger of the inserter and the second anchor is fired.

contralateral portals to do so. When multiple devices are used, they are typically spaced in 3 to 5 mm intervals. Once the device is secured, the surgeon must be sure the fixator head or suture is not prominent in the joint to avoid any unwanted articular damage.

The repair site should then be probed for any gapping prior to and after the knee is taken through gentle range of motion. Any gapping or instability should be addressed with further fixation.

Fibrin Clot Technique

The use of exogenous fibrin clot has been shown in both animal and human studies to improve the chance of healing in what may be an avascular portion of the meniscus (9). The mechanism by which this improves the healing rate is not clear, but it coincides with the evidence that meniscal tears repaired during ACL reconstruction have a higher rate of healing presumably due to the hemarthrosis and its associated chemotactic and reparative properties.

Various methods for preparation and insertion have been used and often involve venipuncture of the patient and preparation of the clot on the back table while the surgeon is repairing the meniscus. The clot may or may not be secured with suture but is often placed on the undersurface of the tear between the meniscus and the tibia (1,9,14).

POSTOPERATIVE REHABILITATION

Differences exist from surgeon to surgeon regarding their post-op protocols. Still, similar principles apply. The goal is to restore painless range of motion while ensuring that the repair site is in no danger during the reha-

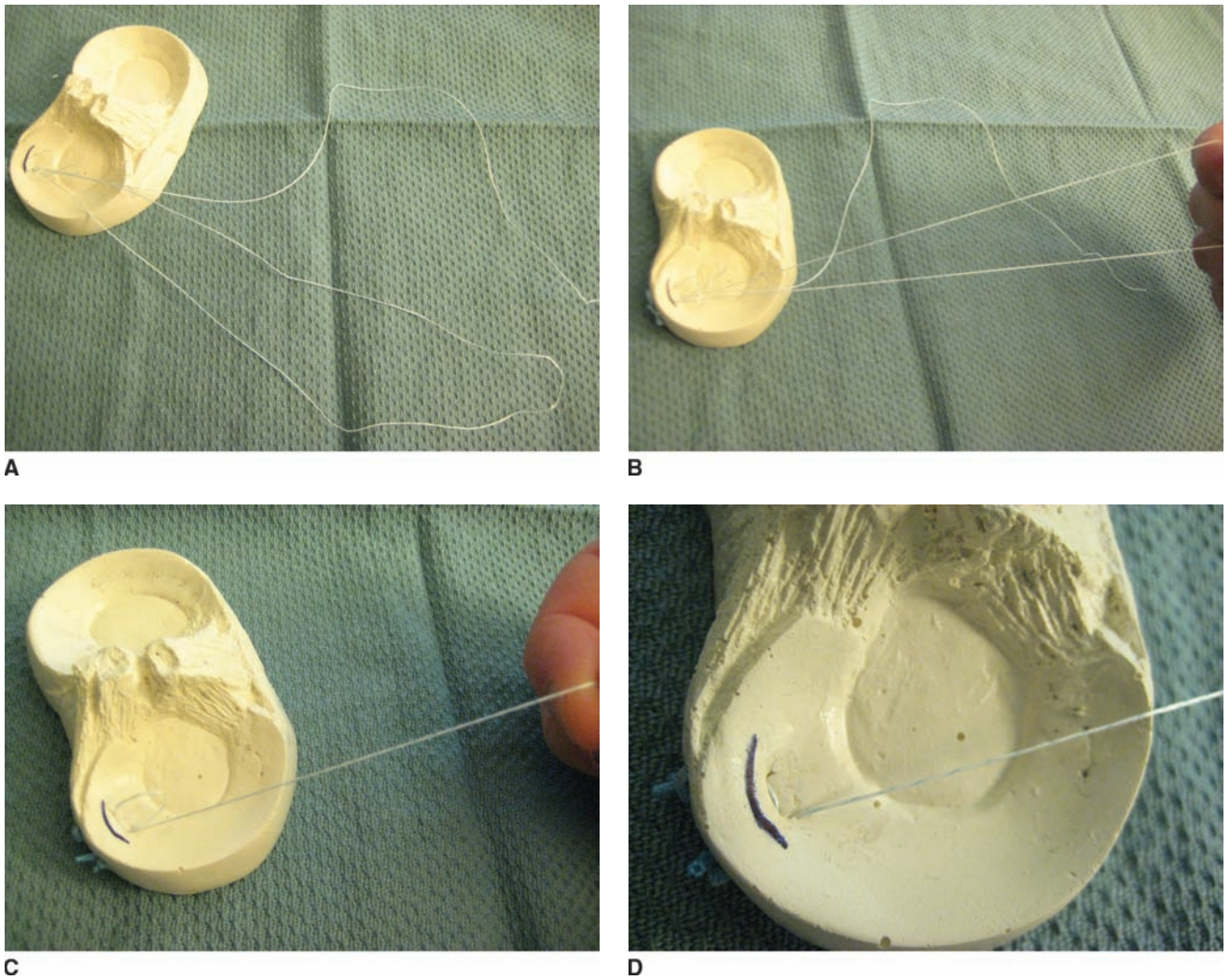

FIGURE 21.5

A: Once both suture anchors have been deployed across the tear, the MaxFire inserter/cannula/barrel assembly is removed from the joint. A large loop and a free strand of suture will remain outside the portal site. **B:** One finger is placed inside the large loop and pulled until the first stitch between the anchors slides down against the meniscus. **C:** The suture is pulled until the desired tension is achieved. The free strand is then pulled, which will reduce the large loop into the portal site and down to the meniscus. **D:** Next, using a MaxCutter device, the suture is passed through the bottom side (concave side) of the instrument. The MaxCutter device is inserted into the portal and advanced to cut the suture.

bilitation course. Adequate pain control is paramount in achieving early range of motion. This may begin in the operating room with intra-articular injections of long-acting analgesics and the application of a cryotherapy cuff to help control pain and inflammation.

Patients are allowed to partial weight-bear in extension (locked in a range of motion hinged brace) immediately after surgery. We feel that after the repair of a longitudinal tear, weight bearing provides hoop stresses to further compress across the tear site. Active and passive range of motion is encouraged but limited to 90 degrees of flexion while the patient is not bearing weight for the first 4 weeks. Once protective quadriceps strength has returned, usually 2 to 3 weeks, the patient is allowed to ambulate with the brace unlocked to 90 degrees. The patient is also instructed to avoid deep knee bends or loaded squats until closer to 10 to 12 weeks post-op. These restrictions are often based on tear type, location, and age of the patient. Currently, there are no multicenter prospective studies comparing rehabilitation protocols, although several small studies exist showing successful results with early accelerated rehab including unrestricted weight bearing and range of motion beginning post-op day 1.

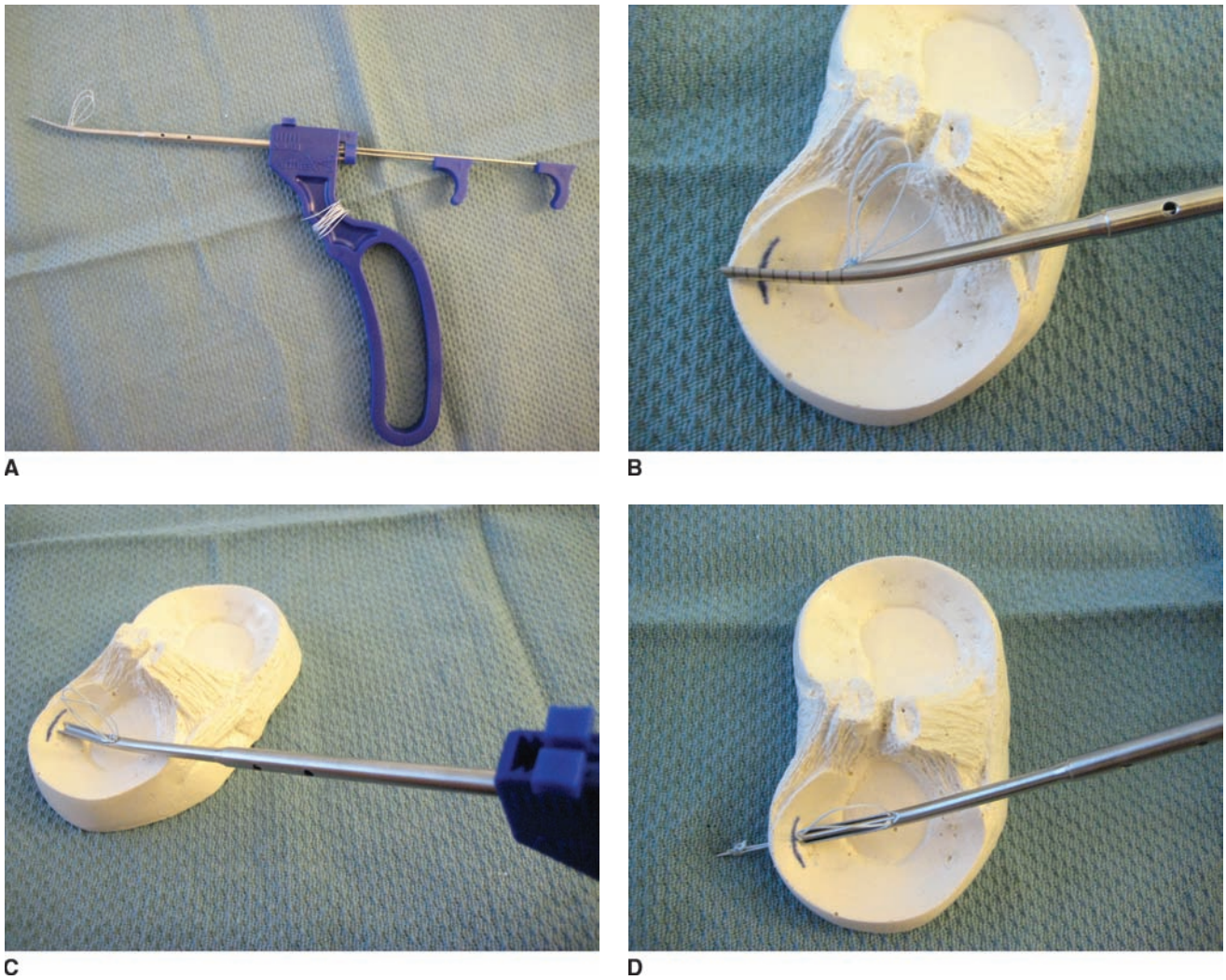

FIGURE 21.6

A: The Meniscal Cinch by Arthrex utilizes an ergonomic pistol-grip handle, a slotted cannula, and external depth stop for the insertion of its implants. **B:** The measurement probe or the graduated tip of the meniscal cinch is used through a low arthroscopic portal, near the surface of the tibia, to measure the approximate distance from the entry point of the implant to capsule. **C:** The stop on the meniscal cinch handle is set based on the depth measurement. The tip of the cinch cannula is placed near the tear. "The tip of the cannula may be used for manual reduction of the tear." **D:** The first implant is advanced through the meniscus by pushing trocar 1 until the trocar handle makes contact with the depth stop and the cannula rests on the surface of the meniscus.

RESULTS

In a recent systematic review of all-inside meniscal repairs, failure rates of all techniques combined ranged from 0% to 43.5% (13). This included the most well-studied device, the Arrow, which had a failure rate of 5% to 45%. The majority of the studies were case series and only one prospective randomized study has been done on any second- or third-generation devices (13). This was a study of Mitek's RapidLoc that showed a 35% failure rate in 20 patients with an average follow-up of 22 months. For devices that have been used for longer periods of time such as the Arrow and T-Fix, there is a trend toward higher failure rates with longer follow-up (8). Overall the success rate of all-inside repair is approximately 85% based on the numerous case series and few randomized trials (13). Given the current literature and lack of prospective randomized trials, evidence-based recommendations on which type of all-inside meniscal device leads to the best outcome cannot be made. The theoretical benefit of suture-based fixators, which can apply compression across the tear site, seems to be a logical advantage over older devices. However, further studies are required to provide evidence that long-term success can be achieved using all-inside techniques.

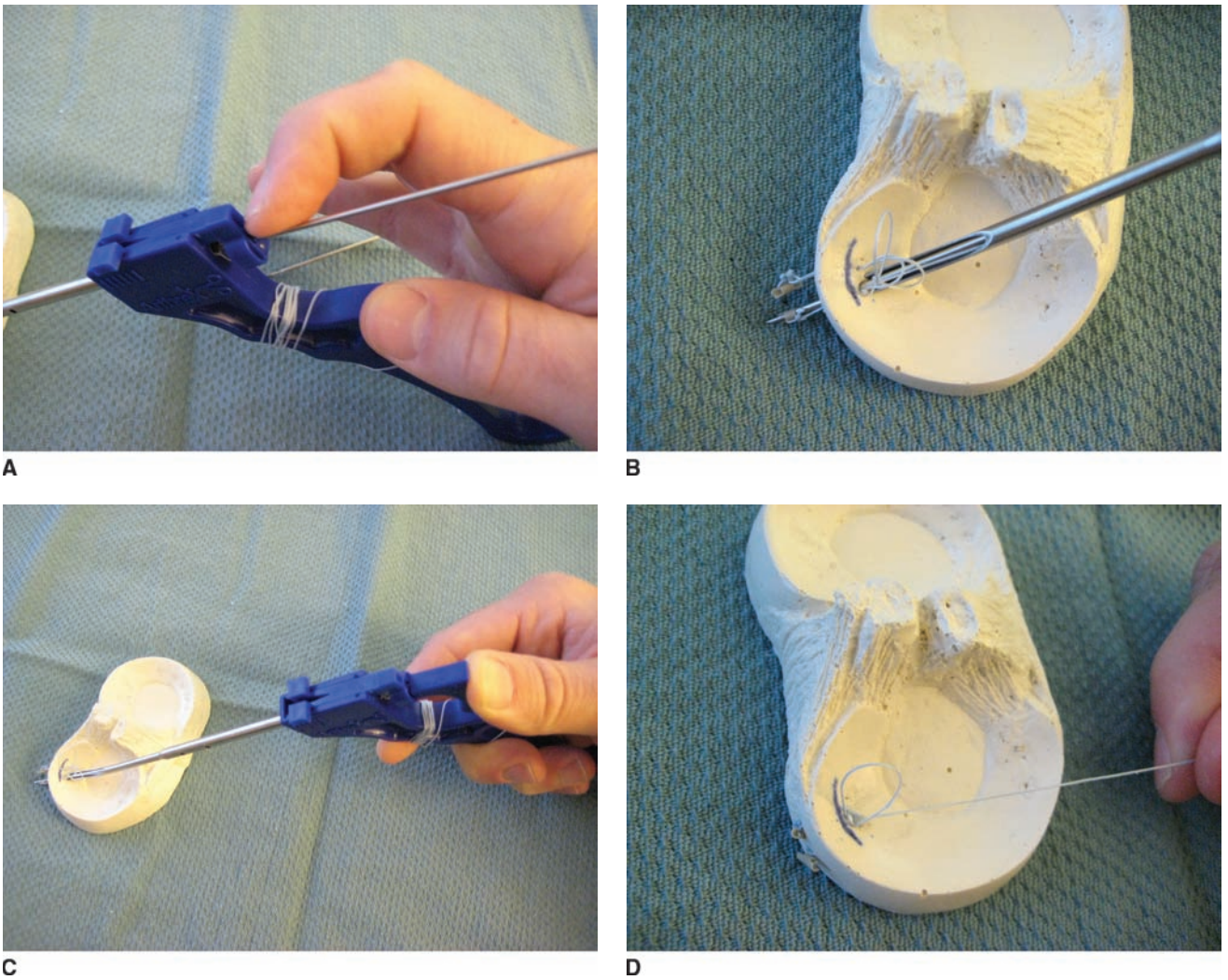

FIGURE 21.7

A: Trocar 1 is removed from the cannula completely and then trocar 2 is pushed down to release it from the holding position. The tip of the cannula is moved to the second insertion point over the meniscus. **B, C:** Trocar 2 is advanced forward by pushing the trocar handle forward and through the meniscus until the trocar handle makes contact with the depth stop and the cannula rests on the surface of the meniscus. **D:** Trocar 2 and the Meniscal Cinch are removed from the joint. The external suture is tensioned to advance the knot to the meniscus.

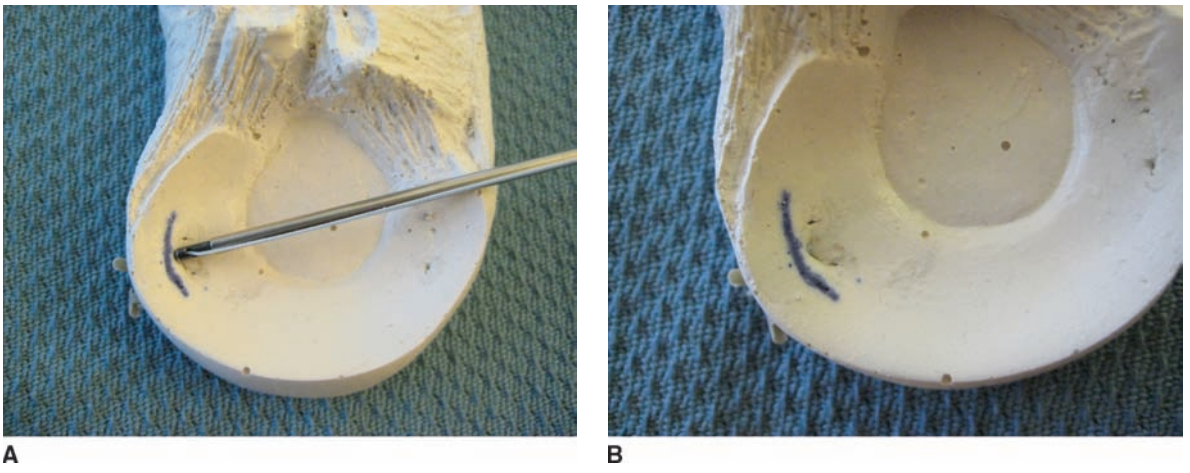

FIGURE 21.8

A: The suture is placed through the knot pusher/suture cutter. The knot is pushed while pulling on the free end of the suture until the knot countersunk in the meniscal tissue**. B:** Using the knot pusher/suture cutter, the suture is cut.

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22 Meniscus Repair: Inside-Out Technique

Charles R. Young and Richard D. Parker

Surgical treatment of knee meniscal pathology has experienced a dramatic shift in approach since its early recognition as a source of knee pain. Formerly thought of as vestigial structures, the menisci are now widely accepted to play a vital role in normal knee biomechanics, proprioception, and load transmission. As such, and with the maturation of arthroscopic techniques, the overall treatment scheme for meniscal disruption has shifted from that of complete excision to partial débridement and, whenever feasible, meniscal preservation. Techniques have evolved to allow reproducible healing of certain defects, which may ultimately avoid the premature development of degenerative knee disorders seen with meniscal volume loss and improve overall patient outcomes.

EPIDEMIOLOGY

Meniscal injury is one of the most common musculoskeletal injury patterns encountered in orthopaedic practice. Estimates of symptomatic incidence from 28 to 61 per 100,000 have been reported (4,9), making it more common than all other acute tendinous or ligamentous injuries. Under this umbrella of meniscal injury, two distinct patterns of injury can be seen that may have implications for optimal treatment and outcome.

One such pattern of injury includes a complex, degenerative pattern of meniscal disruption, with variable underlying articular cartilage injury. This includes horizontal cleavage and stellate tear patterns. These tears tend to occur more commonly in patients above age 30 to 35 and demonstrate increasing incidence with elevated body mass index and positive family history of knee osteoarthritis (14,34). Approach to these tears has largely evolved to include partial excision of the affected meniscus, with a relatively good prognosis for elimination of mechanical knee symptoms but a more guarded outlook for the maintenance of symptom-free knee function over the longer term due to progression of articular cartilage injury and degeneration.

An alternate pattern of injury includes acute traumatic tears, often involving the meniscal periphery. Many of these tears occur in younger and more athletic populations. Simple excision of the torn or displaceable meniscus would, in many cases, require the removal of a substantial percentage of meniscal volume. This holds demonstrated negative implications for the eventual development of degenerative joint disease (2,15,16,22,23,29,30,37,42,44). In select cases, meniscal preservation by way of repair can be attempted to meet the expectations of both returning patients to their normal activities and minimizing the impact of their injury on long-term knee health.

ANATOMY

The menisci are wedge-shaped, semilunar structures that occupy the space between the distal femur and proximal tibia within the knee joint. They are thickest at their peripheral capsular attachments and taper centrally to provide a measure of congruity between the curved femoral condyles and relatively flattened tibial plateau (Fig. 22.1). This congruence is dynamic, with its peak in knee flexion, due to the flexibility and mobility of the menisci. The overall shape of the meniscus differs between the medial and lateral compartments. The medial meniscus has an inconsistent radius, being broader posteriorly, as well as an inconsistent radius of curvature as it extends a greater distance in the sagittal plane than in the coronal plane. This produces an overall "C"

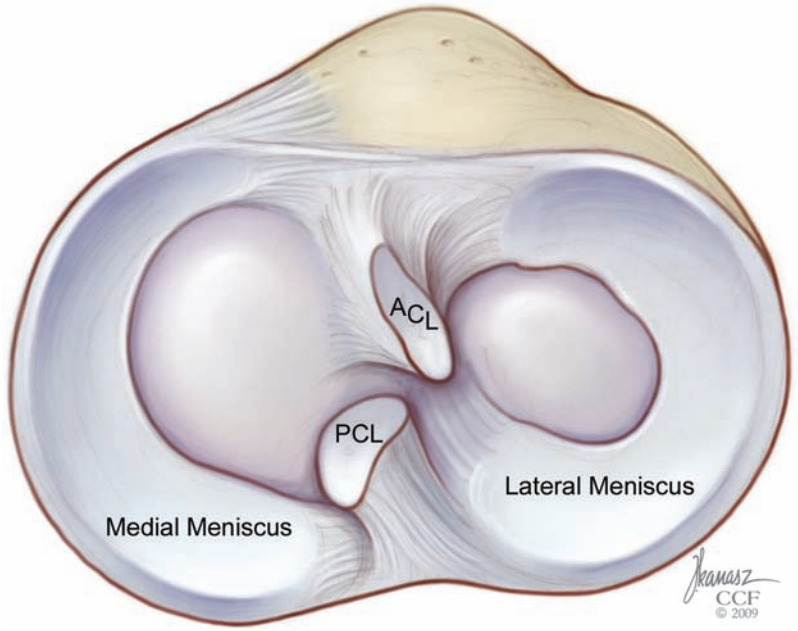

FIGURE 22.1
Medial and lateral menisci and their attachments.

shape, when viewed axially. The lateral meniscus has a more consistent radius throughout its curvature and its root attachments are situated nearer to each other in the sagittal plane. This produces a near complete "O" shape and, consequently, the lateral meniscus covers a greater percentage of the tibial articular surface within its compartment.

The medial and lateral menisci differ in their attachment sites to the tibia, femur, peripheral capsule, and ligaments. As noted, the root attachments for the medial meniscus project both more anteriorly and posteriorly when viewed axially. The remainder of the periphery of the medial meniscus is solidly attached via its coronary ligament to the joint capsule. Additional contributing fibers from the deep portion of the medial collateral ligament anchor it medially and may provide an area of stress concentration, posterior to which many longitudinal tears may originate. By contrast, the lateral meniscus has no collateral ligament attachments and remains unattached to the peripheral capsule at its posterolateral corner, near the popliteal tendon hiatus.

Additional anatomic restraints exist in most individuals. A transverse ligament occurs in approximately two thirds of specimens, connecting the anterior horns of the menisci just anterior to the tibial insertion of the anterior cruciate ligament (ACL) (48,52). This is augmented in a minority of patients (~15%) by anteromedial or anterolateral meniscofemoral ligaments, representing attachments from the anterior horns of the respective menisci to the opposing femoral intercondylar surface. The lateral meniscus is additionally restrained by two meniscofemoral ligaments. These attach the posterior horn of the lateral meniscus to the lateral aspect of the medial femoral condyle, by passing anterior (Humphry) and posterior (Wrisberg) to the posterior cruciate ligament (PCL). Variability in their presence has been reported in the literature; however, more recent reports demonstrate these as relatively constant structures (48,52). No such posterior meniscofemoral restraint occurs at the medial meniscus, which has been implicated in its higher injury rate. It remains unclear, however, whether these additional restraints play primary importance in meniscal stability or rather contribute to overall knee stability and proprioception.

At a microscopic and ultrastructural level, the menisci are composed of sparse fibrochondrocytes encased within a dense extracellular matrix of predominantly Type I collagen. This collagen is arranged into three distinct layers. The most superficial layer is composed of woven fibrils in a mesh-like pattern to provide smooth articulation with chondral surfaces and durability to surface disruption. Below this is a layer of random fibril orientation, which transitions to the deepest layer, composed of circumferential collagen fibrils cross-linked with radial tie fibers. The circumferential fibrils run longitudinally from root to root, generating hoop stresses as axial loads are applied through the knee joint. The cross-linking radial fibers serve as a scaffold for these longitudinal fibrils and help prevent propagation of longitudinal splits.

The remainder of the meniscal dry weight is composed of elastin and proteoglycan molecules. Glycoaminoglycoside side branches of these large proteoglycans account for approximately 1% to 2% of the meniscal mass (17). These molecules are strongly hydrophilic due to their net negative charge, which allows them to tightly bind water molecules. This assists the longitudinal collagen fibrils in resisting compressive forces applied across the meniscus

Aside from its structural organization, the menisci contain neurovascular elements unlike articular cartilage. Detailed studies of the perimeniscal capillary plexus have been undertaken, demonstrating penetration of these vessels into the peripheral meniscal bodies (3). These capillaries extend approximately 20% to 30% of the

radial width into the medial meniscus and approximately 10% to 25% into the lateral meniscus. They arise as distal arborizations from the respective geniculate vessel anastomoses. An additional vascularized synovial fringe extends 1 to 3 mm over the meniscal periphery but does not contribute to normal meniscal blood supply. The central majority of the meniscal bodies have no contributing vascular supply and derive nutrition via diffusion from the surrounding synovial fluid. This distribution has given rise to the red-white classification of meniscal zones. This variable blood supply has implications in the menisci's ability to heal traumatic defects.

Innervation of the menisci arises peripherally and at the root attachments. This includes proprioceptive fibers providing information on joint position and acceleration. Pain fibers also exist in the periphery, as probing or tension on the pericapsular meniscal tissue in awake patients causes a nociceptive response. The central portions of the meniscus lack this sensitivity.

MENISCAL BIOLOGY

Healing of meniscal tissue proceeds along the classic wound healing pathway of acute inflammation, development of granulation tissue, formation of a fibrovascular scar, and eventual maturation of fibrocartilage. This occurs more readily in a well-vascularized and mechanically stable setting. Experimentally induced tears within the vascular zone of the meniscus in a dog model demonstrate expected perimeniscal vascular invasion and mesenchymal cell proliferation. These defects showed mature healing by 10 weeks following injury (24).

Rather than being dormant spectators, meniscal fibrochondrocytes seem to be active in the healing process. When appropriately stimulated by growth factors, as may occur following a tear, they have the capacity to proliferate and synthesize extracellular matrix (24,31,49). In addition, superficial zone cells have the capacity to express α-smooth muscle actin, causing wound contraction. These properties seem to be independent of blood supply and indicate an intrinsic healing potential of the meniscus, if appropriately stabilized.

BIOMECHANICS

The menisci function in knee joint congruity and load transmission. Utilizing hoop stresses created by its longitudinal fibril orientation, the medial meniscus transmits approximately 50% of the overall medial compartment load. The lateral meniscus transmits up to 70% due to the greater percentage of coverage it provides to the lateral tibial plateau (47). These loads increase with knee flexion, from approximately 50% at full extension to nearly 90% at 90-degree flexion. Increasing knee flexion also shifts the distribution of force more posteriorly, increasing stress on the posterior horns leading to mechanical susceptibility (26).

Changes in load transmission are well documented in settings of partial or complete meniscectomy. Contact area on the femoral condyle decreases 50% to 70% following partial meniscectomy (25). Conversely, contact stresses can more than double. These alterations in joint contact pressures following complete or partial meniscal excision are thought to be responsible for changes seen to the articular cartilage over the long-term.

The medial meniscus has an additional role of providing secondary restraint to anterior tibial translation. This is most relevant in ACL deficiency. In this instability state, the posterior horn of the medial meniscus acts as a wedge to prevent anterior tibial translation, leaving it susceptible to injury. Forces recorded across the meniscus increase to 126% of normal at 30-degree knee flexion and 115% of normal at 90-degree knee flexion (32). The lateral meniscus does not contribute significantly to anterior knee stability.

SUITABILITY FOR REPAIR

Not all meniscal tears should be considered for repair. Tear location, type, size, tissue quality, patient age, compliance, and other factors are all important considerations when deciding upon treatment options. The method of treatment must also be selected based on surgeon technical preference and injury characteristics.

Tear location is of primary importance in assessing the healing potential of a meniscal defect. The red-red zone, within 3 mm of the meniscal periphery, is the optimal location for repair due to its well-developed blood supply. The red-white zone, within 3 to 5 mm, has some limited vascularity and an intermediate ability to heal. The white-white zone represents the central portion of the meniscus, >5 mm from the periphery. Tears in this area have no blood supply and have a significantly lower chance of healing (10,28). A watershed area also exists near the popliteal hiatus in the posterior lateral meniscus, as it is devoid of capsular attachment in this region (3). Certain patient characteristics, however, such as young age or high-level athletes, may prompt an attempted repair in a less desirable zone for healing despite the reduced chance of success when the alternative would be substantial meniscal resection.

Circumferential location of the tear may be important in the type of repair chosen. The majority of tears that are suitable for repair are found in the posterior and middle bodies and are excellent candidates for an inside-out technique. Anterior horn tears are often addressed more effectively with an outside-in approach. Those that involve the posterior one third and meniscal root may require all-inside or transosseous repair techniques to avoid injury to posterior neurovascular structures.

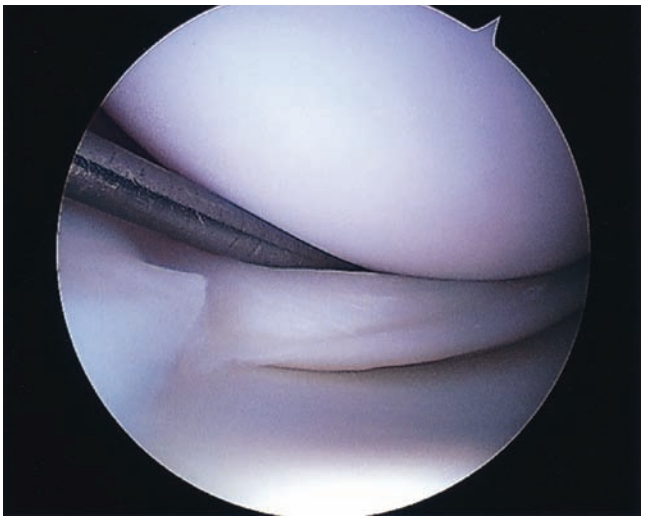

FIGURE 22.2
Unstable longitudinal medial meniscus tear originating near the attachment of the medial collateral ligament.

Tear type is also an important factor. Longitudinal tears (Fig. 22.2), which extend vertically through the meniscus from its femoral to tibial surface, are the most amenable to repair because the tear margins can reliably be brought into close apposition and maintained with transcapsular sutures (12). Radial, parrot-beak, flap and horizontal cleavage tears are not able to be stabilized in the same manner, due to the disruption of circumferential collagen fibrils. Despite some success in repair of radial tear variants, these tear types should be considered for partial excision. Stable (<3 mm central displacement) or incomplete tears (involving only one surface of the meniscus) generally do not require repair. This is especially true for tears <5 mm in length or stable tears identified at the time of ACL reconstruction (50,51).

Tissue quality should be normal at the tear margins. Significant mucoid degeneration or chondrocalcinosis may indicate an unfavorable environment for healing and may be better served by partial excision. Patients older than 30 to 35 years of age may also have decreased expectations for successful healing, especially in the setting of significant articular cartilage disease. No definite recommendations exist for meniscal repair in the setting of diabetes, vascular insufficiency, inflammatory arthropathies, or connective tissue disorders. These are probably best approached on an individual basis.

SURGICAL TECHNIQUE

The inside-out meniscal repair technique involves passage of suture through the meniscal and surrounding capsular structures to approximate and stabilize longitudinal tears (Fig. 22.3). The technique requires arthroscopic evaluation of the tear to determine its suitability for repair, preparation of the tear edges, open exposure of the outer joint capsule, and selection of the appropriate placement, number, and orientation of sutures prior to securing them.

DIAGNOSTIC ARTHROSCOPY

A complete diagnostic arthroscopy should be performed prior to anticipated meniscal repair. Preparation of the extremity should include circumferential access to the knee joint. A thigh holder or lateral post may be used to provide countertraction during evaluation of the joint compartments and to allow access for instrumentation during repair. Often, the most convenient position includes an extremity holder that allows the leg to freely hang over the end of the operating table (Fig. 22.4). The contralateral leg is placed in an abducted leg holder. This allows adequate room for a seated assistant to aid in suture retrieval during passage either medially or laterally. A tourniquet may be used, particularly during open exposure of the joint capsule to aid in hemostasis and visualization of relevant structures. Regional anesthesia is generally avoided to allow postoperative neurologic assessment.

Diagnostic arthroscopy with a 30-degree arthroscope via standard anteromedial and anterolateral portals is then performed. This should include evaluation of the meniscal body and attachments with respect to tear type, location, and size. A posteromedial portal may be used if the posterior horn of the medial meniscus cannot be adequately visualized. The cruciate ligaments should be examined for stability. This is particularly true for the ACL, as medial meniscus repair may be delayed until anterior stability can also be achieved (35). Finally, notation of the status of the articular surfaces should be made. Though it may alter overall knee outcomes, most patterns of chondral injury do not preclude meniscal preservation when it would otherwise be considered. Large osteochondral defects, however, may engage the posterior meniscus during flexion and extension.

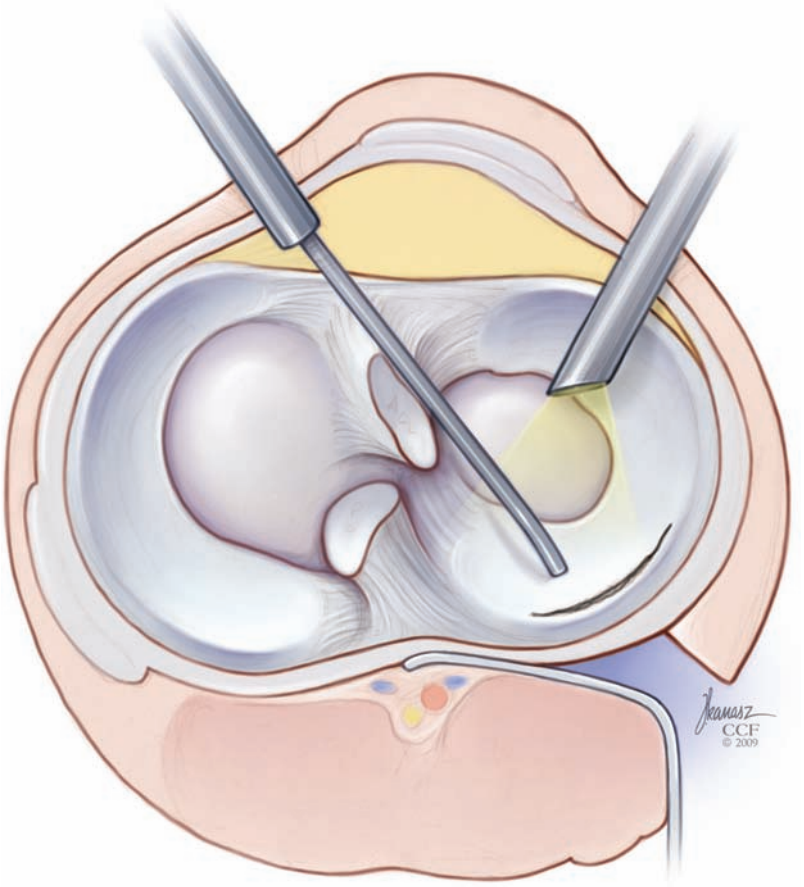

FIGURE 22.3
Inside-out meniscal repair technique.

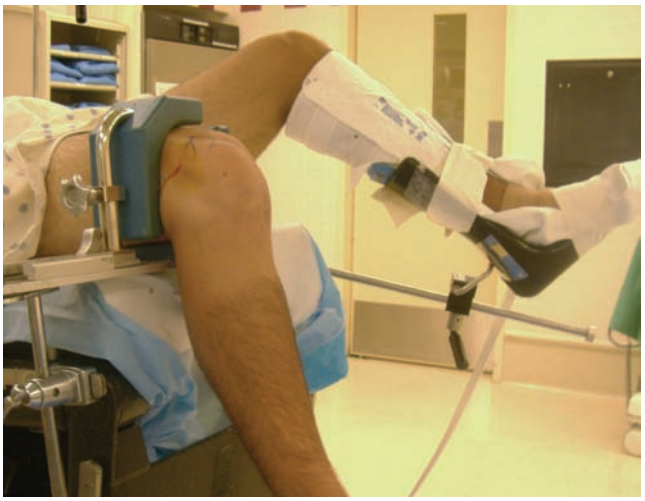

FIGURE 22.4
Suggested intraoperative positioning, allowing varus/valgus countertraction and circumferential access to the joint line.

Besides being implicated in the etiology of the original tear, subsequent meniscal repair may be compromised if continued engagement occurs across this area during normal knee motion.

TEAR PREPARATION

Initial preparation of the meniscus should begin with ensuring that the meniscal tissue is anatomically reducible. Large longitudinal, or bucket-handle type, tears may displace centrally into the joint compartment or intercondylar notch (Fig. 22.5). The medial meniscus may be classically involved in this scenario demonstrating the "double PCL sign" on magnetic resonance imaging. The displaced portion of meniscus can usually be

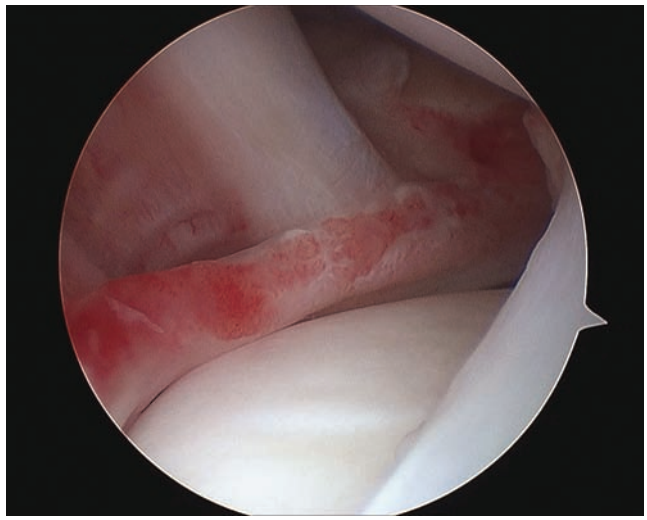

FIGURE 22.5

Bucket-handle lateral meniscus tear with displaceable meniscal fragment (right).

coaxed into its normal position by appropriate varus or valgus stress application to open the joint compartment, followed by manipulation via an arthroscopic probe. An alternate technique that has been recently described involves piercing the displaced fragment with a suture hook to allow shuttling of a vertical traction suture. This suture is then passed via an outside-in technique using spinal needles to simultaneously reduce and fix the meniscus (53).

Chronically displaced menisci may have lost their original viscoelasticity and consequently be difficult to reduce anatomically. Plastic deformation can occur, which leads to an irregular meniscal contour and stress across the eventual repair site. In cases where a chronically displaced meniscus is particularly difficult to reduce, partial excision may be advocated over repair.

Nondisplaced meniscal tears in the peripheral vascular zone, especially when identified in a subacute setting, may already have undergone some early healing response. Often this includes fibrovascular scar formation lining the tear margins. Similar to débridement of bony edges in fractures and nonunions, the meniscal tear margins should be prepared by rasping these surfaces to improve apposition and optimize the healing surfaces. A variety of mechanical rasps are available, including forward-angle, back-angle, double-sided, and 90-degree double-sided instruments. An arthroscopic motorized shaver can also be used for gentle débridement of these edges. The goal is to establish a surface free of interposed material, ideally demonstrating punctate bleeding, which indicates vascular supply sufficient for reliable healing. This can usually be demonstrated by restricting the arthroscopic inflow prior to tourniquet inflation.

SURGICAL EXPOSURE

Exposure of the medial side of the knee begins with a longitudinally straight incision centered just distal to the joint line (Fig. 22.6A). Slight distal exposure is preferred due to the distal trajectory of suture needles as they pass through the capsule from the intra-articular space. The sagittal location of the incision is variable, depending on the exact location of the tear to be repaired. For posteromedial tears, this is generally just posterior to the palpable femoral epicondyle and tibial collateral ligament.

Subcutaneous dissection is continued to the underlying fascia. Primary importance is given to the location of the saphenous nerve and its infrapatellar branches. These lie posterior to the sartorius muscle in 60% of individuals, exiting Hunter canal between the sartorius and gracilis. In knee flexion, the nerve drifts posteriorly, crossing the medial joint line just behind the posteromedial corner. In full extension, the nerve moves anterior to the posteromedial corner, approximately 2 to 3 cm anterior to the semitendinosus. This mobility must be kept in mind depending on the position of the extremity during exposure. To avoid injury, the sartorius fascia is identified and split anteriorly. Blunt dissection is then carried out, sweeping the sartorius posteriorly and developing the deeper interval between the medial gastrocnemius and joint capsule. A spoon or curved retractor is then inserted to maintain this interval and protect the saphenous nerve from injury during needle and suture passage.

Lateral exposure begins with a similar straight longitudinal incision over the lateral joint line (Fig. 22.6B). Again, this is optimally centered just slightly distal to the joint line to aid in suture retrieval. The sagittal position depends upon the location of the tear; however, the most common position for management of posterolateral tears is at the border of the fibular collateral ligament.

Subcutaneous dissection is continued to the fascia, allowing identification of the interval between the iliotibial band and biceps femoris. The fascia is incised at this interval and blunt dissection is used to retract the biceps femoris posteriorly. This protects the common peroneal nerve, which passes posteriorly to the biceps tendon. Maintaining knee flexion during the exposure allows the nerve to drift posteriorly away from the field

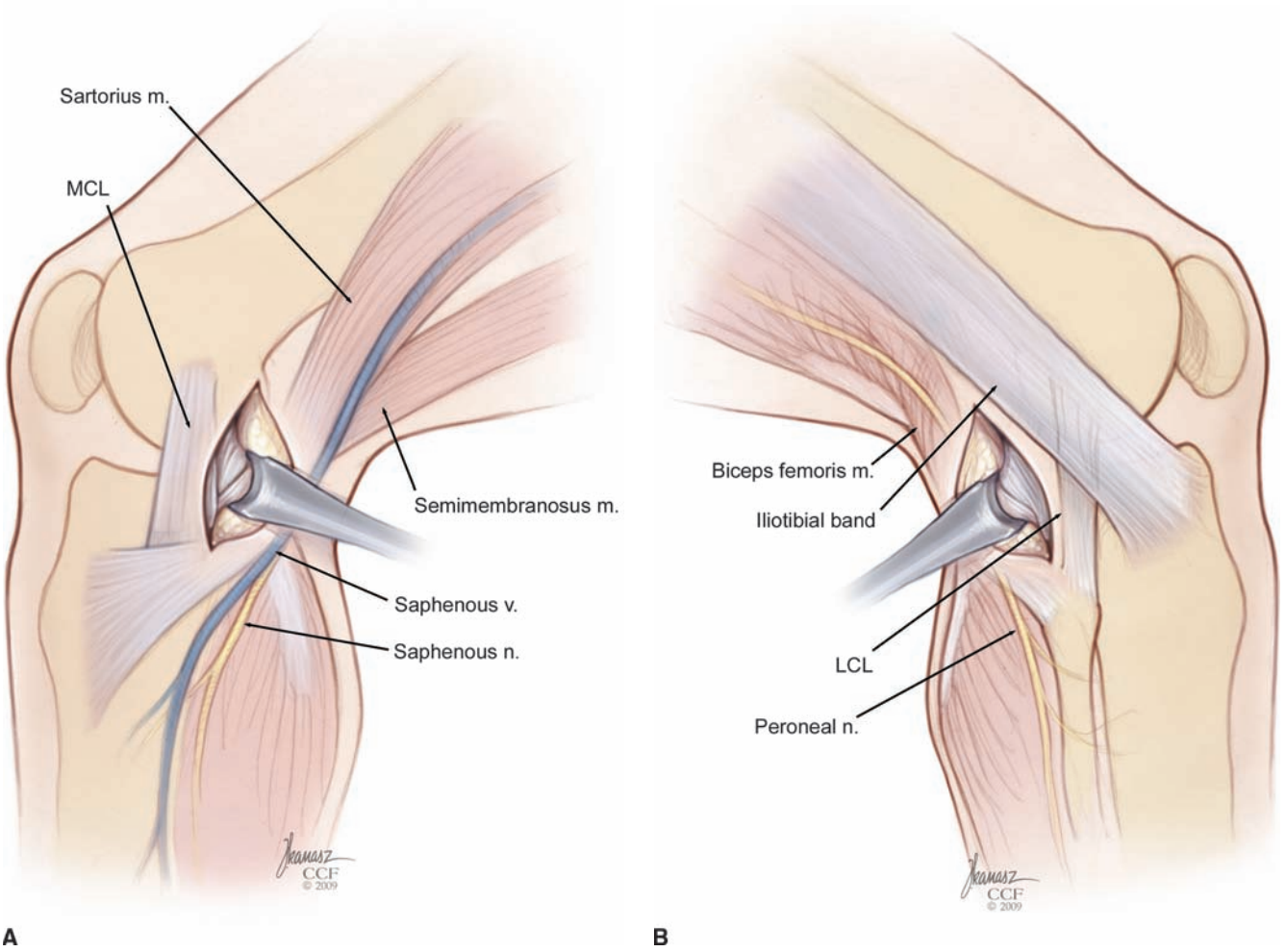

FIGURE 22.6

A,B: Medial and lateral exposures of the peripheral joint capsule.

of dissection. The lateral inferior geniculate artery may also be encountered in this interval, passing deep and medial to the fibular collateral ligament. Deep to the biceps femoris lies the lateral head of the gastrocnemius. Posterior retraction of this muscle using a spoon or other curved retractor allows visualization of the posterolateral joint capsule and protection of the neurovascular structures during needle passage.

SUTURE CHOICE

A variety of suture options exist for inside-out meniscal repair. These include nonabsorbable and absorbable suture material double loaded with long tapered or cutting needles to allow passage through cannulas or suture passage devices (Fig. 22.7). Alternatively, a flexible nitinol wire with a suture passage loop can be used to pass sequential ends of the chosen suture. The suture gauge most often used is 2-0 or 0, to allow sturdy repair without excess prominence of the suture material. Absorbable monofilament polydioxanone suture (PDS II) induces minimal tissue reaction but may only maintain approximately 25% of its original tensile strength at 6 weeks. Nonabsorbable braided polyester suture (Ethibond, Ticron), on the other hand, has no appreciable loss in tensile strength but remains indefinitely on the meniscal surface. Newer composite sutures with ultra-high molecular weight polyethylene core (Fiberwire, Orthocord) may also be used as a nonabsorbable suture option with minimal risk of suture breakage during tensioning.

SUTURE PLACEMENT, ORIENTATION, AND FIXATION

Mattress suture placement is facilitated arthroscopically by use of precontoured cannula or suture passage systems. Cannulated systems (Acufex, ConMed Linvatec) offer single- or double-lumen devices, which are prebent to allow zone-specific placement. Greater curvature is placed on the cannulas intended for more anterior suture passage. Straight cannulas, and cannulas with an upward or downward bend, may also help optimize

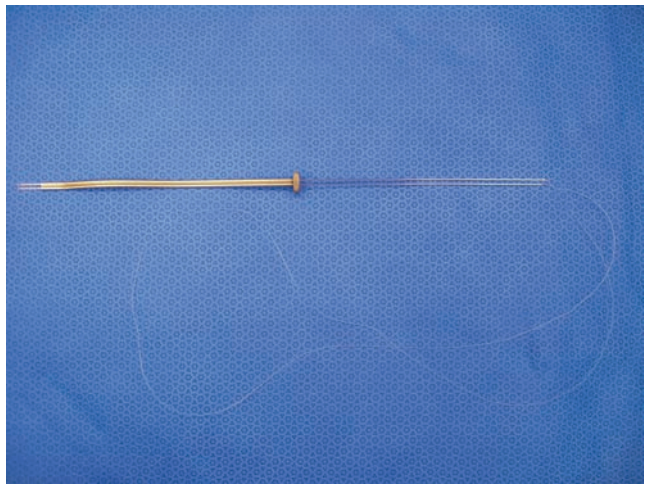

FIGURE 22.7
Double-loaded suture and cannula.

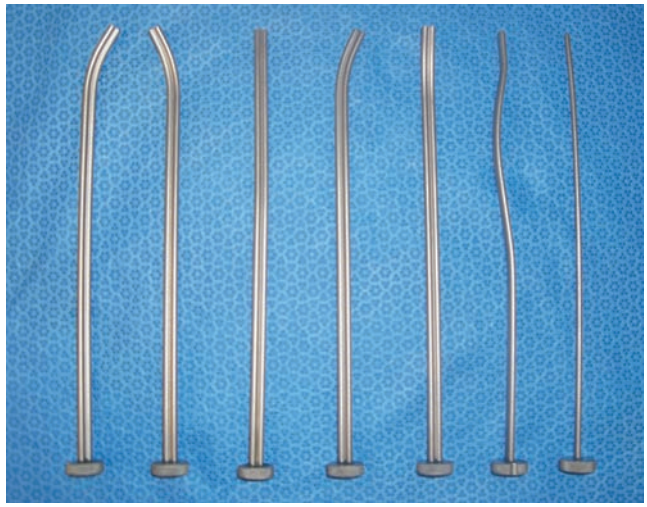

FIGURE 22.8
Zone-specific cannulas. (Left to right: bent up-right, bent up-left, straight, bent left/right, bent up/down, double bent, single cannula.)

placement posteriorly and allow easier negotiation around the femoral condyles. Finally, double-bent cannulas can assist in placement of sutures from a contralateral working portal, as they may help avoid contact with the tibial spines (Fig. 22.8).

The choice between single- and double-lumen cannulas is largely one of surgeon preference. Advantages to the single-lumen devices include a greater degree of freedom in placing respective arms of the mattress stitch. These may also be slightly contoured as needed by placing a bend in them. Double-lumen devices avoid the need for repositioning the cannula between sequential needle passes and may reduce the risk of cutting the first suture arm during passage of the second needle. Care must be taken with limb placement to ensure that adequate tissue between suture limbs, and from each limb to the tear margin, is incorporated for fixation with either device.

Suture passage devices also exist (ConMed Linvatec), which allow ratcheted advancement of needles through a single lumen. Variable angles can be achieved by placement of a variety of cannula heads. Once a needle is loaded, the ratchet trigger allows single-hand advancement of the suture through the joint capsule (Fig. 22.9).

Differences in terms of pullout strength do exist between different suture orientations. Vertical loop mattress constructs have been shown to be approximately twice as strong as similar horizontal loop sutures (7,13,36). This is probably due to the parallel orientation of horizontally placed suture to the underlying longitudinal collagen fibril orientation. The number of sutures placed depends upon the length and characteristics of the individual tear, as well as the chosen suture orientation (i.e., horizontal or vertical). The ultimate goal is to provide the minimum amount of fixation to accomplish an approximated and stable meniscus through the time of final healing. As a general rule, suture arms should be a minimum of 3 to 5 mm apart to avoid suture cutout through meniscal tissue. A 2 to 3 mm margin from the tear edges should also be maintained to avoid cutout. Finally, individual mattresses should be spaced within every 5 mm of tear length to accomplish overall stability (Fig. 22.10). A combination of suture placement above and below the meniscus, through the femoral and tibial surfaces respectively, may help to achieve optimal fixation. At least one arm should engage meniscal tissue central to the tear. The opposite arm may engage centrally, peripherally, or through the adjacent capsule (Fig. 22.11).

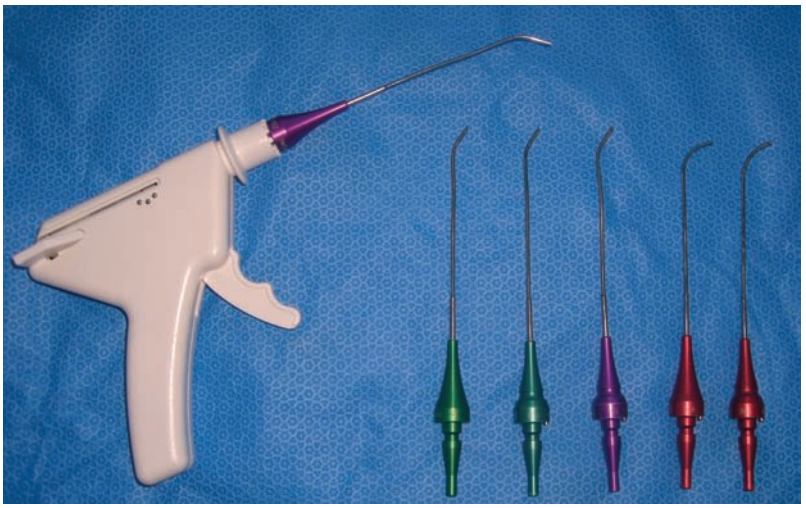

FIGURE 22.9
Sharpshooter (ConMed Linvatec, Largo, Florida) and zone-specific cannula attachments.

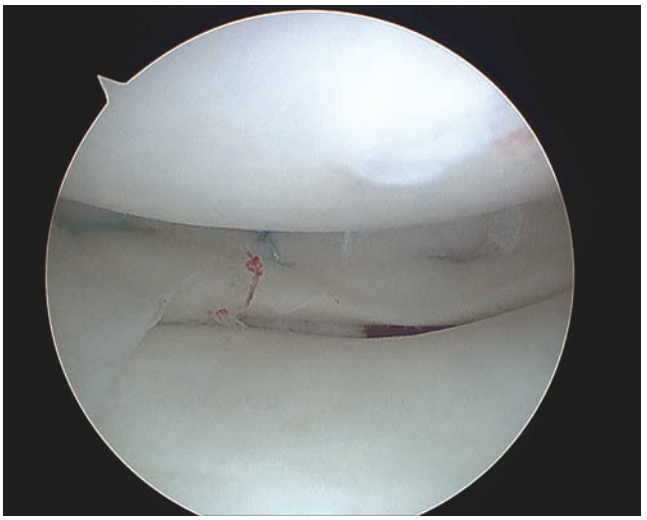

FIGURE 22.10
Composite lateral meniscal repair, with alternating horizontal and vertical mattress sutures.

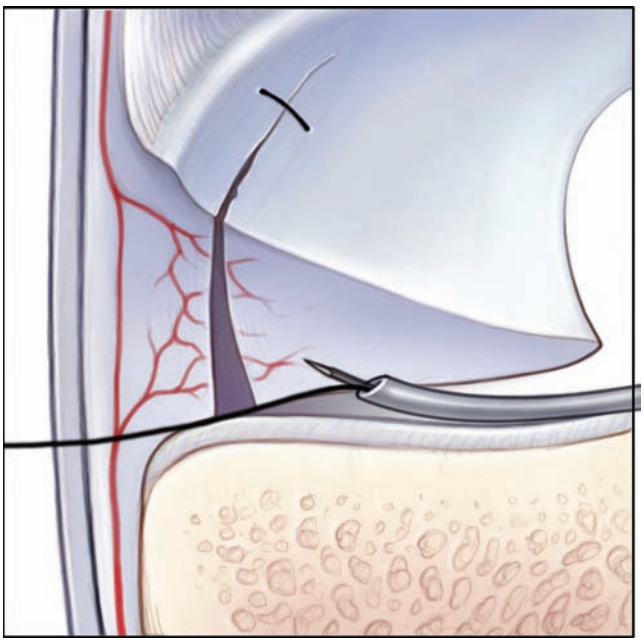

FIGURE 22.11
Schematic of vertical suture placement.

In the setting of multiple longitudinal tears, consideration may be given to repairing one or more of the meniscal defects. This may especially be true in the young or elite athletic population. Repair in this scenario should proceed by stabilizing the most peripheral tear first and then proceeding to more central tears (39). Alternatively, the central tear may be débrided if it is felt unlikely to heal.

The sequence of suture placement should be chosen to allow optimal suture management outside of the capsule. Working in a posterior to anterior direction allows improved visualization of posterior needles as they penetrate the outer surface of the joint capsule. These suture arms are retrieved, cut from their respective needles, and isolated via separate mosquito clamps for later identification and tying. Deep retractor placement and careful advancement of needles in the posterior one third of the meniscus, in either a slight posteromedial or posterolateral direction, will help to avoid posterior neurovascular perforation.

After placement of all sutures, light tension should be applied simultaneously to identify and address any areas of meniscal puckering or deficient fixation. An arthroscopic probe is useful is this evaluation. Any non-capsular tissue between the suture arms should be cleared to ensure that neurovascular structures are not ligated. Sutures are then sequentially tied. This should be done in approximately 20- to 30-degree knee flexion for medial meniscus tears to avoid posterior capsular plication and subsequent loss of knee extension. Knots should be secured for lateral meniscus tears in 90-degree knee flexion to allow vulnerable structures, such as the peroneal nerve, popliteus, and lateral inferior geniculate artery, to fall posteriorly away from the operative field.

An alternate method for inside-out repair includes the use of a cannulated suture hook (1). An absorbable 0 PDS suture is placed vertically through the meniscus, from its femoral to tibial surfaces, using the suture hook. A flexible looped-end needle is then used to shuttle the individual arms of the absorbable suture through the capsule above and below the meniscus, respectively. These are retrieved though a small horizontal incision in the posterior knee, ensuring no extracapsular tissue between the suture arms. The suture is then tensioned and tied as normal. This shuttling method allows reproducible vertical mattress placement, which may be difficult to achieve with zone-specific cannula systems. The limited posterior exposure, however, makes large tears difficult to treat without significant risk to neurovascular structures.

BIOLOGIC ADJUNCTS

In the interest of optimizing meniscal healing rates, techniques have been added to improve the biological milieu available to the healing tissue. Trephination, or creation of channels for neovascularization, has been performed by piercing the adjacent meniscal and capsular tissue with a spinal needle or sharp instrument (27). Care must be taken to avoid disrupting the mechanical properties of a significant amount of surrounding meniscus.

Fibrin clot placement has also been advocated to direct growth factors to the site of repair. In situ clot formation has been described by preparing the tear site and surrounding capsular tissue by abrasion, followed by cessation of arthroscopic inflow for 1 to 2 minutes (40). Maintenance of outflow suction during this time collapses the joint and promotes clot adherence to the exposed meniscal edges. Exogenous fibrin clot placement has also been used to enhance healing in areas where less blood supply is available, such as near the popliteal hiatus (19,46).

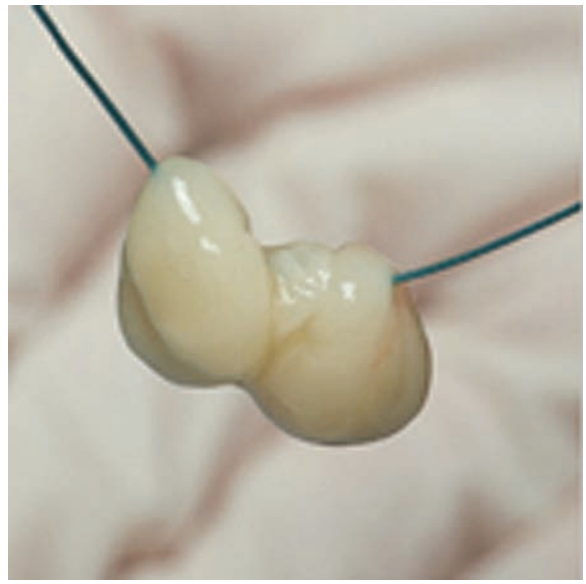

FIGURE 22.12
Platelet-rich fibrin matrix.

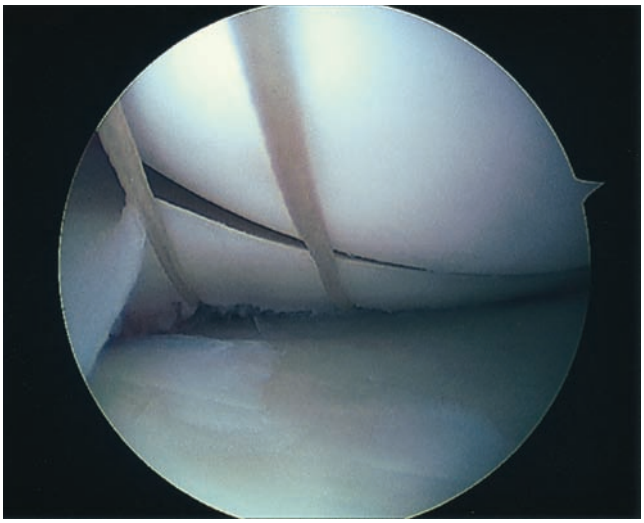

FIGURE 22.13
Shuttling and placement of platelet-rich fibrin matrix.

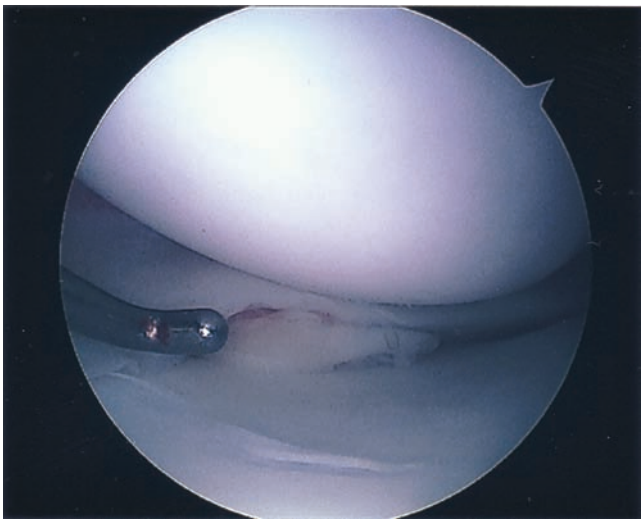

FIGURE 22.14
Shuttling and placement of platelet-rich fibrin matrix.

Recent interest has been taken in optimizing the healing of biologic tissues by adding concentrated platelet-rich plasma–derived autologous growth factors. Commercially available kits now exist (Cascade), which allow a platelet-rich fibrin matrix to be fashioned using autologous peripheral blood (Fig. 22.12). This is then delivered to the tear site via absorbable suture passed analogously to the meniscal repair sutures. Often, the use of a short cannula in the anterior working portal allows easier passage of the fibrin clot through the anterior skin and infrapatellar fat pad (Figs. 22.13 and 22.14). As yet, no controlled trials have been performed to evaluate the efficacy of this technique in increasing the ultimate meniscal strength, durability, or time to healing.

COMPLICATIONS AND PITFALLS

Disadvantages to the inside-out technique include an additional posterior surgical exposure, increased operating time, the need for a surgical assistant to aid in suture retrieval, and the risk of neurovascular complications. The risk of nerve entrapment within the suture fixation can be minimized by establishing clear exposure of the posteromedial or posterolateral joint capsule, deep to the respective gastrocnemius heads. Maintaining a position of knee flexion will allow susceptible structures to fall away from the surgical field. A parabolic curved retractor, such as a soup spoon or large tablespoon, is ideal for retraction of soft tissues while giving the passing needles a curved surface to deflect against into the operative field. Once the needle is identified through the capsule, an assistant can direct it the remainder of the way out, avoiding extracapsular tissue between the suture arms.

Postoperative neurologic deficits must be treated seriously. Motor deficits of the peroneal nerve, including a lack of ankle and toe dorsiflexion, should prompt immediate surgical exploration for nerve entrapment. Sensory deficits, however, may occur as a result of traction neurapraxia, and the indication for exploration may be less clear. Later development of painful neuromas can also occur, particularly on the medial side of the knee from entrapment of the main trunk or infrapatellar branches of the saphenous nerve. These usually require surgical exploration and neurolysis.

Finally, if a tourniquet is used, deflation prior to wound closure may be advisable to achieve adequate hemostasis. In particular, the inferior lateral geniculate artery may be susceptible to injury during a posterolateral approach to the knee.

POSTOPERATIVE REHABILITATION

Postoperative protocols following meniscal repair have evolved greatly and are still largely influenced by surgeon preference. Good results have been demonstrated with a conservative approach, including 2 weeks of knee immobilization in extension, followed by limited motion from 10 to 80 degrees for an additional 2 weeks (11). This bracing is performed in conjunction with limited weight bearing for 6 weeks. The rationale for this approach is to limit displacing forces across the repair site, which can occur in deep flexion and weight-bearing situations. Sports activity, squatting, and heavy stresses are additionally limited for 6 months following repair.

An accelerated approach to postoperative care has also been described (5,41). These authors advocate immediate knee range of motion and weight bearing as tolerated. Full activity release is somewhat individualized but usually achievable by 10 weeks. Good results have been noted, but the proportion of patients returning to full activities has not been reported.

Concomitant ACL reconstruction can also change the postoperative rehabilitation plan. In the conservative approach, immediate knee range of motion is allowed to prevent postoperative knee stiffness. Weight bearing is still limited for 6 weeks. Following this period, however, rehabilitation continues along standard post-ACL reconstruction protocols (11). In the accelerated approach, no specific limitations are placed on knee motion or weight bearing in the early postoperative period.

CLINICAL RESULTS

Several studies have examined the outcomes following inside-out meniscal repair. Clinical outcomes investigations, without comparative controls, have demonstrated a 73% to 91% success rate (6,21,33,43). A retrospective comparison with open meniscal repair demonstrated similar low rates of failure between the two repair techniques up to an average of 4 years after repair (18). These studies made no effort to evaluate the actual healing of the underlying meniscal tissue.

Second-look arthroscopy investigations have shown a 65% to 83% rate of meniscal healing (20,38,39,45). Some of the residual cases in those evaluations showed partial or incomplete healing. The rate of observed healing was generally increased by tear location in the peripheral one third and absence of a locked meniscus. Central avascular tears were significantly less likely to show adequate healing. Complete healing of these tears was seen in one investigation only 25% of the time, whereas partial healing accounted for an additional 38% of cases (39).

Despite incomplete anatomic healing following inside-out repair noted in certain studies, clinical results can still be favorable. Rates of adequate healing noted by arthroscopy or arthrogram in one series of 172 cases equaled 70%, but the rate of clinical healing without knee symptoms totaled 88% in the same group (45).

Concomitant ACL reconstruction improves meniscal healing rates, demonstrating >90% healing at second-look arthroscopy, over isolated meniscal tears in ACL-stable knees (8,35). ACL deficiency remains a poor prognostic finding in terms of meniscal healing. If ACL instability is identified, consideration should be given to concomitant ACL reconstruction or meniscal débridement.

SUMMARY

Meniscal preservation is widely recognized as a preferred intervention for select patients with symptomatic meniscal tears. Results of meniscal excision or débridement have consistently shown late degenerative changes to the articular surfaces of certain individuals. The inside-out meniscal repair technique is a proven method to achieve reliable stabilization of large, longitudinal or bucket-handle tears. In the proper setting of appropriate patient characteristics, tear size, location, configuration, and applied technique, a high proportion of meniscal healing can be anticipated. The surgeon must always keep in mind the relevant anatomy during the required extra-articular approach to avoid known neurovascular complications.

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23 Meniscus Root Repair

Eric J. Kropf and Christopher D. Harner

INTRODUCTION

While a wide spectrum of meniscal tear patterns have been well described, "root tears" represent a unique clinical entity that deserves particular attention. During weight-bearing activities, the menisci function as "shock absorbers" dissipating axial loads and containing hoop stresses. In turn, the articular cartilage is shielded from excessive forces. Normal meniscal function is dependent upon several key anatomic features including circumferentially oriented collagen fibers, the coronary ligaments, and the anterior and posterior root attachments that securely anchor the meniscus to the central tibial plateau (10). Root tears compromise this key attachment site and, as a result, have been shown to significantly alter knee kinematics and function (1,7).

The posterior root attachments play a greater role in maintenance of knee stability and are therefore more susceptible to injury. The posterior root of the lateral meniscus is commonly injured in association with acute anterior cruciate ligament (ACL) tears (3,9). More recently, tears of the posterior root of the medial meniscus have been recognized. Such tears have been implicated as a cause of medial meniscal extrusion, joint space narrowing, and rapidly progressive arthritis (6). Following an increased awareness of this specific injury pattern, root repair techniques have been developed. Our technique, which was developed as a modification to our medial meniscal transplantation technique, seeks to restore meniscal function and knee biomechanics by arthroscopically repairing the meniscal root back to the native insertion site.

In this chapter, we describe our current technique for arthroscopically assisted repair of the posterior medial meniscal root. Importantly, a similar repair of the lateral meniscal root can be performed with several minor modifications. The same principles apply to the lateral meniscus.

PREOPERATIVE PLANNING

Clinical Presentation/Physical Exam

Tears of the posterior root of the lateral meniscus are typically seen with acute ACL injury. The valgus twisting mechanism forcefully loads the lateral compartment and can injure the meniscal root. In all patients with acute ACL injury, especially those with extremely large bone bruise patterns, lateral root tears should be suspected.

Root tears of the posterior horn of the medial meniscus typically present with a bimodal distribution (2). Patients ≤40 years of age classically present after an acute sports-related injury often in conjunction with other ligamentous knee injury. Patients ≥40 years of age present following seemingly minor trauma (missing a step, rising quickly from a seated position, etc.) with acute, severe medial knee pain. The patient may note an audible "pop" and swelling. In the most common clinical scenario, physical examination typically reveals an overweight to obese female who walks with an antalgic gait. A minor effusion and slightly limited flexion are common (2,5). Medial joint line tenderness is present, often in the more posterior aspect of the knee.

Imaging

Standardized plain radiographs are performed in all patients who present with acute knee pain or injury. This typically includes a weight-bearing posteroanterior (PA) view (Fig. 23.1), weight bearing 30-degree flexion lateral, and a patellofemoral view. Early degenerative changes may be seen in slightly older patients, but radiographs

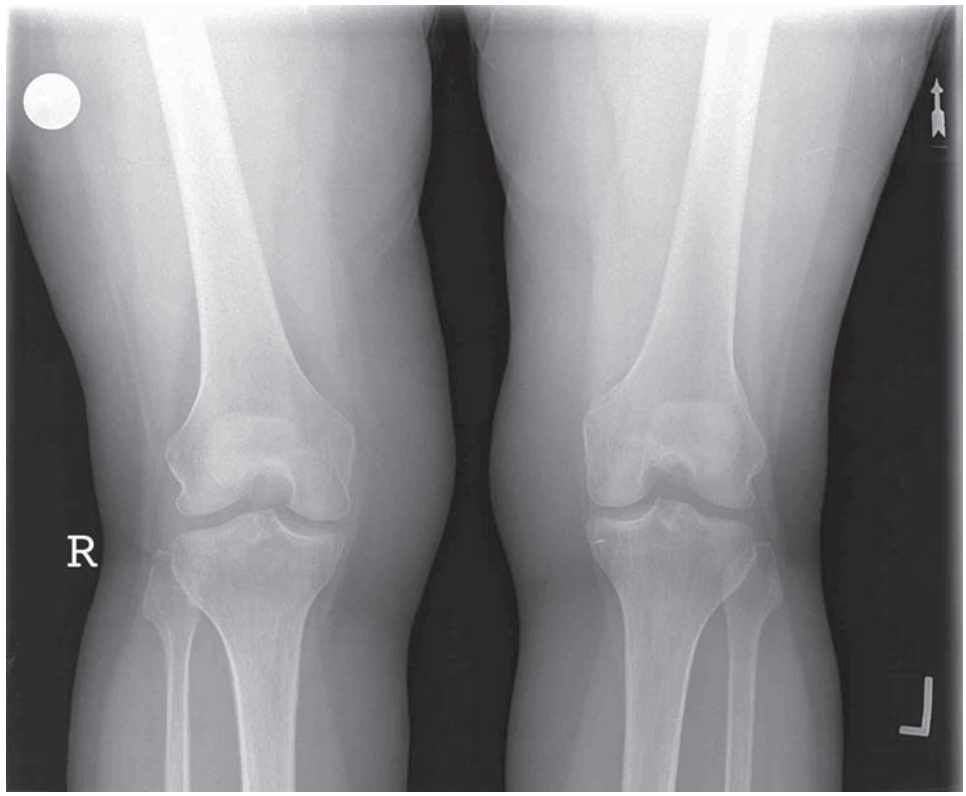


FIGURE 23.1
Plain radiographs (PA flexion weight-bearing view of bilateral knees) in a 55-year-old woman who presented with 3 months of posteromedial knee pain.

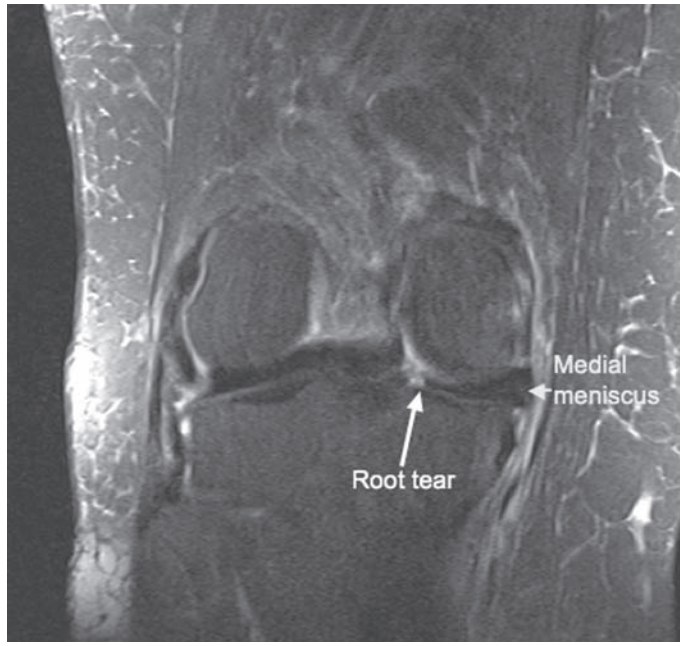


FIGURE 23.2
T2-weighted fat-suppressed coronal image of the right knee. A root tear of the posterior horn of the medial meniscus is seen (*white arrow*).

will be negative in the vast majority of patients. Magnetic resonance imaging has a high false-negative rate for avulsions or radial tears at the level of the posterior root (7) (Fig. 23.2). A high index of suspicion is imperative to detect root tears.

INDICATIONS/CONTRAINDICATIONS

Lateral Meniscus Root Tears

Tears of the posterior root of the lateral meniscus typically occur as the result of acute trauma, often in association with ACL injury. Indications for lateral root repair are similar to those for ACL reconstruction. In the physiologically young patient who wishes to return to his/her previous level of activity, we recommend

repair of the lateral root typically in conjunction with ACL reconstruction. Patients with advanced degenerative changes and low demands (sedentary lifestyle) are typically not surgical candidates.

Medial Meniscus Root Tears

With increasing awareness of this clinical entity, indications for repair of the posterior horn of the medial meniscus are evolving. In the young, active patient, we typically recommend meniscal root repair to restore the integrity and ideally, function of the medial meniscus. Unfortunately, the more common clinical scenario involves the overweight to obese 40- to 50-year-old female who presents with acute medial sided knee pain. In this setting, treatment options must be tailored based on the symptoms and desired functional goals of the individual patient. Irrespective of the ultimate treatment plan, we routinely counsel all patients in this population about the benefits of weight management and activity modification, specifically avoidance of deep squatting and repetitive pounding exercises. For patients who are minimally symptomatic, have low functional demands, are of advanced age or simply wish to avoid surgery, we recommend rest, ice, a brief initial course of nonsteroidal anti-inflammatories (2 weeks), and activity modification.

Patients who were previously asymptomatic or minimally symptomatic who present with an acute posterior horn medial meniscus root tear and worsening symptoms are typically good candidates for meniscal root repair. Advanced age, severe degenerative changes, and excessive varus malalignment are contraindications to surgical repair.

SURGICAL TECHNIQUE

Setup

Spinal or general anesthesia is first induced based on surgeon, anesthesiologist, and patient preference. The patient is positioned supine on the operating table and appropriate preoperative antibiotics are given. A lateral post is affixed to the bed at the level of the greater trochanter. The knee is flexed to 90 degrees with the foot on the table and a sand bag taped to the table to hold the leg in this position. The entire case is done with knee in this position without the need for an arthroscopic leg holder (Fig. 23.3).

An examination under anesthesia is then performed and compared to the contralateral knee. Range of motion and tests of ligamentous stability are performed in all patients. The surface anatomy and planned incisions are marked prior to the sterile prep and drape (Fig. 23.4). Standard portals include anterolateral and anteromedial parapatellar

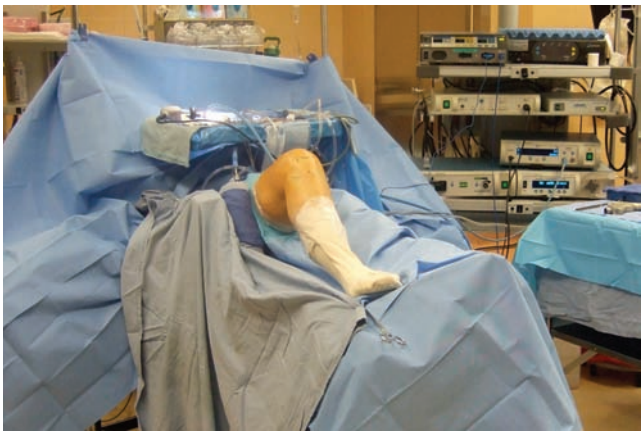


FIGURE 23.3
Room setup and patient positioning.

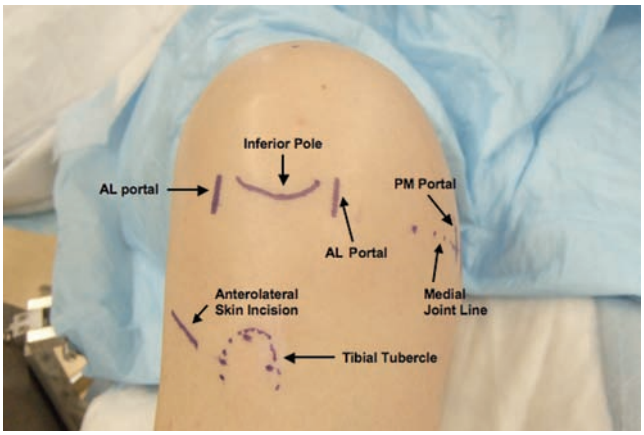


FIGURE 23.4
Anatomical landmarks, proposed skin incisions, and portal sites.

arthroscopic portals, a superolateral outflow portal, and a posteromedial portal. A 3-cm incision is placed over the flare of the anterolateral aspect of the proximal tibia, just distal to Gerdy tubercle and proximal to the origin of the tibialis anterior muscle. The incision is oriented proximal-lateral to distal-medial to follow Langer skin lines. The incisions are then provisionally scrubbed with betadine and preinjected with local anesthetic with epinephrine (Sensorcaine with epinephrine [1:100,000]). Importantly, we have found that this step obviates the need for a tourniquet. The operative extremity is then prepped and draped in the usual sterile fashion from toe to hip.

Diagnostic Arthroscopy

The arthroscope is introduced through the anterolateral portal and a thorough diagnostic arthroscopy is performed with a probe passed through the anteromedial portal. The medial, lateral, and patellofemoral compartments are examined throughout a full range of motion. Associated chondral lesions are addressed as necessary (débridement vs. microfracture).

The medial meniscus is then thoroughly inspected and probed. The posterior horn root must be directly visualized and probed. This is an important step, because in true root avulsions the remainder of the meniscus may appear perfectly normal when viewed through standard diagnostic portals. In patients with varus alignment or "tight" knees, the root cannot typically be visualized through standard anterior parapatellar viewing portals.

Visualization of the Posterior Horn Medial Meniscal Root

To visualize the posteromedial joint space and meniscal root, the 70-degree arthroscope is passed under the PM bundle of the PCL and lateral to the medial femoral condyle (Gillquist view) (4). This view allows for direct visualization of the posterior horn of the medial meniscus and the true root insertion site just anterior to the PCL footprint (Fig. 23.5).

Once the diagnosis of posterior horn root tear is confirmed and deemed amenable to repair, an accessory posteromedial portal is established under direct visualization. With the knee flexed to 90 degrees, an 18-gauge spinal needle is passed approximately 10 mm above the joint line and 5 mm posterior to the edge of the medial femoral condyle. Following the same trajectory, a vertical stab wound is then made with an No. 11 blade through skin, subcutaneous tissues, and capsule. When properly established, this portal should allow for a steady egress of fluid. For better visualization of the root tear, the arthroscope can be introduced over a switching stick via the posteromedial portal.

Preparation of the Meniscus and Insertion Site

Prior to performing root repair, sufficient space within which to work and pass instruments must be established. We typically perform a reverse notchplasty of the posterior medial femoral condyle with a 4.5-mm full radius resector. The shaver is introduced through the anteromedial portal while viewing from the anterolateral portal. The synovial layer and a minimal amount of the undersurface of the posteromedial bundle of the PCL is first débrided. With a bone-cutting tip, approximately 3 mm of articular cartilage and bone is removed from the posterior aspect of the medial femoral condyle (Fig. 23.6). The ACUFEX tip drill guide (Smith and Nephew, Andover, Massachusetts) is passed through the anterolateral portal and placed at the root insertion site to confirm sufficient space exists for later repair. If difficulty exists with passage of the tip guide, the notchplasty is gradually widened. It cannot be overemphasized that the notchplasty be widened to a diameter sufficient for all instrument passage at this point. Later suture management can be difficult and attempts to widen the space after sutures have been passed risks inadvertent damage to the suture material and meniscal root.

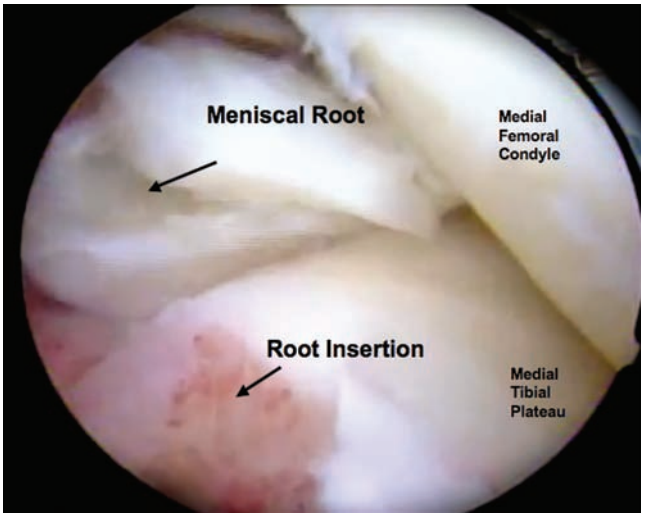


FIGURE 23.5

Gillquist view of the posteromedial knee: The arthroscope is passed between the PCL and the medial femoral condyle allowing direct visualization of the medial meniscal root and the native insertion site.

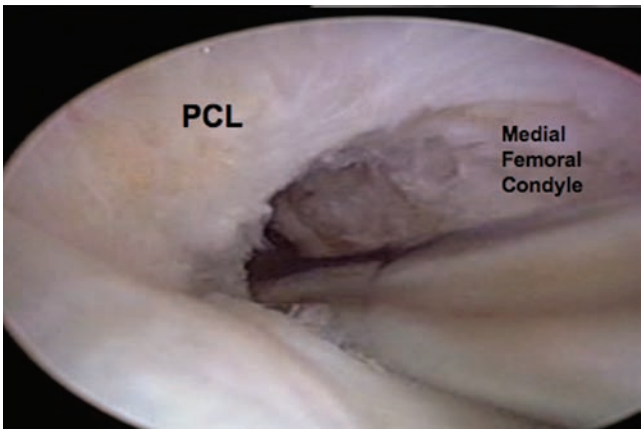


FIGURE 23.6

Reverse notchplasty is routinely performed with a full-radius resector to allow sufficient space for instrumentation.

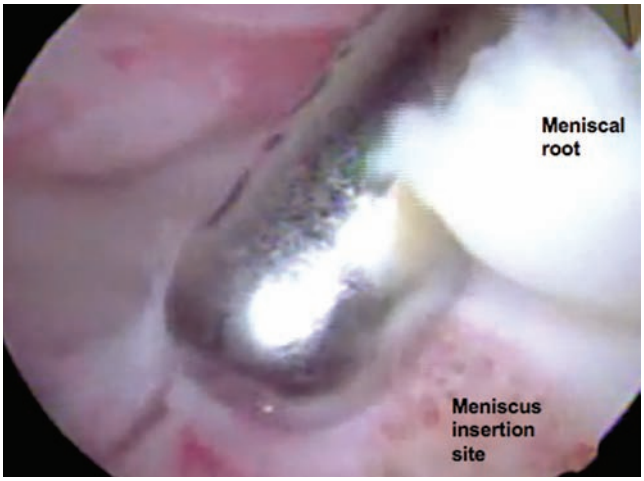


FIGURE 23.7

Preparation of the meniscal root insertion site down to a bleeding bony bed.

The meniscal tissue is then reevaluated and the insertion of the root is identified. The native insertion site is then débrided down to a broad bony bed. A curved shaver and meniscal rasp are interchangeably passed through the anterolateral and posteromedial portals to débride and abrade the tibial insertion site (Fig. 23.7). The insertion site must be débrided down to a wide bony bed to create the most favorable environment for subsequent healing. When using the arthroscopic rasp, small fat globules may emanate from the bony surface indicating appropriate depth of preparation.

Suture Passage

At our institution, in vitro biomechanical studies have been carried out to determine the optimal suture technique for root repair (8). We have also experimented with multiple devices in vivo to further refine our technique and facilitate suture passage in this relatively confined space in the posteromedial compartment of the knee. In this section, we describe our current experience with the "loop suture" technique utilizing the ACCU-PASS suture shuttle device (Smith and Nephew, Andover, Massachusetts) (Fig. 23.8).

Passage of sutures through the meniscal root is best performed with the arthroscope in the anteromedial or posteromedial portal and instruments passed through the anterolateral portal. This affords the best trajectory to ensure a large bite of the meniscal root is captured with the suture loop. To aid in suture management, a clear 8-mm cannula is first placed in the anterolateral portal. While visualizing the root through a medial portal, the ACCU-PASS suture shuttle with a monofilament loop (Smith and Nephew, Andover, Massachusetts) is passed through the clear cannula. The meniscal root is then pierced with the tip of the ACCU-PASS and the monofilament loop advanced through the meniscal root (Fig. 23.9). The ACCU-PASS device is then removed from the knee while the loop is continuously advanced to ensure that the loop is not inadvertently pulled out of the meniscal root tissue. The looped end of the monofilament is next retrieved with an ice tongs or arthroscopic probe and pulled out of the joint through the cannula in the lateral portal. The free ends of the monofilament must be held outside the cannula to prevent their advancement into the joint. If this step has been performed properly, the monofilament loop will be passed through the meniscal root and both ends held in the clear cannula.

Next, the monofilament must be exchanged for the permanent suture in a looped fashion. To accomplish this, one end of a 2-0 Ultrabraid suture (Smith and Nephew, Andover, Massachusetts) is threaded through the monofilament loop and the ends adjusted to equal length. In effect, the Ultrabraid is looped over the ACCU-PASS

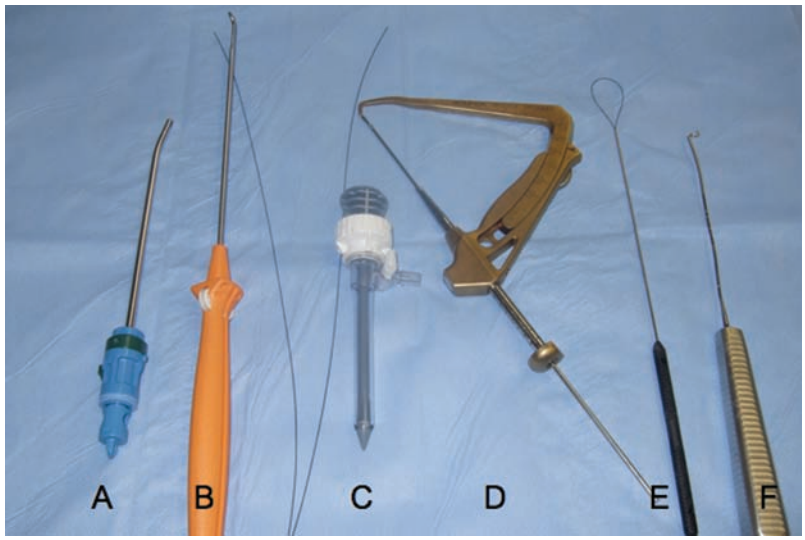


FIGURE 23.8

Surgical instruments employed for posterior horn medial meniscal root repair via the "loop suture" technique. **A:** 4.5-mm curved full-radius resector. **B:** ACCU-PASS (70 degree) suture shuttle. **C:** Clear cannula. **D:** Acufex ACL tip guide with guide pin. **E:** Hewsen suture passer. **F:** Suture pulley probe.

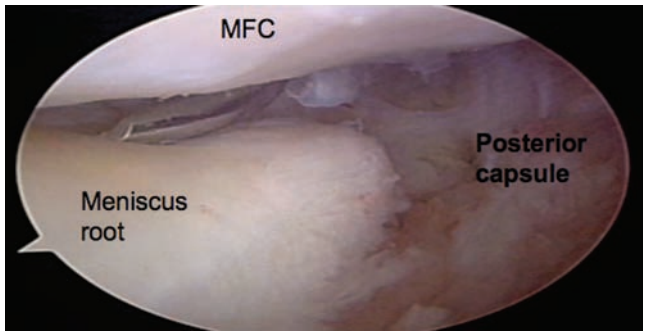
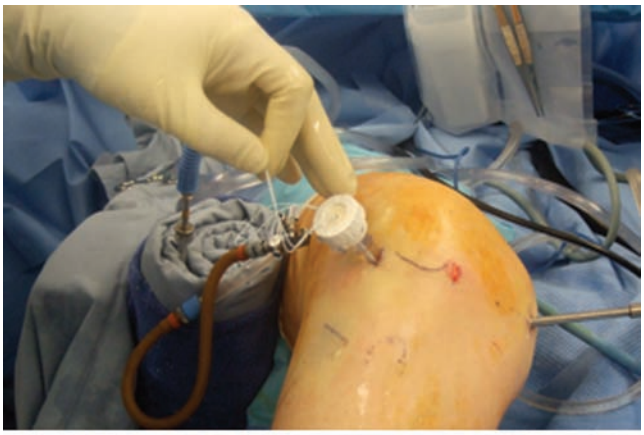
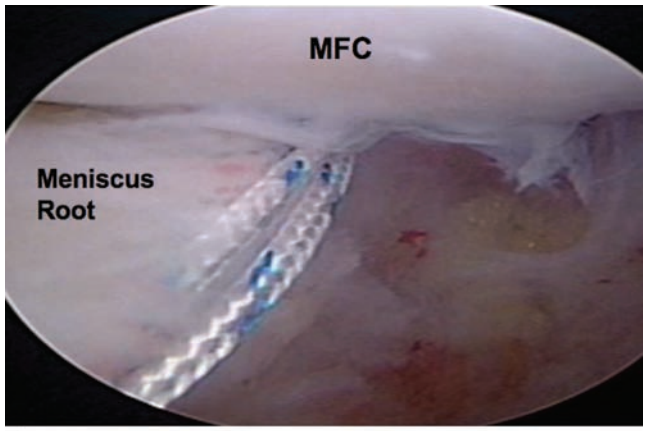


FIGURE 23.9

The meniscal root is pierced with the ACCU-PASS suture shuttle device.



A



B

FIGURE 23.10

The "loop suture" technique. **A:** The free ends of the Ultrabraid are passed through the loop. **B:** The loop is then cinched down around the meniscal root. This configuration has shown superior pull-out strength in recent biomechanical testing.

monofilament loop (loop-in-loop configuration). The free ends of the monofilament are then pulled through, shuttling the Ultrabraid loop through the meniscus and back out of the lateral portal of the knee. Again, care is taken to ensure that the free ends of the suture are not inadvertently pulled into the cannula. Once the suture loop is outside of the lateral portal, the free Ultrabraid suture ends are passed through the Ultrabraid loop (Fig. 23.10). Tension is applied to the free suture ends and the loop is slowly advanced down onto the root of the meniscus. A pulley probe is used to assist in cinching the loop down onto the meniscal root. The pulley probe acts as a fulcrum and prevents the Ultrabraid suture from cutting through the meniscal tissue. The free suture ends can be tugged on at this point to ensure that the root has been firmly captured for later repair. The free suture ends are then held outside the lateral portal and clamped with a hemostat while the tibial tunnel is created.

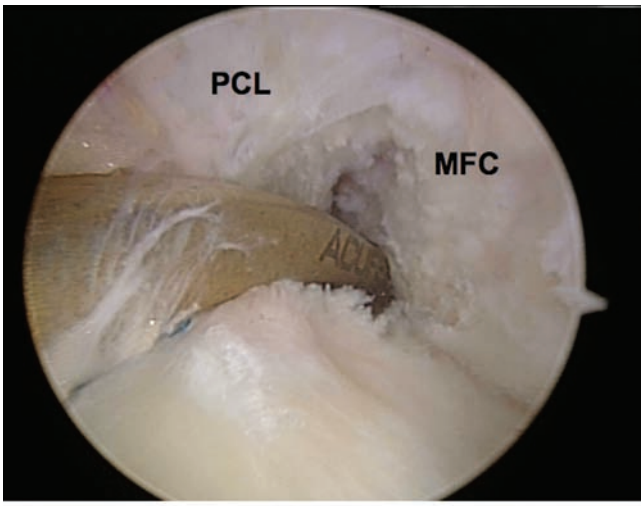
Tunnel Preparation

The arthroscope is then positioned in the posteromedial portal allowing for the best visualization of the native root insertion site. An Acufex ACL tip guide is passed through the anterolateral portal under the PM bundle of the PCL and onto the root insertion site just anterior to the PCL. The drill sleeve is positioned through the tip guide and its position on the skin is marked. The previously outlined lateral incision is then made and sharp dissection carried down to the level of the periosteum. The periosteum is sharply incised and elevated off of the anterolateral surface of the tibia. This is done at a position just distal to the lateral flare of the tibia. The tibia must be subperiosteally stripped a total of approximately 2 cm to allow easy access for placement of a 4.5-mm AO screw and washer that will serve as the final fixation. Throughout the course of the dissection, care is taken to avoid violating the anterior compartment of the leg as this may result in significant bleeding.

Once the dissection is complete, the ACL tip guide is reintroduced through the anterolateral portal and held at the anatomic meniscal root insertion site (Fig. 23.11). The ACL drill sleeve is placed through the incision onto the exposed flare of the lateral tibia. Under direct visualization, a 3/32 in guide pin is drilled up to but not through the far cortex. Similar to PCL reconstruction techniques where drilling in the posterior knee is required, we typically drill to the level of the far cortex on power and then for safety reasons, complete the tunnel by gently tapping the guide pin with a mallet.

Fixation

The 3/32 in guide pin is next exchanged for a Hewsen suture passer (Fig. 23.12). With the arthroscope in the anteromedial portal, the Hewsen suture passer loop is pulled into the anterior aspect of the knee with an



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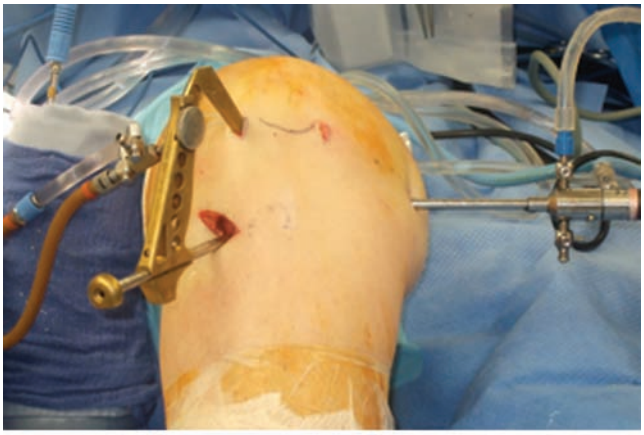

B

FIGURE 23.11

A: The Acufex ACL tip guide is positioned at the anatomic insertion site of the meniscal root. The correct position is confirmed arthroscopically.
B: The guide is then seated on the external tibia just distal to the lateral flare of the tibia.

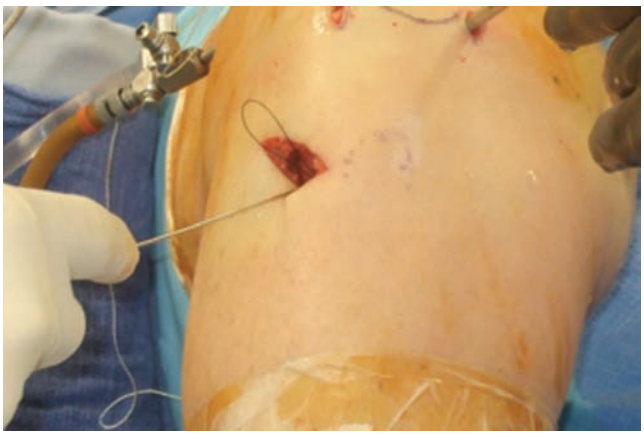

FIGURE 23.12

A Hewsen suture passer is used to shuttle the Ultrabraid suture through the tibial tunnel.

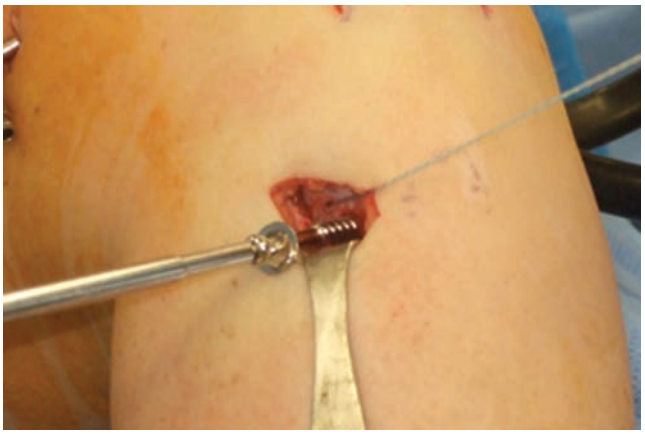

FIGURE 23.13
With the knee held at 30 degrees of flexion, the suture ends are tied over a suture post for final fixation (6.5-mm cancellous AO screw and smooth washer).

arthroscopic probe. An arthroscopic ice tongs is then brought in through the lateral portal, through the Hewsen loop, and the Ultrabraid suture is grasped and pulled back through the Hewsen passer loop. At the level of the external tibia, the Hewsen suture passer is pulled back, shuttling the Ultrabraid suture through the tibial tunnel. The pulley probe is again used as a fulcrum to aid in suture passage. This is an important step, as the Hewsen loop will surely break if excessive force is applied. Tension is now applied to the Ultrabraid sutures and reduction of the meniscal root can be visualized arthroscopically. As final fixation, an AO 6.5-mm cancellous screw and washer is placed 1 cm distal to the tibial tunnel (Fig. 23.13). At 30 degrees of flexion, the sutures are then tied down over the screw/suture post. The fascia of the anterior compartment is closed with interrupted 0-Vicryl figure-of-eight sutures. The wound is irrigated with antibiotic impregnated solution and subcutaneous tissue and skin are closed in the usual fashion.

Postoperative Protocol

The postoperative protocol is designed to maximize early return of range of motion and strength in a supervised setting. This must be done while protecting the knee for 6 weeks to allow adequate time for the meniscal root to heal down to bone. Therefore, we maintain partial weight-bearing status with crutches for 6 weeks. Weight-bearing status is then advanced to full weight bearing gradually over the next 2 weeks. A continuous passive motion unit is utilized from 0 to 90 degrees for the first 4 weeks to prevent stiffness. Bracing is typically not necessary. Prior to surgery, patients are instructed how to perform home physical therapy including; straight-leg raises, quad sets, heel slides, and calf pumps. To protect the root, this is the extent of therapy for the first 4 to 6 weeks. During the second and third months postoperatively patients undergo supervised physical therapy. Return to full unrestricted activity typically occurs at 4 months.

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24 Medial Meniscal Transplant

James R. Romanowski and Christopher D. Harner

INTRODUCTION

One of the earliest treatments for medial knee pain was a total meniscectomy. This procedure, however, led to accelerated arthritic changes and poor patient outcomes (1,10,21). Long-term follow-up (avg: 17.5 years) in patients with prior meniscectomy has shown that 74% of operative knees have arthritic changes versus only 6% of in the nonoperative limb (9). Prospective, 30-year follow-up evaluation of adolescents undergoing total meniscectomy showed the operative knee to have three times the rate of arthritic changes versus the contralateral side (12).

Previously thought of as a developmental remnant, the meniscus' role in force transmission, biomechanics, and joint stability of a healthy knee gradually was understood and appreciated. The importance in articular force dissipation cannot be understated as even a partial meniscectomy of 16% to 34% can lead to a 350% increase in cartilage contact forces (5,11). Consequently, the focus shifted from cavalier excision toward preservation. Damage to the meniscus can take many forms and the ideal treatment for a torn meniscus is repair. Repair, however, is not always possible, particularly in the degenerative setting or with complex patterns not amenable to healing. In these situations, partial and total meniscectomy may be the result.

Although long-term meniscal transplant outcome studies are limited, short-term results have shown significant improvements in pain and function (5). The preventative role on long-term arthritic joint changes remains unknown.

INDICATIONS/CONTRAINDICATIONS

Young patients with isolated, medial compartment pain and a history of medial meniscectomy are most likely to benefit from a meniscal transplant. There are no specific age limits, but the procedure should be avoided in skeletally immature patients to prevent growth plate damage. The upper age limit is related to arthritic changes in the knee. The Fairbanks classification system and associated articular changes actually were based on patient's undergoing meniscectomy and are useful for predicting the outcome of surgical graft placement (6). The Outerbridge classification system is also useful for grading articular changes and selecting patients for surgical intervention.

Meniscal transplant has been shown to be more successful in patients with low grade (Outerbridge I, II), unicompartmental arthritic changes (8,15). Relative contraindications include Outerbridge grade III, IV changes as these been shown to have inferior results. Meniscal transplantation with grade IV chondral changes has a 50% failure rate (15,18).

Successful surgical candidates must also have an acceptable mechanical alignment. For medial meniscal transplants, it is particularly important to address varus alignment deformities. A weight-bearing axis that passes through the medial compartment has been shown to have significantly inferior outcomes when compared to transplant patients who have concomitant high tibial osteotomies to neutralize the alignment of the affected limb (2,22). The goal is to shift the mechanical axis laterally and between the intercondylar tibial spines. Failure to address the limb alignment is a relative contraindication to meniscal transplant.

Ligamentous stability is a prerequisite to medial meniscal transplant. It is not uncommon for patients to additionally have ACL dysfunction, and with loss of this primary stabilizer to anterior translation, increased stresses are placed on the medial compartment.

Alternative interventions should be considered in patients with previous or active infections, inflammatory arthritides such as gout and rheumatoid arthritis, obesity, and inability to follow postoperative rehabilitation (4,19).

PREOPERATIVE PLANNING

Radiographic imaging is critical for both diagnosis and meniscal graft templating. Standard films include a single cassette bilateral 45-degree flexion weight-bearing posterior-anterior radiograph, a 45-degree flexion lateral of the involved knee, and a sunrise view. Additional imaging should include long cassette bilateral lower extremity radiograph evaluating for any varus or valgus malalignment. Should the history/physical suggest additional pathologies, an MRI may be appropriate. An MRI dedicated to cartilage sequences may provide additional information.

Patients have often had prior meniscal or ligamentous surgery. In cases where enlarged bony tunnels are present in the setting of a dysfunctional or absent ACL, a staged reconstruction with bone grafting may be necessary. The interval for definitive surgery is usually 4 to 6 months to allow the bone graft to incorporate.

Deformities resulting in varus or valgus malalignment require osteotomies. If a single stage correction is desired, a closing wedge osteotomy should be pursued as opening wedge methods with graft add complexity and additional concerns of nonunion.

Many methods exist for sizing the medial meniscal allograft. Radiographs, CT scans with and without contrast, MRI, as well as the patients height have all been used for assessing the needed graft dimensions (17). Perhaps the most reliable and cost-effective method is using ipsilateral AP and lateral plain radiographs. The actual coronal width is determined on the AP radiograph as the distance between the medial and lateral metaphyseal margins (Fig. 24.1A). Sagittal width is determined by measuring the distance between a line parallel to the anterior tibia and a second line perpendicular to the articular surface at the posterior margin of the medial tibial plateau (Fig. 24.1B). The sagittal value is multiplied by 0.8 conversion factor. Osteophytes are not included within the measurements.

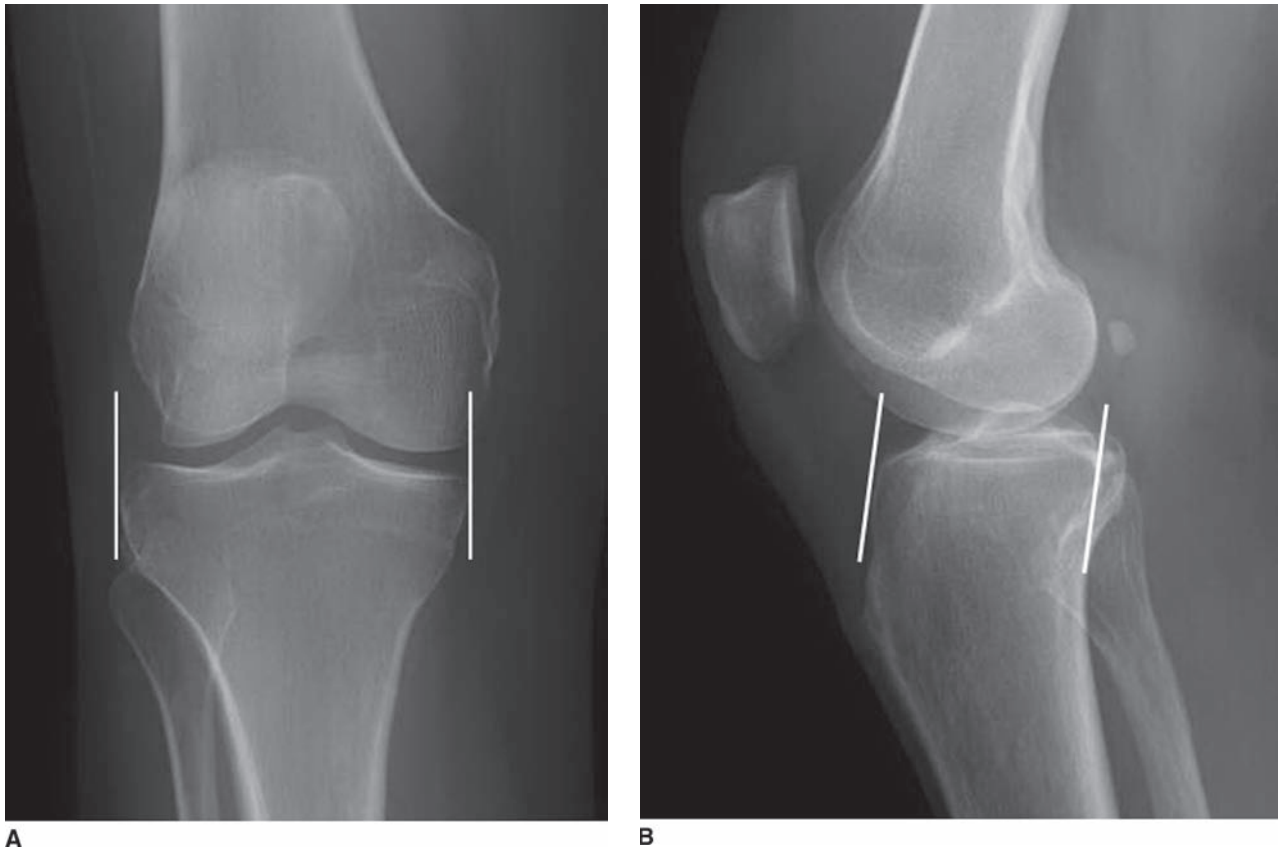


FIGURE 24.1

Radiographic sizing. **A:** AP radiograph. The width of the meniscal allograft is the actual distance between the medial and lateral tibial metaphyseal margins. **B:** Lateral radiograph. The sagittal distance is measured between the anterior border of the tibial plateau and the posterior edge of the medial tibia. A 0.8 conversion factor is used.

SURGERY

Anesthesia

The patient is identified in the preoperative holding area and the surgical site is verified, marked "yes," and signed. An anesthetic regimen is chosen after discussion with the patient, anesthesiologist, and surgeon. General anesthesia is often utilized and augmented with regional blocks for postoperative pain control.

SETUP, PATIENT POSITIONING, AND EXAM UNDER ANESTHESIA

The patient is transferred to a standard operative table and placed supine. After the induction of anesthesia, a Foley catheter is inserted as part of fluid management. An exam under anesthesia is performed. It is not uncommon to have associated ligamentous pathology; therefore, a careful exam is necessary. Ranges of motion and ligamentous stability are assessed through Lachman, pivot shift, anterior/posterior drawer, and varus/valgus stress testing at 0 and 30 degrees. The patient's heels are even with the end of the operative table and a bump is placed under the ipsilateral hip. The involved extremity is flexed to 90 degrees and a second bump is secured with tape to allow the heel to rest in this position during surgery. A lateral post is placed at the level of the greater trochanter to allow the extremity to balance in the flexed position and prevent it from falling into abduction (Fig. 24.2). It is not necessary to use a tourniquet.

ANATOMIC LANDMARKS AND INCISIONS

The identification of several anatomic landmarks is necessary as multiple incisions are made for placement of the meniscal allograft. Once the surgical incisions are marked, a subcutaneous injection of 1% marcaine with 1:200,000 epinephrine is placed under each site. The superior and inferior poles of the patella, patella tendon borders, tibial tubercle, medial joint line, and anterolateral tibial crest are identified (Fig. 24.3). The patient is then sterilely prepped and draped. The following incisions are placed with the knee positioned in 90 degrees of flexion. Standard anterolateral and anteromedial (AM) arthroscopy portals are utilized. The anterolateral portal is made on the lateral border of the patellar tendon at the level of the inferior pole of the patella and extended distally approximately 1 cm. The AM portal is also started at the same level, but approximately 1 cm medial to the medial border of the patellar tendon. A medial parapatellar arthrotomy is utilized for securing the anterior horn of the allograft to that of the native meniscus. This incision is just medial to the patellar tendon beginning at the level of the inferior pole of the patella and extended distally to the joint line. The incision may incorporate and extend distally from the AM portal. As an extensile approach, it may be further extended for tibial tunnel

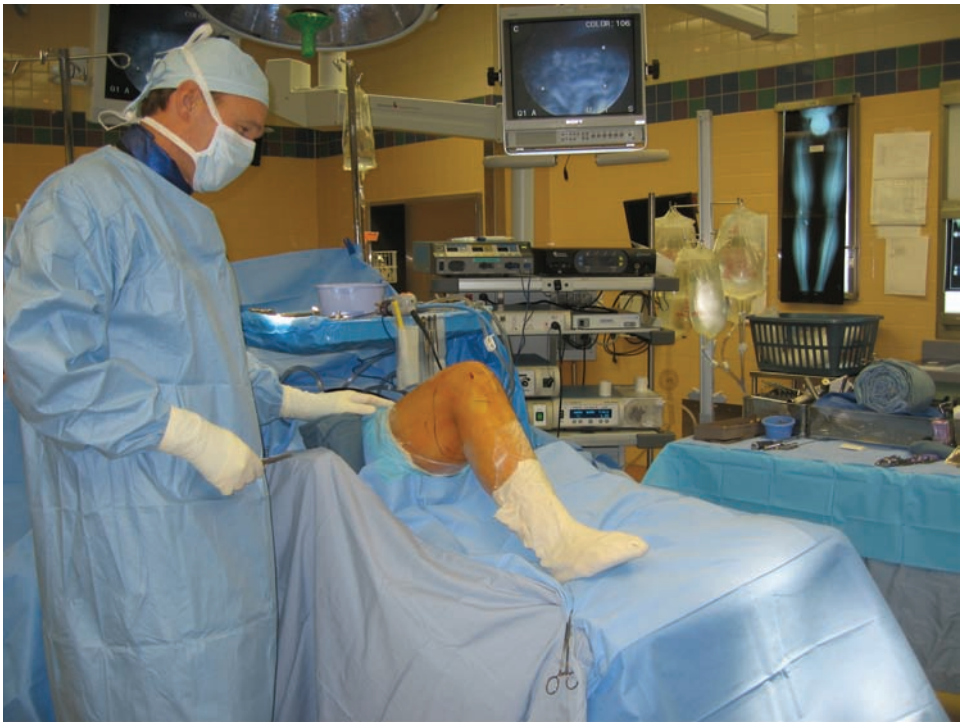


FIGURE 24.2

The patient is positioned with the knee flexed at 90 degrees, secured by a lateral post on the thigh and bump at the foot.

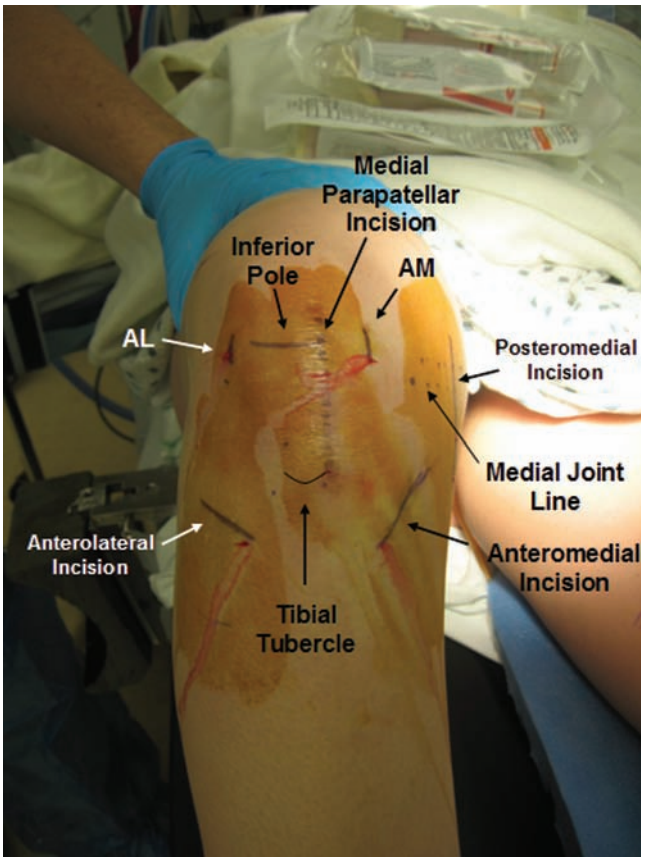


FIGURE 24.3

Anatomic landmarks and placement of surgical incisions. The anterolateral incision is made along the crest of the proximal tibia. The PM incision is made along the posterior border of the MCL. The medial parapatellar incision is made along the medial border of the patellar tendon and may be extended distally for ACL tibial tunnel placement as needed. The AM incision is occasionally used when ACL reconstruction is necessary or if present from prior surgery. A subcutaneous injection of 1% marcaine with 1:200,000 epinephrine is placed under each incision. AL, anterolateral portal; AM, anteromedial portal.

placement when additional ACL reconstruction is necessary. It remains imperative to recognize the joint line as some patients have patella baja that may risk further damage to the meniscus when the inferior pole is used as a reference. Oftentimes, patients may have prior surgical incisions and it may be necessary to incorporate these as part of the approach.

A posteromedial (PM) incision is also necessary for placement of the transplant allograft. Similar to inside-out meniscal repair techniques, the vertical incision is placed over the PM joint line, just posterior to the MCL. Approximately one third of the incision is superior to the joint line and two thirds is distal. Careful attention is paid toward identifying and avoiding the saphenous nerve. The PM portal is established early for visualization of the posterior meniscal root, while the arthrotomy is not necessary until allograft passage.

An anterolateral incision is necessary for anterior and posterior meniscal root tunnel placement. This curvilinear incision is placed along the anterolateral border of the proximal tibia at the level of the tibial tubercle and extends for approximately 4 cm. The anterior compartment is entered via a similar curvilinear fascial incision and subperiosteal elevation pushes the tibialis anterior musculature laterally as to protect the underlying neurovascular structures.

An outflow portal is utilized and, with the leg in full extension, is marked at the level of the superior pole of the patella and at the lateral border of the vastus lateralis.

DIAGNOSTIC ARTHROSCOPY

Prior to performing a meniscal transplant, it is necessary to perform a diagnostic arthroscopy. Although most patients have had a prior arthroscopy that resulted in a meniscectomy or as part of the evaluation for transplant suitability, there is often an extended interval as the allograft match process may take months to years. This delay may result in further arthritic changes that preclude transplantation. The standard anterolateral and AM portals are used. The medial, lateral, and patellofemoral compartments are assessed for pathologic changes involving the cartilage and menisci (Fig. 24.4). The ACL and PCL are also evaluated. After evaluation of the medial compartment and determination that the patient is a suitable meniscal transplant candidate, the graft may be prepared.

An ACL reconstruction is often necessary and this is addressed first. Both the femoral and tibial tunnels are created and the graft may be passed. Tibial fixation should be avoided until after the meniscal transplant, as this may create difficulty with visualization of the medial compartment.

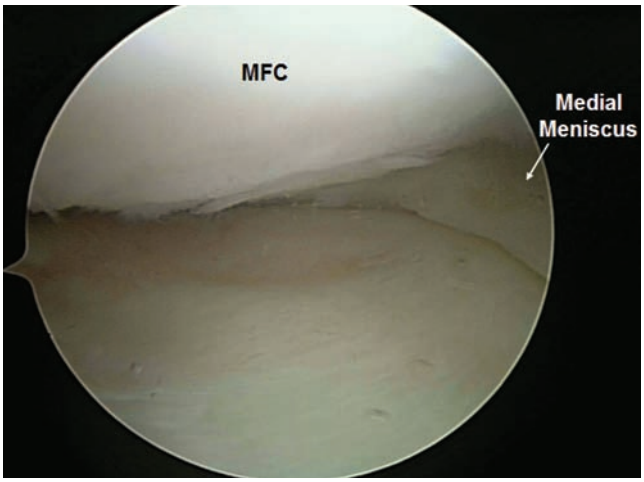


FIGURE 24.4

Arthroscopic view of medial compartment of the knee. Note the early arthritic changes on the medial femoral condyle (MFC) and near complete loss of the medial meniscus.

GRAFT SELECTION AND PREPARATION

Graft selection begins with a reputable tissue bank. Each distributor has certain specifications for sizing. It is necessary to be familiar with the requirements, but usually depends on radiographic assessment of the affected knee. The graft is often supplied as a proximal tibia with both menisci present. After a 20-minute thaw in 0.9% normal saline and antibiotic bath (cephazolin), the specimen is inspected for any defects. Using a No. 15 blade scalpel, both the anterior and posterior root insertions are released via subperiosteal dissection (Fig. 24.5). This dissection also provides guidance for the root tunnel placement within the affected joint, as it shows the relationship to bony landmarks such as the medial tibial spine. It is important to have some flexibility in the root insertion, as this is variable between individuals and bone block allografts make custom fit less probable (3). Bone plug allograft transplants often have incomplete representation of the entire root insertion and are technically more difficult to perform. A 2 Ultrabraid suture (Smith and Nephew, Andover, Massachusetts) is passed separately in each root as a "loop" stitch. The superior surface of the allograft is marked "T.O.P." to maintain orientation during arthroscopy. Three individual 0 Cottony Polydek (Teleflex Medical, Mansfield, Massachusetts) simple sutures are placed in the posterolateral horn of the allograft. Once the graft is prepared, it is set aside in a moist sponge until the recipient site is ready.

MEDIAL COMPARTMENT PREPARATION

The degenerative medial meniscus is prepared for donor allograft. An arthroscopic 4.5-mm full radius shaver and arthroscopic biter are used to debride the remaining meniscus to a stable rim in preparation for the allograft (Fig. 24.6). If possible, leave the outer one third of the meniscus, as this provides hoop restraint and a well-vascularized foundation for the donor meniscal allograft to be sutured.

Posterior Root Tunnel Preparation

Next, the posterior root insertion is prepared. With the arthroscope in the AM portal, an arthroscopic shaver is inserted through the AL portal and the posterior root insertion is debrided. The PM portal is established for additional visualization of the posterior meniscal root insertion. An 18-gauge spinal needle is used to establish the trajectory of the portal, and a Gillquist view is utilized to observe the needle and switching stick entering the posterior joint. Arthroscopic visualization may switch between the AM and PM portals as needed.

A meniscal rasp is also used to further debride the root insertion surface for the allograft to heal. An ACL tip guide set at 50 degrees is placed in the AL portal and centered in the posterior root footprint (Fig. 24.7). If the native root is not obvious, the position is immediately posterior to the medial tibial spine. The boom is placed directly on bone within the anterior compartment approximately 1 cm off the tibial crest. This is approached with a curvilinear anterolateral incision on the proximal tibia and the anterior compartment fascia is released 4 cm. Gentle elevation of the tibialis anterior allows for direct visualization of the bony surface. A second tunnel will be placed in the area; therefore, the tunnel needs to be slightly proximal and posterior allowing, for a 1-cm bone bridge. With the ACL guide locked in, a 3.2 drill bit is inserted under arthroscopic visualization. If necessary, the drill bit may be left just under the cortical bone of the plateau and a mallet used to complete the advancement as not to overpenetrate or deflect. A Hewson suture passer (Smith and Nephew, Andover, Massachusetts) is then placed temporarily within the tunnel until utilized later in the procedure.

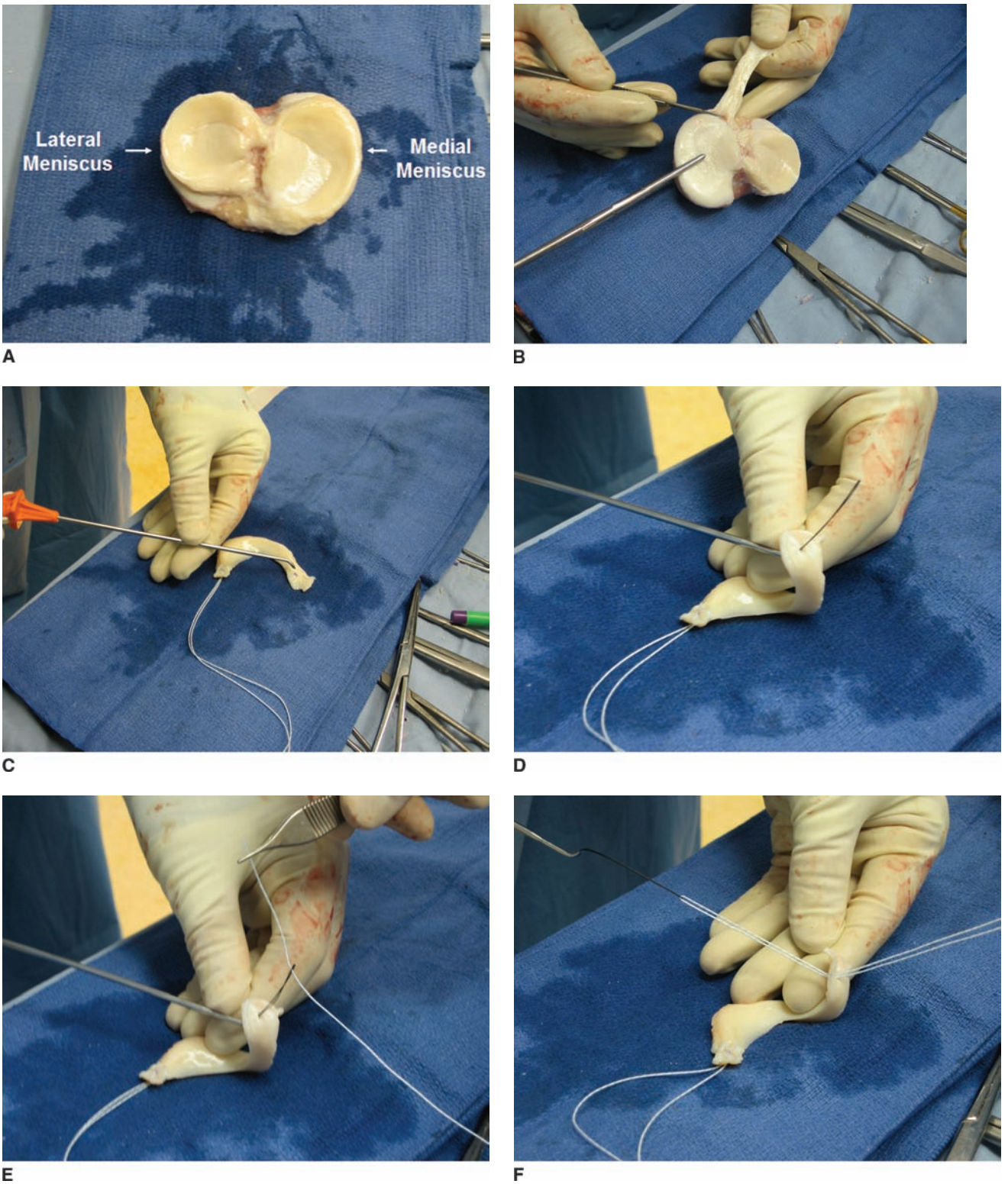
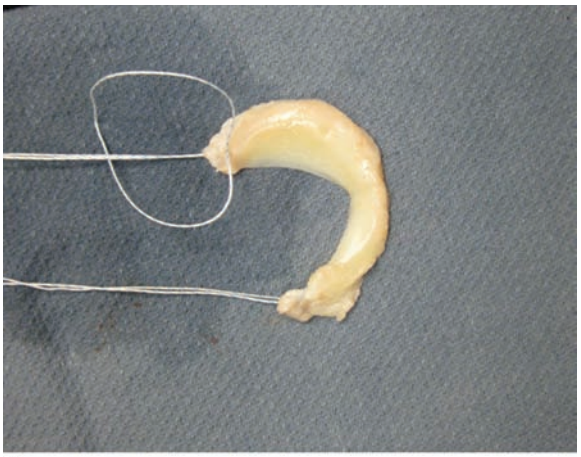


FIGURE 24.5

Graft preparation. **A:** Proximal tibial allograft with menisci intact. Medial and lateral menisci are labeled. **B:** The posterior horn of the medial meniscus has been released and the anterior horn is released with a No. 15 blade scalpel at the anterior meniscus insertion. **C:** The anterior meniscal horn is marked and an Acupass suture shuttle (Smith and Nephew, Andover, Massachusetts) is lined up for insertion. **D:** The suture shuttle is inserted and advanced. **E:** The suture shuttle is loaded with 2 Ultrabraid (Smith and Nephew, Andover, Massachusetts). **F:** The suture is advanced through the meniscal allograft.



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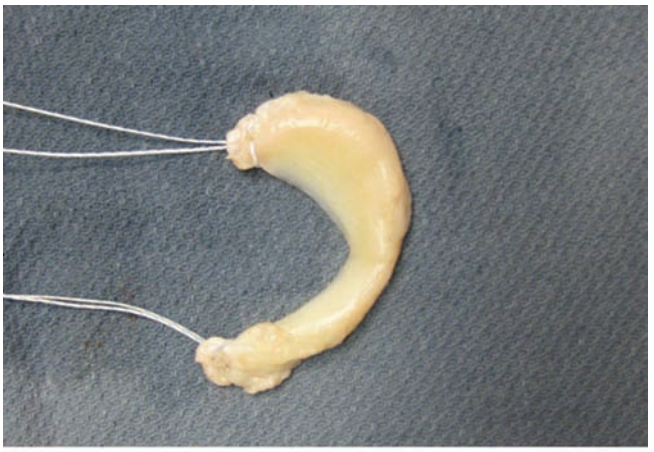

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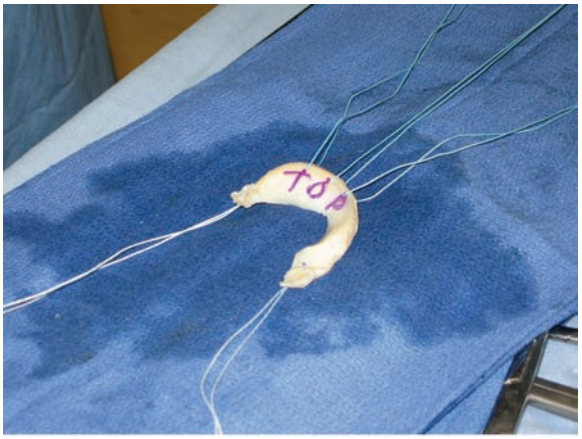

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FIGURE 24.5 (*Continued*)

G: The suture ends are brought through the suture loop. **H:** The loop is tensioned around the meniscal root. **I:** The allograft is labeled for orientation and additional 0 Cotton Polydek is placed in the periphery 1 cm apart. The graft is now ready for placement.

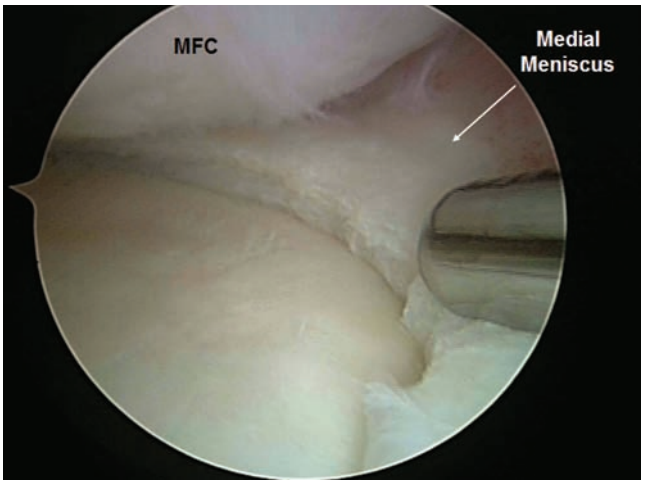
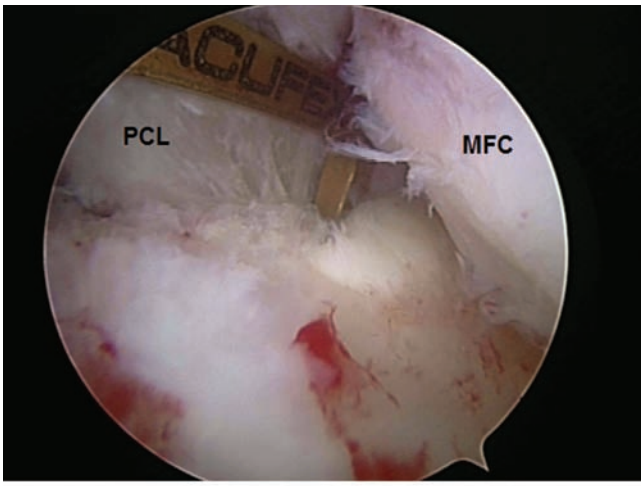


FIGURE 24.6

Preparation of medial compartment. The medial compartment is prepared by arthroscopic debridement of the remaining medial meniscus to a smooth outer rim. The peripheral one-third should be preserved for the vascular and nerve contributions. MFC, medial femoral condyle.



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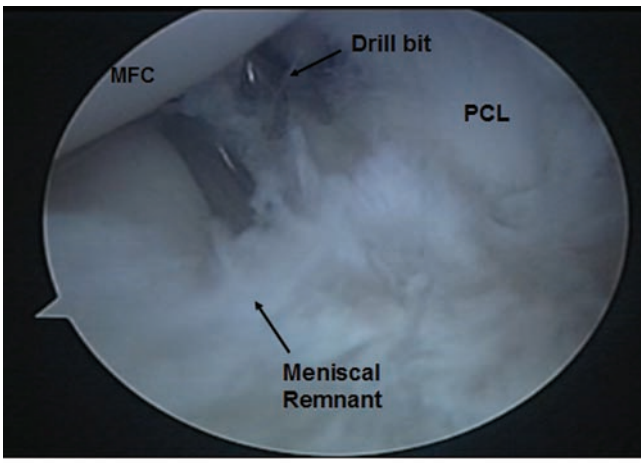

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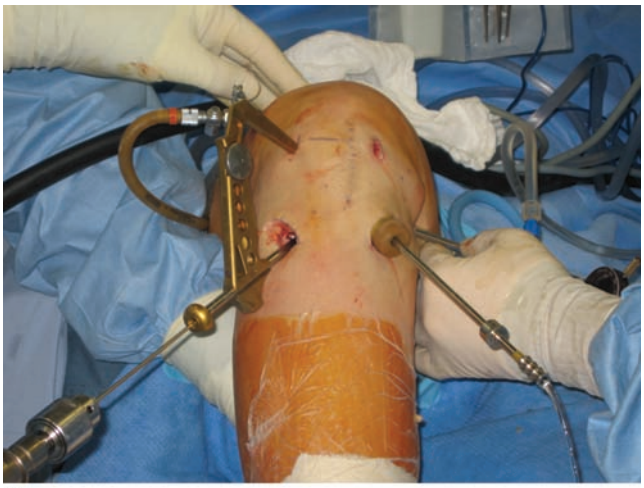


C

FIGURE 24.7

Preparation of the posterior root tibial tunnel. **A:** Arthroscopic view through the AM portal. The tip drill guide (Smith and Nephew, Andover, Massachusetts) is placed at the footprint of the posterior meniscal root. A reverse notchplasty may be performed to improve Gillquist visualization. **B:** View from PM portal. The drill bit is centered in the posterior root insertion. **C:** External view of posterior tibial root tunnel drilling through the anterolateral skin incision on the proximal tibia. The drill and guide are then removed and a Hewson suture passer placed (Smith and Nephew, Andover, Massachusetts). AM, anteromedial; MFC, medial femoral condyle; PCL, posterior cruciate ligament; PM, posteromedial.

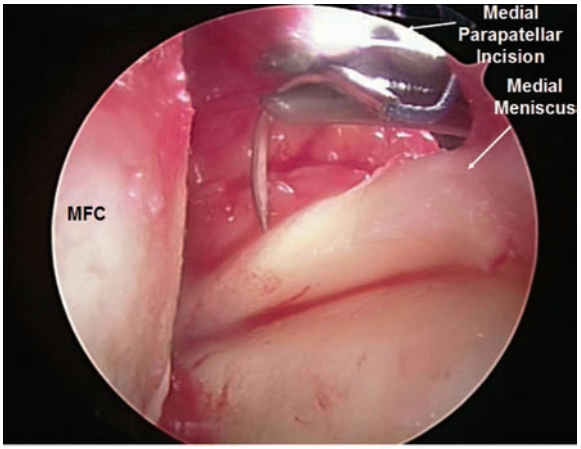
Anterior Horn/Root Preparation

The next step involves preparation of the anterior horn and root of the medial meniscus. This portion of the meniscus cannot be approached arthroscopically. A medial parapatellar arthrotomy is made through an incision along the medial border of the patellar tendon from the inferior pole of the patella to the level of the joint line. The medial border of the patellar tendon is preserved and a capsulotomy performed, revealing the remnants of the native meniscus. Three separate simple, vertical sutures are passed in to the anterior horn using 0 Cottony Polydek (Fig. 24.8). The needles are left on the suture and clamped with hemostats.

Under direct visualization or using the arthroscope in the AL portal, the anterior root insertion is identified (Fig. 24.9). Again, the ACL tip guide set at 50 degrees is placed within the prepared footprint. The guide boom is placed within the same anterolateral proximal tibial incision and locked onto the bone 1 cm anterior and distal to the posterior root tunnel. A 3.2 drill bit is used to create the tunnel and a Hewson suture passer temporarily placed.

Posteromedial Preparation

With the knee flexed at 90 degrees, a vertical skin incision is made just posterior to the MCL and incorporating the PM portal. Careful, blunt dissection reveals the sartorial fascia (Layer I) overlying the MCL and a vertical incision is made within this fascia. The plane between Layers I and II is developed as the medial head of the gastrocnemius and semimembranous are palpated. A second vertical incision along the posterior border of the superficial MCL and posterior oblique ligament allows entry into the knee joint. Palpation of the joint line identifies the native meniscus and a vertical capsulotomy is created just superior to the remnant tissue. This entrance into the joint should be large enough to slide the meniscal graft.



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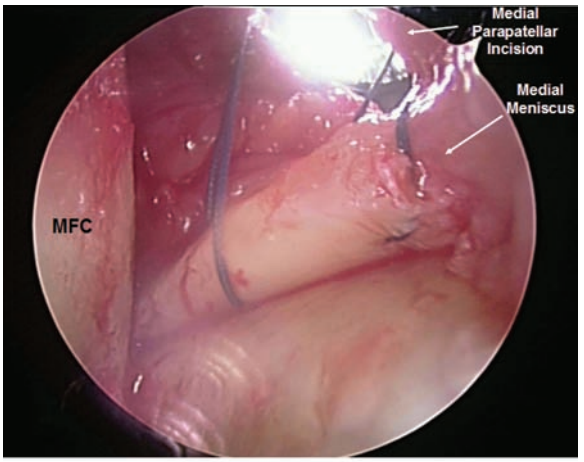

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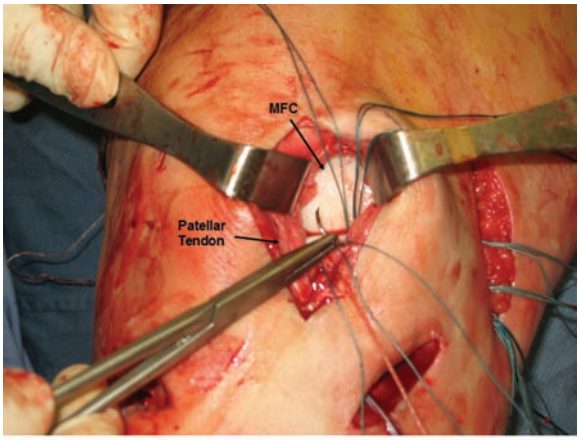

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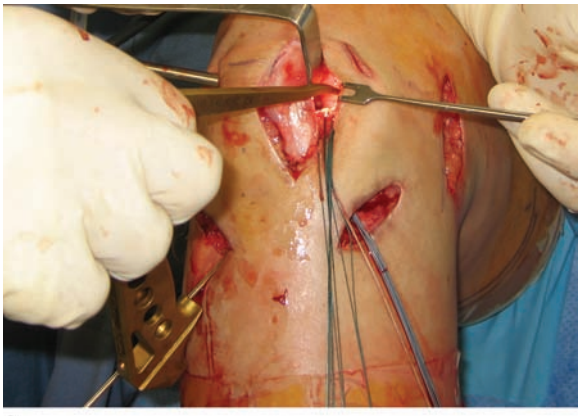
FIGURE 24.8

Preparation of the anterior horn medial meniscal remnant. **A:** Arthroscopic view from the AL portal. Needle positioning for simple suture passage through the native anterior horn. Passage is via the medial parapatellar incision. **B:** Sutures are spaced 1 cm apart. **C:** External view of suture placement. MFC, medial femoral condyle.



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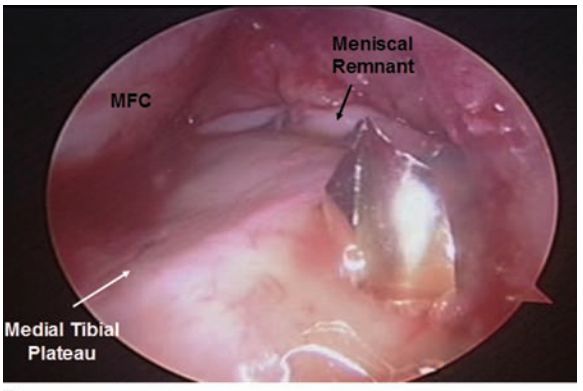

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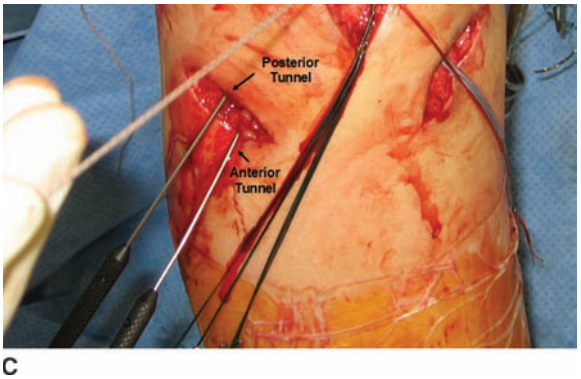

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FIGURE 24.9

Preparation of the anterior root tibial tunnel. **A:** Placement of the ACL tip guide into the footprint of the anterior meniscal root. **B:** Arthroscopic AL portal view of drill bit. **C:** The drill bit is replaced with a Hewson suture passer (Smith and Nephew, Andover, Massachusetts). Both suture passers are loaded into their respective meniscal root tunnels. MFC, medial femoral condyle.

GRAFT PASSAGE

The posterior horn suture passer placed previously is visualized within the PM incision and the loop is brought to the skin surface. The posterior root suture of the prepared allograft is loaded into the suture passer and pulled through the tunnel. The posterior horn is then positioned within the joint with advancement of the suture (Fig. 24.10).

A curved clamp is then placed from the anterior medial parapatellar arthrotomy, through the joint, exiting through the PM arthrotomy. The anterior root sutures are loaded in the clamp and pulled anteriorly through the joint to seat the medial portion of the allograft meniscus. This suture is then loaded into the anterior root suture passer and brought through anterior root tibial tunnel for final positioning of the graft.

Securing the Graft

The graft position is inspected with the arthroscope. With the knee in 15 degrees of flexion and valgus, tension is placed on the root sutures. With satisfactory positioning of the allograft, the sutures are tied over the bone bridge within the anterolateral incision.

The knee is then placed in 90 degrees of flexion and attention is directed toward the medial parapatellar arthrotomy. The 0 Cottony Polydek sutures placed earlier within the native meniscus are sewn into the allograft to provide anterior security. The graft should be flush to native remnant on the joint line.

The posterior horn is secured by suturing the three 0 Cottony Polydek sutures placed earlier within the allograft to the posterior capsule.

Additional sutures are placed under arthroscopic visualization with 2-0 Ticron (Covidien, Mansfield, Massachusetts) utilizing an inside-out technique. Again it is imperative to place the allograft side-to-side to the native meniscal remnant as to maximize the presence of the allograft within the medial compartment.

After the medial meniscus is secured, if an ACL reconstruction was performed, then the graft may be fixed into place at this time.

CLOSURE

After successful placement of the medial meniscal allograft, attention is now paid toward closure. The wounds are first irrigated out copiously. For the anterolateral and AM incisions (if performed), the fascia is reapproximated with 0 absorbable braided suture, the subcutaneous tissue with 2-0 absorbable braided suture, and the skin with either staples or 4-0 monofilament absorbable suture. The medial parapatellar incision is closed in a similar fashion.

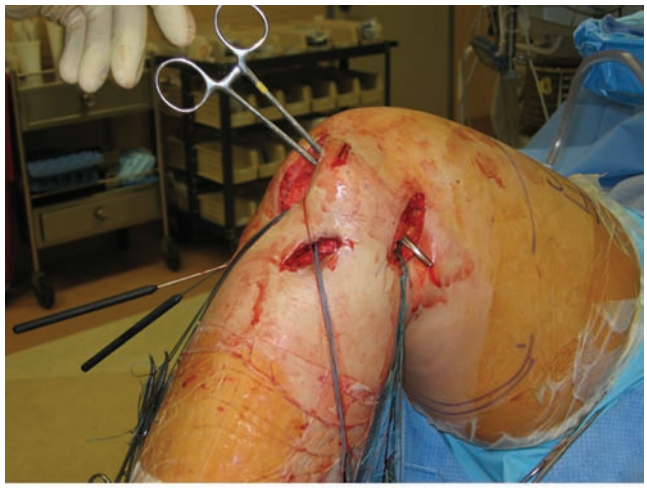
The PM incision is more complex in closure. The posterior oblique ligament (POL) is sewn to the superficial MCL with 0 nonabsorbable braided suture. It is not necessary to close the sartorial fascia as this typically heals on its own without negative sequelae and there is risk of saphenous nerve entrapment during its closure. The subcutaneous tissue is closed with 2-0 absorbable braided suture, and the skin with either staples or 4-0 monofilament absorbable suture.

The arthroscopic portal sites are closed with 3-0 nonabsorbable monofilament. Dressings are applied as is a hinged knee immobilized locked in extension.

POSTOPERATIVE REHABILITATION

Appropriate, supervised rehabilitation is critical toward maximizing patient outcome in the setting of meniscal transplantation. The rehabilitation course is divided into four phases, each with criteria for advancement to the next level (7). Phase I begins the day of surgery and usually lasts 8 weeks. The goals include graft protection during healing, achieving full knee extension, and minimizing early loss of quadriceps function. Before leaving the operating room, patients are placed in a knee immobilized locked in extension. Given the duration of the surgery, complexity, and potential for postoperative pain, the majority of patients are admitted for observation. Continuous passive motion is started the day of surgery and continues for approximately 3 weeks. The initial settings are 0 to 60 degrees, with daily increases of 10 degrees to a maximum of 90 degrees. The machine is used for 2 hours, three times a day. Quad sets, straight leg raises, and heel slides are utilized. Ambulation is weight bearing as tolerated with crutch assistance. As the quadriceps regains function around 6 weeks, the brace may be unlocked during ambulation and the crutches are discarded as balance normalizes. Once the extension lag is eliminated and the quadriceps continues to develop, the second phase is entered (Tables 24.1 and 24.2).

Phase II usually spans the 8- to 12-week period. The goals are focused on continued gait training, quadriceps development, and range of motion (ROM). The patient is no longer limited to 90 degrees of maximum flexion and closed-kinetic chain flexion exercises are instituted and limited to 0 to 60 degrees. Open kinetic chain extension exercises are started and are focused on the 45 to 90 degree arc. Once the gait normalizes, the brace use may be discontinued and advanced to Phase III.



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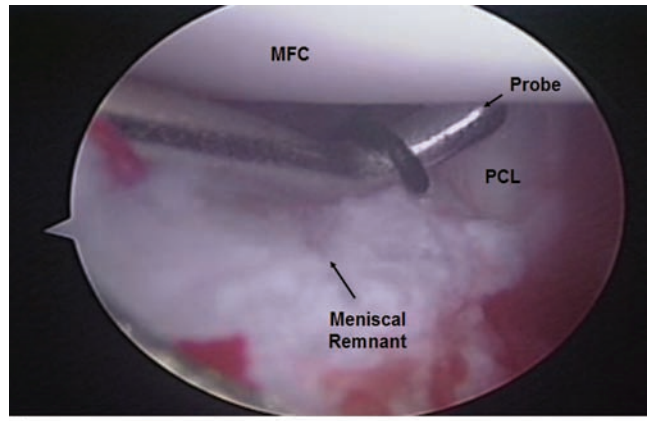

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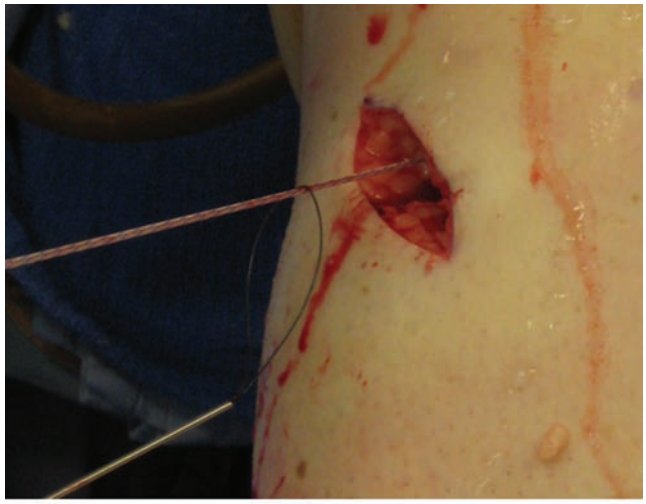

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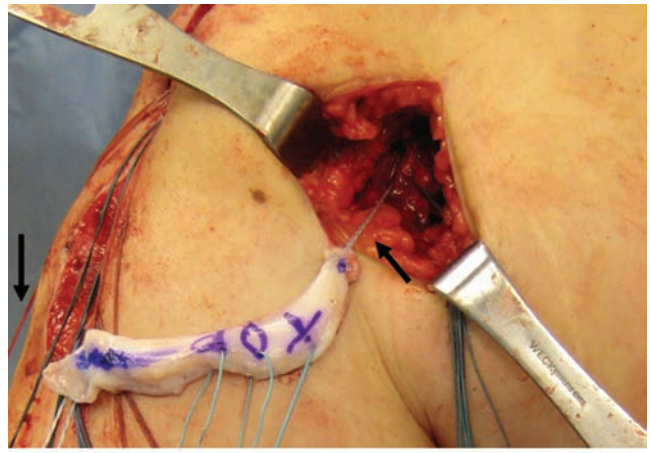

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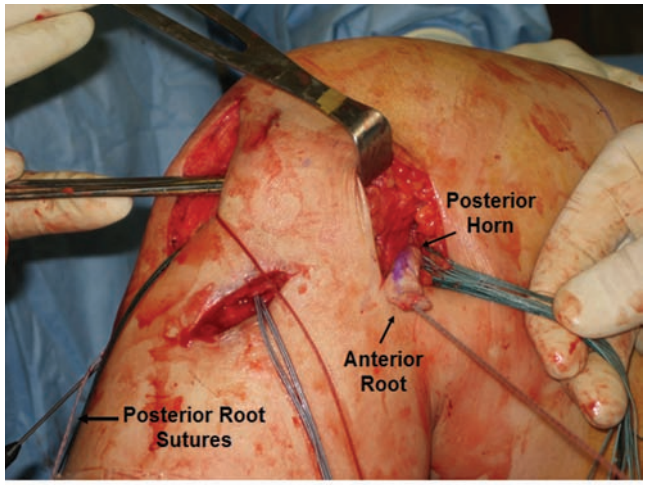

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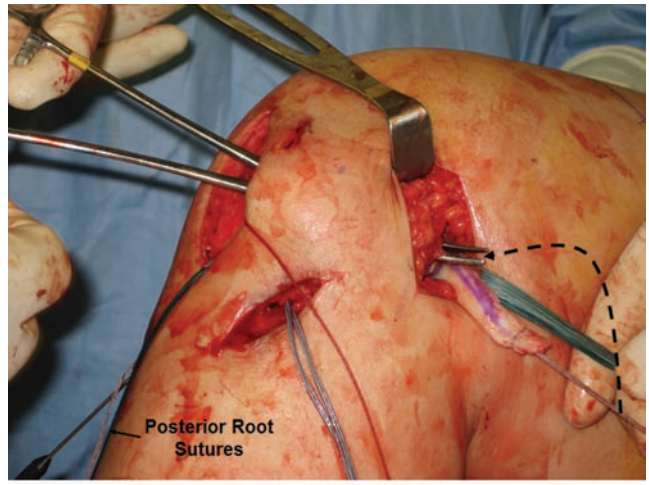
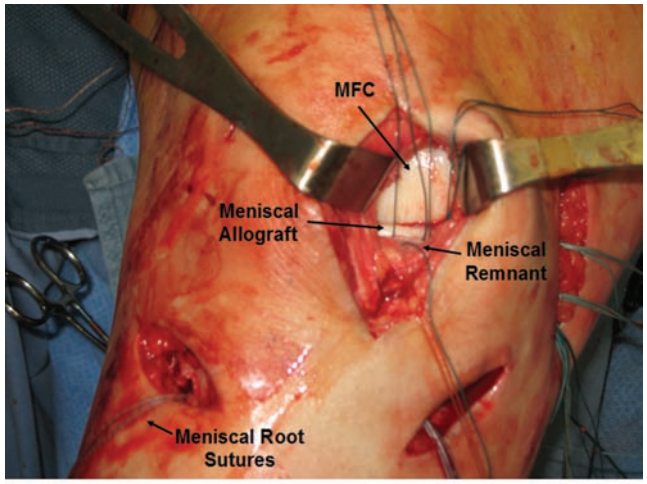


F

FIGURE 24.10

Graft passage. **A:** The knee is now prepared to accept the meniscal allograft. **B:** Arthroscopic view from PM incision. The posterior root tunnel suture shuttle is retrieved and brought into the incision to allow for loading of the posterior root allograft suture. **C:** The posterior root sutures are engaged into the posterior tibial tunnel and brought out through the anterolateral incision via the Hewson suture passer (Smith and Nephew, Andover, Massachusetts). **D:** Posterior horn sutures are advanced into the joint. *Black arrows* show suture path. **E:** The posterior meniscal root and horn of the allograft are pulled into the joint. **F:** The anterior root sutures are loaded into the tonsil (*dashed line*).



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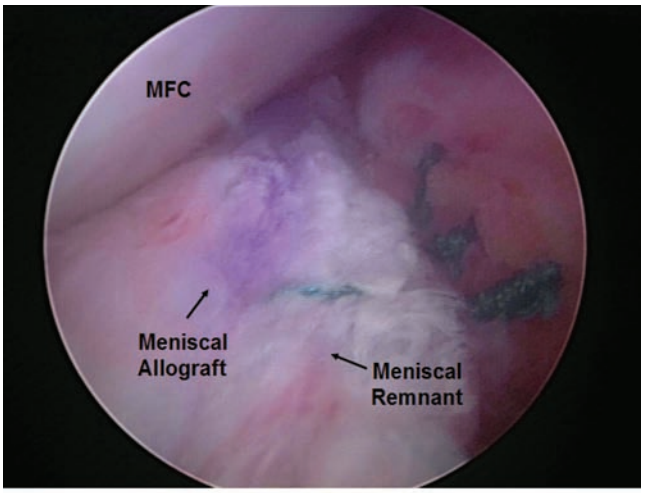
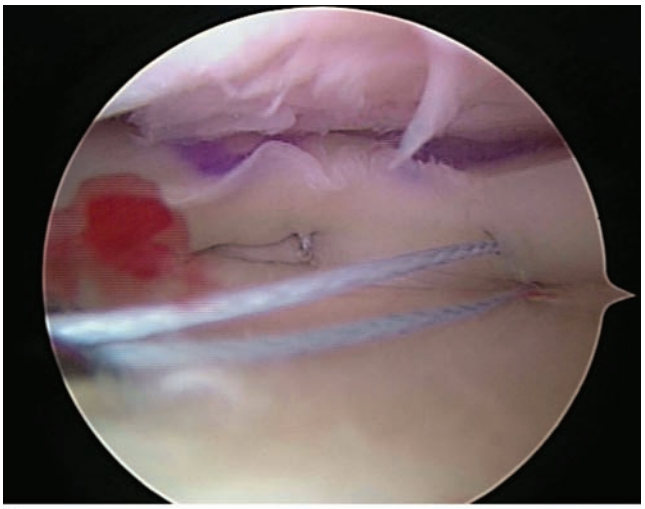


H

FIGURE 24.10 (*Continued*)

G: The anterior portion of the allograft is advanced into the joint with the root sutures loaded into the Hewson suture passer. The suture is pulled through the anterior root tunnel and tied to the posterior root sutures over a bone bridge. Apposition between the allograft and native meniscus is noted. **H:** Arthroscopic view on final anterior horn position.



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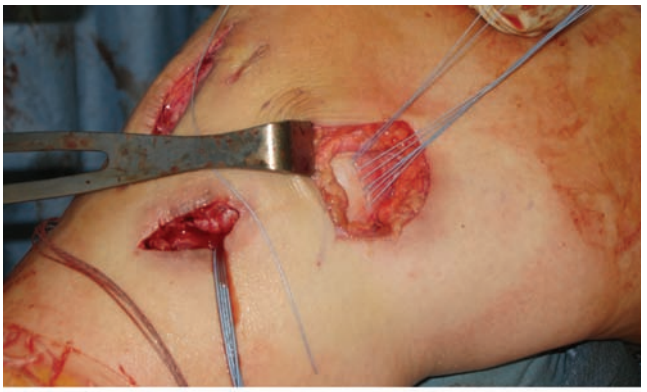

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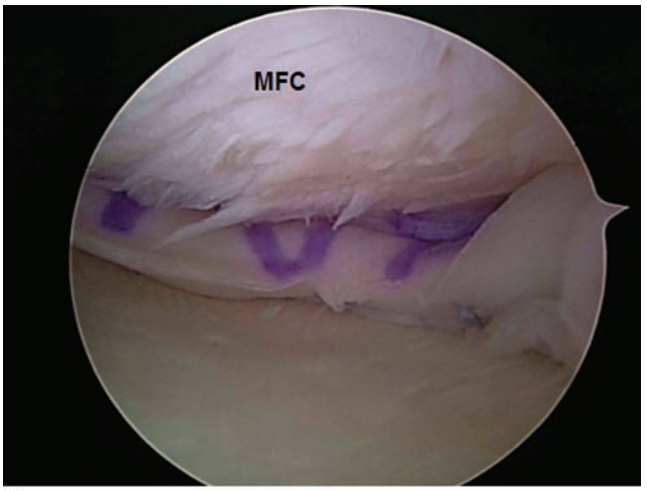

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FIGURE 24.11

Placement of inside-out medial meniscal sutures. **A:** Arthroscopic view of suture placement within the allograft. **B:** External view. **C:** Final graft placement.

TABLE 24.1 Rehabilitation Protocol

Phase I (0–8 wk)	
Goals	Full knee extension Minimize swelling Preserve quadriceps function Protect allograft
Weight bearing	As tolerated with crutch assistance
ROM	0–90 degrees
Brace	(0–6 wk)—locked in extension for ambulation and sleeping (6–8 wk)—may unlock for ambulation as quadriceps function recovers
Physical therapy modalities	Heel slides (0–90 degrees) Straight leg raises Quad sets Electrical stimulation Patella mobilization Ankle pumps
Advancement criteria	No extension lag Full extension Resolution of inflammation
Phase II (8–12 wk)	
Goals	Continued graft protection Normalization of gait Further quadriceps development
Weight bearing	As tolerated
ROM	Full
Brace	Discontinue once extension lag has resolved, normal gait, and full extension
Physical therapy modalities	Closed-kinetic chain exercises (0–60 degrees) Open-kinetic chain exercises (45–90 degrees) Balance development Stationary bike ROM
Advancement criteria	Normal gait ROM of at least 0–100 degrees
Phase III (3–9 mo)	
Goals	Hamstring development Further lower extremity strengthening, proprioception, ROM
Physical therapy modalities	Hamstring curls (0–60 degrees) Aquatic therapy (no breaststroke) Pool jogging Stationary bike, elliptical, stairmaster ROM
Advancement criteria	Strength, ROM, proprioceptive recovery
Phase IV (9 mo–)	
Goals	Maintenance of strength, ROM Gradual return to activity
Physical therapy modalities	Home regimen with functional activity exercises.

Phase III is the longest segment of rehabilitation, spanning the 3- to 9-month period. Attention is turned toward the hamstrings with continued development of the quadriceps and ROM. Low impact activities are instituted and include walking, stationary bicycling, elliptical machine, and other controlled aerobic modalities. Toward the end of this phase, functional training exercise may begin.

Phase IV involves return to activity. This period allows for gradual reentry into the desired recreational sport; however, return to competitive play is not encouraged.

TABLE 24.2 Surgical Steps

1. Diagnostic arthroscopy. Make AL and AM portals.
2. Prepare medial compartment. Leave outer 1/3 of meniscal rim if possible.
3. Prepare allograft.
4. Reconstruct ACL if necessary. Do not fix tibial side.
5. Make PM incision. Develop plane between Layers I and II.
   a. Place small vertical incision on posterior border of MCL for PM portal.
6. Prepare posterior root tunnel/footprint.
   a. Make anterolateral incision on proximal tibia.
7. Make medial parapatellar arthrotomy.
   a. Place suture in anterior meniscal horn remnant.
8. Prepare anterior root tunnel/footprint.
9. Extend PM arthrotomy
10. Load posterior root allograft suture into posterior root tunnel suture shuttle via PM arthrotomy.
11. Pull posterior root of allograft into native posterior root footprint.
12. Pull anterior root of allograft into knee joint.
13. Tie root sutures over bone bridge in anterolateral skin incision.
14. Tie anterior horn of allograft to native meniscus via medial parapatellar arthrotomy.
15. Tie posterior horn of allograft to native meniscus and capsule.
16. Close POL to MCL
17. Tie remaining allograft to native meniscus with arthroscopic inside-out technique.
18. Secure tibial side of ACL reconstruction if necessary.
19. Close wounds.

COMPLICATIONS

As with any allograft transplantation, there is risk of donor-to-recipient disease transmission including HIV and hepatitis C. After review of 547 cases of meniscal transplant, there were no reports of HIV or hepatitis C, and the bacterial infection risk is reported as high as 4.5% in one series although the majority of cases series have a 0% infection rate (13,14). Graft tearing appears to be the most common overall complication, occurring in 8.2% of meniscal transplants and some series report a reoperation rate of 26% related to these tears (13,20). Host immune response related to the donor graft is uncommon, with the occurrence ranging from 0% to 8.7% (8,20). There are reports of difficulties with ROM, occurring in up to 11% of patients (16).

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25 Lateral Meniscus Transplant

Seth A. Cheatham and Darren L. Johnson

Fairbanks was the first to discuss the importance of the meniscus in the protection of articular cartilage of the knee in his study on radiological changes after meniscectomy (1). Since then, numerous studies have demonstrated the important role the meniscus plays in load transmission and joint stability (2,3). Before his publication, the meniscus was thought of as a vestigial remnant of leg muscle, which could be removed without any harmful effect. It was commonplace for a total or subtotal meniscectomy to be performed for suspected meniscal pathology. More recently, meniscal preservation is usually attempted whenever possible with the use of standard repair techniques (3). If the tear is irreparable, minimal or partial resection of the torn portion only is recommended. However, there still remain circumstances in which subtotal or total meniscectomy is the only option. These usually involve situations in which there is extensive meniscal damage and degeneration. Although a small subset of these patients still do reasonably well with meniscus deficient knees, many others have persistent compartmental symptoms with progressive degeneration of the affected compartment (1,4). It is this subset of patients who may be candidates for meniscal allograft transplantation.

During the normal gait pattern, the articular surface of the knee bears up to six times the body weight, with over 70% of that load borne by the medial tibial plateau (5). The menisci serve to increase the contact area and dissipate the compressive forces at the articular cartilage. The lateral meniscus carries 70% of the lateral compartment load, compared to just 40% by the medial meniscus (6). By converting joint loading forces to radial hoop stresses on circumferential collagen fibers, the menisci transmit 50% of the joint load when the knee is extended and 90% when the knee is in flexion (7). Loss of just 20% of a meniscus can lead to a 350% increase in contact forces (8). Radial meniscus tears extending to the periphery and thus disrupting all hoop-stresses results in tibiofemoral contact forces equivalent to a completely meniscectomized knee.

Clinically, patients who have undergone lateral meniscectomy do worse than those who have undergone medial meniscectomy. These findings have been corroborated in the literature (7,9,10). The degenerative changes noted following lateral meniscectomy are often more rapid than those seen following medial meniscectomy (1). A concerning subset of this population is the young athlete with genu valgus that undergoes complete lateral meniscectomy. These findings may in part result from the fact that the lateral compartment has fewer congruent articular surfaces and these articular surfaces undergo a greater degree of translation than the medial compartment. The lateral meniscus also contributes to the stability of the knee, particularly with rotation. Furthermore, the fact that the lateral meniscus carries the majority of the load of the lateral compartment may also contribute to these findings (7).

INDICATIONS

The ideal patient for a meniscal allograft transplantation is one who presents with pain in a meniscus-deficient compartment, is not significantly overweight, has normal alignment, is ligamentously stable, has normal cartilage, and is relatively young but skeletally mature. Although there is no upper chronologic age limit, patients who have a meniscus-deficient knee and are over the age of 50 often have significant arthritis. Skeletal maturity is necessary to avoid causing asymmetric physeal arrest and progressive angular deformity with the use of current meniscal allograft techniques.

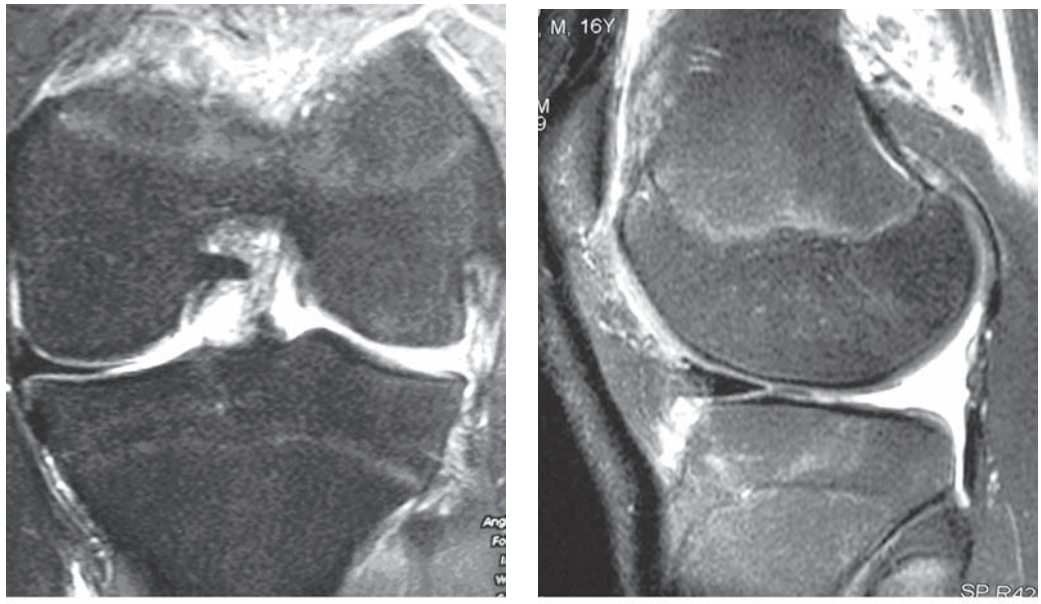
Contraindications include inflammatory arthritis, synovial disease, a history of knee infections, immunodeficiency, obesity, and skeletal immaturity. The most common contraindications include advanced arthritis (outerbridge grade III or IV) on the tibia, flattening of the femoral condyle, or marked osteophyte formation (11,12). As they are considered relative contraindications, comorbidities such as ligamentous instability, malalignment, and focal chondral defects must be addressed at the time of or prior to meniscus transplantation.

The surgeon must identify the specific motivation for a patient seeking transplantation and adjust expectations for partial, short-term pain relief. Meniscal allograft transplantation may potentially delay osteoarthritis, but it is primarily a pain relieving operation. The patient should seek treatment for pain in the meniscal deficient compartment and understand that at best, meniscal transplantation does not prevent the need for total knee arthroplasty.

PATIENT EVALUATION

Postmeniscectomy patients usually present with subtle joint line pain, swelling with activity, and knee pain induced by changes in the ambient barometric pressure. At times, they also present with occasional painful giving way and crepitus. After taking a detailed history, the physical exam should assess the status of ligament stability, alignment, and the articular cartilage. It is also of the utmost importance to request and review previous operative pictures and video if available. Evaluation of the location and reason for previous incisions is also critical as many of these patients have undergone prior surgical procedures including ligament reconstructions and attempted meniscal repair. Patients generally will have tenderness in the involved joint line, full range of motion, and potentially a slight effusion.

Routine radiographs include weight-bearing anteroposterior (AP) views of both knees in full extension, a non–weight-bearing 45-degree flexion lateral view, and a merchant view of the patellofemoral joint. A 45-degree flexion weight-bearing posteroanterior (PA) view should also be taken to identify joint space narrowing not appreciated on the full extension views (13). Furthermore, long leg alignment films must be taken if there is any suspicion of malalignment. Articular cartilage may be assessed by MRI. MRI, in conjunction with intraoperative pictures, is useful in determining how much meniscus remains (Fig. 25.1A and B). A three-phase bone scan is rarely indicated. If the status of the cartilage and the amount of meniscus that was previously resected are unclear, it is strongly encouraged to perform a diagnostic arthroscopy in order to evaluate the knee for a meniscal allograft. This is especially true if the patient has not had any surgical intervention for over a year as it is not uncommon for articular cartilage degeneration to occur over this timeframe. This is particularly true on the lateral side where once articular cartilage begins to breakdown, it can be quite a rapid progression.



A B

FIGURE 25.1

A, B: Coronal and sagittal MRI views demonstrating a significant amount of lateral meniscus missing.

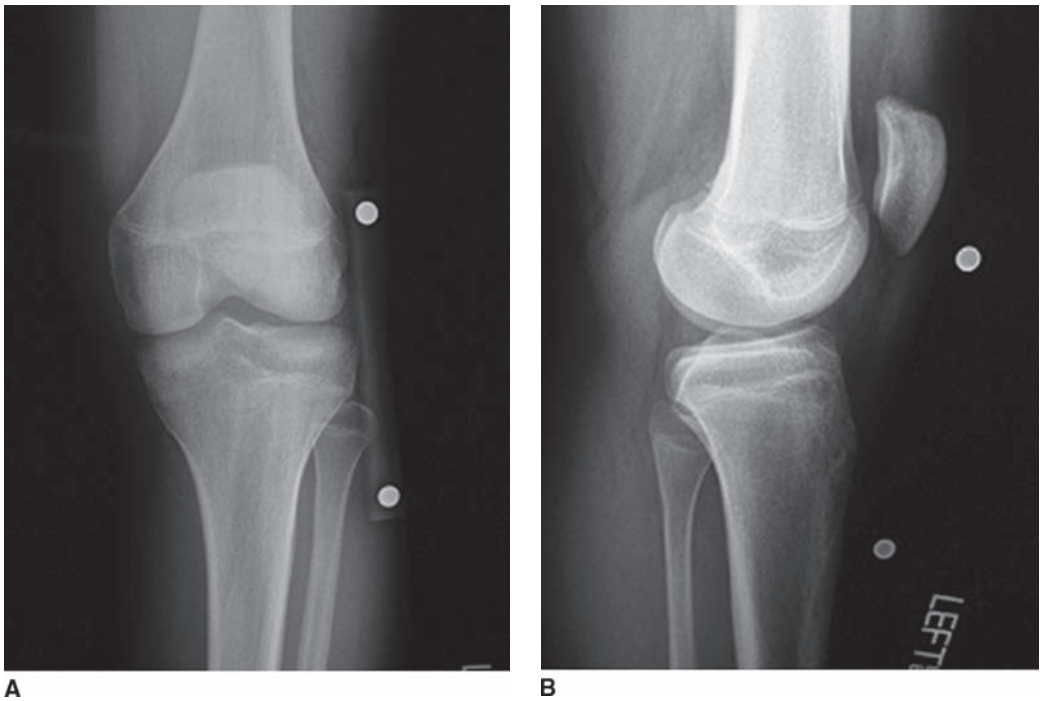


FIGURE 25.2

A, B: AP and lateral views of the left knee with magnification markers in place.

ALLOGRAFT SIZING

The appropriate size of an absent meniscus cannot be determined by measuring the meniscus in the opposite knee as meniscal allografts are side and compartment specific. While newer information is emerging in support of MRI, MRI and CT scans are not recommended as they have been shown in previous studies to misjudge the size of the allograft (14). The best method for estimating the appropriate size of an absent meniscus is with plain radiographs (14,15). The technique described by Pollard is commonly used. Preoperatively, measurements are made on AP and lateral radiographs, with magnification markers placed on the skin at the level of the proximal tibia. The meniscal width is calculated based on the width of the compartment as seen on AP radiographs after correction for magnification. The meniscal length is based on the lateral radiograph using the sagittal length of the tibial plateau (Fig. 25.2A and B). Following correction for magnification, the length is multiplied by 0.8 for the medial meniscus and by 0.7 for the lateral meniscus. This technique has been shown to lead to a size match in at least 95% of cases, which is crucial to optimizing graft survival and protection of the articular surfaces (15). This is especially true when using a bone bridge technique as the distance between the anterior and posterior horns of the lateral meniscus is a fixed distance and attached to the bone bloc. Underestimating the size of the graft will lead to meniscal tears once activities are resumed.

GRAFT PROCUREMENT AND PRESERVATION

Because of inherent difficulties in harvesting and distributing fresh donor allografts to a size-matched recipient within a few days of harvest, fresh menisci suitable for allograft implantation have been replaced by tissue bank preserved meniscal allografts. Therefore, the first, and most critical, step in graft procurement is stringent donor screening and selection. The American Association of Tissue Banks has defined a stringent protocol to increase the likelihood of obtaining disease-free grafts (16). Serologic screening is performed for HIV p24 antigen, HIV-1/HIV-2 antibody, human T-lymphocyte virus 1 and human T-lymphocyte virus 2, hepatitis B core antibody, antibodies to hepatitis C virus, and syphilis. Most banks also perform polymerase chain reaction testing, which can detect one HIV-infected cell in over 1 million cells. The current window of time for development of detectable antibodies to HIV is approximately 20 to 25 days. Blood cultures for aerobic and anaerobic bacteria are conducted as well and lymph node sampling may be performed.

Graft processing including debridement, ultrasonic/pulsatile washing, and use of ethanol to denature proteins, further lowers disease transmission risk. Freezing also lowers the risk, but HIV can survive these graft processing measures (17). Safety clearly relies heavily on adequate screening and not necessarily graft processing. Nevertheless, the current risk for HIV transmission from frozen connective-tissue allografts is estimated to be 1 in 8 million (18).

The tissue is procured within 12 hours after death or within 24 hours after death if the body has been stored at 4°C. Currently, tissue may be harvested with the use of sterile surgical technique or it may be procured in a clean, nonsterile environment and secondarily sterilized. Harvested tissue may be preserved in one of the four ways: cryopreservation, fresh-frozen, fresh, or freeze dried (lyophilization). Fresh and cyropreserved allografts contain viable cells, whereas fresh-frozen and lyophilized tissues are acellular at the time of implantation. Fresh tissue is harvested under sterile conditions within 12 hours after death. The tissue is stored in a culture medium at 4°C or 39°F to maintain cell viability. These grafts must be transplanted within several days after being harvested and are therefore logistically difficult to work with (19). Cryopreservation includes the use of a cryoprotectant, dimethylsulfoxide. Fresh-frozen grafts are rapidly frozen to −80°C, killing cells but maintaining material properties. Lyophilization is uncommonly used as it is implicated in graft shrinkage, decreased cell viability, and diminished biomechanical properties (20). Unlike fresh osteochondral grafts, the morphologic and biochemical characteristics of meniscal allografts do not depend heavily on cell viability. Therefore, the most commonly implanted grafts are either fresh-frozen or cyropreserved (21). Animal studies have not shown any significant differences between these two preservation methods.

IMMUNOGENICITY

Animal studies have not demonstrated a predictable humeral or cellular-based immunologic rejection response from bone allografts in rabbits or implanted meniscal allografts in goats or mice (22,23). The most immunogenic portions of the meniscal allograft are the cellular elements of the cancellous bone anchors or trough (24). However, studies of even massive bone allograft implantation demonstrated a low rate of clinically meaningful immunogenic reactions (25). Although meniscal allograft rejection has been reported, most series have not reported significant sequelae related to immunologic reaction. DeBoer and Koudstaal (26) implanted a nontissue-antigen matched cryopreserved meniscal allograft in the lateral compartment of a patient's knee that remained metabolically active with excellent clinical results. Several other studies have reported antibodies against the HLA complex using nontissue-antigen matched cryopreserved meniscal allografts without accompanying graft failure (27).

SURGICAL TECHNIQUES

Meniscal allograft transplantation replaces an absent or deficient meniscus in an anatomic position and restores the original meniscofemoral or meniscotibial articulation. The transplantation can be performed either open or with an arthroscopically assisted technique. The two methods have similar outcomes, but arthroscopic techniques are now routinely used because of the reduced surgical morbidity.

Meniscal allografts are anchored with either a bone bridge that rigidly fixes the distance between the anterior and posterior horns, or separate bone plugs on the anterior and posterior horns. Fixation of soft tissue with bone, as opposed to soft tissue alone, is preferred because of its superior load transmission properties (28). Bone plugs are not recommended for lateral meniscal allografts because the distance between the horns is only 1 cm or less (29). The use of bone plugs with a lateral meniscus presents a risk of tibial tunnel communication with compromised fixation. Therefore, it is commonly accepted that a bone bridge be utilized when performing a lateral meniscal allograft transplant. The two most common bone bridge techniques are the bridge in slot technique and the dovetail technique. We prefer the bridge in slot technique because of its simplicity and secure bone fixation, the ability to more easily perform concomitant procedures such as osteotomy and ligament reconstruction, and the advantages of maintaining the relationship of the native anterior and posterior horns of the meniscus (29).

The graft must also be securely sutured to the capsule using standard meniscal repair techniques. Peripheral capsular fixation is a prerequisite for healing and vascularization of the graft. A peripheral meniscal remnant is considered to be important in establishing and maintaining vascular supply to allow ingrowth of the meniscal allograft. The absence of peripheral healing and revascularization induces cell death and matrix disorganization, leading to failed meniscal transplantation. Vertical mattress stitches using nonabsorbable suture material in an inside-out fashion is the gold standard and our preferred technique. All-inside bioabsorbable devices are a reasonable alternative to sutures but their pullout strength is less than that of vertical sutures and they provide only single point fixation.

INITIAL PREPARATION

The patient is placed under general anesthesia with regional block supplementation and intravenous prophylactic antibiotics are administered. As with all knee arthroscopies, an exam under anesthesia is performed on the affected knee to assess for range of motion and ligament stability. The nonoperative leg is placed in a well-padded leg holder in the lithotomy position. The operative leg has a tourniquet placed high on the thigh and is secured with an arthroscopic leg holder. The leg holder should be proximal enough on the thigh to allow enough access to the posterolateral structures in order to perform a safe inside-out meniscal repair. Standard arthroscopic

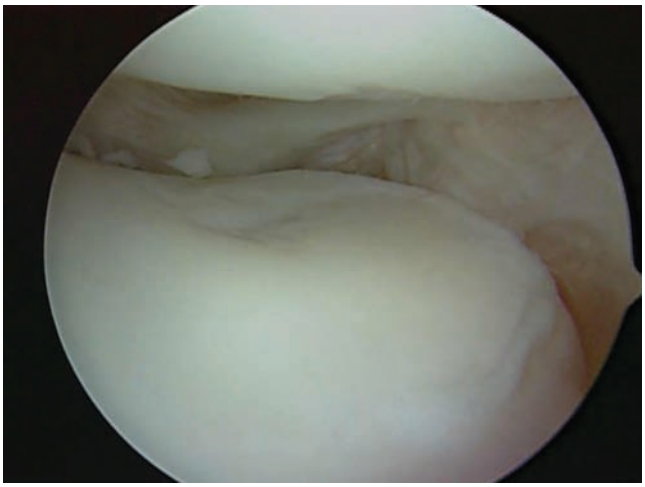


FIGURE 25.3

Arthroscopic view of the lateral compartment after debriding back to a 1 to 2 mm rim of lateral meniscus.

portals are made and a diagnostic arthroscopy is performed in order to assess for chondral injuries, particularly in the operative compartment. The debridement of residual meniscus should be performed without a tourniquet to verify a vascularized recipient meniscocapsular interface during debridement.

The lateral meniscus should be debrided back until a 1- to 2-mm peripheral rim remains and punctate bleeding is present. A remnant of the posterior and anterior horns may be left for identification later when sliding in the bone bridge (Fig. 25.3). A low modified notchplasty on the lateral femoral condyle, protecting the ACL femoral insertions site, should be performed with an electrocautery unit and a 5.5 shaver. This allows increased visualization of the posterior horn of the lateral meniscus and is also helpful when passing the graft later in the procedure.

BRIDGE IN SLOT SURGICAL TECHNIQUE

A 2 to 3 cm mini-arthrotomy is performed in line with the anterior and posterior horn insertion sites of the lateral meniscus. This allows correct orientation of the slot and introduction of the graft. This arthrotomy should be performed directly adjacent to the patellar tendon. A posterolateral incision is also necessary for suture passage during the meniscal repair portion of the procedure. The incision should extend approximately one third above and two thirds below the joint line and allow adequate exposure to protect neurovascular structures during passage of the inside-out sutures. The short head of the biceps musculature is stripped from the posterior capsule and a spoon is placed to protect the peroneal nerve. By staying above the tendon of the long head of the biceps, the peroneal nerve is always safe. An additional incision is made through the iliotibial band inline with its fibers and spread with a self-retainer. This is in order to ensure that the sutures are tied beneath these structures to minimize the chances of capturing the knee due to soft tissue tethering.

Slot orientation follows the normal anatomy of the meniscus attachment sites. A line is made with a 4-mm burr to make a reference slot in the tibial plateau. Its height and width will equal the dimensions of the bur, and its alignment in the sagittal plane should parallel the slope of the tibial plateau (Fig. 25.4). Slot dimensions should be confirmed by placement of a depth gauge in the reference slot, which also measures the anteroposterior length of the tibial plateau (Fig. 25.5). With use of a drill guide, a guide pin is placed just distal and parallel to the reference slot and advanced to but not through the posterior cortex (Fig. 25.6). This is a critical step in ensuring that the graft is placed in an anatomic location. The pin is subsequently overreamed with an 8-mm cannulated drill bit, again with care not to breach the posterior cortex (Fig. 25.7). The trough can then be unroofed with the aid of a pituitary. A box cutter is then used to make a slot 7 to 8 mm wide by 10 mm deep, which is smoothed and refined with a 7 to 8 mm rasp to ensure that the bone bridge will slide smoothly into the slot (Fig. 25.8).

The allograft arrives from the tissue bank as a hemiplateau with the meniscus attached. All nonmeniscal tissue is removed and the exact locations of the anterior and posterior horn anchors are identified. Using a cutting guide, the bridge is then cut to a width of 7 or 8 mm and a depth of 10 mm (Fig. 25.9). The bone bridge should intentionally be undersized by 1 mm to facilitate graft passage and to reduce the risk of inadvertent bridge fracture during insertion. The prepared bridge is then tested for ease of passage through calibrated troughs on the back table. The posterior wall of the bridge should be flush or slanted slightly anterior to the fibers of the posterior horn attachment to allow for insertion at the most posterior edge of the prepared slot. Bone anterior to the anterior horn should be left in place to allow for safer graft manipulation during insertion. A vertical mattress traction suture of 0 polydioxanone (PDS) is placed at the junction of the posterior and middle thirds of the meniscus to assist with graft insertion (Fig. 25.10).

On occasion, the anterior horn attachment can be larger, up to 9 mm wide. If the anterior horn attachment site is wider than the intended width of the bone bridge, the attachment should be left intact, and the width of the

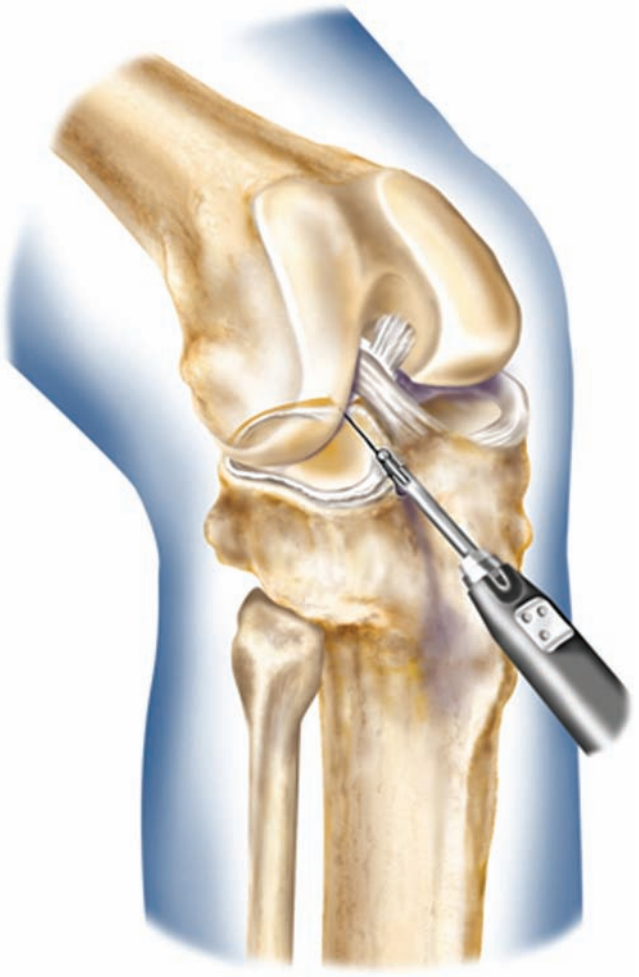


FIGURE 25.4

A 4-mm burr is used to make a reference slot in line with the anterior and posterior horns, parallel to the sagittal slope of the tibial plateau and a width no greater than the burr. (Courtesy of Stryker Endoscopy, San Jose, CA.)

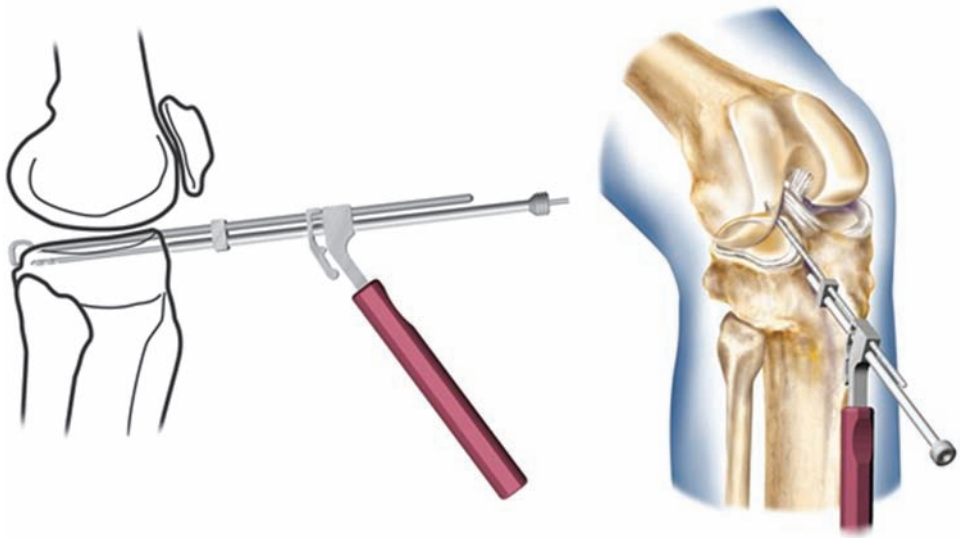


FIGURE 25.5

Stryker guide placed within the reference slot and hooked onto the posterior tibial plateau. The drill guide is in place to measure length of the tibial slot. (Courtesy of Stryker Endoscopy, San Jose, CA.)

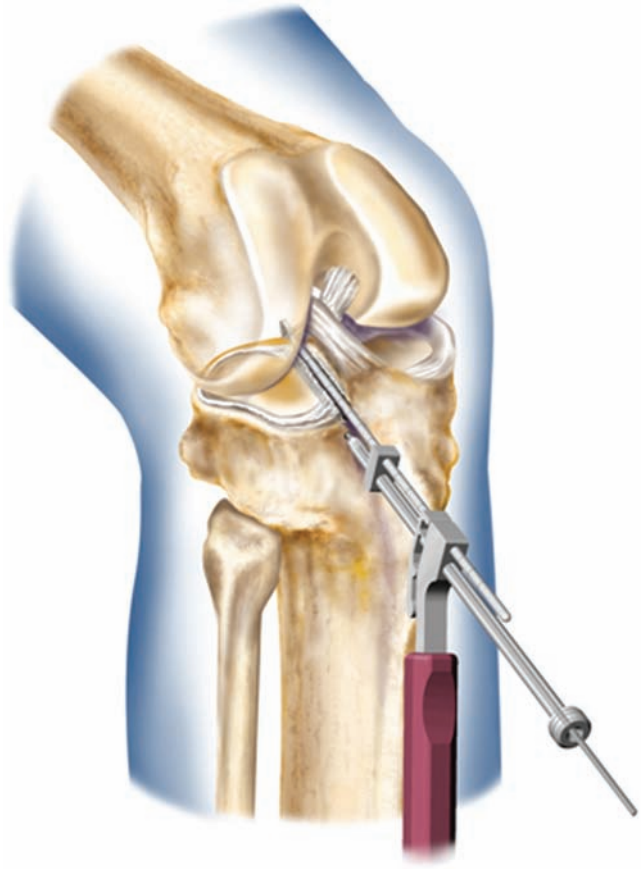


FIGURE 25.6

Guide pin placed through the guide handle, care to drill to the posterior tibial cortex but not through it. (Courtesy of Stryker Endoscopy, San Jose, CA.)

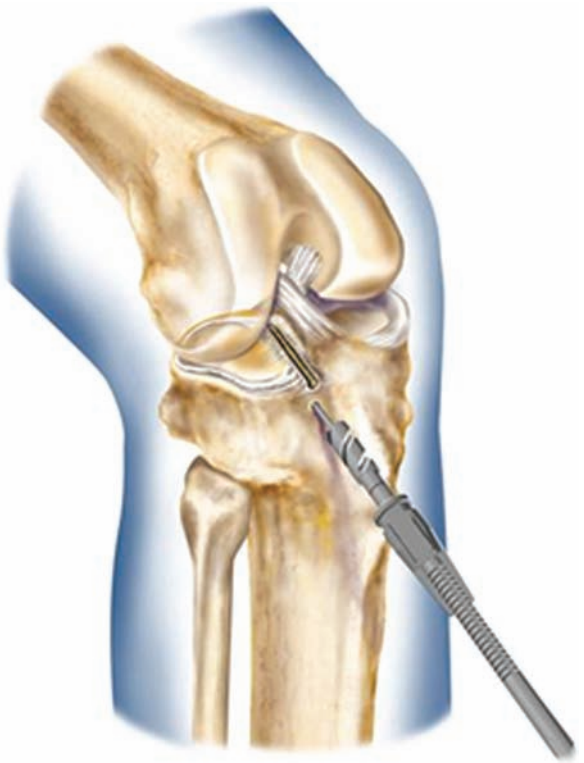


FIGURE 25.7

An 8-mm cannulated reamer is advanced over the guide to the measure depth. (Courtesy of Stryker Endoscopy, San Jose, CA.)

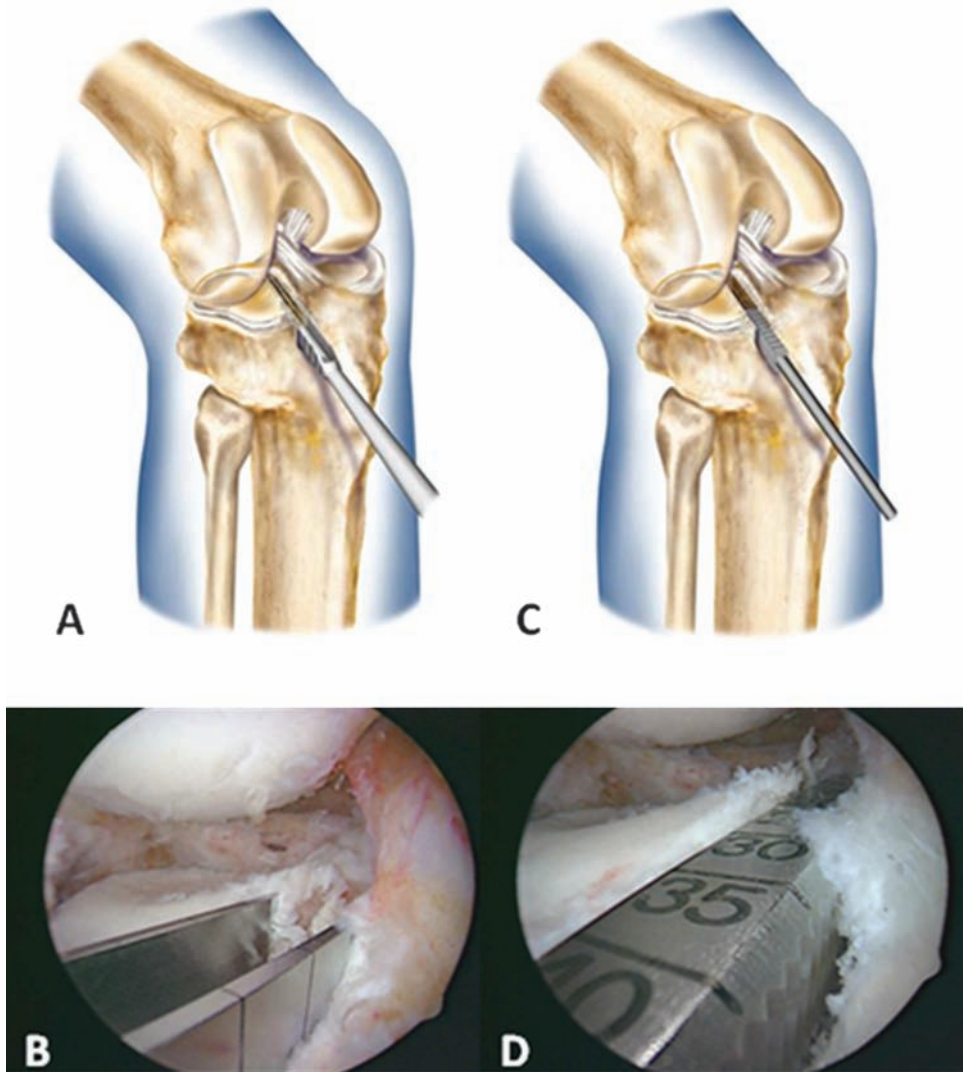


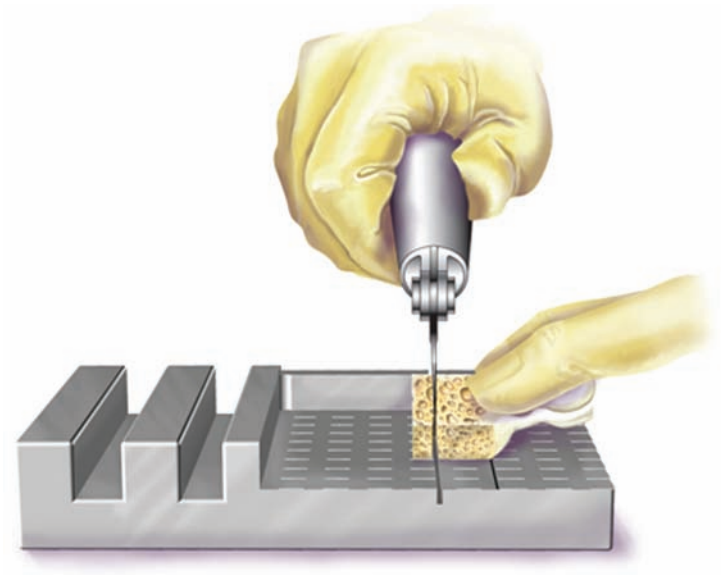
FIGURE 25.8

A: Box cutter is used to convert the rounded slot to a box-shape. **B:** Arthroscopic view of the box cutter in place. **C:** Rasp is used to smooth the edges of the slot. **D:** Arthroscopic view of 8 mm rasps in the bone trough. (Courtesy of Stryker Endoscopy, San Jose, CA.)

bone bridge should be increased accordingly in the area of the anterior horn insertion only. The remainder of the bone bridge should be trimmed to 7 mm as intended. To accommodate the increased width, the corresponding area of the recipient slot should be widened accordingly.

A single barrel, zone-specific meniscal repair cannula placed through the anteromedial portal with the scope in the anterolateral portal is directed toward the capsular attachment of the posterior and middle thirds of the meniscus. A long, flexible nitinol suture passing-pin is placed through the capsule, just anterior to the popliteus tendon, to exit the accessory posterolateral incision. The proximal end of the nitinol pin is then withdrawn from the anterior arthrotomy site, the allograft traction sutures are passed through the loop of the nitinol pin, and the pin and sutures are withdrawn through the posterolateral incision. With the aid of traction sutures, the meniscal allograft is pulled into the joint through the anterior arthrotomy while the bone bridge is advanced into the tibial slot, and the meniscus is manually reduced under the condyle with a finger placed through the arthrotomy. Appropriate varus stress to open the lateral compartment aids in graft introduction and reduction (Fig. 25.11). Once the meniscus is reduced, the knee is cycled to ensure proper anatomic placement and capturing by the tibiofemoral articulation. Once again, it is critical that the trough is posterior enough. If there is any question at this time, x-ray may be brought in to confirm trough position. The graft is then attached to the capsule with standard inside-out vertical mattress sutures placed from posterior to anterior, equally on the dorsal and ventral meniscal surfaces (Fig. 25.12). This fixation can be supplemented with appropriate all-inside fixation devices placed in the most posterior aspect of the meniscus to minimize the risk of neurovascular injury if one desires. In regards to the bone bridge fixation, there are a variety of ways to ensure fixation. Some advocate leaving the bone bridge without supplemental fixation. Others use an interference screw to add additional compression to the bone bridge within the slot. Still others supplement fixation with sutures tied over a bone bridge. Standard closure of the arthrotomies and accessory incisions is then performed.

A



B

FIGURE 25.9

A diagram showing the allograft bone block being cut to appropriate size. (Courtesy of Stryker Endoscopy, San Jose, CA.)

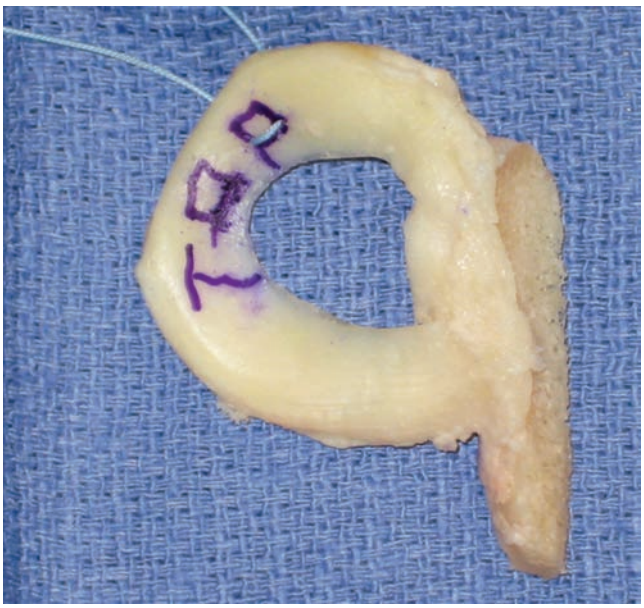


FIGURE 25.10

Lateral meniscal allograft with bone bridge cut to size and traction suture placed at the junction of the posterior and middle thirds.

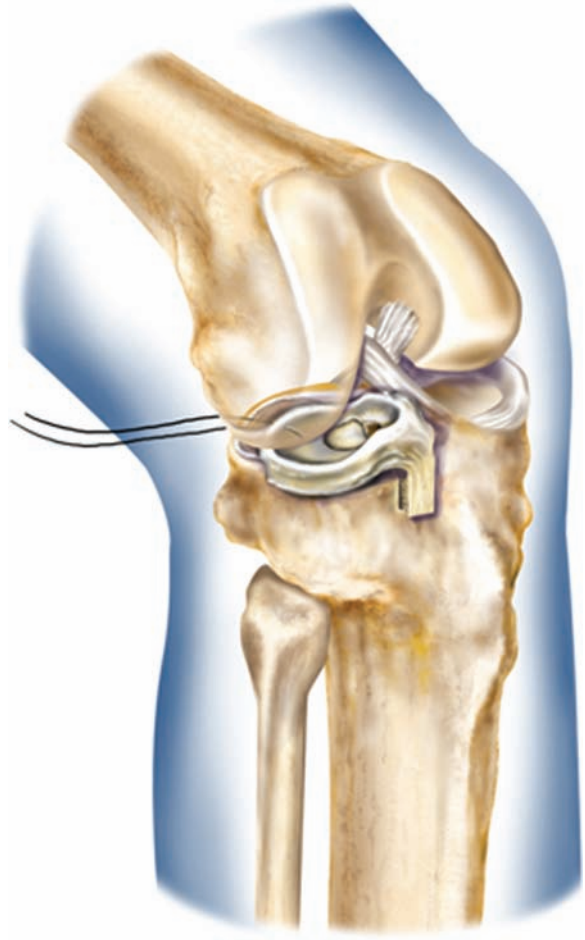


FIGURE 25.11

Diagrammatic representation of meniscus insertion. (Courtesy of Stryker Endoscopy, San Jose, CA.)

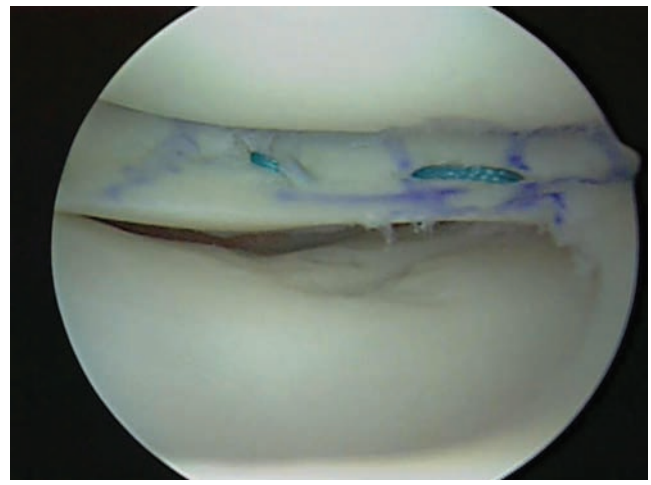


FIGURE 25.12

View of the meniscal allograft in place, secured with inside/out sutures.

REHABILITATION

Currently, there are no standardized rehabilitation protocols that exist for patients undergoing meniscal allograft transplantation. There have been numerous studies published on meniscal allograft transplantation but none have focused on rehabilitation. In our postoperative protocol, patients begin quadriceps sets, straight leg raises, and calf pumps immediately after surgery. Many authors recommend the use of a continuous passive motion machine. We recommend active and passive range of motion from 0 to 90 degrees with protected weight bearing using a hinged knee brace locked in extension during weight bearing for the initial 4 weeks. Goals for range of motion are to achieve full knee extension symmetrical to the noninvolved side within 1 week and 90 degrees of flexion within 4 weeks. After this initial period, full weight-bearing range of motion is allowed, and activities

such as cycling, swimming, and closed-chain kinetic exercises may begin. It is important during this time period that there is no impact loading of the knee flexed past 90 degrees for the first 3 months. Forced flexion and pivoting activities should be avoided. At 6 to 9 months, patients are encouraged to return to running and other sporting activities, provided that the strength is at least 85% of normal. The ability to return to preinjury sporting activities appears to be limited, but there has not been enough long-term follow-up to confirm this idea. It appears most authors limit athletic activity to light sports in the first year.

COMPLICATIONS

Complications are generally rare. Most complications are similar to that of meniscal repair and include incomplete healing, persistent symptoms, infection, stiffness, and neurovascular injury. The complications following meniscal allograft transplantation were reviewed in an analysis of Matava (30). Of the 547 patients in the review the most common complication was graft tearing resulting in 45 tears or 8.2%. In series by Stollsteimer et al. (35) and Graf et al. (31), this resulted in reoperation in 26% and 25% of patients with tears, respectively. In both series, treatment was partial meniscectomy or repair, which effectively eliminated mechanical symptoms and relieved pain.

There have been no reports of viral infection, namely HIV or hepatitis transmission in the literature. Bacterial infection following meniscal transplant has been reported in three studies ranging from 3% to 4.5% (34,35). However, it is unclear whether these infections resulted from the surgical procedure or the transplantation of a contaminated graft as bacteriologic data was not provided.

Three studies (33–35) reported postoperative immunologic responses but no follow-up. No reports of neurovascular injury are in the literature. Two case series (33,34) have reported loss of motion following transplantation resulting in 5 closed manipulations under anesthesia (33). Additional complications have been reported attributable to concurrent procedures at the time of the meniscal transplant, such as nonunion of osteotomy sites, revision ACL reconstruction, and hardware failure. Minor complications such as suture granulomas have also been reported.

OUTCOMES

The literature demonstrates that allograft meniscus transplantation generally leads to 85% good to excellent results. The risk for graft failure increases with irradiated grafts, uncorrected malalignment, outerbridge grade IV bipolar chondromalacia, and lack of bone anchorage of the allograft (33). Physical appearance of the graft does not seem to be clearly correlated with outcome. Milachowski et al. (34) found that graft shrinkage does not affect outcomes. Moreover, Stollsteimer et al. (35) described significant pain relief in all 23 patients despite graft shrinkage of 37% on average. There is a trend toward better results in more recent literature, which reflects a collective improvement in patient selection, graft processing, and surgical technique over the last 15 years.

Articular cartilage degeneration is associated with poorer outcomes. Garrett reported that 35 of 43 (81%) patients were asymptomatic at minimum 2 years, with most of the failures occurring in knees with grade IV chondromalacia (36). Shelton and Dukes found that significant decreases in pain were reported for patients who had less than grade II outerbridge changes, whereas patients with degenerative compartments had only slight improvement in symptoms (37). All second-look arthroscopies demonstrated complete peripheral healing, however, and although there was an average shrinkage of 15%, cellular viability was confirmed on biopsy.

Absence of allograft bone fixation is also correlated with poorer outcomes. Noyes and Barber-Westin reported on 96 grafts, which were secured with bone in the posterior horn but not in the anterior horn. Clinical failure occurred in 58% of the grafts, 31% healed partially, and only 9% healed completely (32). Rodeo (38) reported that 14 of 16 (88%) grafts with anterior and posterior horn bone fixation were successful, while only 8 of 17 (47%) grafts without bone fixation were successful. This emphasizes the importance of the bridge in slot technique as the difficulties with bone plugs for lateral meniscus transplants have already been discussed.

Combining procedures to treat comorbid conditions that would otherwise be contraindications to meniscal allograft transplantation has been successful. A study by Zukor et al. (39) found that 26 of 33 (79%) patients who have had a combined osteochondral allograft with meniscus transplantation were clinically successful at 1-year follow-up. Cole and colleagues have recently reported that meniscus transplantation alone or in combination with other reconstructive procedures to address concomitant articular cartilage injury results in reliable improvements in knee pain and function at minimum 2-year follow-up. They have found that 90% of patients were classified as normal or nearly normal using the International Knee Documentation Committee (IKDC) knee examination score at final follow-up (40). Sekiya et al. reported that 24 of 28 (86%) patients had normal or near-normal IKDC scores subsequent to ACL reconstruction and meniscus transplantation (41). Additionally, about 90% of the patients had normal or near-normal Lachman and pivot shift exams. Cameron and Saha performed an osteotomy along with allograft meniscal transplantation in 34 of 63 patients. The patients with realigned knees had a success rate that was comparable to the group as a whole, with good to excellent results in 85% and 87%, respectively (42).

CONCLUSIONS

Allograft meniscus transplantation is a reasonable treatment alternative for patients who have a meniscus deficient knee and no more than grade II or early grade III arthrosis. Clinical studies support the procedure's effectiveness in alleviating pain, swelling, and improving functional outcomes. However, results are poor for patients with advanced arthrosis, which remains the primary contraindication for allograft meniscal transplantation. In the young athletes, we need to have a low threshold for performing this procedure when they exhibit any lateral sided symptoms. In the future, we may be able to utilize quantitative MRI sequences that will be able to detect when the cartilage is "sick" but not irreversibly injured and the patient is still asymptomatic. Despite the technical difficulty of performing a meniscus transplantation, intermediate-term studies have demonstrated the efficacy of this procedure with very high levels of patient satisfaction, provided that the relevant comorbidities have been appropriately treated.

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26 Bone-Patellar Tendon-Bone ACL Reconstruction

Chealon D. Miller, MaCalus V. Hogan, and Mark D. Miller

INTRODUCTION

The anterior cruciate ligament (ACL) is an important stabilizing and biomechanical function for the knee. Reconstruction of the ACL is one of the most commonly performed procedures in the field of sports medicine. It is estimated that 200,000 ACL tears occur each year with 100,000 ACL reconstructive surgeries done each year in the United States (22). Restoration of normal knee function and protection from further intra-articular injury are the goals of treatment and have led to research for the development of new operative techniques. Preparation for ACL surgery should include consultation with the patient regarding functional expectations and postoperative activity. Reconstruction of the ACL with the bone-patella tendon-bone (BPTB) autograft secured with an interference screw has been described as a successful method of ACL reconstruction, in particular with young men with no antecedent knee pain.

Reconstruction of the ACL with BPTB autograft secured with interference screws was first described by Jones in 1963 and later popularized by Clancy in 1982 (5,13). The BPTB autograft reconstruction accomplishes some of the fundamental goals of ACL reconstruction: ease of graft harvest, minimal harvest-site morbidity, and biomechanical properties that are similar to those of the native ligament. It also possesses high initial strength and stiffness and can be secured predictably with rapid incorporation into host tissue that allows for early, aggressive rehabilitation while recreating the anatomy and function of the native knee (4,10,23). Arthroscopically assisted BPTB autograft also has the advantage of a single incision, leading to shorter operating times, reduced postoperative morbidity, improved cosmesis, and quicker rehabilitation. The disadvantages of bone patellar-tendon bone ACL reconstruction include graft site morbidity, disruption of the extensor mechanism, patella fracture, patella baja, and patellofemoral pain (6,14,15). It is important for the orthopaedic surgeon to be aware of the advantages and disadvantages of using BPTB autograft and compare those to factors related to other graft choices and apply pertinent information to each individual patient who is a candidate for reconstruction. Regardless of graft choice, a clear understanding of the critical stages of arthroscopic ACL reconstruction and knowledge of the potential pitfalls can help avoid complications and produce consistently excellent results. This chapter seeks to provide a reproducible technique for endoscopic ACL reconstruction using BPTB autograft.

HISTORY AND PHYSICAL EXAMINATION

ACL injuries can occur in numerous ways, but there are a few mechanisms that predominate. Although up to one third of the time the patient is unable to give clarity to the mechanism of injury, when an account is given patients with ACL injuries often report a noncontact pivoting injury with a deceleration and rotational component during running, cutting, or jumping (11,27). The injury is often associated with an audible "pop" heard by the patient at the time of injury. The patient usually falls to the ground and is not able to resume activity. An effusion usually ensues within a few hours in comparison to a meniscus tear where swelling usually occurs within 24 hours (22,37). In contrast to noncontact injuries, contact injuries can also lead to ACL disruption and usually involve a hyperextension and/or valgus force to the knee by a direct blow.

The physical examination and preoperative assessment of the knee joint is critical to successful outcomes from ACL surgery. With an adequate history and physical examination, an ACL injury can often be diagnosed

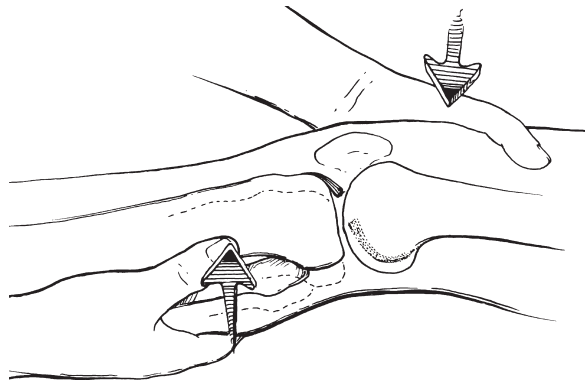

FIGURE 26.1
Lachman test.

proficiently without additional studies. Most sports medicine physicians agree that the examination is most accurately performed immediately after the injury, before swelling, pain, and muscle spasms occur. Collateral ligament and meniscal injuries can be identified through the history and physical examination; therefore, a complete examination of the knee should be performed in order for improved interpretation of diagnostic studies, for optimal surgical tool acquisition in preparation for the operating room, and for optimal physician-patient communication about expected outcomes. Poor outcomes are associated with poor range of motion, weak quadriceps function, and excessive swelling. Therefore, it is plausible to delay surgery until full extension is achieved, optimal skin and soft tissue factors have resolved (minimal swelling), and quadriceps function is in the activated state (34).

The physical exam should begin with examination of the uninjured knee. This helps to familiarize the patient with the knee examination and helps the examiner determine patient-specific normal parameters. Examination of the injured knee begins with visual inspection for evidence of swelling and lacerations. After inspection, palpation ensues with confirmation of any suspected effusions and to what degree they are present. Next quantitative measures of the patient's active and passive range of motion are obtained and recorded. After taking the patient through a range of motion, the patient's knee can be brought to 90 degrees and inspection of meniscal pathology may proceed with palpation of the medial and lateral joint line. While at 90 degrees of flexion, the anterior drawer test is performed to evaluate anterior tibial translation. This is performed by stabilizing the foot of the affected knee while placing an anterior force on the tibia. Next the patient is brought out into 20 to 30 degrees of flexion and the Lachman test is performed (Fig. 26.1). This test has become the hallmark of anterior laxity testing in the knee and involves stabilization of the femur with one hand while an anterior force is applied to the tibia with the other hand (41). The degree of translation of the tibia as well as the characterization of the endpoint is recorded. The laxity is based on comparison of the contralateral knee and not as the degree of absolute translation. Grade 1 laxity is 1 to 5 mm of translation. Grade 2 laxity is 6 to 10 mm of translation. Grade 3 laxity is more than 10 mm of translation. Varus and valgus stressing can also be applied to the knee at 20 to 30 degrees to assess lateral collateral ligament and the medical collateral ligament (MCL) competency, respectively. The knee can then be brought out into extension with varus and valgus stressing applied once again to determine if there are other associated injuries (37). The pivot shift test is a special maneuver to assess the rotational component of ACL competency, requires an intact MCL, and begins with the patient in extension (22). The examiner places a valgus directed force, axial load, and internal rotation on the extended knee and proceeds to slowly flex the knee. At approximately 30 degrees of flexion, a reduction of the subluxation can be felt or heard. The test is based on the lateral tibial plateau subluxing anteriorly with extension and reducing with flexion and is pathognomonic of ACL deficiency (8,9) (Fig. 26.2). This maneuver is often poorly tolerated by awake patients and should be performed toward the end of the physical examination secondary to subsequent patient apprehension and guarding. The pivot shift test is often best tested under anesthesia.

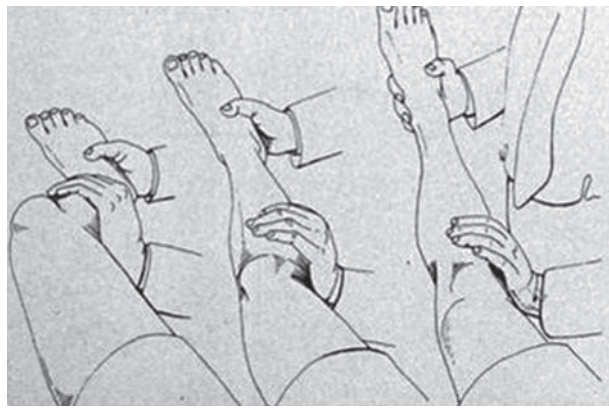

FIGURE 26.2
Pivot shift test.

DIAGNOSTIC STUDIES

Plain radiographs of the knee should be obtained during the initial evaluation to rule out fractures about the femorotibial joint. The Segond fracture is an avulsion of the anterolateral capsule of the tibia and is thought to be a pathognomonic radiographic finding of ACL injury (43). If the patient is immature skeletally or skeletally mature with osteopenia, an avulsion of the tibial insertion of the ACL, which results in a nonfunctioning ACL, can also be seen on plain radiographs. Plain radiographs also reveal osteochondral lesions, loose bodies, degenerative joint disease, and overall alignment of the knee. Specific to planning for BPTB autograft reconstruction, appropriate preoperative radiographic assessment of the patellar tendon with a true lateral radiograph is important to ensure adequate graft length (10,18). Radiographs also help to note the presence of any ossicles within the tendon. These ossicles can be associated with Sinding-Larsen-Johansson (proximal ossicles) or Osgood Schlatter syndrome(distal ossicles) and can compromise graft competency or length if improperly addressed (19).

Following radiographs, an MRI is the most useful diagnostic study for detecting ACL tears with a reported accuracy of 70% to 100% (22,26). The normal ACL is seen as a defined band through the intercondylar notch. With disruption, the ligament is ill-defined, with a mixed signal intensity representing local edema and hemorrhage (42). MRI can also reveal any associated meniscal tears, chondral injuries, or bone bruises. The typical bone bruise pattern is increased signal intensity on T2-weighted images on the lateral tibial plateau and lateral femoral condyle and these are present in up to 80% of patients with ACL injuries (12,31,38). Patients who cannot undergo MRI imaging may be candidates of stress radiographs; however, these are primarily used to diagnose posterior cruciate ligament (PCL) injuries.

ANESTHESIA AND POSITIONING

Reconstruction of the ACL can be performed under regional (spinal or epidural) or general anesthesia supplemented by a femoral and/or sciatic nerve block to assist with postoperative analgesia (10,25). Once the appropriate anesthesia has been chosen and induced, preoperative antibiotics should be given to the patient should be given to the patient. An examination under anesthesia can then be performed. The previously mentioned tests specific for ACL function are performed including the Lachman, anterior drawer, and pivot shift examinations. One can also determine PCL function with a posterior drawer test and collateral ligament function with the knee in extension and 30 degrees of flexion. The surgeon should test the extent of combined injuries by assessing external rotation stability in 30 and 90 degrees of flexion indicating a posterolateral corner (PLC) or combined PCL/PLC injury, respectively.

After performing the examination under anesthesia, a nonsterile tourniquet is placed on the operative extremity high on the thigh. A reliable technique for placement of the tourniquet is to bend the knee of the operative leg and place the foot on the edge of the bed with the hip in about 40 to 45 degrees of abduction. The person applying the tourniquet uses their chest against the anterior portion of the patient's knee for stabilization. Padding is applied to the upper thigh and the tourniquet is applied as far proximal as possible. After application, the skin just distal to the tourniquet is tugged slightly to prevent slippage. The contralateral leg is placed in the lithotomy position in a commercially available well-leg holder with care taken to prevent injury to the hip and padding for protection of the peroneal nerve. The foot of the bed is then lowered allowing the operative extremity to hang free with the knee in 90 degrees of flexion and allowing flexion to 120 degrees during the procedure (Fig. 26.3).

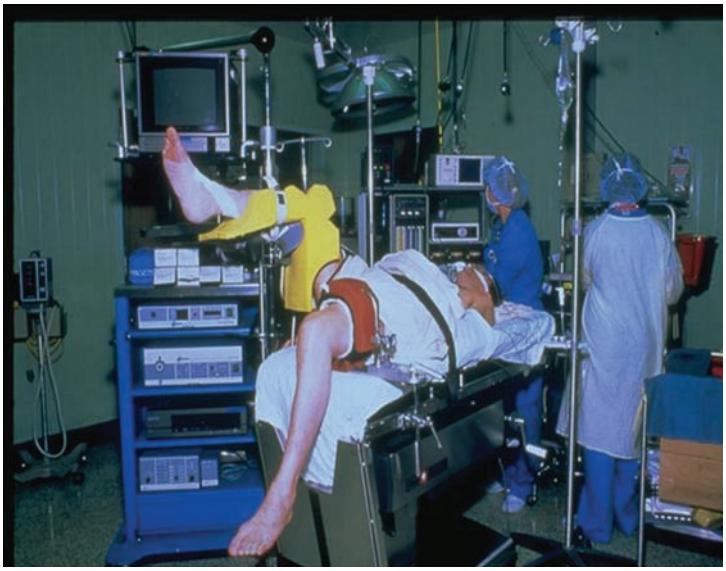

FIGURE 26.3
Positioning for BTBP ACL reconstruction.

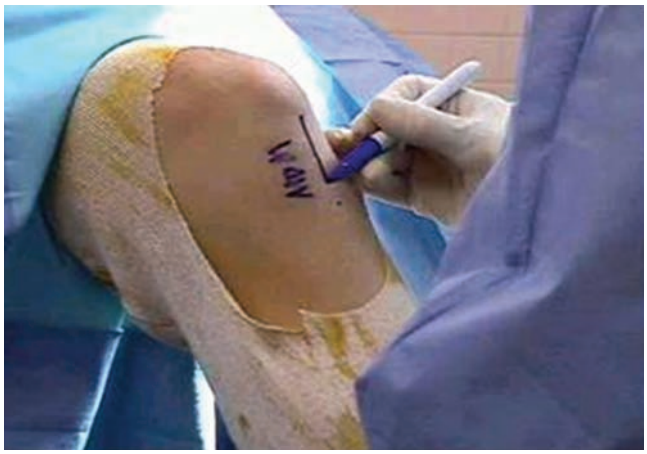

FIGURE 26.4
Marking from anterior patella to tibial tubercle for graft harvest.

The operative leg is then prepped and draped using standard sterile technique. Once draped, markings are made on the patient's skin for the tibial tubercle, the borders of the patella, and portal sites. A marking is then made for the proposed incision for graft harvest (Fig. 26.4). The operative leg is exsanguinated with a commercially available Esmarch bandage. The tourniquet is inflated to 275 to 300 mm Hg and the procedure begins.

PREFERRED OPERATIVE TECHNIQUE

A diagnostic arthroscopy is performed to verify injury to the ACL and to assess for associated injuries that may be present. The standard anterolateral and anteromedial portals are made and the suprapatellar pouch is entered. A limited fat pad debridement is performed to enhance visualization. After debridement of the fat pad, the patellofemoral joint is visualized, the lateral gutter is inspected, and then the medial gutter is inspected. The gutters are cleared of any loose bodies and then the scope is introduced into the medial compartment. Associated cartilage damage and meniscal pathology is identified and noted and then the scope is introduced into the lateral compartment and the cartilage and meniscus is evaluated in the lateral compartment as well. Injuries seen during the diagnostic arthroscopy are addressed during harvest preparation; therefore, the following step involves inspection of the intercondylar notch. The PCL is identified and examined with a probe and the probe is then used to confirm the incompetency of the ACL. Arthroscopic photographs of the torn ACL are taken for both office and patient records. To confirm the ACL tear, the arthroscope is used to inspect the lateral wall of the intercondylar notch and an anterior drawer test can be performed to assess ligament failure (Fig. 26.5).

Once the diagnostic arthroscopy is complete and the ACL tear has been confirmed, the patellar tendon autograft harvest begins. A 4- to 6-cm incision is made along the previously made skin markings from the midpatella to the tibial tubercle. The incision is made slightly medial to midline to avoid scarring over the prominent parts of the patella and tibial tubercle. The skin incision is taken down through the skin and subcutaneous fat and full-thickness flaps are made down to the paratenon. The paratenon is then divided and dissected off of the tendon both medially and laterally. Care is taken to preserve the paratenon for later reapproximation and closure. This layer has been shown to be important in tendon regeneration (10,33).

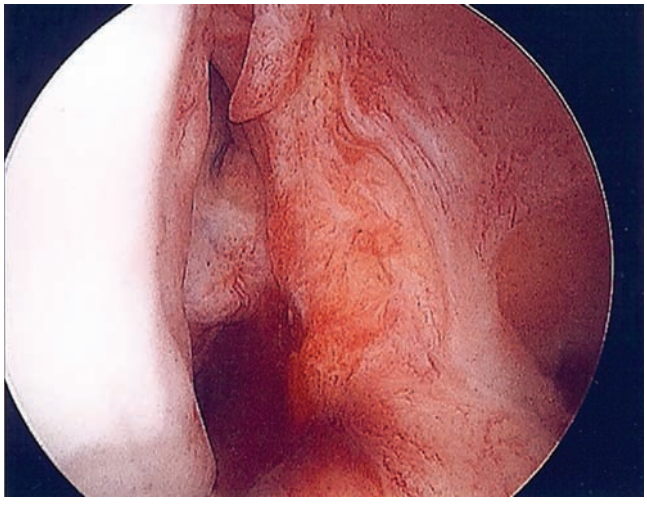

FIGURE 26.5
Empty lateral wall seen on arthroscopy.

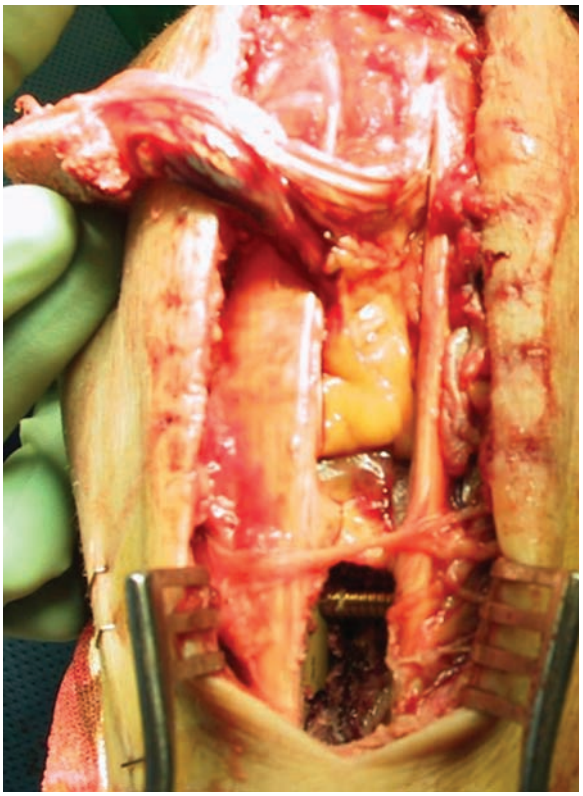

FIGURE 26.6
BPTB graft harvest seen from lateral side.

The patellar tendon width is measured and the central third of the patellar tendon is chosen. For patellar tendons that measure <30 or >38 mm, the harvested graft should be 9 and 11 mm, respectively. Once the proper graft size is determined a 10 blade is used for graft harvest. The graft is harvested with the knee in flexion in order to keep the tendon under tension. A rectangular bone block is then harvested from the tibial tubercle cutting through the cortex to a depth of approximately 10 mm. A curved ¼ in osteotome is used to make sure that the corners of the bone block are free from the remaining tubercle. The osteotome is then inserted into the distal aspect of the tibial tubercle cut, horizontally and used as a lever to release the bone block from the tibial tubercle (Fig. 26.6).

The patella graft-harvesting retractor is placed under the skin and the patella is levered distally for better exposure of the patella bone block harvest site. The oscillating saw is angled toward the midline, in a convergent manner, for the longitudinal cuts to create a trapezoidal or triangular bone block (Fig. 26.7). Care should be taken to avoid diving too deep into the patella in order to prevent patella fracture and chondral damage. The ¼ in osteotome used for the tibial tubercle osteotomy can be used in the patella to complete the osteotomy at the corners and periphery. The osteotome is also used to level the bone block from the surrounding patella. The patella tendon graft is then carefully dissected free from the remaining patella tendon and brought to the back table for preparation.

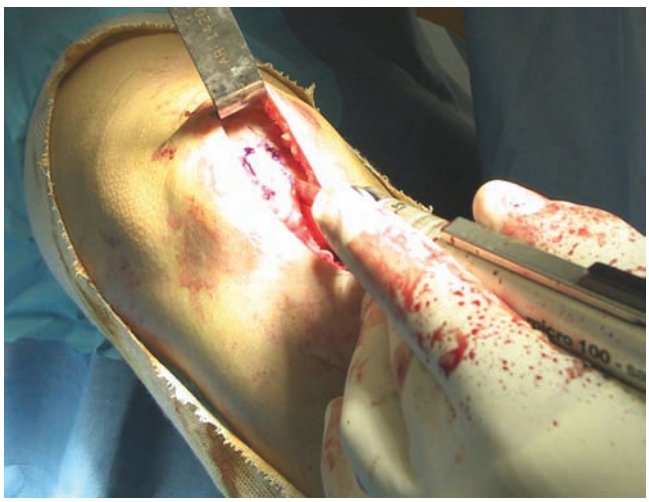

FIGURE 26.7
BPTB graft harvest patellar cuts.

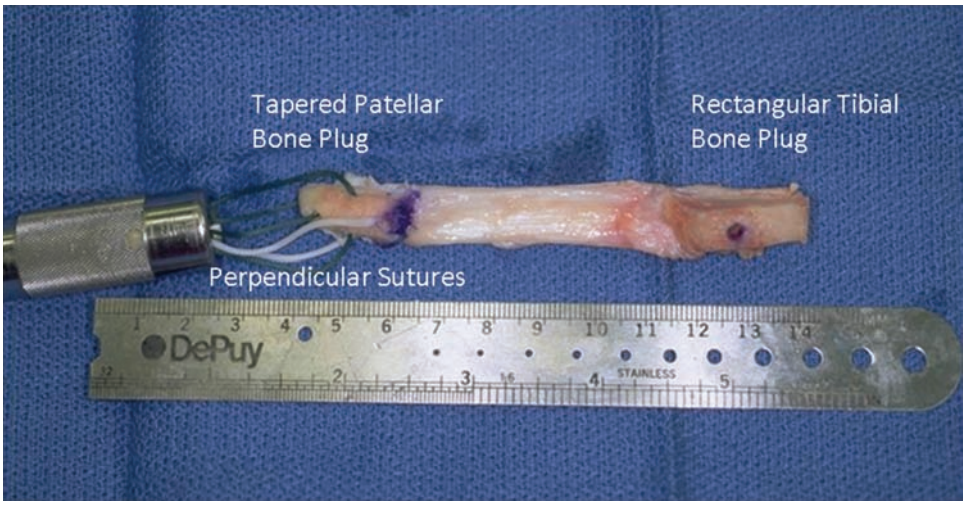

FIGURE 26.8
BPTB graft with bone plugs.

Once the graft is brought to the back table, the bone blocks are sculpted using a small rongeur and an ACL graft-shaper clamp so that they fit through the appropriately sized hole of a sizing block (usually 10-mm sizing block). The tibial bone block should be rounded at the leading end to assist in graft passage from the tibial tunnel into the femoral tunnel. Excess bone removed from the bone blocks should be saved to fill harvest defect sites prior to closure at the end of the case. A single hole is drilled using a 2-mm drill bit 5 to 8 mm from the end of the tibial bone block in an anterior-to-posterior direction and a number 5 nonabsorbable suture is threaded through the hole (Fig. 26.8). Two evenly spaced holes are made in the patella bone block perpendicular to each other (90–90 holes) and 5 nonabsorbable sutures are threaded through each hole (Fig. 26.8). The bone-tendon junction at each end of the BTPB graft is marked with a surgical pen, and measurements of the entire graft including the bone blocks are made for tunnel angulation. The graft is then placed in a moist lap and is stored in a safe place to prevent inadvertent contamination on the back table.

While the graft is being prepared on the back table, any meniscal work can be addressed. Chondral repair procedures such as osteochondral transplantation or microfracture should be performed after ACL reconstruction to improve arthroscopic visualization. The remnant ACL is excised using a shaver and biters to allow full access to the lateral wall of the intercondylar notch and to prevent impingement of the graft on soft tissue. The tibial footprint of the ACL insertion site is cleared allowing for visualization of an outline for proper tibial tunnel placement. The roof and lateral wall of the intercondylar notch is then cleared of soft tissue as well with special attention paid to protection of the PCL while débridement of the wall ensues. After the soft tissue is débrided, a large burr and a rasp are used to complete the notchplasty.

The notchplasty should be performed to ensure the creation of a smooth tunnel-shaped notch that allows for easy visualization and access to the posterior notch and avoids impingement of the ACL graft on the lateral wall and roof. The over-the-top position is then identified with care to avoid mistaking the intercondylar ridge (resident's ridge) for the over-the-top position (Fig. 26.9) (2). However, this intercondylar ridge has become a recent

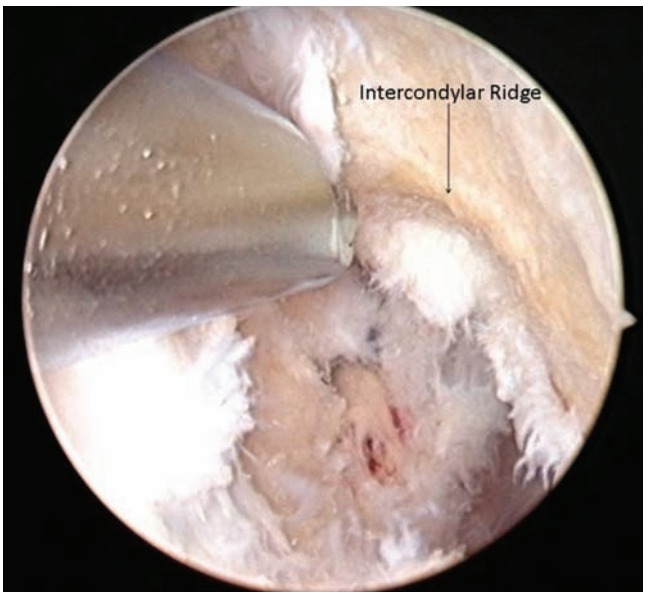

FIGURE 26.9
Intercondylar ridge.

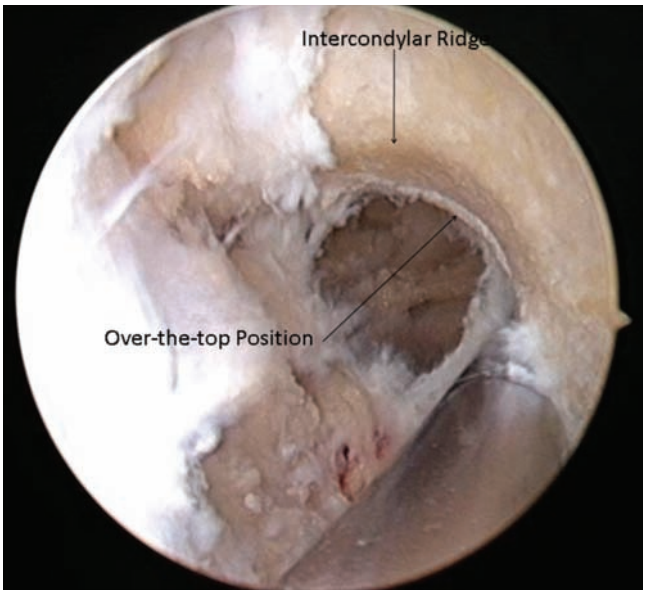

FIGURE 26.10
Over-the-top position.

area of interest for double-bundle reconstruction. A fringe of white periosteal tissue, denoting the junction of the femur and the posterior joint capsule, usually can be seen posteriorly when the over-the-top position has been identified (Fig. 26.10). An arthroscopic probe is then used to verify this position.

Attention is then turned to tunnel placement. The femoral tunnel should be located near the 10 o'clock position on the femur for the right knee and the 2 o'clock position on the left knee for optimal results and to resist rotatory loads more effectively (4,33). The starting point on the tibia should be the midpoint from inferior to superior with respect to the tibial tubercle harvest site and midpoint between and the tibial tubercle and the posteromedial edge of the tibia. Too medial or too central a starting point results in compromise of the medial collateral ligament or vertical tunnel placement, respectively. A commercially available guide is used to ensure property entry of the tibial tunnel into the joint. Landmarks for placement of the tibial tunnel include a position 7 mm anterior to the fibers of the PCL, the upslope of the lateral face of the medial tibial intercondylar eminence, the posterior aspect of the anterior horn of the lateral meniscus, and center of the native ACL footprint (10,20,24). In the sagittal plane, the tunnel should be angled posteriorly to prevent graft impingement, and in the coronal plane, the tibial tunnel should be angled 70 degrees to the medial tibial plateau (10,29). The elbow or tip aimer of the ACL tibial guide is placed through the anteromedial portal and the tip of the guide is visualized arthroscopically and placed at the landmarks mentioned above. The angle of the guide is set to 50 to 55 degrees. The guide pin is inserted using the commercially available guide and placing the starting point along the medial aspect of the anterior surface of the tibia between the tibial tubercle and the posteromedial edge of the tibia. The guide pin is inserted into the proper location and soft tissues are resected using an arthroscopic shaver if necessary (Fig. 26.11). The commercially available guide is then removed. A reamer based on graft size (usually

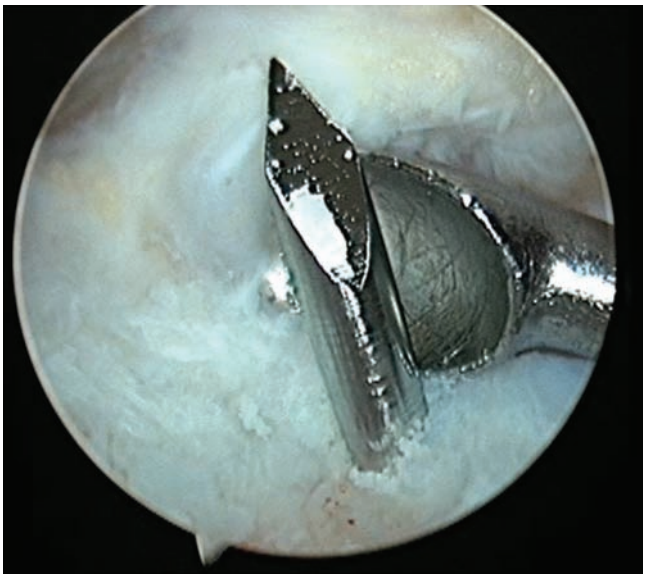

FIGURE 26.11
Tibial guide pin insertion.

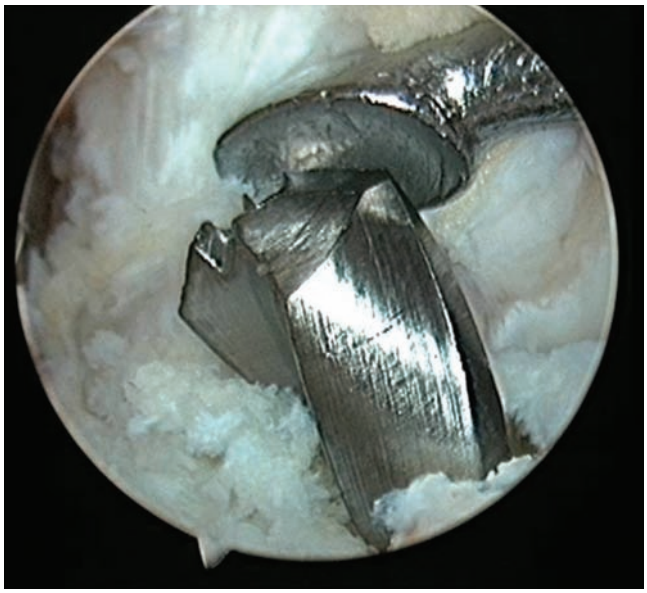

FIGURE 26.12
Tibian tunnel reamer.

10 mm) is used to ream the tunnel until the reamer is seen arthroscopically just past the tibial articular surface (Fig. 26.12). The inflow pump is turned off just before penetration of the joint by the reamer; determined by resistance to advancement of the reamer during tibial drilling. Once the articular surface is reached, the reamer is removed and excess bone from reaming of the tibial tunnel is saved for incorporation into the graft harvest sites. The arthroscopic shaver is then used to débride all soft tissue surrounding the tibial tunnel to allow easier graft passage and to smooth the posterior edge of the tunnel to prevent graft abrasion.

The femoral tunnel is made by first inserting an over-the-top guide through the tibial tunnel for the transtibial technique. The inferomedial arthroscopic portal can also be used (medial portal technique) but will not be described here. The guidewire is placed at its desired position by using the predetermined offset. This offset is determined by taking the diameter of the graft adding 2 mm and dividing by two. The tongue of the femoral offset guide is placed in the 10 o'clock or 2 o'clock position (Fig. 26.13). A beath needle (a long guidewire with an eyelet at one end) is inserted through the offset guide and is drilled through the anterolateral femur with the knee hyperflexed. Hyperflexion ensures that the Beath needle exits through the distal thigh. Care must be taken to make sure that the Beath needle does not bend; therefore, the position of the knee should not change until the graft has passed. Once the needle is placed, the offset guide is removed. A 10-mm acorn reamer is placed over the guidewire and the femoral tunnel is drilled 5 mm and pulled back in order to ensure that the posterior wall is not violated (Fig. 26.14). Once this is assured, the femoral tunnel is drilled to a depth of 30 to 35 mm. The shaver is used to clear all excess bone debris out of the tunnel and posterior notch.

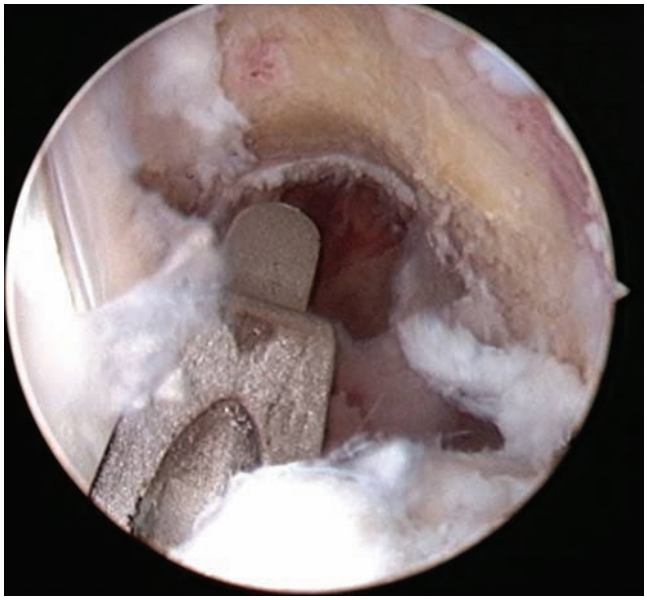

FIGURE 26.13
Femoral offset guide at over-the-top position.

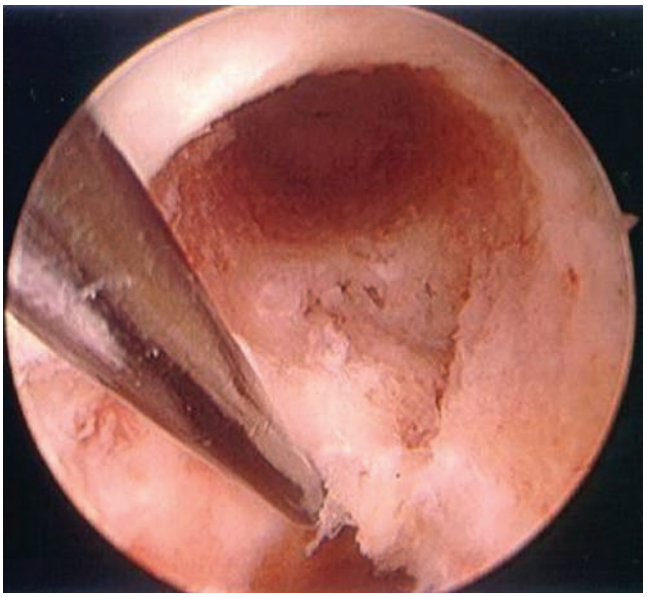

FIGURE 26.14
Posterior wall blowout.

The graft is then obtained from the back table and the sutures from the patella bone block are clamped to the drape close to the knee to ensure that the graft will not fall to the ground. The suture limbs from the tibial bone block are threaded through the eyelet of the Beath needle and the needle is pulled through the anterolateral thigh. The knee is then brought out into a neutral position and the remainder of the graft is pulled carefully into the knee. Markings previously placed on the graft measuring 30 mm are used to ensure full incorporation of the graft into the femoral tunnel.

FIXATION

Now that the graft has been passed, we turn our attention to fixation. A well-agreed upon advantage of BPTB graft use is the ability to obtain early rigid fixation and stability in the setting of bone-to-bone healing (28). Both aperture (i.e., interference screws), nonaperture (i.e., extracortical suspensory) systems, as well as screw and washer constructs are available. Both femoral and tibia fixation can be achieved through the use of such devices. Our preference is to use interference screws for both femoral and tibia fixation. Interference screws have been shown to provide initial strength in excess of that needed for early range of motion and rehabilitation (40). Both metal and bioresorbable screw options are available, with controversy regarding which material provides the ultimate advantage over the other. However, to date several studies have shown there is no difference in initial strength of fixation or bone-to-bone healing between the two materials (3,16).

We first determine our interference screw diameter. We take into consideration both bone block quality and size. In the setting of good bone quality and size (i.e., a 10-mm bone block), we use a 7-mm diameter screw. When bone quality is in question or there is a loose fit, we recommend a 9-mm screw. Our practice is to match the screw length to that of the graft plug while maintaining 10 mm of bone plug-interference screw contact.

Once we have selected a screw, we hyperflex the knee to facilitate parallel screw placement in relation to our bone plug. Using either the anteromedial portal or the patella tendon defect, we put in place an offset femoral guide (tunnel notcher), which is used to ensure optimal guidewire placement. The interference screw is then introduced over the guidewire while equal tension is applied to the sutures that were previously placed at the ends of the graft. The screw is placed against the cancellous surface of the bone and inserted until flush with the bone block (Fig. 26.15). Tension is then applied to the sutures at the end of the tibial block to check fixation strength. Simultaneously, the knee is brought through full range of motion and into full extension a dozen or more time to remove crimp. During this step, we address any signs of impingement and/or graft motion. Any motion >2 mm signifies poor placement and should be corrected.

We then turn our attention to tensioning and fixation of the tibial end of our graft. We prefer to tension and secure the tibial graft in full knee extension. An interference screw is then introduced over a guidewire anterior to the bone block (Fig. 26.16). If needed, additional fixation can be obtained through the use of a staple or screw and washer construct. Any excess bone is removed and used as bone graft for our patella and tibial harvest sites during closure.

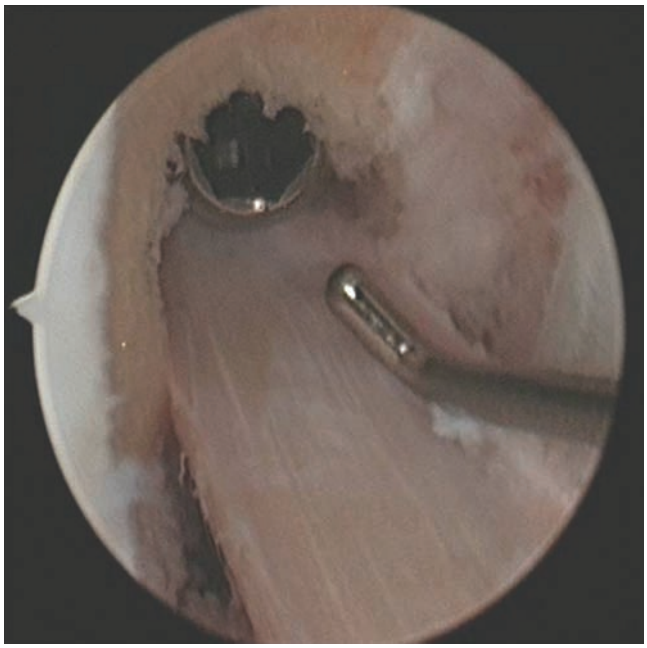

FIGURE 26.15
Femoral interference screw.

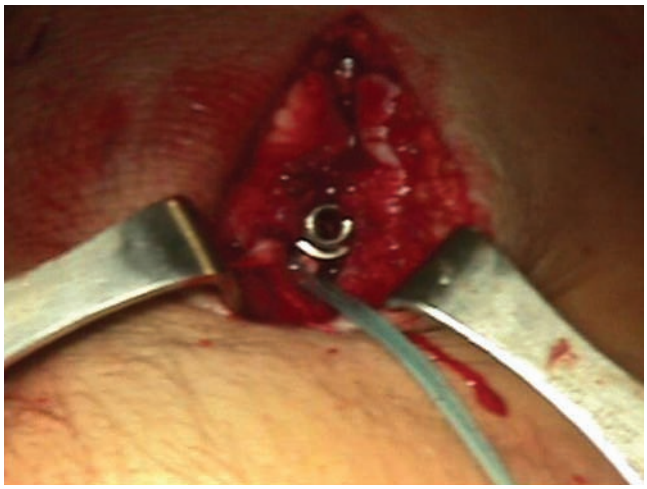

FIGURE 26.16
Tibial interference screw.

CLOSURE

The wounds are well irrigated and 0-Vicryl (Ethicon, Summerville, New Jersey) is used to close the patella defect by close approximation of the paratenon. The remainder of the incision is closed in layers using Vicryl suture and the skin is closed using a running subcuticular Prolene (Ethicon, Summerville, New Jersey). The portal sites are closed using a 2-0 nylon suture. A sterile dressing is applied, followed by an elastic bandage from the toes proximally past the knee.

POSTOPERATIVE REHABILITATION

The top priority and goal of rehabilitation during the early phase is reducing knee stiffness. Range of motion should be assessed during the patient initial presentation, particularly the ability to reach full extension. If preoperative range of motion is a concern, we refer patients for physical therapy prior to undertaking surgery. After surgery, ice and cryotherapy is used to minimize effusion and pain. A protocol-driven rehab program is initiated 2 to 3 days after surgery. Both the patient and the physical therapist are given a copy of the rehab protocol. We allow patients to weight bear as tolerated without a brace, provided no meniscal repair was performed. In the event of meniscal repair, a hinged knee brace is used with range of motion set at 0 to 90 degree of flexion and the patient is allowed only partial weight bearing for 6 weeks.

Early rehab goals include proprioceptive training and closed-chain exercises with focus on proper quadriceps recruitment. During the later phase of rehabilitation, the primary goal is strengthening. A stationary bicycle, treadmill walking, and aquatic therapy are used to maximize knee motion and strength. Crutches are used until the patient is able to weight bear without a limp. Weight machines are used at 5 to 6 weeks, with plyometrics at 8 weeks. By 12 weeks, patients are usually allowed to return to jogging and progress toward return to sport. Return to sport is usually allowed between 4 and 6 months. Our return goals include strength at least 85% that of the nonoperative side.

COMPLICATIONS

The most common complication following BPTB ACL reconstruction is postoperative patellofemoral pain. Anterior knee pain has also been accredited to graft harvest during autogenous BPTB procedures (7,30). Others have associated this complication with postoperative flexion and extension, as well as quadriceps strength (1,32). In one of the largest series to date, Shelbourne and Trumper showed that there was no difference in the incidence of patellofemoral pain between patients who underwent ACL reconstruction and control patients who had not undergone surgical intervention (35). They concluded that anterior knee was not an intrinsic complication to BPTB harvest, and that the incidence of such pain could be prevented with a rehabilitation program focused on restoration of full hyperextension. Decreased sensitivity as a result of disturbance to the infrapatellar branch of the saphenous nerve and patella tendonitis may also contribute to postoperative anterior knee pain; however, these findings usually resolve within a year (10).

Patella fractures have been also been reported following BPTB ACL reconstruction, and have been associated with both direct and indirect forces (36,39). This complication can be avoided with careful technique during graft harvest, and not creating additional stress risers during the bone block cut. In the event of intraoperative patella fracture, rigid fixation should be done immediately as to allow early postoperative range of motion. Extensor mechanism disruption is also rare but has been reported during the postoperative period (17,21).

Proper tunnel placement and adequate fixation are imperative to ACL reconstruction. Careful technique during reaming, guide pin placement, notchplasty and fixation can help minimize these complications. One must make sure not to violate the posterior cortex of the femur during reaming. This can be prevented by maintaining the knee in flexion, and not reaming more than 30 mm in depth. A poorly done notchplasty can lead to impingement, and therefore loss of extension. Impingement can also occur if the tibial tunnel is placed too anteriorly and ultimately can lead to pathologic laxity. Care also must be taken not to lacerate the suture or cause graft fracture during interference screw placement. Each of the above-mentioned complications can be prevented with careful technique and direct visualization during each step. In the unfortunate event of any of these complications, they should be addressed immediately.

The importance of postoperative early range of motion cannot be overstated. The incidence of arthrofibrosis has decreased over the years as a result of advances in rehabilitation protocols. If motion is not restored by 6 weeks postsurgery, the senior author performs a manipulation under anesthesia followed by aggressive physical therapy. If this approach fails, then an arthroscopic debridement or revision procedure may be needed. Any subsequent procedures must be followed by aggressive physical therapy.

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27 Anatomical ACL Reconstruction with BPTB Autograft via Rectangular Tunnels

A single-bundle technique based on the concept of double-bundle reconstruction

Konsei Shino, Shigeto Nakagawa, and Tatsuo Mae

INTRODUCTION

The autogenous bone-patellar tendon-bone (BTB) of 10-mm width has been one of the most frequently used ACL grafts to reconstruct as a single bundle via round tunnels (6,8). As the rectangular shape of its cross section is close to that of the natural ACL, it could fairly mimic the natural fiber arrangement inside the ACL if it is properly placed in the tunnels created in the right attachment areas (Fig. 27.1) (2,4). In order not only to mimic the natural fiber arrangement inside the ACL, but to maximize the graft-tunnel contact area in the femur as well as in the tibia, this rectangular tunnel technique was developed (Fig. 27.2). Consequently, this procedure follows the concept of the double-bundle reconstruction (11). The instruments were developed in cooperation with Smith & Nephew Endoscopy (SNE), Andover, Massachusetts (Fig. 27.3).

SURGICAL TECHNIQUE

Positioning and Skin Incision

Using a leg holder, the distal thigh is kept horizontal to obtain a consistent view of the intercondylar notch, regardless of knee flexion angle. A skin incision of 3 in is made along the medial border of the patellar tendon, and then curved medially to the entry point of the tibial tunnel, located just above the pes anserinus (Fig. 27.4).

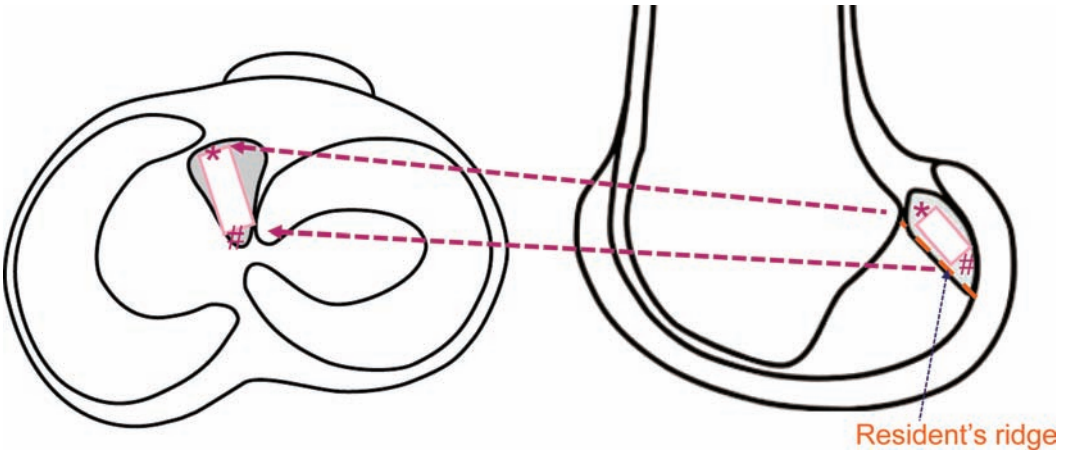

FIGURE 27.1

Placement and orientation of the BTB graft in the right knee. Points A and B in the femoral attachment correspond A´ and B´ in the tibial attachment, respectively.

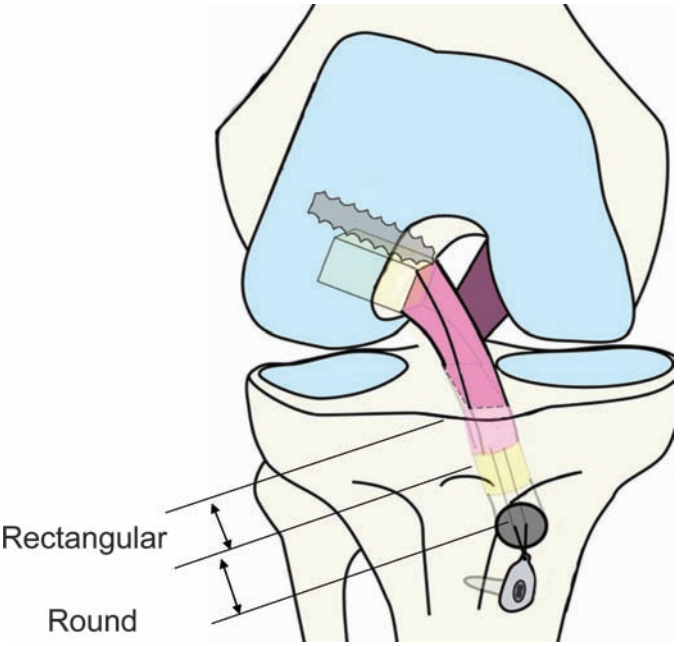

FIGURE 27.2

Schema of the rectangular tunnel ACL reconstruction with bone-patellar tendon-bone graft (RT BTB ACL-R). This half rectangular tibial tunnel makes it possible for the tendinous portion of the BTB graft to closely fit to the proximal portion of the tibial tunnel.

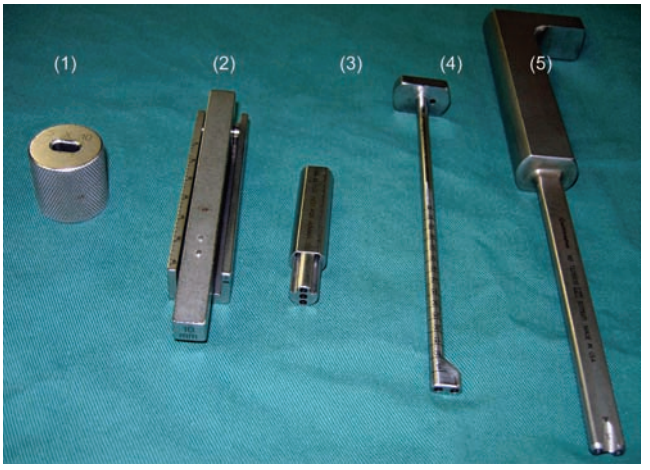

FIGURE 27.3

Instruments for the rectangular tunnel ACL reconstruction: (*1*) graft sizing template of 5 × 10 mm; (*2*) bone-plug shaper; (*3*) 10-mm in-line offset pin guide; (*4*) 5 × 10 mm inside-out femoral dilator/pin guide; (*5*) 5 × 11 mm outside-in tibial dilator/pin guide.

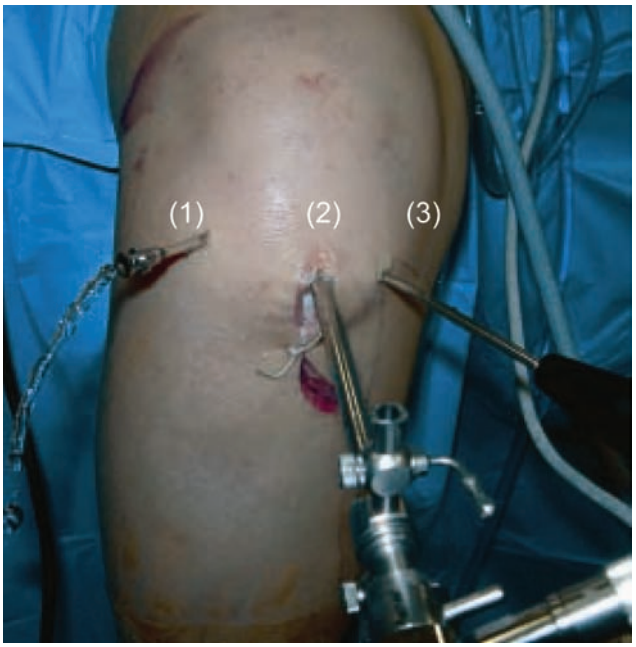

FIGURE 27.4

Skin incision and arthroscopic portals for the right knee. (*1*) anterolateral portal; (*2*) anteromedial portal; (*3*) far anteromedial portal: 2 to 2.5 cm posterior to the anteromedial portal and just above the medial meniscus.

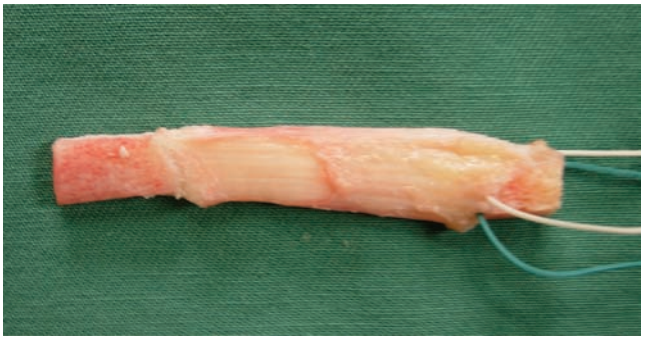

FIGURE 27.5

Prepared bone-patellar tendon bone graft. Note that the bone plug on the left is shaped into a rectangular parallelepiped socket of 5 mm thick × 10 mm wide × 15 mm long. Also note that the upper longer side from the medial portion of the patellar tendon is assigned to the anteromedial bundle, while the lower shorter one from the central portion is for the posterolateral bundle.

Graft Harvesting and Preparation

A 10-mm wide BTB graft is harvested from the medial half of the patellar tendon with 15-mm long bone plugs on both ends. This offers the graft's tendinous portion with uneven length. The medial longer side is assigned to the anteromedial bundle, while the central shorter one is for the posterolateral bundle.

The bone plug from the tibia is shaped with the bone-plug shaper (SNE#72200447) into a rectangular parallelepiped socket of 5 mm thick × 10 mm wide × 15 mm long to snugly pass the graft sizing template (SNE#6901101) and used for the femoral socket. The patellar bone block is left as a triangular pillar for the tibial tunnel (Fig. 27.5).

Arthroscopic Portals

In addition to routine anterolateral and anteromedial portals, the far anteromedial portal, 2 to 2.5 cm posterior to the anteromedial portal and just above the medial meniscus, is routinely created (9). This portal makes it possible for instruments to get more perpendicular access to the ACL femoral attachment area on the lateral wall of the notch. Principally, the surgery is performed with instruments through the far anteromedial portal under visualization with a 45-degree oblique 4-mm arthroscope via the anteromedial portal (Fig. 27.4) (1).

Femoral Socket Preparation

Viewing the ACL femoral attachment area, the fibrous tissues including ACL stump (Fig. 27.6A) on superior-posterior half of the lateral wall of the intercondylar notch is thoroughly removed using a radiofrequency device. Mechanical shavers are not utilized in order to preserve subtle undulation of the bony surface around the attachment area. After cleaning up, a nearly longitudinal linear "resident's ridge" is consistently visualized on the wall, 7 to 10 mm anterior to the posteromedial articular cartilage margin of the lateral femoral condyle

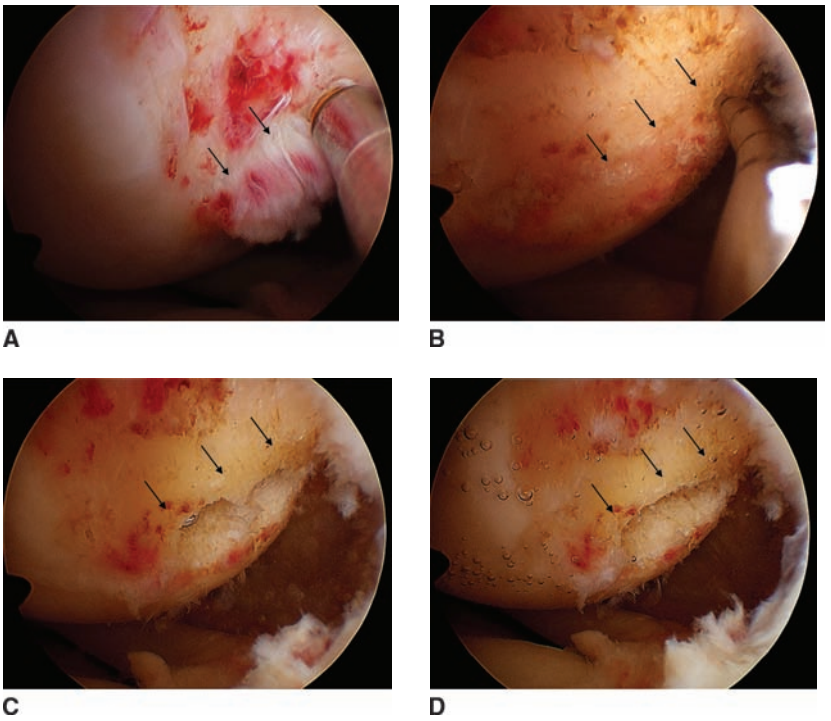

FIGURE 27.6

Creation of the rectangular femoral socket within the attachment area of the left knee. **A:** Under a clear view with an oblique arthroscope through the anteromedial portal, the ACL stump (*arrows*) and the surrounding synoviofibrous tissues are delicately removed. **B:** The bony surface undulation around the attachment area is clearly observed. Note the subtle, nearly longitudinal linear "resident's ridge" (*solid black arrows*) 7 to 10 mm anterior to the medial articular cartilage margin of the lateral femoral condyle. Also note the awl is marking the point for the upper guide pin. **C:** The created two continuous 5-mm round holes. **D:** The created 5 × 10 × 22 mm rectangular parallelepiped socket inside the attachment area. Note the "resident's ridge" (*solid arrows*).

(3). As this ridge indicates the anterior border of the attachment area, the crescent-shaped attachment area is clearly delineated (Fig. 27.6B) (5,7).

After marking two points with 5-mm distance in the center of the attachment area along its long axis using a microfracture awl, two parallel guide pins are drilled from these points to the lateral femoral cortex via the far anteromedial portal with the knee fully flexed. The upper pin is overdrilled with a 5-mm cannulated drill bit to the lateral femoral cortex, while the lower one is overdrilled to 20 mm in depth. Then, the two round holes are dilated into a 5 × 10 × 22 mm rectangular parallelepiped socket using the lower pin as a guide with the inside-out dilator/pin guide (SNE#6901100) (Fig. 27.6C and D).

Notchplasty is not required unless marginal osteophytes are formed.

Tibial Tunnel Preparation

Viewing the ACL tibial attachment area, a guide pin is inserted from the medial tibial cortex to the center of the ACL tibial attachment as a reference central pin using a tibial drill guide set at the angle of 45 degrees (SNE#7205517, 7205519). The pin is overdrilled halfway or 2 to 2.5 cm with a 10-mm cannulated drill bit or a bone dowel harvester for a bone plug to be grafted to defects in the graft-harvest site. The anteromedial and posterolateral pins are drilled in line with the long axis of the attachment area with 5-mm distance using the offset pin guide around the reference central pin (SNE#6901105). The line of these pins forms an angle of 20° to the sagittal plane or runs from the anterior horn of the medial meniscus to the posterior horn of the lateral meniscus. After removing the central pin, they are overdrilled with a 5.0-mm cannulated drill bit, followed by dilation into a 5 × 11 mm rectangle to the articular surface with the outside-in dilator (SNE #72200555) (Fig. 27.7).

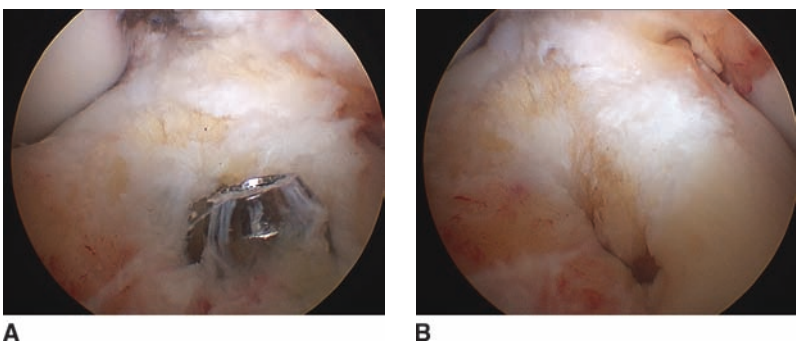

FIGURE 27.7

A: The tibial dilator inside the attachment area. **B:** The tibial aperture inside the attachment area.

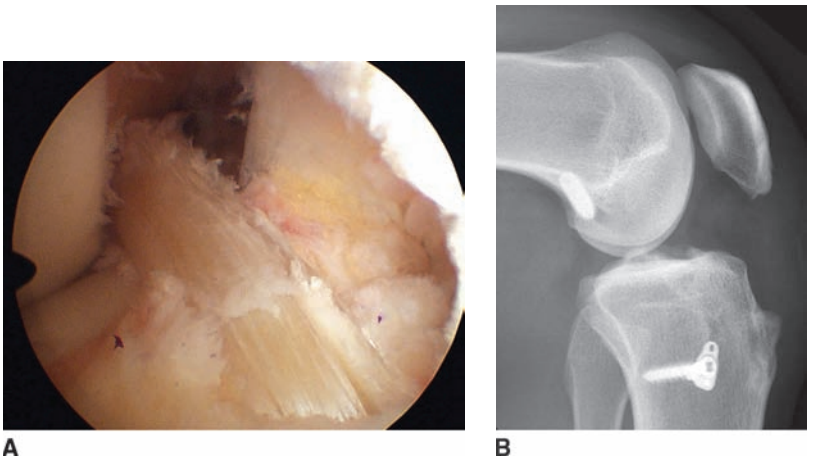

FIGURE 27.8

A: An anatomically placed BTB graft *in situ* scoped via the anterolateral portal showing nice physiological obliquity. **B:** Lateral radiograph showing fixation hardwares. An interference screw of 6 mm for femoral fixation, and DSP with a screw for tibial side. Note that the screw is located in the far back of the lateral femoral condyle.

Graft Passage

With two leading sutures, the graft is passed from the tibial tunnel to the femoral socket with its parallelepiped bone plug kept on the top, and with its cancellous bone surface maintained anteriorly (Fig. 27.8A). Care is taken to pull the sutures along direction of the tunnels.

Graft Fixation

For femoral fixation, a 6 mm × 20 to 30 mm interference screw is used in outside-in fashion through the 5-mm hole from the lateral femoral cortex to the bottom of the socket using a 6.5-mm skin protector (SNE#6901106) via an additional small lateral femoral incision. For inside-out interference fixation, the screw is introduced through the far anteromedial portal. Otherwise, the other pullout techniques including DSP (Double Spike Plate, MEIRA, Aichi, Japan) system through an additional lateral skin incision of 3 to 4 cm are utilized (10).

Tibial fixation is achieved with another interference screw or a modified pullout suture technique using the DSP system. With the latter, it is possible to fix the graft under predetermined amount of tension (10). The tensioning sutures distally connected to DSP are tied to a tensioner mounted on the metal shell boot fixed to the tibia with a bandage. Then, the creep of the construct is meticulously removed by repetitive manual pulls of the graft suture. After the reading of the tensioner is stabilized at the intended level of 15 to 20 N for 2 minutes with knee flexed 15 degrees, the graft is temporarily fixed by hammering DSP bottom spikes into the tibial cortex, and the DSP is secured with a screw (Fig. 27.8B). Care is taken to remove the periosteum where the DSP is placed.

Complications and Their Management

There are few intraoperative or postoperative complications specific to this technique. The most troubling one is loss of femoral fixation by insidious blowout of femoral cortex during interference screw fixation of the bone plug. This trouble is prone to happen in small-size female patients with narrower femoral attachment area or in those who are lacking in deep flexion angle over 130 degrees. To manage it, a pullout fixation including the DSP system is recommended. For those lacking in flexion angle over 130 degrees, the rectangular femoral tunnel could be created in outside-in manner via 2 to 3 cm lateral femoral incision. With the anterolateral-entry femoral aimer (SNE#7210984), outside-in drilling of the guide wires from the lateral femoral cortex to the attachment area could be performed under an excellent view of the aimer in place through an arthroscope via the anteromedial portal.

No patient has sustained a patellar fracture during the postoperative period.

POSTOPERATIVE REGIMEN

Postoperatively, the knee is splinted in 10 degree flexion for a week. Partial weight bearing is allowed at 2 to 3 weeks, followed by full weight bearing at 4 to 5 weeks, when full extension is permitted. Jogging is recommended at 3 months. Return to strenuous activity is not allowed until 6 months.

DISCUSSION

The original ACL could grossly be divided into two bundles: the anteromedial and posterolateral bundles (2). Thus, it is reasonable to separately reconstruct two bundles through two separate tunnels created in the femur and tibia with two doubled grafts such as the semitendinosus tendon. With the graft placement as described

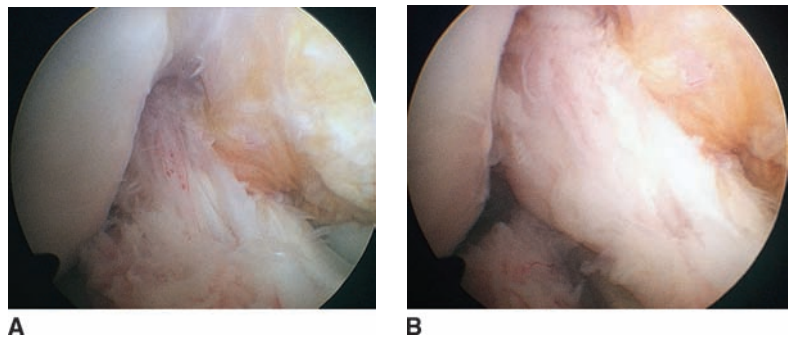

FIGURE 27.9

Arthroscopic appearance of a 38-month-old BTB graft in the right knee of a 22-year-old male American football player at the time of hardware removal. Note that the anterior portion is taut **(A)**, while the posterior part is slack in flexion **(B).**

above, the concept of the double-bundle reconstruction could successfully be brought to that with BTB graft. The anterior portion is relatively tense throughout range of motion, while the posterior portion becomes tense approaching extension while slack in flexion (Fig. 27.9). Thus, the technique described here is the one to mimic the original two bundles inside the natural ACL with BTB graft.

There may be an opinion that correctly oriented BPTB graft allows reproduction of the anteromedial and posterolateral bundles in a standard round tunnel technique as well. However, as cortical thickness of the ACL femoral attachment area behind the resident's ridge is greater than that of the area anterior to the ridge, it is better to keep the tunnel aperture inside the attachment area just behind the resident's ridge to create a more robust tunnel to avoid widening of the tunnel (5). Furthermore, in the round tunnel technique, there is a futile gap between the proximal portion of the round tibial tunnel and tendinous portion of the graft due to length mismatch between the native ACL and the patellar tendon (8).

It may be of concern that notchplasty is not performed in this procedure. It is reasonable that the anatomically orientated graft placed in the tunnels kept inside the attachment areas is unlikely to impinge the notch as the normal ACL.

Because less area is occupied by socket/tunnel in the attachment areas, this technique is more advantageous for revision surgery using BTB or quadriceps tendon-bone graft. In fact, we have successfully performed more than 40 revision ACL reconstructions with this technique.

As snug fitting is achieved not only at the bone plug–femoral socket interface but in the proximal half of the tibial tunnel as well, earlier graft remodeling could be expected. The postoperative rehabilitation might be accelerated.

One critical issue for this technique is not difficulty in creating the rectangular socket tunnel, but fixation of the bone plug to the femoral socket located in the real far back in the lateral condyle. As the short tunnel of 3 cm or less did not always allow to securely fix the 15-mm long bone-plug with the EndoButton, interference screw fixation is our current choice. However, it is advisable to prepare backup pullout fixation as describe above in case of loss of fixation due to insidious blowout of femoral cortex.

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28 Anatomic Single-Bundle ACL Reconstruction: Hamstring

John Xerogeanes and Jordan L. Goldstein

INDICATIONS/CONTRAINDICATIONS

Surgical reconstruction of the anterior cruciate ligament (ACL) is performed to restore functional stability to the ACL-deficient knee and prevent ensuing meniscal damage from an unstable joint. Much progress has been made in surgical techniques for ACL reconstruction allowing for surgery to be performed for almost any age individual who wishes to remain active. There are multiple auto and allograft choices that are currently used to reconstruct the ACL. Hamstring autografts are typically used in younger individuals who are involved in sports/activities that require kneeling or in older individuals who wish to use autograft rather than allograft. Persons with a history of extensor mechanism trauma, patellofemoral pain, or open growth plates are also better suited for a hamstring autograft rather than bone patellar tendon bone (BTPB) autograft. In addition, cosmesis and postoperative pain is less with hamstring autograft than a BTPB autograft without any resulting deterioration in clinical outcome. The only absolute contraindication to hamstring autograft is the previous harvest of hamstring tendons.

PREOPERATIVE PLANNING

A complete and thorough history and physical examination is mandatory before proceeding with surgery. Diagnosis is confirmed by documenting abnormal laxity with a positive Lachman test. Instability may be demonstrated with a positive pivot shift test. Other physical exam findings associated with concomitant pathology must be noted to prepare for any additional surgery (meniscal injury, posterolateral corner injury, etc.). Radiographs that demonstrate the bony anatomy should be obtained to rule out any bone injury and to assess skeletal maturity. MRI may be performed to further elucidate and confirm any further pathology. It is very important to counsel patients that there is a 22% to 58% chance that they will have numbness over the proximal medial aspect of the tibia after surgery and that this may be permanent but not usually bothersome to the patient. Finally, a check with OR staff should be made to make sure that all equipment to be used is available on the day of surgery.

ANESTHESIA AND POSITIONING

The procedure is performed as an outpatient procedure using either general or regional anesthesia. Two grams of Ancef is given (600 mg Clindamycin if allergy is present) within an hour of incision. After anesthesia is given, but prior to final positioning, the patient is examined thoroughly. A full motion and ligamentous examination is performed on both knees. A padded nonsterile tourniquet is placed high on the thigh and a leg holder is placed around the proximal thigh. The contralateral leg is placed in the lithotomy position with

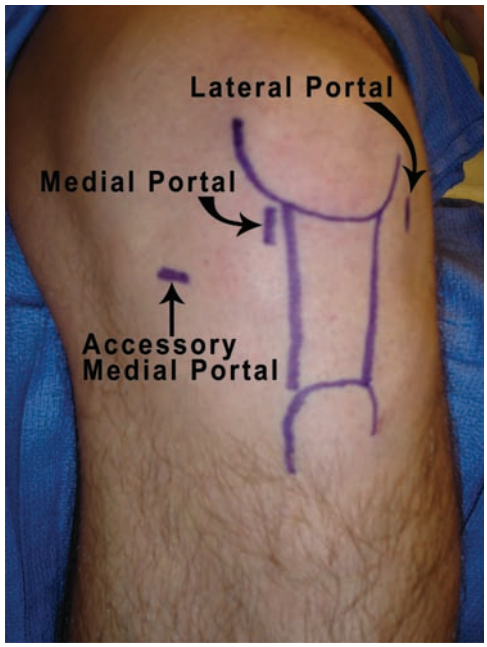

FIGURE 28.2
Location of arthroscopic portals.

a leg holder, being careful to pad the proximal lateral leg and heel. The foot of the bed is dropped, but the leg is kept elevated until the tourniquet is inflated using a padded mayo stand. Routine alcohol and iodine skin preparation is then performed. The leg is then draped in the standard sterile fashion. It is then elevated and wrapped with an esmark bandage followed by tourniquet inflation.

The key surgical landmarks are then marked. The patella, patella tendon, and tibia tubercle are outlined with the leg at 90 degrees of flexion. The medial portal is marked in flexion and is located just medial to the patella tendon at the inferior pole of the patella. The leg is then extended and the lateral portal marked. The incision for lateral portal placement is at the intersection of a line drawn horizontally in line with the inferior pole of patella and a vertical line drawn just lateral to lateral border of patella. The senior author prefers to use this portal because it does not go directly through the fat pad and thus decreases the need for excessive fat pad resection (Fig. 28.1). A solution of marcaine and lidocaine with epinephrine is injected in the knee joint via the lateral portal and 5 to 10 mL of this local anesthetic is injected into the skin of both the lateral and the medial portals.

HAMSTRING TENDON HARVEST

A small 2 cm vertical incision is used to harvest the tendon. The superior aspect of this incision is approximately 1 thumbs breadth below the tip of the tibial tubercle and one third the distance between tibia tubercle and the posterior medial border of tibia. The "speed bump" of the pes anserine can usually be felt over the skin by running your fingers down the proximal third of the tibia. The top of the incision should correlate with the superior boarder of this "speed bump" or the gracilis tendon. An 18-gauge needle is placed through the center of the planned incision down to bone and 8 mL of local anesthetic is then injected (Fig. 28.2). This injection helps separate the underlining fat and skin from the sartorious fascia. A no. 15 blade is used to incise the skin and subcutaneous fat. To help clear the fat from the visual field, a 2 × 2 raytek sponge is used with pickups to bluntly clear all the fat medially (Fig. 28.3). At this point, you can usually feel or visually identify the gracilis and semitendinosus tendons under the sartorial fascia. The incision should be just big enough to fit one index finger into the wound (Fig. 28.4).

An inside-out technique is used to harvest the tendons. In this technique, it is vital to identify the superior portion of the sartorious fascia over the gracilis tendon. There is a small leash of vessels that enter the fascia in this area; it is important to coagulate these vessels to help prevent postoperative hematomas (Fig. 28.5). An inverted "L" incision is utilized to gain access to the tendons. With the skin retracted by the assistants, a safety tip Bovie is used to make a horizontal cut along the superior boarder of the sartorial fascia, starting approximately 2 to 3 cm medial to the tibial tubercle. Care is taken to cut through and coagulate the leash of vessels previously mentioned. The fascia is cut down to bone and the incision is carried to the medial boarder of the tibial tubercle. The vertical limb of the inverted incision is then made in a similar fashion and is carried distally 3 cm. An Allis clamp is used to grasp the superior lateral corner of the pes complex just created (which is the corner of this inverted "L" incision). Tension is then applied to this complex and the Bovie is used to subperiostally peel the complex medially. After the complex is peeled 1 to 2 cm medially, the periosteum and the pes complex usually separate. The separation is completed with the use of a blunt metzenbaum scissors. After the separation begins, you will see the shiny white anterior fibers of the superficial medial collateral ligament.

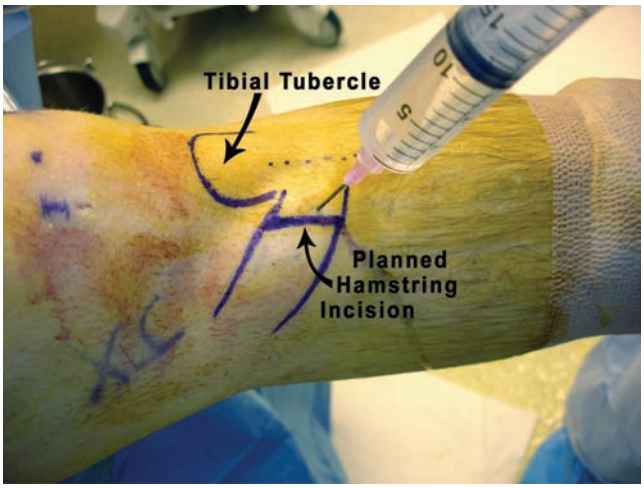

FIGURE 28.2

An 18-gauge needle is placed through the center of the planned incision down to bone and 8 mL of local anesthetic is then injected.

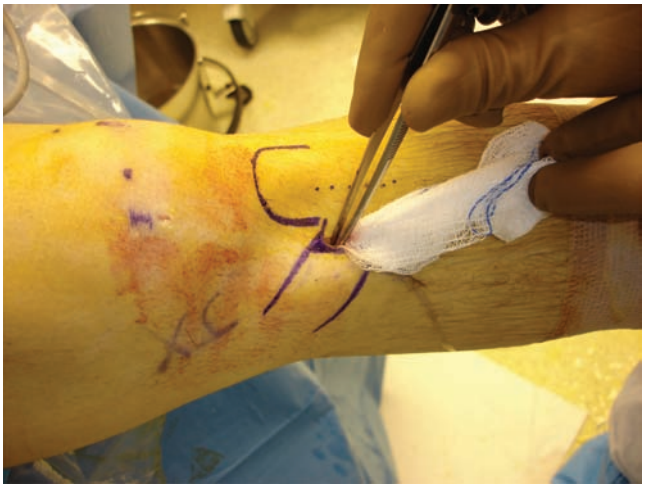

FIGURE 28.3

A 2 × 2 raytek sponge is used with pickups to bluntly clear all the fat medially.

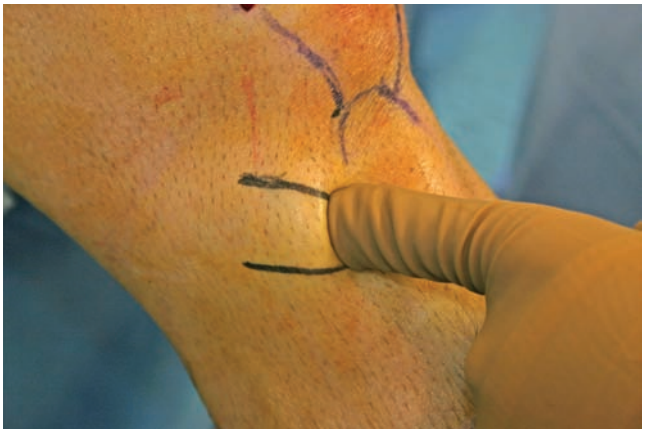

FIGURE 28.4

The incision should be just big enough to fit one index finger into the wound.

On the undersurface of the pes complex, you will see the triangle formed by the conversion of the gracilis and semitendinosus tendons (Fig. 28.6). A right angle clamp is placed near the apex of this conversion and used to bluntly hook the gracilis tendon (Fig. 28.7). The gracilis is then grasped by an Allis clamp and a knife is used to separate it from the sartorial fascia and semitendinosus tendon. A baseball-style whip stitch is placed in the end of the gracilis tendon using a 2 Ethibond suture while holding tension on the tendon with the Allis clamp. An Allis is then used to grab the end of the semitendinosus tendon where it is attached to the sartorious fascia. A second right angle clamp is used in a similar fashion as above to bluntly hook the semitendinosus tendon and separate it from the sartorial fascia. A whip stitch is again placed in the semitendinosus tendon and the ends of the suture are clamped with a hemostat. Use blunt finger dissection to help dissect the gracilis and

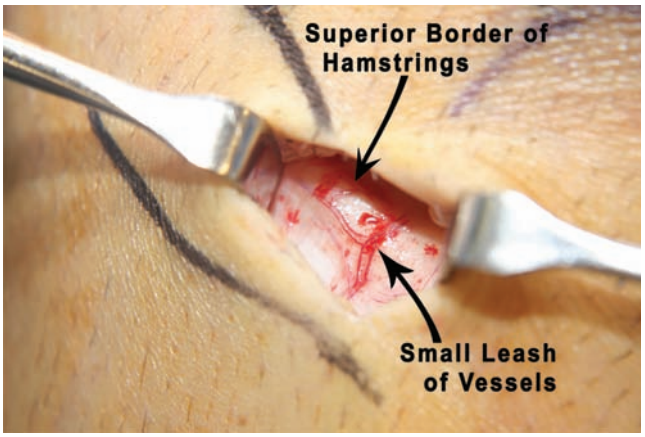

FIGURE 28.5

Notice the small leash of vessels that enter the fascia just above the gracilis;it is important to coagulate these vessels to help prevent postoperative hematomas.

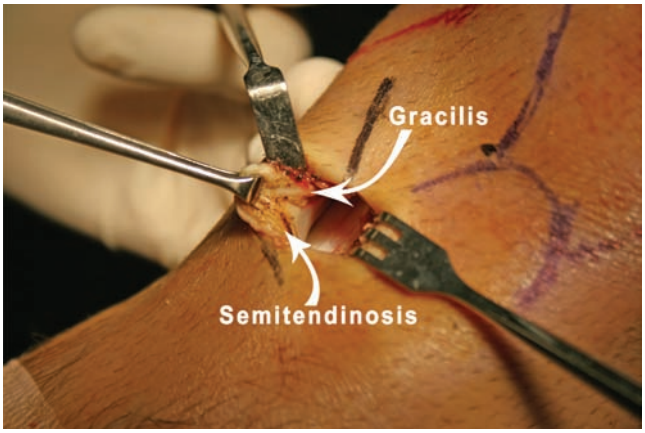

FIGURE 28.6

The undersurface of the pes complex demonstrating the triangle formed by the conversion of the gracilis and semitendinosus tendons.

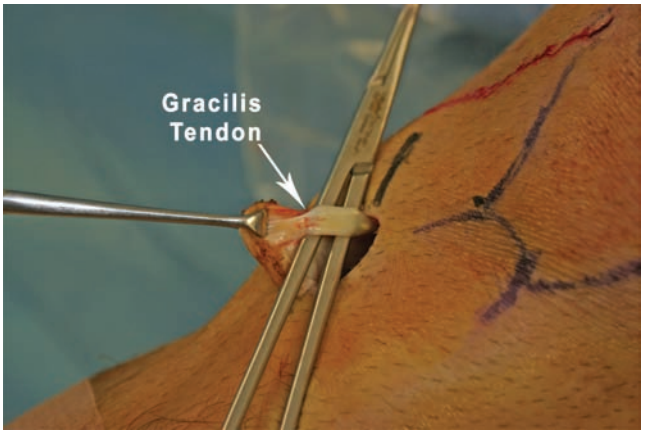

FIGURE 28.7

A right angle clamp is placed near the apex of this conversion and used to bluntly hook the gracilis tendon.

semitendinosus tendons free of soft tissue proximally. The technique involves applying tension to the tendon while pulling it out of the wound and freeing it of any attachments proximally with your finger (Fig. 28.8). One should be able to feel back to the musculotendinous junction. Sharp dissection with a scissors may also be necessary to help free the tendon of any adhesions or connections. The gracilis tendon is usually easy to free of any connections, while the semitendinosus tendon is often more complicated. Almost always the semitendinosus tendon has inferior tendinous connections to the medial head of the gastrocnemius. These are usually found around 5 and 6.5 cm proximal to the semitendinosus insertion on the tibia. These fascial connections must be released before attempting to harvest the tendon; otherwise, premature amputation of the tendon will occur. The surgeon should be able to freely advance his finger along each tendon to the musculotendinous junction without encountering any adhesion or bands. He can then safely begin to harvest with a tendon stripper.

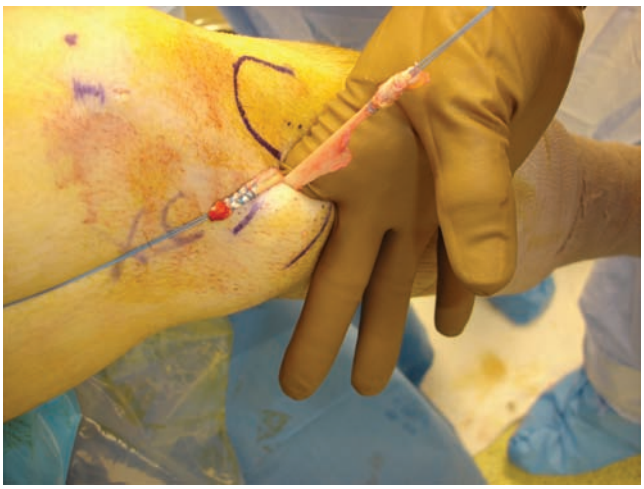

FIGURE 28.8

Blunt finger dissection being used to help dissect the gracilis and semitendinosus tendons free of soft tissue proximally.

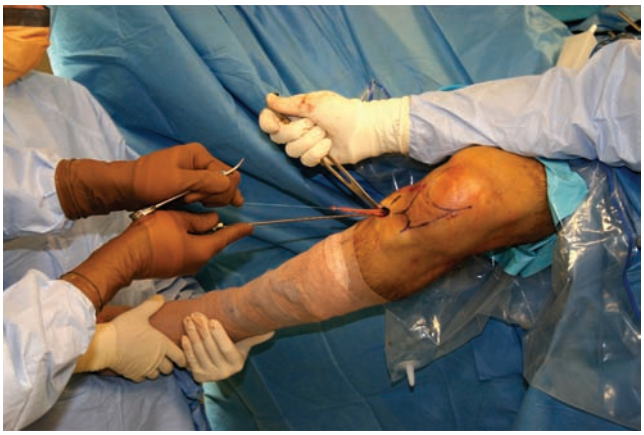

FIGURE 28.9

The tendon is harvested with a "push-pull" technique by gently pushing the tendon stripper up proximally while pulling hard on the graft with the hemostat distally.

To harvest the tendon, first place the closed tendon stripper over the gracilis tendon and then place the leg in a figure four position. The use of an army/navy retractor may be helpful to visualize the path of the tendons. To avoid transecting the tendon, apply and keep maximum tension to the tendon. This allows the tendon stripper to be passed up the tendon in a natural trajectory. The tendon is harvested with a "push-pull" technique by gently pushing the tendon stripper up proximally while pulling hard on the graft with the hemostat distally (Fig. 28.9). If the tendon stripper does not advance smoothly or you encounter resistance early on, stop harvesting and make sure the tendon is free of all soft tissue connections. Once you have easily advanced the tendon stripper to the 13 cm marker on the harvester, you can be aggressive with the rest of the harvest. This is because 13 cm corresponds to the musculotendinous junction and no other adhesions that can cause premature graft amputation remain. The semitendinosus tendon is harvested in a similar fashion. A successful graft usually results in grafts that are about 21 to 28 cm in length.

GRAFT PREPARATION

The tendons are brought to the back table and all muscle is removed from the tendons using a key elevator. Grafts are then cut to the desired length depending on how much graft you desire in the tunnels. The minimum length of graft needed would be 14 cm in length. If 14 cm is available, then doubled over you have 7 cm, which allows for 2 cm in femur, 2 cm in tibia, and 2 to 3 cm in joint. We usually cut the tendons at 18 cm so that when the doubled over tendons are around 9 cm and there is not an abundance of graft protruding from the tibial tunnel after femoral fixation. Thus, if one wishes to reinforce tibial fixation by tying over a post, it can easily be done through the original hamstring harvest incision rather than having to make an additional distal tibia incision.

Using the graft preparation board, place a baseball-style whip stitch on the other end of each tendon. After placing the sutures in the graft, place the two tendons side by side and then fold them in half around a cut blue loop from a surgical sponge (or a suture) so that you now have a doubled gracilis and semitendinosus graft. This blue loop is only in place temporarily and will be replaced by the closed loop EndoButton (Smith and Nephew Endoscopy, Andover, Massachusetts) once the correct EndoButton length is determined. Size the doubled

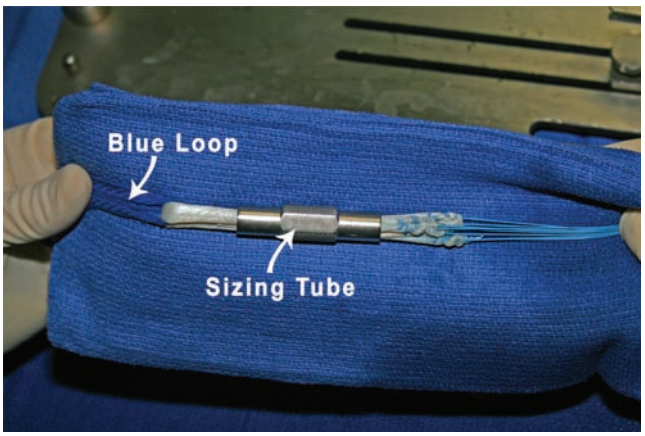

FIGURE 28.10
Size the doubled hamstring graft with incremental sizing tubes—the entire graft should fit through the tube.

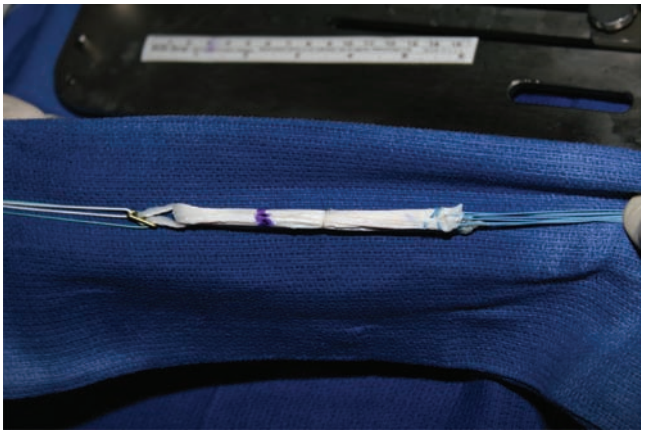

FIGURE 28.11
Hamstring graft with EndoButton attached and blue circumferential mark made.

hamstring graft with incremental sizing tubes—the entire graft should fit through the tube (Fig. 28.10). After sizing, place the graft in a moist sponge and mark the sponge with a marking pen so there is no confusion to accidently dispose of the sponge.

After the surgeon selects the length of the graft and closed loop EndoButton, the assistant on the back table can finish preparing the graft. The axilla of the graft is placed through the loop of the closed loop EndoButton and the four ends equalized so that they are all the same length. A 2-0 Vicryl suture is tied in the central portion of the graft to hold the four strands of graft material together. A circumferential mark is placed on the graft with a marking pen correlating to the total depth of femoral tunnel drilled with the Linvatec Sentinel drill described later. The mark is measured from the most proximal tip of the graft distally (Fig. 28.11). This mark tells you that the graft is pulled far enough into the femoral tunnel to allow the EndoButton to flip. This is approximately 7 to 10 mm more than the amount of graft that will ultimately be in the tunnel after flipping. Thus, after flipping the EndoButton the mark will be approximately 7 to 10 mm distal from the entrance of the femoral tunnel.

ARTHROSCOPIC PORTAL PLACEMENT

We use three working portals for ACL reconstruction. Because we use a pressure-sensing scope (Linvatec), we do not use an inflow/outflow cannula. With the leg in extension, the anterior lateral portal incision is made through the previously described location. A poke hole incision is made with a no. 11 blade keeping the blade parallel to the leg. After popping into the joint with the blade, insert the trocar and cannula into the joint. This portal avoids the need for excessive fat pad removal, which can be a source of postoperative pain in patients. The anteromedial portal is made with the knee flexed to 90 degrees using an 18-gauge needle for localization. This portal is usually located just medial to the patellar tendon at the level of the inferior pole of the patella. It is important that the portal "hug" the patella tendon because in this technique we need to have ample room to place a second anterior accessory medial portal. A no. 11 blade is used to incise the skin with the blade pointing up so as to not accidently cut any meniscus. The knife should be viewed in the joint. The placement of the accessory anteromedial portal will be described in the next section.

PREPARATION OF INTERCONDYLAR NOTCH AND ACCESSORY MEDIAL PORTAL PLACEMENT

After a routine diagnostic arthroscopy is performed and any meniscal and chondral injuries are treated appropriately, attention is turned to the intercondylar notch. Any fat pad that is hindering adequate view of the torn ACL is removed with a shaver. Fat pad resection should be limited to only the amount that is necessary for visualization. In addition, any fat that is present toward the medial femoral condyle is removed as well - this is the fat just above the medial meniscus and in front of the medial femoral condyle with the knee flexed 90 degrees. This fat pad resection is imperative to allow visualization for creation of the accessory anteromedial portal. The surgeon should be careful to not shave any of the medial meniscus during this aspect of the case.

The torn fibers of the ACL from the tibial insertion site are removed with a motorized shaver to help with visualization for later drilling of the tibial tunnel. Not all the fibers should be removed from the tibial attachment site; only enough to help adequately see the tibial footprint (Fig. 28.12). Similarly, the femoral footprint is debrided as well. Again, do not debride the entire femoral footprint down to bone, as you want to be able to see some of the ACL soft tissue stump so you can localize and re-create the anatomic femoral insertion.

To create the accessory anteromedial portal, have the scope camera in the standard anterolateral portal looking medial toward the medial femoral condyle. The knee should be at 90-degree flexion. Palpate with your finger the medial joint line just anterior to the medial femoral condyle—you should see the capsule moving intra-articularly with palpation. Use a spinal needle to enter the joint just above the medial meniscus and just anterior to the medial femoral condyle. You should see the spinal needle enter just above the medial meniscus and just anterior to the medial femoral condyle (Fig. 28.13). The spinal needle should be able to reach the anatomic ACL insertion on the femur. Note the angle of the spinal needle, and then remove it. Use no. 11 blade and incise the skin and capsule keeping the blade parallel to the joint line and the cutting part of the blade facing opposite the femoral cartilage. Make sure the blade is above the meniscus to avoid meniscal damage (Fig. 28.14). By incising the skin in this direction, you allow for some maneuverability of instruments through this portal in the anterior/posterior direction, which is more important than superior/inferior direction. Now place the scope camera in the standard anteromedial portal looking lateral. This allows for excellent viewing of the native ACL femoral insertion, which is best identified by the stump of remaining tissue on the femur (Fig. 28.15). A shaver can be placed through the newly created accessory anteromedial portal to remove any more remnant of ACL tissue on the femur.

With the technique outlined below, a formal notchplasty is never needed. By placing the graft anatomically, the graft is much more horizontal than the traditional ACL reconstruction. Thus, traditional impingement will not occur, eliminating the need for a notchplasty. In cases of congenitally narrowed intercondylar notches, a limited notchplasty may be performed.

FEMORAL ACL FOOTPRINT ANATOMY

It is vital to understand the true femoral footprint anatomy. Traditional ACL reconstruction that we are all accustomed to utilizes “clock face” measurements and “specific points” to define the femoral tunnel placement. This technique is based on identifying each person’s true anatomic ACL footprint. This discussion is based on a knee that is flexed 90 degrees. Thus, it is vital to always identify the footprint with the knee in the 90-degree flexed position.

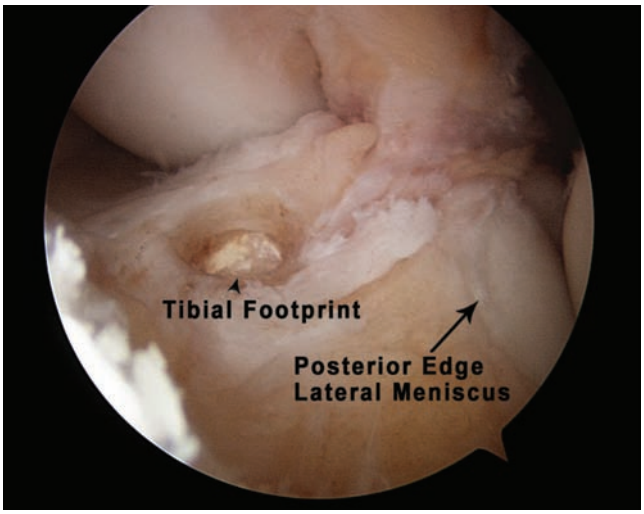

FIGURE 28.12

Tibial footprint of native ACL marked by electrocautery.

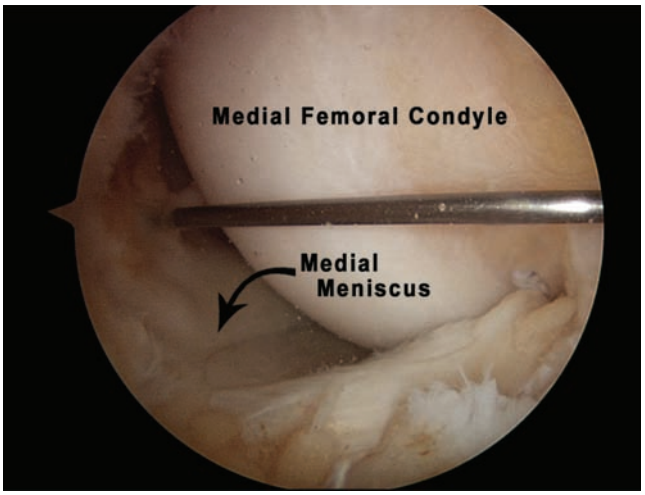

FIGURE 28.13

Spinal needle entering joint just above the medial meniscus and just anterior to the medial femoral condyle.

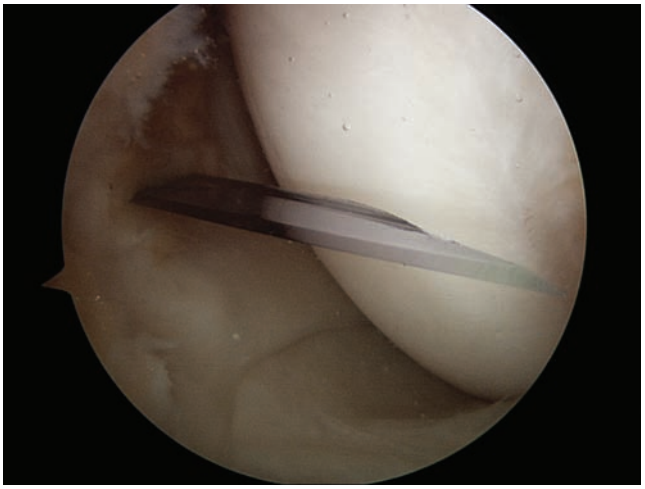

FIGURE 28.14

A no. 11 blade entering joint just above the medial meniscus and just anterior to the medial femoral condyle. Notice that blade is horizontal and that the cutting edge is away from cartilage.

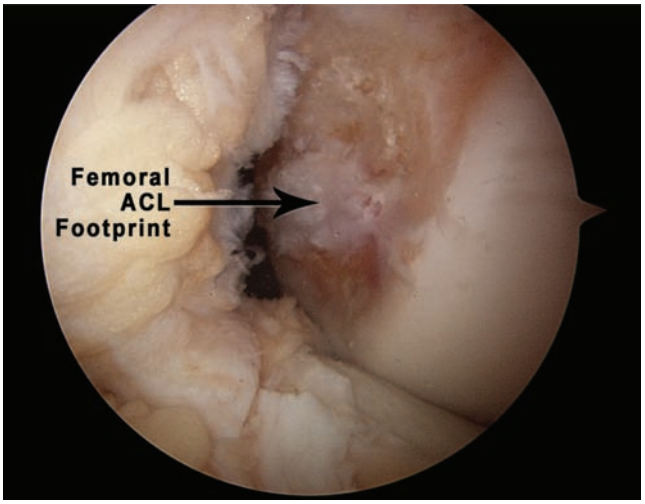

FIGURE 28.15

Native soft tissue ACL femoral footprint.

1. Identify the soft tissue remnant of the ACL looking from the standard **anteromedial** portal and then you can confirm proper location by indentifying the bony landmarks; the intracondylar ridge, and the bifurcate ridge (Fig. 28.16). The lateral intercondylar ridge (also known as "residents' ridge") forms the anterior border (or superior limit in 90-degree flexion) of the ACL footprint. The lateral bifurcate ridge separates the AM and PL bundle femoral insertion sites. Note that the central portion of the PL footprint is just above the contact point of the lateral femoral condyle and the tibial plateau; this is a very important landmark. Also note that the AM and PL footprint is below the equator of the lateral wall—thus just below the 3 o'clock position (for a Left knee).

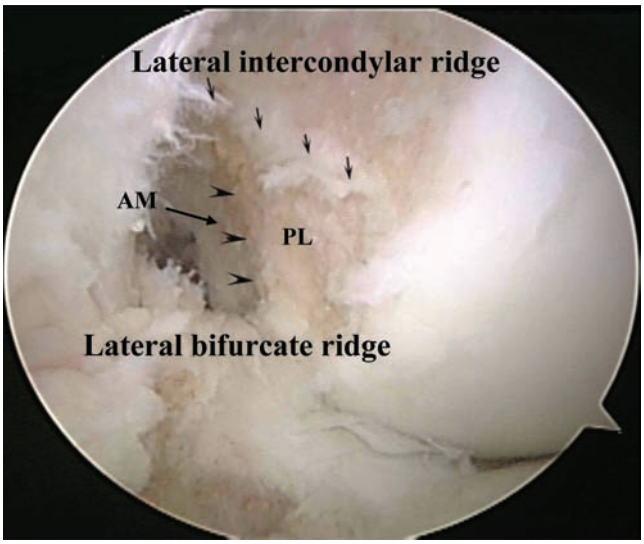

FIGURE 28.16
Boney landmarks for native ACL. (With permission from Fu FH.)

2. The soft tissue remnants of the torn ACL can help guide you to the anatomic footprint (Fig. 23.15). Notice that the center of footprint is more anterior (forward) and inferior than the traditional ACL femoral placement. This concept is important because it obviates the need to place the graft with a 1-mm posterior wall or in the over-the-top position.

FEMORAL TUNNEL PREPARATION

Unlike traditional ACL reconstructions, we start with the femoral tunnel first. We do this because it is easier and it saves time as well as limit fluid extravasation that occurs with drilling of the tibial tunnel. We need excellent visualization of the femoral footprint for this technique. Thus, performing this step prior to any tibial tunnel drilling means that there will be no bone debris, no water loss, and no blood in the joint. Secondly, once we define the appropriate graft length and EndoButton length needed, the assistant can go to the back table to prepare the graft and have it ready immediately after the tibial tunnel is completed.

Start with the arthroscope in the anterolateral portal looking into the notch. Make sure the knee is at 90 degrees of flexion. It is often helpful when first performing this technique to make a preliminary mark in the posterior notch at the 3 o'clock position (or 9 o'clock position on a right knee) on the femur using a shaver or an ablation device. This will act as a reference point for femoral tunnel placement throughout the procedure.

A key aspect of this technique is that the standard **anteromedial** portal is used for viewing, not drilling. This allows for greatly improved femoral footprint visualization. The accessory medial portal is used to drill the femoral tunnel.

Switch the arthroscopic camera to the standard anteromedial portal looking laterally. Again, it is vital to hold the knee at 90 degrees of flexion. One should have a perfect unobstructed view of the femoral ACL footprint. It may be necessary to use the motorized shaver to further clean the footprint, especially the posterior wall. Key landmarks to identify include the soft tissue remnant of the ACL insertion, the intracondylar ridge superior to the footprint, the femoral- tibial contact point (which is just inferior to the PL bundle footprint of the ACL), the posterior wall of the femur, and the previous surgical mark made at the 3 o'clock position. The center of the femoral footprint is then marked using an ablation device (Fig. 23.17). Note that this mark is centralized between all the previously noted landmarks. Finally, it should be noted that the central mark indicating the drill point for the femoral tunnel is usually just below and anterior the previous preliminary 3 o'clock mark.

The femoral tunnel is ready to be drilled. To drill the tunnel, we utilize three pieces of equipment: an Arthrex spade tip guide pin (Arthrex, Naples, Florida), a traditional femoral offset guide, and a Linvatec Sentinel drill bit (Linvatec, Largo, Florida). The Arthrex spade tip guide pin acts as a traditional guide pin, a suture passer, and measuring tool that can measure the entire length of the femoral bone drilled from cortex to cortex. The tip of the guide pin is "spade shaped" so that when it pierces through the lateral femoral cortex, it can then be pulled back gently and hooked onto the outside lateral cortex (much like a depth gauge). The markings on the guide pin can then be read to tell the length of bone that has been drilled (Fig. 28.18). It saves valuable time eliminating the need to remove the pin, measure the length of the femoral tunnel, and then replace the eyelet pin. It can also be used with any type of femoral fixation. The femoral offset guide is not used in the traditional sense. It is used to easily guide the spade tip pin to the proper anatomic location. Once in the proper location after knee hyperflexion, it is usually not hooked on the posterior cortex but actually is placed slightly more anterior. Thus, we are assured that we will not "blow out" the posterior cortex with the drill. When selecting an offset guide size, we usually use a guide that will place the edge of the tunnel 2 mm anterior to the posterior

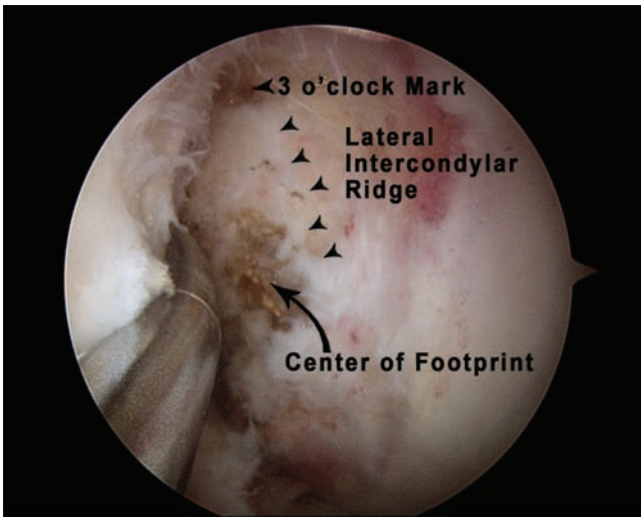

FIGURE 28.17

Center of femoral ACL footprint marked by electrocautery. Notice that this central mark is inferior and just anterior to the 3 o'clock mark made previously.

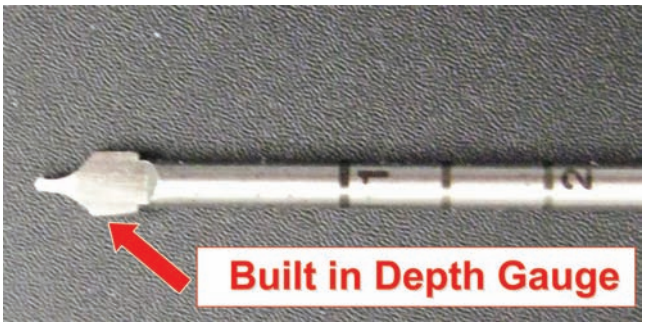

FIGURE 28.18

Arthrex spade tip guide pin (Arthrex, Naples, Florida).

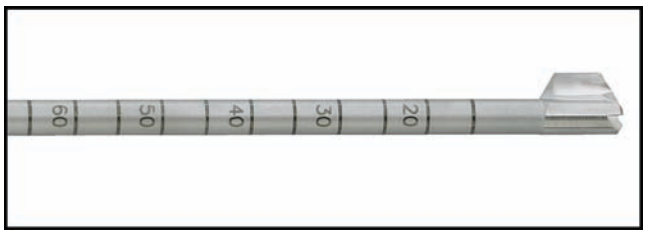

FIGURE 28.19

Linvatec Sentinel drill bit (Linvatec, Largo, Florida).

cortex. For example, if we plan on drilling an 8-mm femoral tunnel, then a 6-mm offset guide will be used (8 mm/2 = 4 mm radius, for an additional 2 mm offset, 4 + 2 mm = a 6-mm offset guide). This will usually place us close to the anatomic footprint with the spade tip drill. However, as stated above, during knee hyperflexion, we often have to move it 1 mm further anterior to remain on the anatomic footprint so that the offset guide is not truly hooked on the posterior cortex. The Linvatec Sentinel drill is an essential piece of equipment for this technique. Its half-cylinder design enables it to safely slide pass the medial femoral condyle without damaging the articular surface (Fig. 28.19). Thus, by using the accessory anteromedial portal, the angle of engagement with the lateral femoral condyle is much closer to perpendicular than it would be by drilling through a standard anteromedial portal. Furthermore, it also allows a skin incision of 5 mm to drill a 10-mm tunnel due to the half-cylinder design of the reamer.

Once the spade tip with offset guide is visually touching the starting point for the femoral tunnel at 90-degree flexion, the assistant hyperflexes the knee to greater >100 degrees. It is kept in this position throughout all steps of femoral tunnel preparation. This serves three purposes: first, it allows the offset guide to be placed at a more anatomic angle in the ACL femoral footprint; second, it forces the guide wire to exit the lateral thigh above the intermuscular septum decreasing any injury risk to the peroneal nerve; and finally it allows a longer femoral tunnel to be drilled.

With the offset guide in correct placement, the spade tip guide pin is drilled into the marked position on the femoral footprint and out the lateral femoral cortex only (not through skin). The offset guide is removed and the spade tip guide wire is pulled back slightly to "hook" the lateral cortex. The femoral tunnel length is then recorded based on the measurements from the spade tip guide wire (Fig. 28.20). The tunnel length is usually between 30 and 40 mm. The guide wire is then advanced out of the skin laterally.

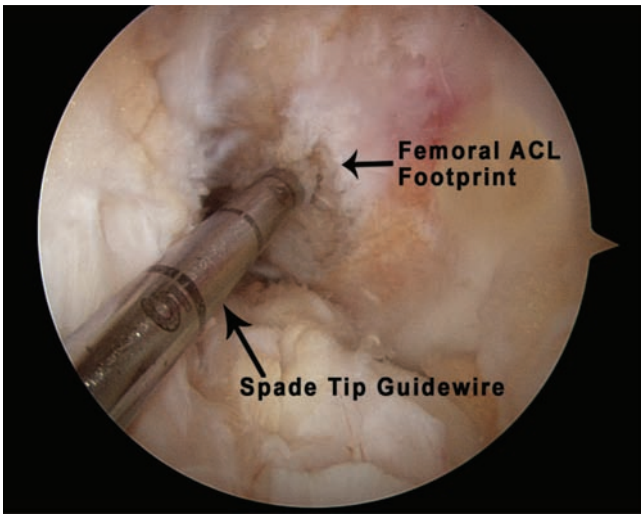

FIGURE 28.20

Arthrex spade tip guide wire drilled through femoral footprint and just through lateral femoral cortex. It is then pulled back and "hooked" on to the lateral femoral cortex to measure the length of the femoral tunnel.

Measurements for drilling and choosing the correct size closed loop EndoButton are made at this time. When calculating measurements, at least 15 mm or more of soft tissue graft in the bone tunnel is optimal. For instance, in a 40-mm tunnel with a desired 20 mm of soft tissue graft in bone, the maximum loop length of the EndoButton would be 20 mm. However, in this technique where the femoral distances are always between 30 and 40 mm, we almost always use a 15-mm closed loop EndoButton.

Unlike the standard EndoButton technique, the guide pin is not immediately overdrilled with the 4.5-mm EndoButton drill. Because the femoral bone distance can be measured from the spade tip pin, we can determine the appropriate depth of the femoral tunnel to be drilled with the Sentinel reamer. By drilling with the Sentinel reamer first, it removes any chance of chatter and tunnel obliquity that can occur by drilling with the Sentinel drill after the EndoButton drill. In summary, the sequence of action is drill with the spade tip guide pin, measure, ream up to lateral cortex with Sentinel drill (but not through the lateral cortex) than drill through lateral cortex with EndoButton drill.

The correct Sentinel reamer is chosen based on graft sizing (i.e., 8 mm reamer for a graft that fits through an 8-mm tube). With the blade facing away from the femoral condyle, it is inserted over the spade tip guide wire from the accessory anteromedial portal. This avoids injury to the medial femoral cartilage as it is entered into the joint (Fig. 28.21). Once the reamer is touching the femoral ACL footprint over the guide wire, reaming is begun. It is imperative that the lateral cortex is not broken or reamed during this technique; otherwise, the EndoButton will not function properly as there is no cortex to hinge upon. Usually, one should ream about 10 mm more than length of desired soft tissue graft in the femoral tunnel. This usually corresponds to 4 to 5 mm less than the total femoral tunnel length measured with the spade tip guide wire. In the example noted above, reaming should continue to 35 mm. This will allow ample room for the EndoButton to clear the lateral femoral cortex and "flip" into correct position and still place a minimum of 20 mm of graft in the tunnel. In small patients where the total femoral distance is 30 mm or less, we recommend drilling

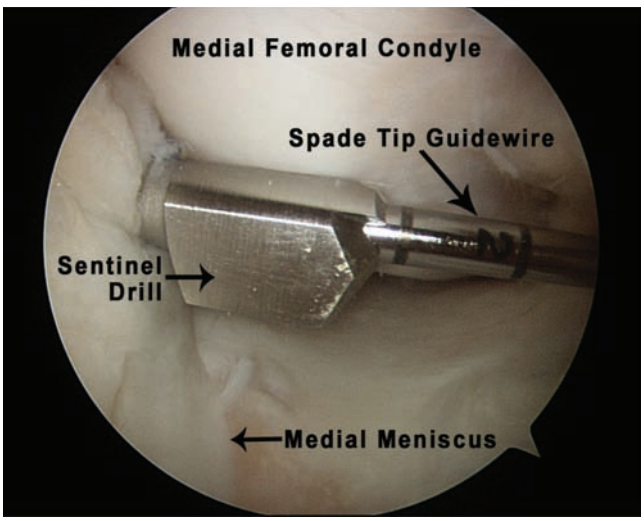

FIGURE 28.21

Linvetec Sentinel drill entering joint over Arthrex spade tip guide wire through the accessory anteromedial portal. Notice that the blade is facing AWAY from cartilage. Do not start drilling until blade is on bone. Remove drill with blade facing away from cartilage.

the tunnel to within a 3 to 5 mm of the cortex. This again gives you ample room to flip the EndoButton and maximizes the amount of graft that can be left in the tunnel. If excessive bone debris is impairing visualization while reaming, place a small outflow cannula through the anterolateral portal—this will help clear the debris and improve visualization. It cannot be overemphasized that the lateral femoral cortex should not be breached with the reamer (Fig. 28.22). If it is, then the lateral cortex essentially has a tunnel opening the same diameter of the reamer and salvage procedures would need to be employed. These include an interference screw, use of an EndoButton Direct Fixation (Smith and Nephew), or utilizing a second lateral incision to tie over a post or washer.

Once the drilling to the correct depth is achieved, carefully remove the reamer from the knee keeping the blade portion facing away from the medial femoral condyle. Then overdrill the guide pin through the lateral cortex with the 4.5-mm EndoButton drill. Place a shaver through the accessory anteromedial portal and clear the tunnel of any debris. Pass the two free ends of a 2 Ethibond passing suture through the eyelet of the spade tip guide wire, and then pull the guide wire through the femur laterally. The ends of the suture are pulled gently out of the lateral femur to bring the looped end of Ethibond suture into the joint and to the entrance of the femoral tunnel (Fig. 28.23). The leg can now be let down from the hyperflexed position.

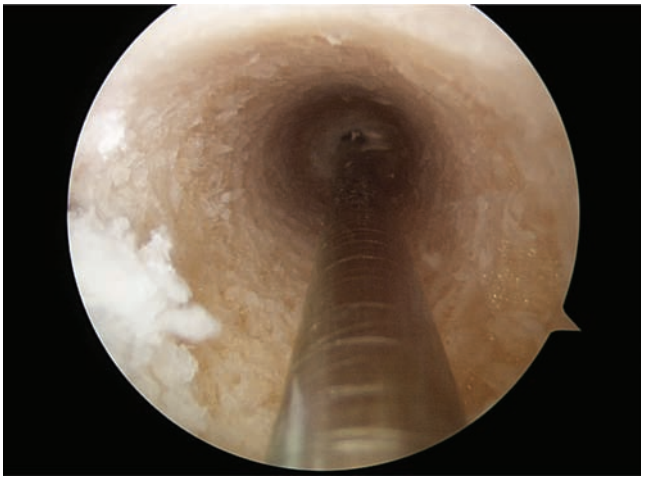

FIGURE 28.22

Arthroscopic image looking up femoral tunnel after drilling with Sentinel drill. Notice that lateral cortex is still intact.

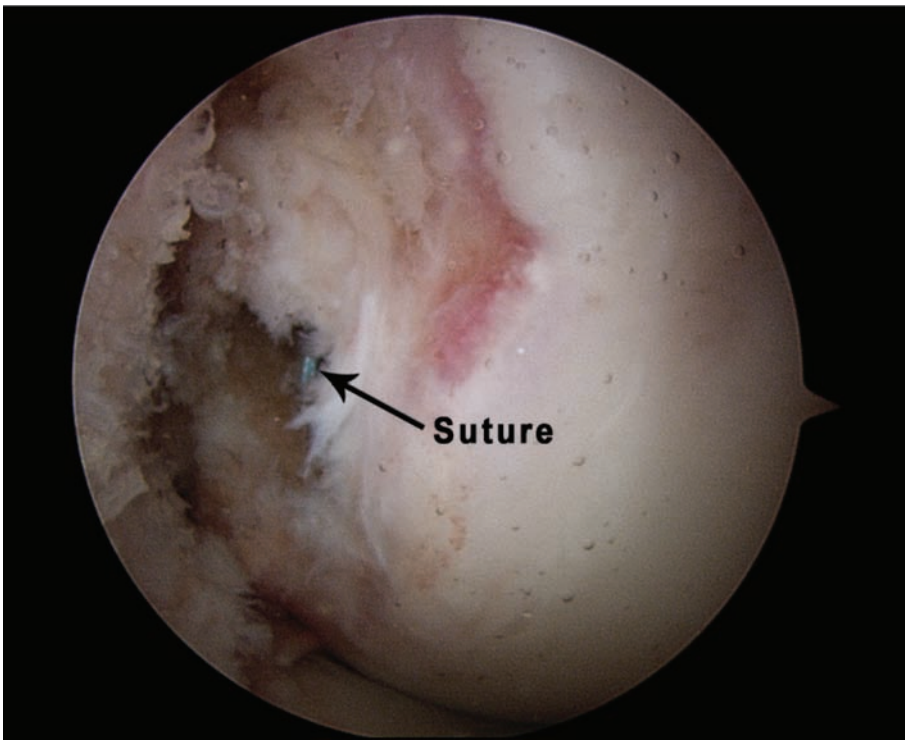

FIGURE 28.23

The looped end of Ethibond suture is brought into the joint via the eyelet of the spade tip guide wire and pulled to the entrance of the femoral tunnel.

TIBIAL TUNNEL

The arthroscopic camera should be placed back into the anterolateral portal. A tibial drill guide is placed in the standard anteromedial portal and is used to facilitate anatomic pin placement. Anatomically, if we identify the posterior aspect of the anterior horn of the lateral meniscus, then move the medially, we will be near the junction of the tibial insertions of the PL and AM bundles of the ACL. We then move the guide tip into the center of the anterior half of the footprint. We will check to see that we are anterior to the traditional ACL tunnel placement (Fig. 28.24). Unlike a transtibial ACL reconstruction, the starting point of the tibial tunnel has no bearing on femoral tunnel placement. In an anatomic ACL reconstruction, the tibial tunnel position is anterior to the traditional ACL tibial tunnel placement. The reason tibial tunnels have traditionally been placed posteriorly is to prevent graft impingement on the notch during extension as well as to achieve lower placement on the femoral wall. However, because the femoral tunnel is now placed anatomically with an accessory medial portal approach, it is much lower than traditional femoral tunnels. Thus, the graft lies more horizontal and will not impinge in extension.

We start the drilling for the tibial tunnel in the anterior medial third of the tibia, using the previous hamstring harvest site, so a separate incision is not necessary. A tibial tunnel length of at least 30 mm is optimal. With the tibial guide aimer set to 55 degrees, this can usually be achieved.

Place the bullet against the bone directly and drill a guide wire through the bullet to the tibial guide tip. Evaluate the location of the guide wire by extending the knee. Make sure that the wire fits in the central or central medial portion of the notch. Again, unlike a transtibial ACL reconstruction, the guide pin does not need to be hidden on full extension. The low femoral tunnel creates a more horizontal graft and minimizes impingement (Fig. 28.25). If the correct placement is not achieved, a 3-mm offset guide can be used to drill

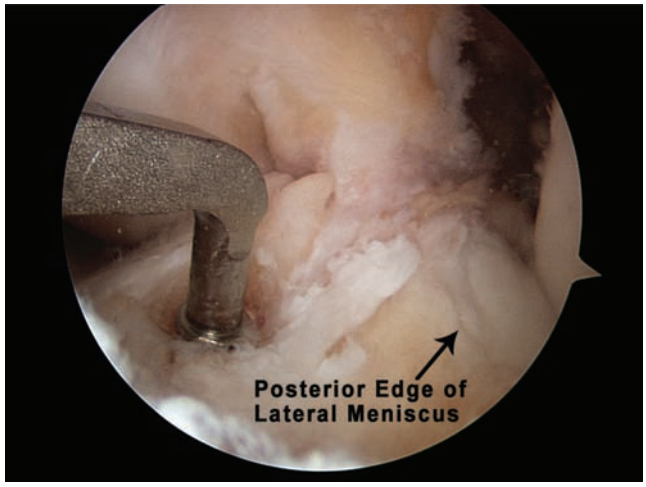

FIGURE 28.24

ACL tibial drill guide placed at previous mark made with electrocautery. Notice that our position is slightly anterior to the posterior aspect of the anterior lateral meniscus.

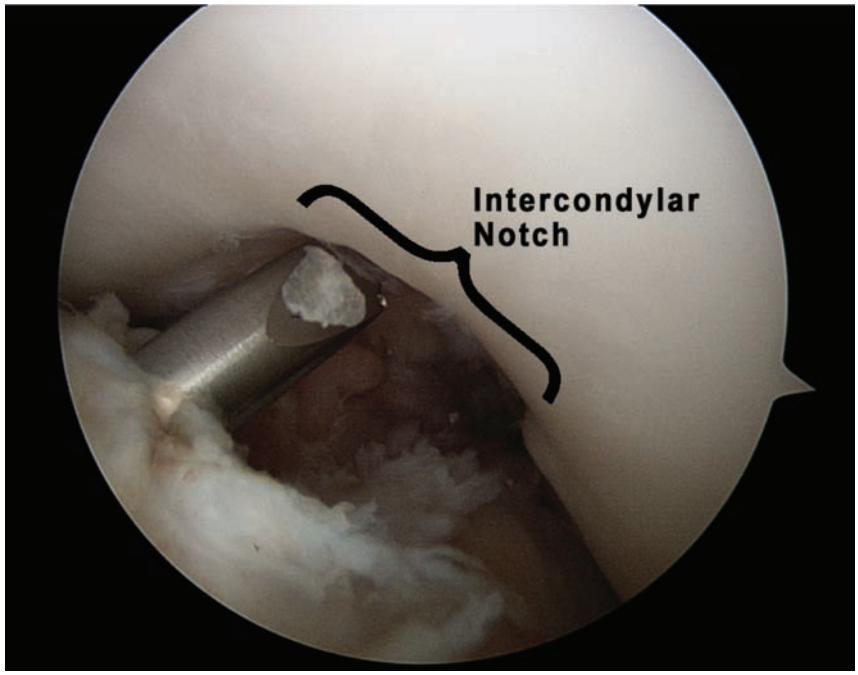

FIGURE 28.25

Arthroscopic image of tibial drill guide pin drilled through the tibia and the knee in extension.

another guidewire in the anatomic location. Once an acceptable pin is placed, it is overdrilled with the correct size reamer. A traditional acorn or badger reamer can be used - there is no need for the Sentinel reamer. If one desires, dilation of the tibial tunnel can be performed with dilators. The senior author routinely dilates the tibial tunnel up to the size the tunnel was drilled with (i.e., use an 8-mm dilator after drilling with an 8-mm reamer) to make passage of the graft easier.

The rest of the procedure can be performed with our without water in the knee. Place a probe through the accessory anteromedial portal to hook the 2 Ethibond suture at the entrance of the femoral tunnel and pull it down into the joint near the tibial tunnel entrance. Use a grasper through the newly drilled tibial tunnel to grab the Ethibond suture and pull it through the tibial tunnel. The passing suture is now through the tibial and femoral tunnels.

PASSING THE GRAFT

The EndoButton should have a 2 and 5 Ethibond suture through each eye. The 5 suture will be the pulling (leading) suture. Carefully bring the graft from the back table to the knee, and place both the 2 and 5 suture strands through the loop of the passing suture. The Ethibond passing suture is then pulled out of the lateral aspect of the leg carrying 2 and 5 Ethibond sutures with it.

Place the arthroscope in through the anterior lateral portal to view the graft as it is advanced through the joint and into the femoral tunnel. Pull on the 5 Ethibond suture to pull the EndoButton through the tibial tunnel and into the joint. Wrap the 5 suture around a hemostat to help gain leverage to pull the graft up. It is usually easier to advance the graft with the knee hyperflexed to >90 degrees—in the same position that the femoral tunnel was drilled. Once the marking on the graft is at the insertion of the femoral tunnel and you feel the EndoButton "pop" through the lateral cortex, pull on the 2 Ethibond suture to flip the EndoButton (Fig. 28.26). You should now be able to toggle the EndoButton by pulling reciprocally on the 2 and 5 sutures ensuring that it is hooked appropriately on the lateral cortex. To further test that the EndoButton is hooked appropriately, pull tension vigorously on the suture tied to the ends of the graft coming out from the tibial tunnel. The graft is then cycled appropriately.

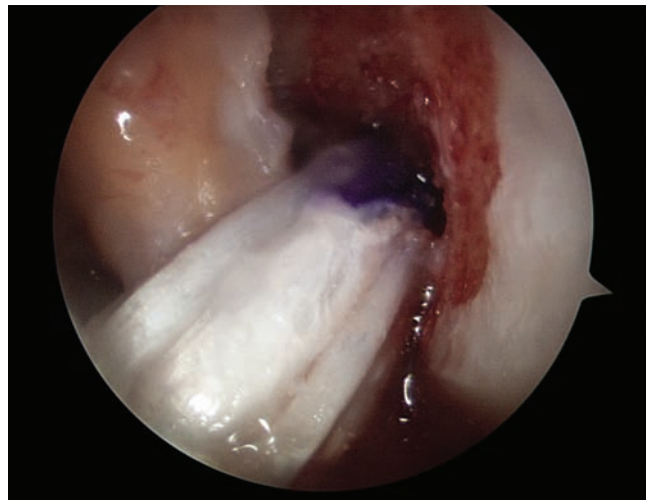

FIGURE 28.26

ACL graft being passed through joint. Notice that the circumferential mark is at the entrance of femoral tunnel indicating that EndoButton is ready to be "flipped."

TIBIAL FIXATION

We prefer interference screw fixation on the tibia. Bioscrews are our preference secondary to being able to drill through them during revision surgery. We have been using a Linvatec Biomatrix screw (Linvatec, Largo, Florida) secondary to the porous ingrowth potential. While passing the graft, each limb of the gracilis and semitendinosus is kept separated at the tibial tunnel entrance so that a nightnol guide wire can be placed between the graft ends (i.e., the guide wire is placed between the limbs of both the gracilis and semitendinosus grafts). With the knee slightly flexed and keeping strong tension on the sutures to tension the graft, the screw is placed over the guide wire between the free limbs of the graft. The size of the screw is usually 25 mm in length and has a diameter 1 mm greater than what was used to ream the tibial tunnel. After placement of the screw, confirm arthroscopically that the screw is not protruding into the joint and to assess the tension on the graft (Fig. 28.27). Remove the guidewire and cut any graft protruding through bone.

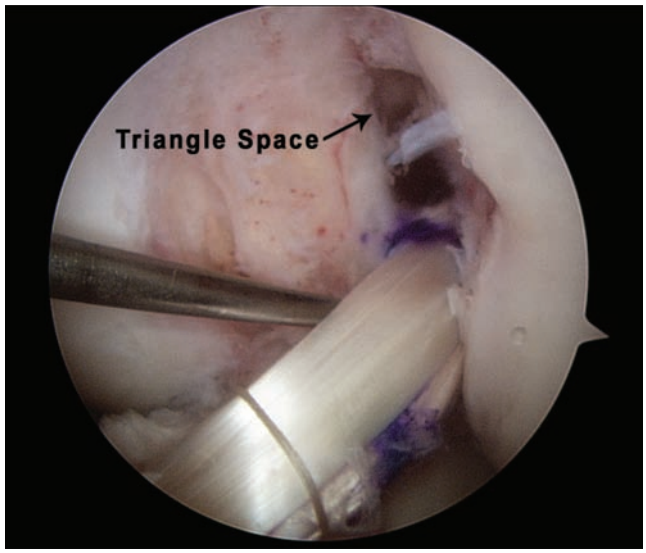

FIGURE 28.27

Final ACL construct. Notice the space between the ACL graft and the native PCL. This "triangular" space is present in native knees.

CLOSURE

The tibial incision is closed with a 2-0 Vicryl suture followed by injection of local anesthetic. The portal incisions are usually not closed with suture. Local anesthetic is given around the tibial incision and intra-articularly. A sterile soft dressing is applied. Routine bracing is not used.

RECOMMENDED READINGS

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29 Aperture Fixation in Primary Arthroscopic Double-Bundle, Single-Bundle, and Single-Bundle–Augmented ACL Reconstruction

Peter U. Brucker and Andreas B. Imhoff

INTRODUCTION

The native anterior cruciate ligament (ACL) consists of two functional bundles, which have synergistic, yet distinct biomechanical functions with respect to anterior tibial translation and combined rotatory load. Conventional ACL reconstruction techniques have focused on restoration of the structurally stronger anteromedial bundle, while the rotatory stabilizing function of the posterolateral bundle was neglected for years. In ACL reconstruction, graft placement is considered one of the main factors for successful treatment of ACL ruptures (3). Therefore, single-bundle ACL reconstruction techniques have accomplished this dilemma by modified tunnel placement more centrally within the common and widely spread anatomical footprint of both bundles femorally and tibially. Since a substantial group of patients present unsatisfactory results following single-bundle ACL reconstruction, various double-bundle ACL reconstruction techniques have been introduced recently for respecting the complex anatomy of the native ACL more closely.

Graft fixation was recognized as another essential factor for successful ACL reconstruction (3). Indirect extra-anatomical and extra-articular fixation techniques have potential disadvantages, such as graft-tunnel motion (4), windshield wiper effect (6), and suture stretch-out (10). In contrast, anatomical aperture fixation by direct tendon-to-bone contact adjacent to the joint space using bioabsorbable interference screws may overcome these problems. Additionally, aperture fixation seals the exits of both the femoral and the tibial tunnels toward the joint preventing or, at least, reducing a synovial fluid leakage into the tendon-bone interface.

ACL ruptures do not only represent one single entity, since various rupture patterns have been recognized (13). Strictly speaking, complete and partial ruptures of the ACL may need differentiated reconstruction techniques especially in autologous hamstring tendon graft techniques for reduction of hamstring donor site morbidity (5,9). This seems to be relevant, because the hamstring muscles are known to protect the ACL graft due to their synergistic function (8). Consequently, a concept of differentiated anatomical ACL reconstruction techniques using hamstring autografts has to be implemented.

DIFFERENTIAL INDICATION FOR DOUBLE-BUNDLE, SINGLE-BUNDLE, AND SINGLE-BUNDLE–AUGMENTATION ACL RECONSTRUCTION

Surgical treatment options for an individually adapted ACL reconstruction depend on various parameters such as age, profession, concomitant lesions (cartilage, meniscus, ligaments), comorbidities (prior meniscus surgery, osteoarthrosis, malalignment), sports and pivoting activities, and level of sports. In addition, the rupture pattern of the ACL must be also taken under consideration (13). Objective instability signs of the Lachman, pivot shift, and anterior drawer test may help the orthopaedic surgeon to differentiate between complete and partial ACL ruptures. ACL ruptures can therefore be addressed surgically in a single-bundle (complete ruptures), double-bundle (complete ruptures), or in an augmentation technique (partial ruptures).

Low-demanding recreational athletes or patients performing nonpivoting sports activities, though complaining of considerably subjective and objective instability, patients with higher age, or "knee abuser" patients with signs of instability and moderate osteoarthrosis may be sufficiently treated with a single-bundle ACL reconstruction (7). However, young and high-demanding athletes with pivoting sports activities may need an anatomical double-bundle ACL reconstruction addressing both the anteromedial and the posterolateral bundles of the ACL.

SURGICAL TECHNIQUE FOR PRIMARY ACL RECONSTRUCTION USING APERTURE FIXATION

Double-Bundle ACL Reconstruction

Patient Positioning, Surgical Setup, and Portal Placement Under general (including complete muscular relaxation for secure hamstring tendons harvest) or spinal anesthesia, the patient is placed supine with both lower extremities in a straight position. A lateral thigh pillar is used for stabilization of the knee flexed to 90 and 130 degrees. A nonsterile tourniquet at 250 to 300 mm Hg is routinely applied in the most proximal part of the thigh.

In addition to a standard high anterolateral camera and standard anteromedial instrument portal, a secondary accessory anteromedial instrument portal is established 1.5 cm medially to the primary anteromedial portal. For correct placement of this accessory portal, a needle may be utilized for control of the optimal direction angle for later positioning of the femoral posterolateral bundle tunnel. Both anteromedial portals should be directly superior to the basis of the medial meniscus.

Graft Harvesting and Preparation In cases of clinically unambiguous diagnosis of an ACL rupture, harvesting of the autologous hamstring tendons is performed prior diagnostic arthroscopy. In rare ambiguous cases, the diagnostic arthroscopy is accomplished in advance of the tendon harvest for detailed assurance of the rupture extension, for example, in potential partial ACL ruptures. Usually, both the larger semitendinosus and the smaller gracilis tendon were harvested for reconstruction of the anteromedial and the posterolateral bundles of the ACL, respectively. Alternatively, only the semitendinosus tendon may be utilized for reconstruction of both bundles if the length of the harvested tendon exceeds 28 cm.

In detail, an oblique transversal incision of 3 cm over the anserine pes is performed. The superficial anserine pes is cut in the direction of the collagen fibers following digital palpation of the semitendinosus and gracilis tendon. The identified tendons were secured by suture loop retention. The semitendinosus alone or both tendons were mobilized by release of soft tissue collaterals as well as adhesions and finally detached at their tibial insertion site. The ultimate harvesting of each tendon is accomplished using adequately sized tendon strippers (Arthrex, Naples, Florida).

At the back table, the muscle tissue of the harvested tendons is removed, and overlapping stitches of nonabsorbable sutures (e.g., Ethibond, Ethicon, Norderstedt, Germany) or absorbable sutures (e.g., Vicryl, Ethicon, Norderstedt, Germany) are applied at both ends of the tendons. Usually, the double-strand semitendinosus and the double-strand gracilis tendon graft measure 6 to 8 mm and 5 to 6 mm in diameter, respectively. If the diameter of one tendon graft is less than the aforementioned size, a triple-strand graft preparation is performed. Each graft is marked at 25 mm on the loop site. In cases of a single tendon harvest (semitendinosus), the minimally acceptable length of the double-looped graft is 8 cm for both the anteromedial and the posterolateral bundles.

Diagnostic Arthroscopy and ACL Footprint Preparation Following standard diagnostic arthroscopy of all three compartments, concomitant intra-articular pathologies (meniscal lesions, cartilage defects) are addressed prior to reconstruction of the ACL.

The femoral dimensions of the footprint of the anteromedial and the posterolateral bundles at the intercondylar notch are identified and evaluated including mechanical probing since anatomical variations of the ACL and partial ACL ruptures may be present. Then, the torn and/or insufficient parts of the ACL are arthroscopically removed by sufficient exposure of the lateral femoral notch including their posterior osseous border and by preserving the tibial stump of the ACL due to its proprioceptive and vascular function. Usually, a notchplasty is not necessary in cases of later correct femoral and tibial tunnel positioning.

Femoral Tunnel Placement for the Anteromedial and the Posterolateral Bundles On the femoral site, the tunnel for the anteromedial bundle is drilled first using mostly a 4-mm offset drill guide (Arthrex, Naples, Florida) via the anteromedial portal. In detail, the drill guide is placed at the posterior aspect of the notch at the 1:30 o'clock (left knee) or the 10:30 o'clock position (right knee) with respect to the coronal plane. The guide wire is positioned in 130 degrees of flexion and then overdrilled by an acorn drill of the corresponding graft size to a depth of at least 25 mm. A bony bridge of 1 mm between the posterior wall of the anteromedial tunnel to the posterior cortex of the notch should be preserved for avoidance of later tunnel blowout. An osseous notch is created in both femoral tunnels using a notching device (Arthrex, Naples, Florida) at the anterior-superior edge of the tunnels for aperture fixation by bioabsorbable interference screws (Fig. 29.1).

In contrast, the femoral tunnel for the posterolateral bundle is drilled through the accessory anteromedial portal. Therefore, a modified 4-mm offset drill guide is placed in the anterior-inferior aspect of the already-established femoral tunnel aperture for the anteromedial bundle representing a 2:30 o'clock in the left or a 9:30 o'clock position in the right knee for the posterolateral bundle. This posterolateral tunnel placement is performed in 90 degrees of flexion to preserve the peroneal nerve and the chondral surface of the lateral femoral condyle from iatrogenic damage. Then, the guide wire is overdrilled with an acorn drill of the corresponding graft size as well to a depth of 25 mm. This technical aspect allows a bony bridge of approximately 1 mm between both femoral tunnels (Fig. 29.2). The divergence of both femoral tunnels permits additional stability

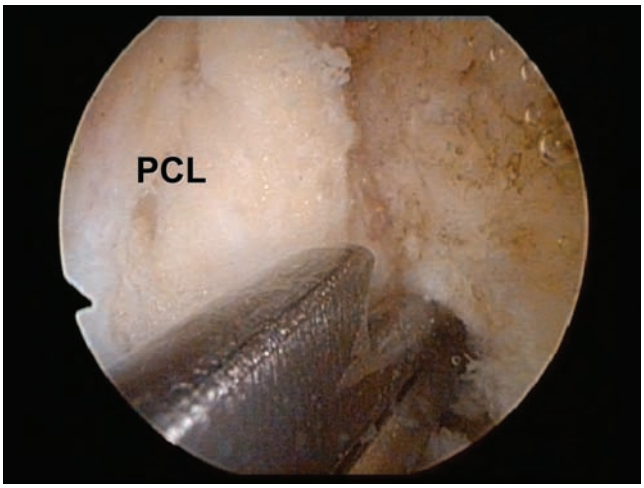


FIGURE 29.1

Preparation of an osseous notch at the anteromedial tunnel aperture for later placement of the bioabsorbable interference screw (left knee). PCL, posterior cruciate ligament.

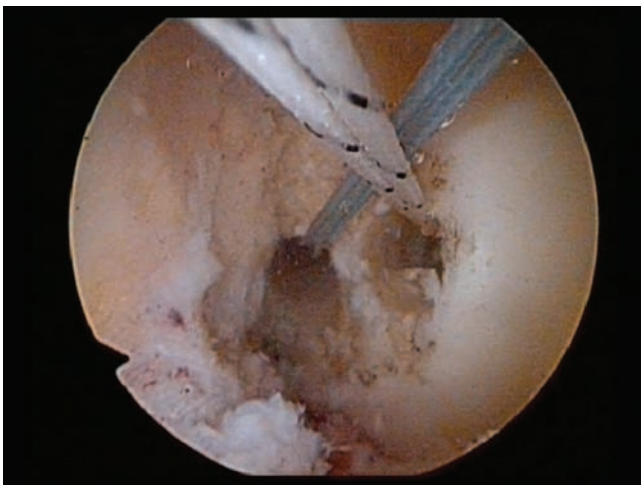


FIGURE 29.2

Femoral tunnel placement for the anteromedial and the posterolateral bundles allowing a bony bridge between both tunnels (arthroscopic view from the standard anteromedial portal for enhanced visualization at 100 degrees of knee flexion). The Fiberwire and the Tigerwire suture are located within the tunnels of the anteromedial and the posterolateral bundles, respectively.

of the bone bridge, which is accomplished by separate anteromedial portal utilization for each femoral tunnel placement. These notches reduce drive failure and screw breakage by decreasing peak screw insertion torque. A Fiberwire and a Tigerwire 2 (Arthrex, Naples, Florida) are pulled through the femoral tunnels of the anteromedial and the posterolateral bundles via standard anteromedial and accessory anteromedial portal, respectively.

Tibial Tunnel Placement for the Anteromedial and the Posterolateral Bundles On the tibial site, the tunnel for the posterolateral bundle is drilled followed by the tunnel drilling for the anteromedial bundle. Both tunnels can be positioned utilizing the oblique transversal anteromedial incision of the hamstrings donor site. The diameter of the tibial tunnel for the anteromedial and the posterolateral bundle is usually 7 and 5 mm, respectively. The tip of the tibial drill guide for the posterolateral bundle is placed 3 mm anteriorly with respect to the anterior boarder of the posterior cruciate ligament in cases of a 5-mm tunnel diameter at the posterolateral aspect of the tibial footprint of the ACL, while the starting point of the tunnel for the posterolateral bundle is placed anteriorly to the tibial insertion site of the superficial medial collateral ligament. In contrast, the tunnel for the anteromedial bundle is localized more anteriorly and centrally. Keeping the first guide wire for the posterolateral bundle in situ, the tip of the tibial drill guide is positioned within the anteromedial aspect of the tibial footprint of the ACL respecting a sufficient distance to the posterolateral tibial tunnel (Fig. 29.3). For prevention of a notch impingement in cases of an inadequately anterior position of the anteromedial tibial tunnel, an arthroscopic impingement test is performed in extension (Fig. 29.4).

If correct positions of both guide wires are achieved, both guide wires are subsequently overdrilled according to the size of the grafts. In detail, the tibial tunnel for the posterolateral bundle has a more oblique direction (45 degrees to the sagittal plane), while the tibial tunnel for the anteromedial bundle has a more sagittal orientation (20 degrees to the sagittal plane). Both exits of the tibial tunnels approximate the oval anatomical footprint of the native ACL. Distally, however, a bony bridge of at least 1.5 to 2 cm should be preserved in between both tibial tunnels for maintaining a sufficient bony bridge (Fig. 29.5).

The Fiberwire and the Tigerwire 2 sutures are pulled through their corresponding tibial tunnels in a retrograde fashion using an arthroscopic grasper (Figs. 29.6 and 29.7).

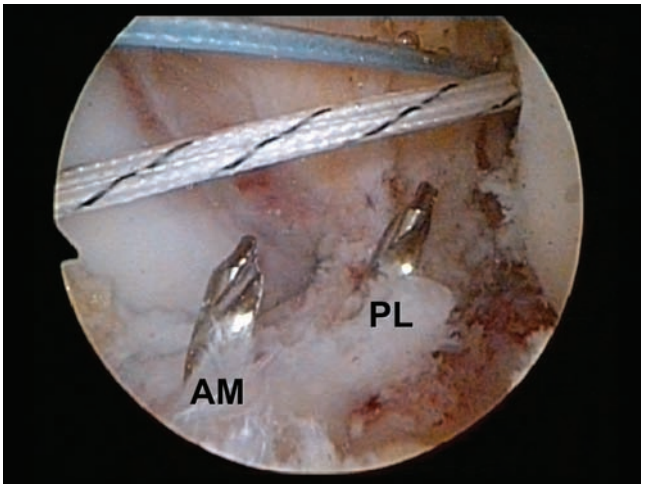


FIGURE 29.3

Tibial tunnel placement for the anteromedial (AM) and the posterolateral (PL) bundles within their respective tibial footprint areas.

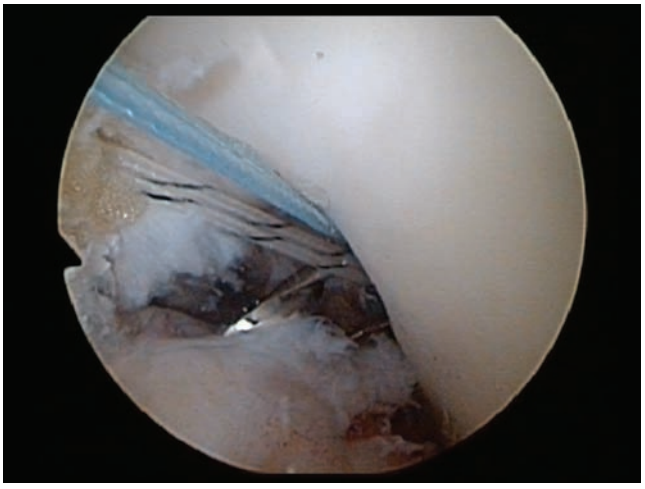


FIGURE 29.4

Arthroscopic impingement test in extension by keeping both tibial guide wires in situ.

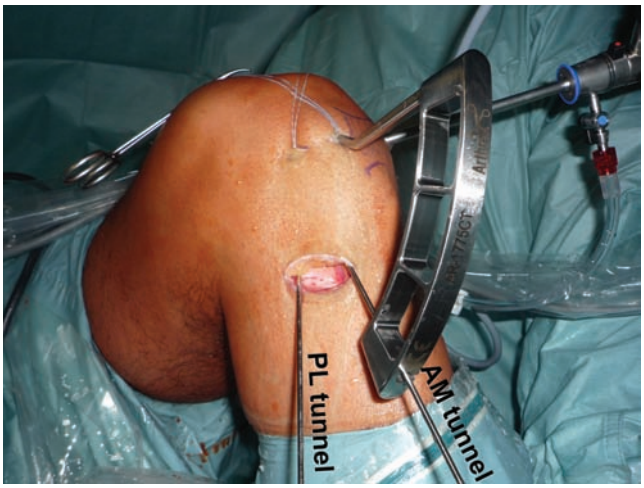


FIGURE 29.5

Orientation of the tibial tunnels for the antermedial (AM) and posterolateral (PL) bundles.

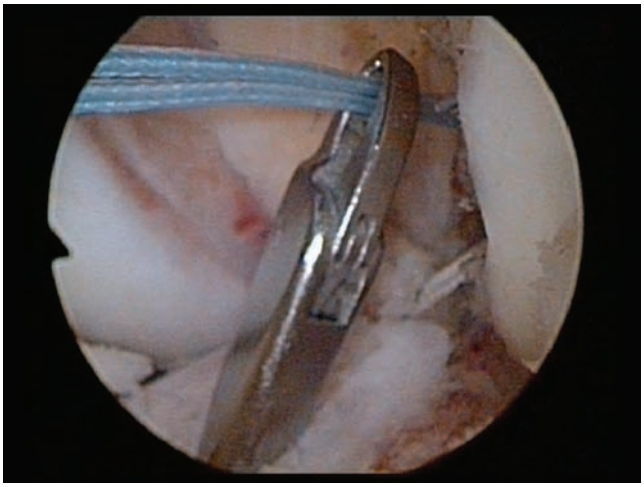
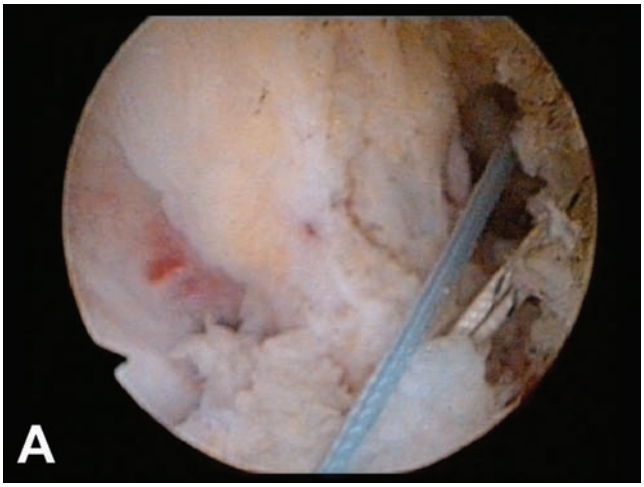


FIGURE 29.6

Retrograde tibial shuttle of the antero-medial bundle suture (Fiberwire) using an arthroscopic grasper.



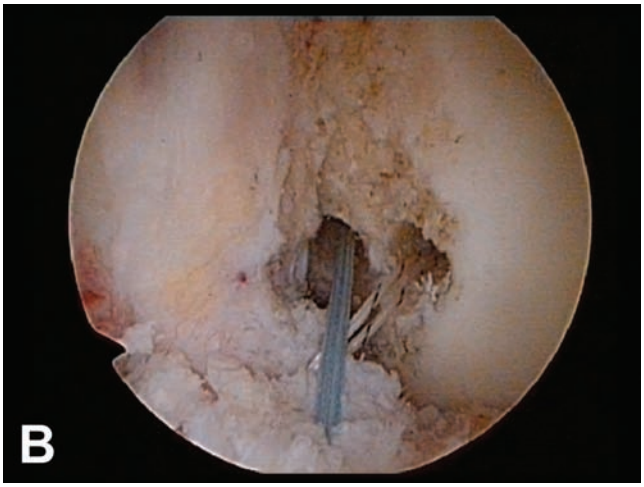


FIGURE 29.7

Intra-articular orientation of the anteromedial (Fiberwire) and the posterolateral bundles (Tigerwire) from an arthroscopic view via the **(A)** standard anterolateral portal and **(B)** standard anteromedial portal.

Anteromedial and Posterolateral Graft Passage and Fixation The anteromedial bundle is passed first in a transtibial technique and fixed at the femoral site in 130 degrees of flexion. In detail, a bioabsorbable interference screw (Arthrex, Naples, Florida), usually with the same size as the tunnel diameter, is passed via a guide pin using the standard anteromedial portal and exactly placed within the created area of the tunnel notch (Fig. 29.8). While screw fixation, the graft must be tensioned on both suture sites to avoid movement and twisting of the graft within the tunnel. For smoother passage of the posterolateral bundle, the anteromedial bundle is pushed away by a blunt suture grasper. Likewise, the posterolateral bundle is passed transtibially and fixed with a bioabsorbable interference screw (Arthrex, Naples, Florida) via the accessory anteromedial portal in 90 degrees flexion and graft tensioning. Usually, the size of the screw is identical to the size of the tunnel diameter. An arthroscopic impingement test is reperformed to exclude a notch impingement of the graft. In addition, the knee is cycled 20 times with 80 N of tension of both bundles using a tensiometer (Arthrex, Naples, Florida) throughout a range of motion from 0 to 130 degrees of flexion.

The anatomical fixation of both the anteromedial and the posterolateral bundles on the tibial site is separately accomplished over two bioabsorbable interference screws (Arthrex, Naples, Florida) using a guide pin anteriorly within the tibial tunnels (Fig. 29.9). If necessary, a tunnel notching device may be additionally used prior screw placement. In contrast to the aforementioned screw sizes, the size of the screw for the anteromedial bundle is usually 1 mm larger than the tibial tunnel diameter.

Each bundle is tensioned with 80 N and fixed independently. Therefore, four bioabsorbable interference screws are overall used. The posterolateral and the anteromedial bundles are tibially fixed in 20 degrees of flexion in combination with tibial external rotation and 45 degrees of flexion in tibial internal rotation, respectively. For correct aperture fixation, all bioabsorbable interference screws are placed closely to the joint line.

Single-Bundle ACL Reconstruction

Patient Positioning, Surgical Setup, and Portal Placement as well as *Diagnostic Arthroscopy and ACL Footprint Preparation* in ACL single-bundle reconstruction is equivalent to the ACL double-bundle reconstruction technique. However, the accessory secondary anteromedial portal in single-bundle ACL reconstruction is not

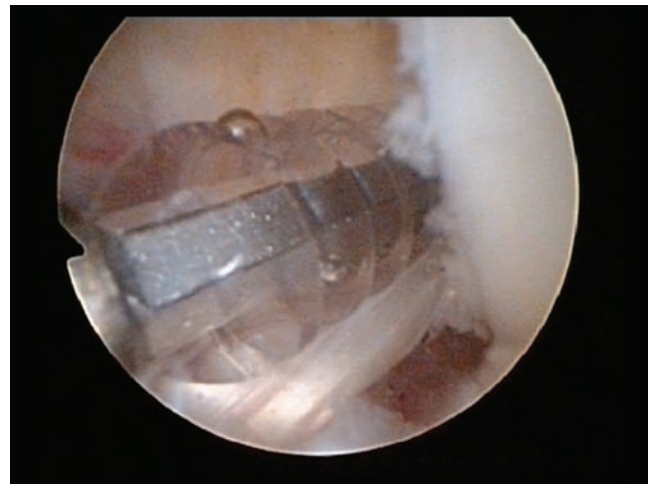


FIGURE 29.8

Prearrangement of the aperture fixation of the anteromedial bundle on the femoral side using a bioabsorbable interference screw (Arthrex, Naples, Florida).

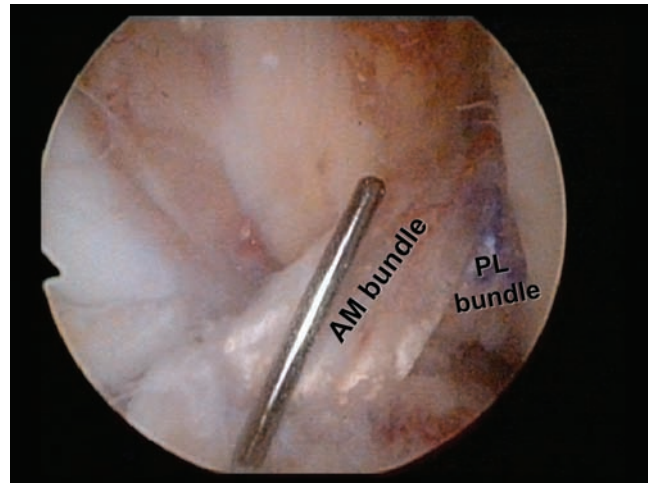


FIGURE 29.9

Arthroscopic view of the correct placement for the guide pin anteriorly within the tibial tunnel of the anteromedial bundle for subsequent aperture fixation of the anteromedial bundle tibially.

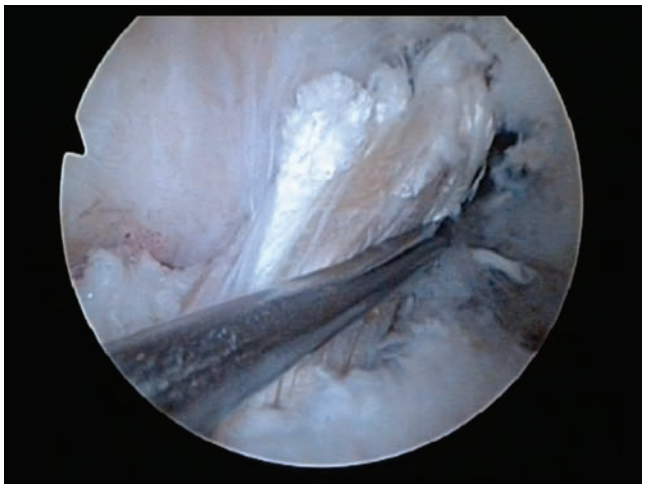


FIGURE 29.10
Single-bundle ACL reconstruction femorally and tibially fixed by aperture fixation. Intraoperative probing demonstrating adequate tension of the triple-strand semitendinosus ACL graft (left knee).

required. *Graft Harvesting and Preparation* is also similar as in the double-bundle ACL technique, although harvest of the semitendinosus tendon alone by leaving the gracilis tendon intact and subsequent triple- or quadruple-strand semitendinosus tendon graft preparation is sufficient.

Femoral and Tibial Tunnel Placement of the Single Bundle In contrast to the anatomical placement of the anteromedial and the posterolateral tunnel on both the femoral and the tibial sites in double-bundle ACL reconstruction, the tunnel aperture in single-bundle reconstruction is localized in the anatomical center of the ACL footprint. In detail, a 4-mm offset drill guide (Arthrex, Naples, Florida) is placed on the femoral site at the posterior aspect of the notch at the 2:00 o'clock (left knee) or the 10:00 o'clock position (right knee) using the anteromedial portal at a knee angle of 130 degrees flexion, followed by overdrilling and notching similarly as for the anteromedial tunnel in the double-bundle ACL technique. On the tibial site, the tip of the tibial drill guide is positioned within the tibial ACL stump anteriorly to the posterior cruciate ligament in between the anatomical center of the tibial anteromedial and posterolateral bundle insertion. The arthroscopic impingement test and subsequent overdrilling of the tibial tunnel is performed as aforementioned in double-bundle ACL reconstruction.

Graft Passage and Fixation The graft passage of the semitendinosus tendon and the aperture fixation technique of the graft using bioabsorbable interference screws correspond to the anteromedial bundle technique in double-bundle ACL reconstruction (Fig. 29.10).

Single-Bundle–Augmentation ACL Reconstruction

Patient Positioning, Surgical Setup, and Portal Placement in ACL single-bundle reconstruction is equivalent to the ACL double-bundle reconstruction technique. However, an accessory secondary portal on the medial side in single-bundle–augmentation ACL reconstruction is not required but the anteromedial portal may be slightly more medial in the augmentation technique for the posterolateral bundle.

Diagnostic Arthroscopy and ACL Footprint Preparation significantly differs in the single-bundle–augmentation technique. The diagnosis of a partial ACL rupture is a crucial prerequisite, in which one of both functional bundles of the ACL must be structurally and functionally intact. Therefore, detailed diagnostic arthroscopy is mandatory as well as positive probing of one intact bundle demonstrating sufficient tension (Fig. 29.10), since elongation of a structurally intact bundle may be also present. The preparation of the ACL footprint must be limited to the affected anteromedial or posterolateral bundle by remaining the other bundle and its femoral and tibial footprint intact (Fig. 29.11).

Graft Harvesting and Preparation is also similar as in the double-bundle ACL reconstruction technique; however, harvest of only one hamstring tendon is sufficient. Usually, the semitendinosus and the gracilis tendon are used for augmentation of the anteromedial and the posterolateral bundles, respectively.

Femoral and Tibial Tunnel Placement of the Augmented Bundle Femoral and tibial placement of the tunnel for the augmented bundle corresponds to the double-bundle ACL reconstruction technique. In contrast, the augmentation technique of either the anteromedial or the posterolateral bundle is technically more demanding since visualization due the intact bundle of the ACL is limited. Especially, the tibial insertion site of the posterolateral bundle is hardly visualized. In this case, arthroscopic visualization of the footprint and correct placement of the guide pin may be improved by pushing the anteromedial bundle away using an arthroscopic probe (Fig. 29.12).

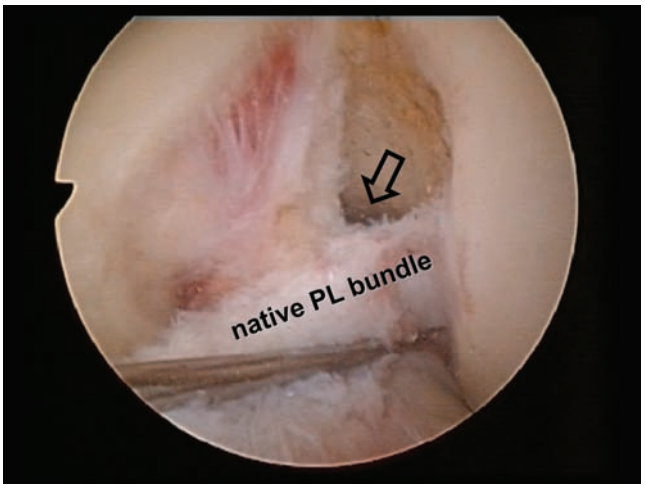


FIGURE 29.11

Completed preparation of the ACL footprint limited to the anteromedial bundle insertion area (*arrow*) at the lateral femoral notch. Structurally intact posterolateral (PL) bundle verified by digital probing (left knee).

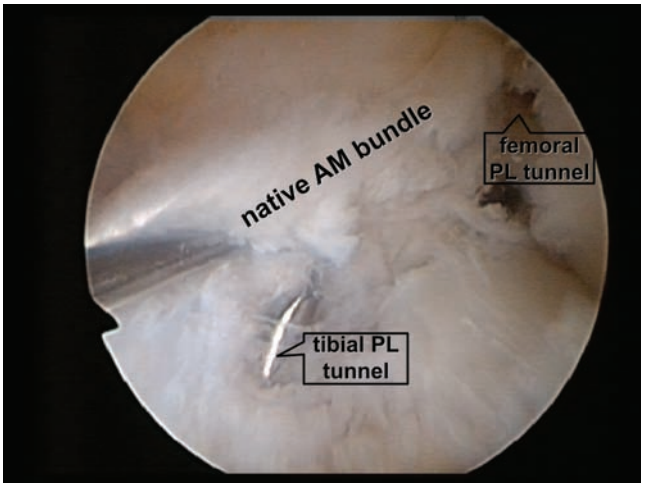


FIGURE 29.12

Placement of the tibial tunnel for the posterolateral (PL) bundle within the anatomic footprint of the native posterolateral bundle insertion area. The intact anteromedial (AM) bundle is pushed away for enhanced visualization of the posterolateral bundle footprint tibially and femorally using an arthroscopic probe (left knee).

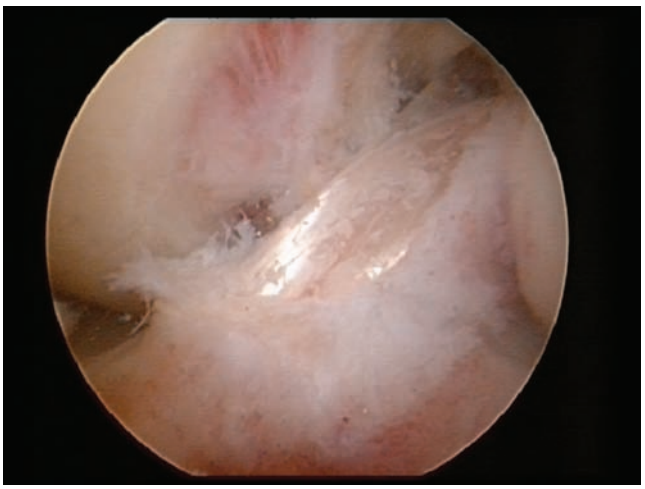


FIGURE 29.13

Anteromedial bundle–augmented ACL reconstruction (triple-strand semitendinosus graft) using aperture fixation in situ.

Single-Bundle–Augmented Graft Passage and Fixation The graft passage and the aperture fixation of the augmented anteromedial or the posterolateral bundle are performed in an identical modality as described for the double-bundle ACL reconstruction technique (anteromedial bundle augmentation: Fig. 29.13; posterolateral bundle augmentation: Fig. 29.14).

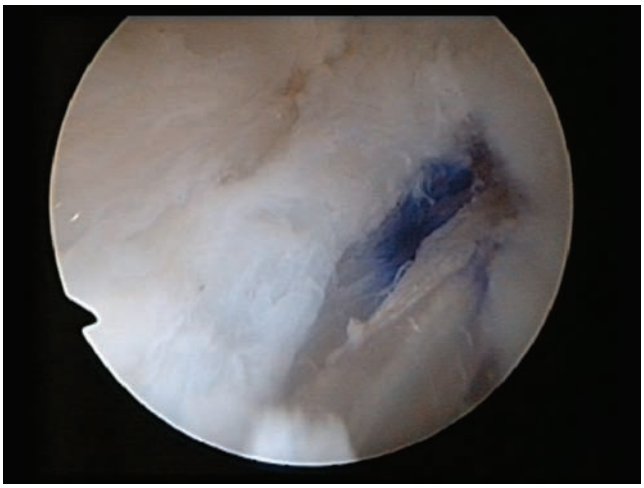


FIGURE 29.14

Posterolateral bundle–augmented ACL reconstruction (double-strand gracilis graft) using aperture fixation in situ.

Wound Closure and Postoperative Rehabilitation In all aforementioned ACL aperture fixation techniques, the superficial anserine pes is sutured, followed by inverted subcutaneous suturing, and single or continuous stitches of the arthroscopic portals and the graft donor site, respectively.

Postoperatively, an identical rehabilitation protocol following single-bundle, double-bundle, and single-bundle–augmentation ACL reconstruction technique is implemented. In the initial postoperative period, the leg is embedded in extension. After removal of the first wound dressing, a brace is used upon the knee allowing full range of motion. Continuous passive motion, isometric exercises, and physical therapy are started immediately. Until wound healing is completed, partial weight bearing up to 20 kg is performed following 2 weeks postoperatively. Swimming and cycling can be started after 6 to 8 weeks, while jogging in a straight line can be usually performed after 12 weeks. A stabilizing brace may be used for at least 6 to 12 weeks; however, the patient is requested to progressively eliminate bracing wear. Pivoting activities and contact sports are allowed usually after 8 to 9 months if there is no significant difference in muscle strength compared to the contralateral side.

CONCLUSION

A tremendous number of single-bundle, double-bundle, and augmentation ACL reconstruction techniques are described in the literature. However, many of these techniques do not completely address the complex anatomy of the native ACL. In detail, most ACL reconstruction techniques have mainly focused on the restoration of the structurally stronger anteromedial bundle, while less consideration was given to the posterolateral bundle, which significantly contribute to rotational stability (11,12). The presented concept of double-bundle, single-bundle, and single-bundle–augmented ACL reconstruction not only respects the importance of both the anteromedial and the posterolateral bundles by emphasizing the particular rupture pattern of the ACL but also includes patient-specific parameters such as comorbidities, patient expectations, and sports exposure. This concept also allows definitive intraoperative decision for the double-bundle, the single-bundle, or the single-bundle–augmented ACL reconstruction technique.

Direct aperture fixation of the autografts using bioabsorbable interference screws is performed in the double-bundle (2), single-bundle, and single-bundle–augmented ACL reconstruction technique. This aperture fixation technique attempts to reproduce more closely the native ACL and its biomechanical function. From a biological point of view, aperture fixation may also prevent or, at least, reduce a synovial fluid leakage into the tendon-bone interface, which seems to be advantageous since exposure of the bone by proinflammatory cytokines within the synovial fluid may contribute to the development of bone loss and tunnel enlargement (1,14). However, long-term clinical outcome studies must prove this concept of an individually adapted anatomical reconstruction of the ACL.

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30 Anatomic Double-Bundle ACL Reconstruction

James R. Romanowski, T. Thomas Liu, and Freddie H. Fu

INTRODUCTION

Anterior cruciate ligament injuries remain one of the most common injuries facing orthopaedic surgeons today. Approximately 100,000 ACL reconstructions are performed each year, the majority (85%) of which are performed by surgeons who reconstruct ≤10 annually (4,5,7). The prevalence of the injury has subsequently led to the focus of significant resources on research and improving the clinical outcome. Even though single-bundle reconstruction techniques have enjoyed relatively successful outcomes, shortcomings inherent to the surgical technique remain. Success rates are often reported in the 80% to 90% range; however, good-to-excellent results are limited to approximately 60% of patients (1). Surgical technique is considered the most common cause of ACL failure. Therefore, it is imperative to consider the four principles of anatomic double-bundle ACL reconstruction: (a) anatomic tunnel placement, (b) restoration of the two functional bundles of the ACL, (c) proper tensioning of each bundle, and (d) individualized reconstruction (Table 30.1) (7,8,14).

The anterior cruciate ligament comprises two bundles—the anteromedial (AM) and the posterolateral (PL) (Fig. 30.1) (2). One of the biggest advances over the past few decades has been the improved understanding in the anatomy of the ACL as well as the kinematic contributions of each bundle. Depending on the position of the knee, these individual bundles exhibit variable tension. The AM bundle experiences the greatest tension during flexion with corresponding laxity of the PL bundle. As the knee extends, the PL bundle increases tension with subsequent laxity of the AM component. Particularly interesting is the trend toward "anatomic" reconstruction. Anatomic reconstruction is a concept that is applicable to both single- and double-bundle approaches with the goal remaining the same—improved patient outcomes. Central to the concept of anatomic ACL reconstruction is the fact that every patient's anatomy is unique. One of the primary tenants of orthopaedic surgery is anatomy and surgical intervention seeks to repair or replicate the native structure.

INDICATIONS/CONTRAINDICATIONS

Patients with symptomatic ACL tears or dysfunction are candidates for single- or double-bundle ACL reconstruction. Symptoms typically are related to instability rather than pain. Cutting- or pivoting-type activities are commonly associated with the knee "giving out." This population generally involves high-level athletes or individuals with physically demanding employment or activities that require stability of the injured joint. Age is not a contraindication, but rather the presence of open growth plates in younger patients and cartilage wear in older

TABLE 30.1 Principles of Anatomic Double-Bundle Reconstruction

1. Anatomic tunnel placement.
2. Restoration of the two functional bundles of the ACL.
3. Proper tensioning of each bundle.
4. Individualized reconstruction.

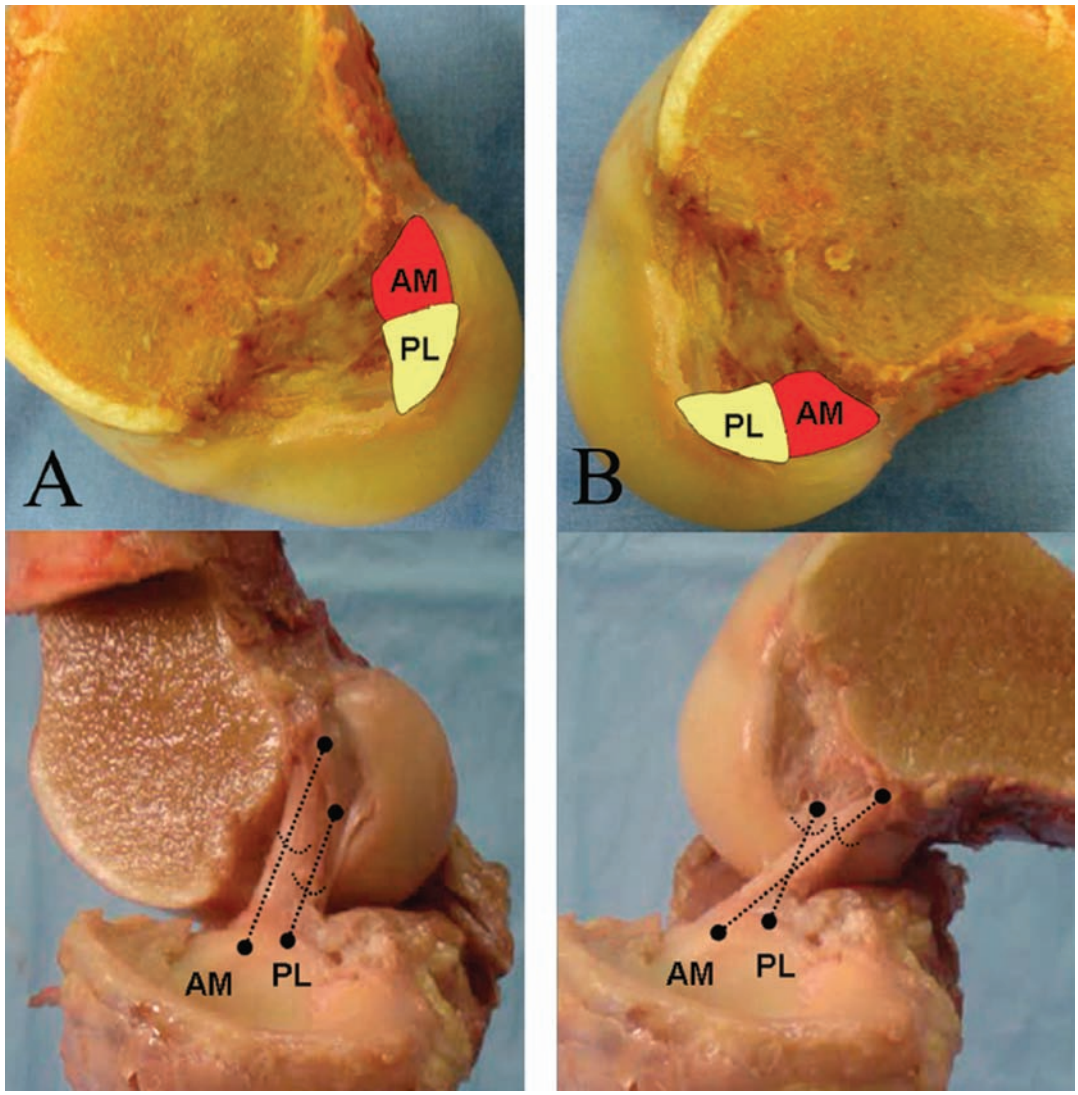


FIGURE 30.1

Cadaveric dissection of ACL double-bundle footprint. The position of both the AM and the PL bundles are shown in full extension **(A)** and 90-degree flexion **(B)**. (Reprinted from Chhabra A, Starman JS, Ferretti M, et al. Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. *J Bone Joint Surg Am.* 2006;88(suppl 4):2–10, with permission.)

populations may preclude surgical intervention. For sedentary or asymptomatic individuals, a conservative approach should be employed. A relative contraindication to double-bundle approaches is the presence of open growth plates. Other criteria that prompt single- rather than double-bundle reconstruction include narrow femoral notch, small insertion sites, and significant lateral femoral condyle contusion (discussed in more detail later in this chapter). Absolute contraindications include active infection, end-stage multicompartmental arthritis, or unwillingness to cooperate with the postoperative restrictions and rehabilitation.

PATIENT EVALUATION

Critical to the success of ACL reconstruction surgery is a thorough patient evaluation. The history provides details that can help direct the physical exam. Injuries may either be from direct trauma or noncontact maneuvers such as a low-energy pivot or twist during landing. Varus- or valgus-type injuries may suggest associated damage to the LCL or MCL, respectively. Meniscal damage should be suspected when complaints focus on mechanical symptoms such as locking or catching. Patients typically describe a "pop" with a joint effusion within the first 24 to 48 of injury. For patients who attempt return to play or other functional demands, continued instability symptoms usually manifest as the knee "giving out" with pivoting or deceleration.

Physical examination begins with exposure of both lower extremities to allow for comparison. Overall alignment is documented as extremes in varus or valgus may compromise the ACL reconstruction outcome if not

addressed. A posttraumatic effusion alone is common and is strongly suggestive of intra-articular derangement, particularly of the ACL. Quadriceps atrophy is common. Ecchymosis is uncommon, but if present should be carefully evaluated for additional injuries. Bony prominences, the patellofemoral articulation, and medial and lateral joint lines are palpated with tenderness suggestive of fractures, patella dislocation, and/or meniscal pathology. ACL-directed exam maneuvers include the pivot shift, Lachman, and anterior drawer test. The pivot shift is the most sensitive of physical exam tests, but also the most difficult to perform as effusion, pain, and muscle spasm often are factors during the acute presentation (10). Additional exam maneuvers can help rule out additional ligamentous or meniscal damage including the McMurray, posterior drawer, reverse pivot shift, and Dial tests, along with varus/valgus stress testing at 0 and 30 degrees of flexion. Deficiencies found on physical exam are subjective and examiner dependent; therefore, more objective measures are available, such as an arthrometer. When used for the ACL, side-to-side differences >3 mm are suggestive of a tear. The range of motion should be evaluated and deficiencies are indications for preoperative physical therapy with modalities that focus on inflammation control, motion, and quadriceps strengthening.

Radiographs are necessary for the evaluation of the acutely injured knee. Besides ruling out fractures, x-rays can assess overall limb alignment, joint space narrowing, prior hardware, and more subtle findings such as a Segond fracture suggestive of an ACL tear. For younger patients, particular attention toward the growth plates is necessary as this affects preoperative planning. Standard films include a full-length cassette of the bilateral lower extremities, 45-degree non–weight-bearing lateral, weight-bearing extension, and 45-degree flexion posteroanterior x-rays, and merchant views of the bilateral patellofemoral joints.

The majority of patients who present for evaluation have already had an MRI performed that can help verify the ACL rupture as well as study the knee for additional injuries. Although MRI is not necessary, it can provide valuable insight during the preoperative planning period. Specific MRI protocols have been developed that focus on the ACL as a double-bundle structure and can identify not only full-thickness ACL tears but also isolated bundles ruptures that may affect the surgical reconstruction.

More recently, computed axial tomography scans protocols that include three-dimensional reconstructions have been developed to allow for valuable information regarding bony architecture, bone loss, and tunnel positioning related to prior surgical intervention. This modality is rarely needed during the workup of the primary ACL tear but can be invaluable in determining single versus staged revision reconstruction of an ACL tear.

PREOPERATIVE PLANNING

Once it has been decided to perform an ACL reconstruction, important consideration should be given toward the surgical timing. Surgery should not be performed until three criteria are met: (a) resolution of joint effusion, (b) improvement of range of motion to 0 to 120 degrees as the risk of arthrofibrosis for acute reconstruction approaches 37% (6,15), and (c) regain of quadriceps muscle function. Satisfying these criteria will decrease the likelihood of postoperative complications.

Graft Selection

Graft selection begins with an open discussion between the surgeon and the patient concerning the advantages and disadvantages of both allograft and autograft use for ACL reconstruction. Patient demands, activity, age, and comfort with the potential risk for disease transmission and immunologic reaction to the allograft are factors that must be considered and contribute to the ultimate choice in graft. Allografts, however, eliminate donor site morbidity, allow for faster short-term recovery, and provide the increased volume of graft often necessary for double-bundle reconstruction (11). More recently, studies have reported up to a three times greater failure rate with allograft in the use of single-bundle constructs among younger and more athletic populations; therefore, graft demands must be factored into the selection process (9,12). Our practice appreciates the concerns of allograft in the young, athletic population and has actively pursued autograft sources such as the hamstrings and quadriceps tendon for reconstruction. In patients with considerable growth remaining, single-bundle hamstring autograft sources and occasionally soft tissue allograft such as the tibialis anterior are chosen to minimize the risk of growth arrest. Multiligamentous injuries are often addressed with allograft as well, given the volume of graft needed for the reconstruction. For older, more sedentary patients with symptomatic instability related to low-demand recreational or functional activities, allograft is almost universally chosen. Occasionally, patients will require only single AM or PL bundle augmentation and graft volume becomes less of an issue, allowing allograft or traditional autograft sources such as the hamstring tendons to be easily implemented. When allograft is chosen, our practice favors the use of tibialis anterior as a graft source. However, posterior tibialis, Achilles tendon, quadriceps tendon, bone-patellar tendon-bone (BPTB), and hamstring tendons may also be used. The long-term outcome of double-bundle reconstruction is unknown, but early results are encouraging (3,13). For this reason, as well as the absence of chronic anterior knee pain related to the harvest of BPTB autograft and biomechanical deficiencies related to hamstring harvest, allograft tissue is typically chosen. If a patient chooses to pursue double-bundle reconstruction but prefers to use autologous tissue only, then the quadriceps muscle is the only graft choice with enough predictable volume to satisfy this need.

SURGICAL TECHNIQUE

Anesthesia

An anesthetic regimen is determined after a discussion between the patient, the orthopaedic surgeon, and the anesthesiologist. Typically, ultrasound-guided peripheral nerve blocks involving the femoral and sciatic nerves are employed with a "light" sedation by experienced staff. This provides satisfactory intraoperative pain control as well as decreased postoperative narcotic use, decreased nausea, and ten times less likely hospital admission (16). The operative extremity is identified in the holding area, marked "yes," and initialed.

Exam Under Anesthesia

An exam under anesthesia is performed evaluating the ACL with Lachman, anterior drawer, and pivot shift testing. Range of motion is also documented. Additional tests are performed based on the history, mechanism of injury, radiographic and MRI findings to help rule out associated ligamentous, AM, and PL rotatory instability.

Setup

The patient is placed supine on the OR table and positioned with the foot of the bed maximally flexed. The nonoperative leg is placed in a well-padded leg holder that allows for comfortable hip flexion and abduction that respects all bony and neurovascular prominences (Fig. 30.2). A tourniquet is placed and the operative leg is secured in a leg bolster. An additional 10 to 15 degrees of hip extension allows for increased knee flexion of the operative knee that assists with later tunnel creation and graft passage.

Surface Landmarks/Portal Placement/Diagnostic Arthroscopy

Anatomic landmarks are identified, including the superior and inferior poles of the patella, medial and lateral patellar tendon borders and joint lines, tibial tubercle, and anterior and posterior medial tibial crests (Fig. 30.3). An Esmarch is used to exsanguinate the leg and the tourniquet is insufflated. A tourniquet is not necessary but may improve visualization of the essential intra-articular landmarks necessary for anatomic double-bundle reconstruction. The anterolateral (AL) portal is created with a no. 11 blade scalpel as a vertical incision just adjacent to the lateral border of the patellar tendon at the level of the inferior pole of the patella. The primary purpose of this portal is for visualization of the tibial ACL footprint.

The (AM) portal is established with the assistance of an 18-gauge spinal needle. The purpose of this portal is for visualization of the femoral notch; thus, aiming along the superior aspect of the ACL would provide the best view. Once the ideal trajectory is established, a vertical incision is made usually just superior to the medial meniscus and intermeniscal ligament along the medial border of the patellar tendon. Because these portals are adjacent to the patellar fat pad, débridement is required for visualization. A diagnostic arthroscopy is performed including the patellofemoral, medial, and lateral compartments. Meniscal or other nonligamentous pathology is addressed at this time as the lack of ACL tension allows for easier access to the compartments. Meniscal repair may be approached by a variety of techniques depending on surgeon familiarity and comfort. In our practice, we utilize an inside-out technique for peripheral tears >1 to 2 cm long. For smaller tears, all-inside devices may be used, and for complex tears, a simple débridement is performed. Articular surfaces are assessed for chondral defects and approached either with débridement or microfracture depending on the extent of damage.

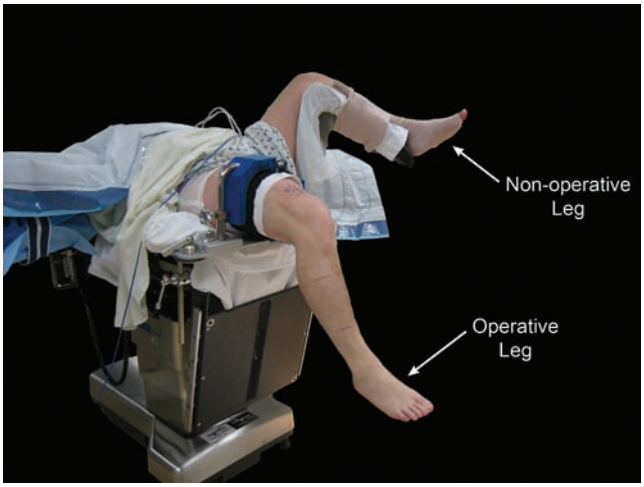


FIGURE 30.2

Patient positioning. The operative extremity is secured in a bolster and the foot of the table is maximally flexed to allow for range of motion. The nonoperative extremity is placed in a padded leg holder and secured with an elastic wrap.

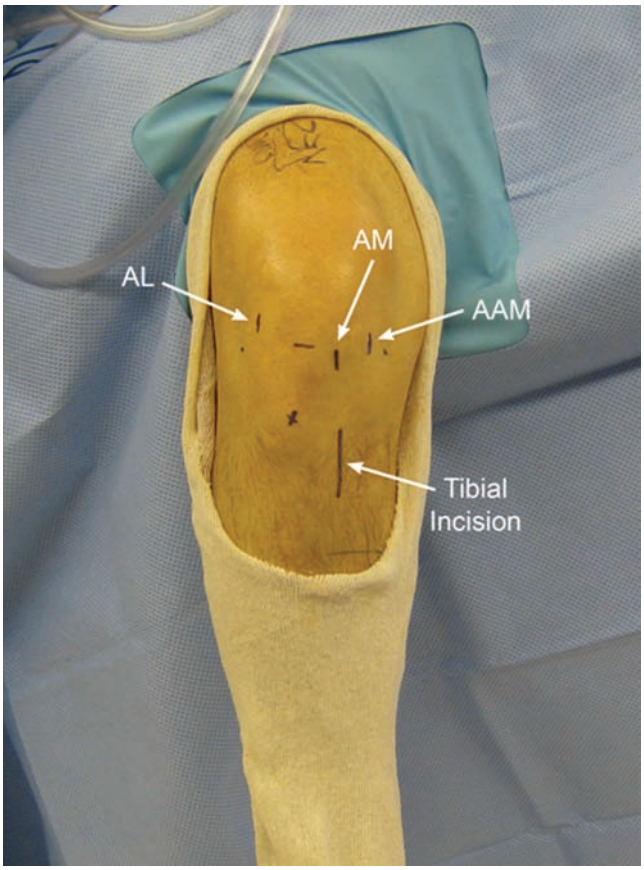


FIGURE 30.3

Surgical incisions. The patient's leg is marked with the usual skin incisions. The anterolateral portal (AL) is made first, with the anteromedial portal (AM) and the accessory anteromedial portal (AAM) established after the trajectory is determined by arthroscopic visualization. The inferior pole of the patella (–) and the tibial tubercle (×) are identified.

The accessory anteromedial (AAM) portal is established after pilot placement with an 18-gauge spinal needle. Careful placement of this portal is critical for the creation of the femoral tunnels. If the skin incision is too medial, then access to the AM femoral tunnel is difficult as the medial femoral condyle interferes with the pathway. If it is too lateral, then interference may occur with the AM portal instrumentation as well as the acute entrance angle for the AM femoral tunnel on the notch, risking posterior wall blowout. This vertical incision is often 1 to 2 cm medial and slightly proximal to the AM portal.

Tear Identification

ACL ruptures may present in a variety of patterns and can be classified according to location (femoral, mid-substance, tibial), partial versus full thickness, and isolated single AM or PL bundle versus combined double-bundle tears. This portion of the procedure is more time consuming but is necessary for accurate assessment of the ACL tear pattern (Fig. 30.4). Furthermore, this information has a significant role in the surgical approach.

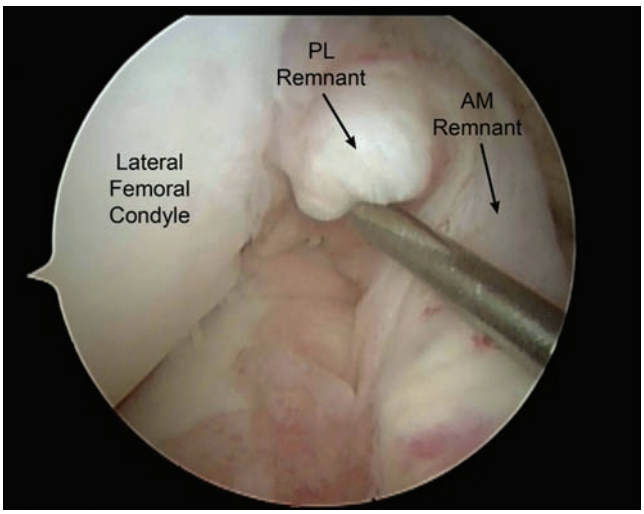


FIGURE 30.4

Diagnostic arthroscopy. View from the AL portal demonstrates an ACL rupture with both the AM and the PL bundles identified.

For isolated single-bundle tears, an AM or PL bundle augment may be utilized rather than full débridement and takedown of the native ACL with complete reconstruction.

Once the individual bundles are identified, the fibers may be traced to their femoral and tibial origins. This critical step allows for native footprint identification and tunnel creation. Low-voltage thermocautery and arthroscopic shavers are used to assist with gentle débridement of the damaged tissue within the notch. In the acute setting, it is easier to identify the natural sulcus that separates the bundles rather than in chronic cases dominated by scar tissue and resorption. In this scenario, the bony intra-articular landmarks are key toward identification of the anatomic footprints. Within the notch on the medial aspect of the lateral femoral condyle, the intercondylar ridge represents the superior border of the ACL footprint with the knee flexed at 90 degrees. Further dissection reveals the bifurcate ridge separates both the AM and the PL bundles (Fig. 30.5). Dissection should be limited to thermocautery in this area as the synovator may remove these subtle references. In accordance with Wolff law, chronic ACL tears often will lose these bony landmarks, and it becomes necessary to rely on generic, less anatomic formulas for tunnel placement. The PL femoral tunnel center is approximated to the lower one third of the notch, 5 to 7 mm proximal to the articular surface, and 3 mm anterior to the posterior cartilage ridge (Fig. 30.6). The peripheral rim of the ACL origin and insertion is preserved based on its proprioceptive role.

On the tibial side, the bundle insertions are identified after dissection in a similar manner. For chronic tears or in cases where the sulcus is not identified, the PL insertion is usually just AM to the posterior root of the lateral meniscus. The AM footprint is anterior to the PL insertion.

Single-Versus Double-Bundle Reconstruction

The appropriateness of a single- versus double-bundle reconstruction is ultimately based on the constraints of the individual's anatomy. With the bony landmarks identified, the anatomic footprint on both the femoral

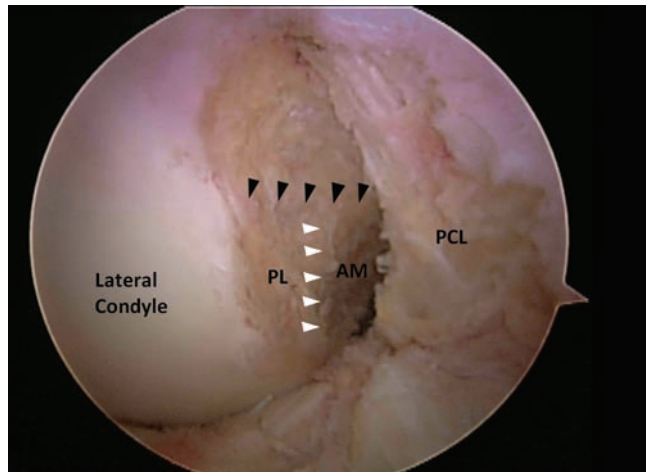
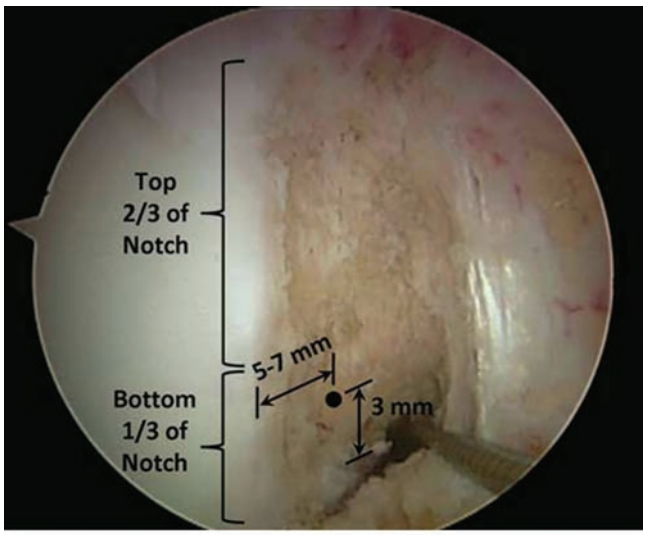
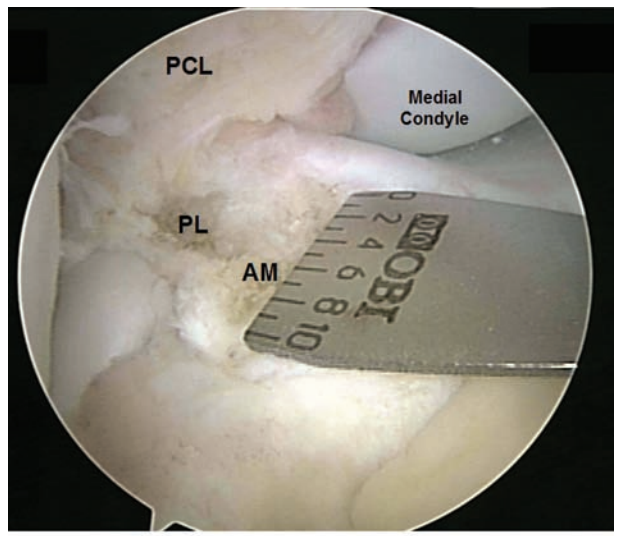


FIGURE 30.5

Arthroscopic landmarks. The ACL footprint has been identified with the knee in 90 degrees of flexion. The lateral intercondylar ridge (*black arrowheads*) and the lateral bifurcate ridge (*white arrowheads*) are identified. View from AAM portal.



A



B

FIGURE 30.6

Reference for chronic ACL tears. **A:** The femoral ACL insertion site is located in the bottom 1/3 of the lateral notch wall. **B:** On the tibial side, the relationship between the ACL and the PCL and menisci can be used.

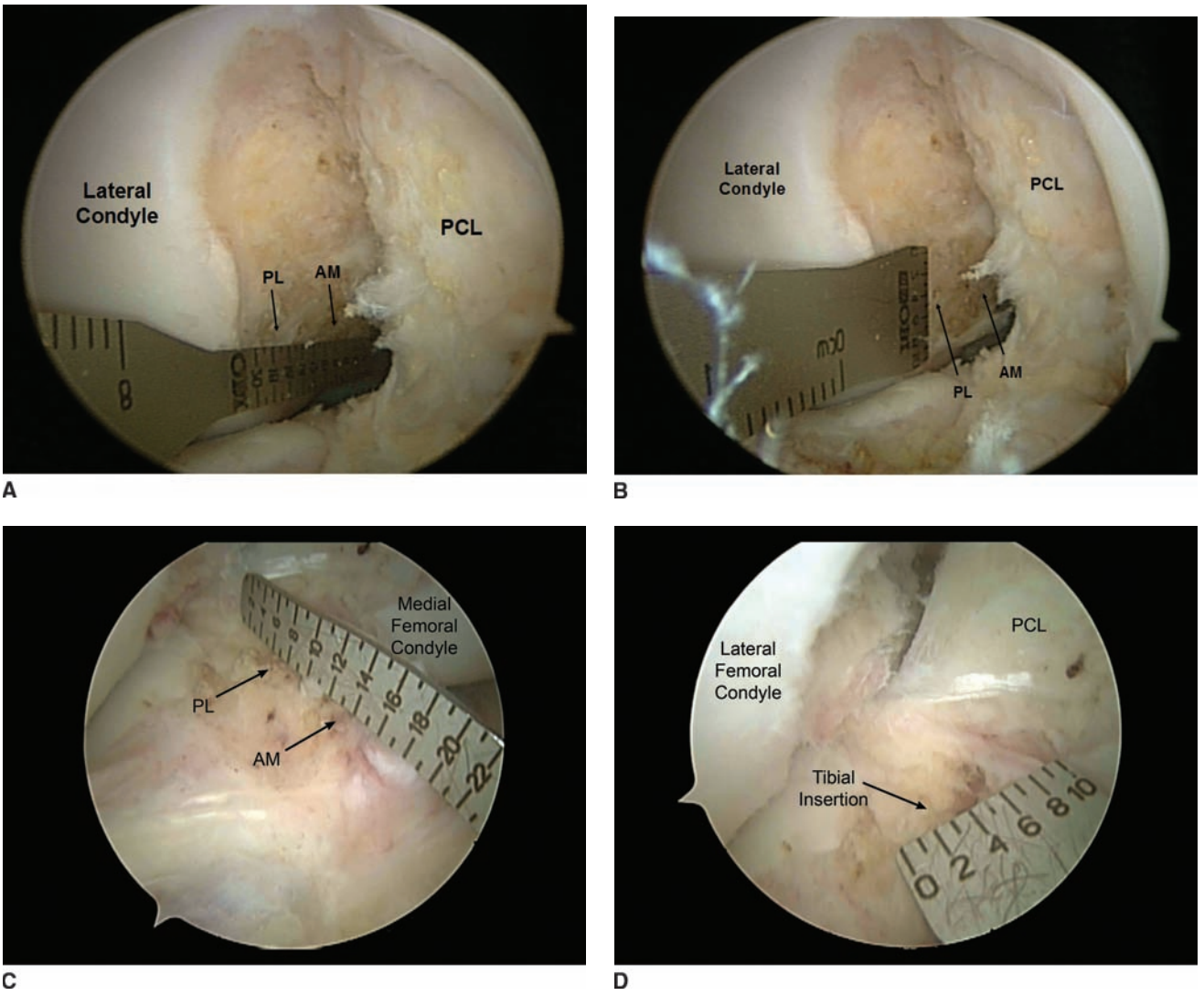


FIGURE 30.7

Measurement of the ACL footprint. **A:** Length of the total femoral footprint. **B:** Anterior-posterior length of both the AM and the PL footprints. **C:** Total tibial footprint length. **D:** Width of tibial AM and PL footprints.

and the tibial surfaces is measured (Fig. 30.7). Based on the intercondylar and bifurcate ridges, the AM and PL dimensions are documented. The tibial insertion sites are measured and are usually 1 to 2 mm larger that the femoral counterpart. The diameter of the PL bundle is usually smaller than the AM tunnel, averaging 5 to 7 mm. The larger AM bundle averages 6 to 8 mm. With these dimensions in mind, a 20-mm proximal-distal length femoral footprint could easily accommodate an 8-mm AM and 7-mm PL graft with a 2-mm bone bridge.

Within the University of Pittsburgh experience, total ACL insertion sites ≤14 mm require single-bundle constructs, as there is not enough footprint to accommodate two tunnels plus an intervening 2-mm bone bridge. There is also the additional risk of converging tunnels, particularly at the aperture, that potentially converts a two-tunnel construct into a single tunnel. A narrow notch can pose a similar problem, as angling the tunnels differently while placing them anatomically without convergence will be difficult if given less room distally to maneuver. In scenarios not amenable to double-bundle reconstruction, prior identification of the native ACL landmarks allows for an anatomic single-bundle construct. The femoral tunnel is centered just posterior to the bifurcate ridge as the AM bundle occupies a majority (~60%) of the footprint. The tibial tunnel is centered between AM and PL insertions.

Tunnel Placement

After identification of the AM and PL footprints on both the femur and the tibia, attention is now directed toward creation of the ACL tunnels. With the arthroscope placed in the AM portal, the medial aspect of the

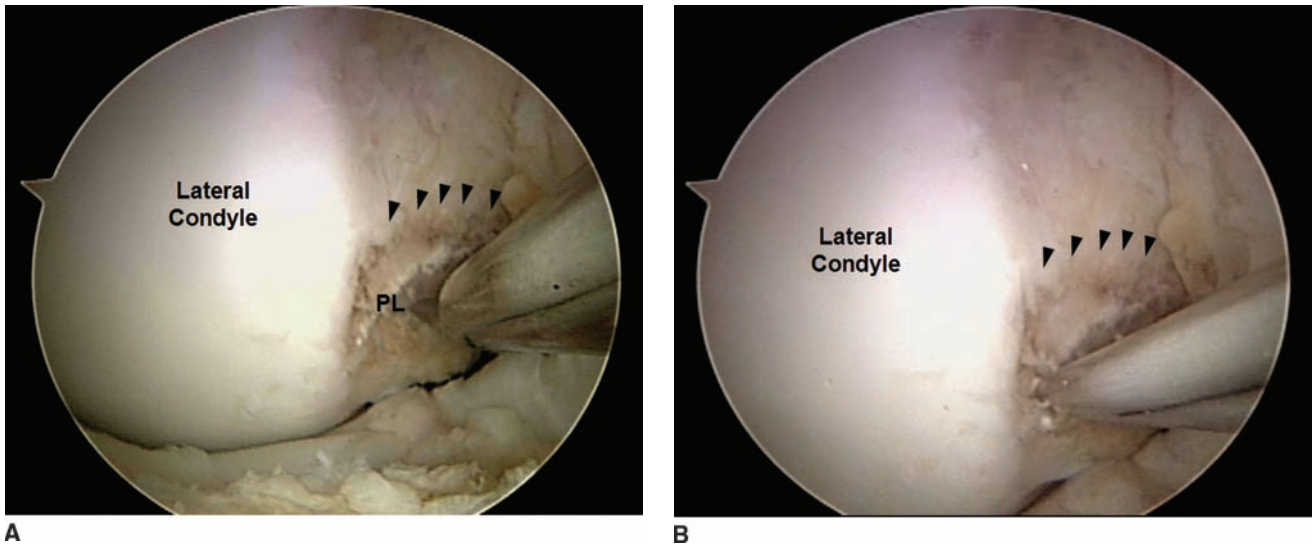


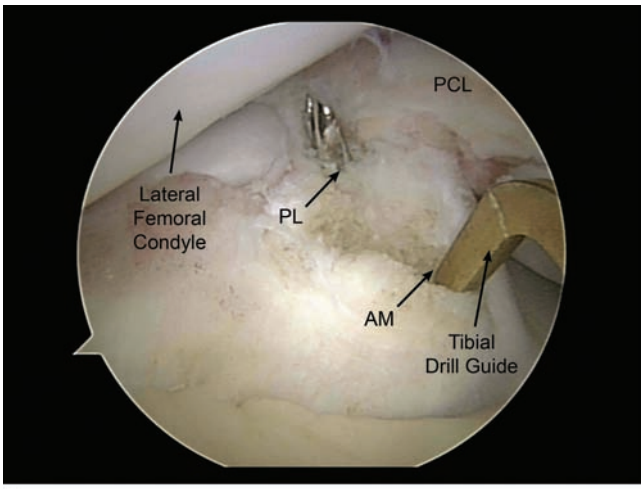
FIGURE 30.8

Preparation of femoral PL tunnel. View from AM portal. Instrumentation placed through AAM portal. The lateral intercondylar ridge is demonstrated (*black arrowheads*). **A:** Pilot hole is created with an awl. **B:** Placement of 3.2-mm guidewire into PL pilot hole.

lateral femoral condyle is visualized. Because of variations in patient anatomy, the AM femoral tunnel is not consistently created with a transtibial approach or via the AAM portal. Furthermore, as guidepins are used for reamer passage, subtle motion at the footprint during flexion can misplace the tunnel entrance. Consistent with the anatomic principles, the aperture of the tunnel must lie within the bundle origin/insertion. Pilot holes are reliably placed in the center of both the PL and the AM footprints using an awl. The PL tunnel is created first (Fig. 30.8). With the knee flexed to approximately 110 degrees, using the AAM portal a 3.2-mm guidewire is centered within the pilot hole and seated to the lateral femoral cortex with a mallet. A reamer is passed over the guidepin and drilled to a depth of at least 30 mm. Based on the initial PL footprint dimension, the diameter of the initial reamer is 1 mm less than the desired tunnel diameter. The tunnel is then expanded with dilators to match the predetermined size. Within our practice, the EndoButton CL (Smith and Nephew, Andover, Massachusetts) construct is chosen as it allows for circumferential graft incorporation within the tunnel and avoids additional incisions. This method is not required as other forms of graft fixation may work, albeit without the advantages mentioned above. A 4.5-mm reamer is drilled within the tunnel and exits the lateral femoral cortex. The total tunnel depth is measured and appropriately sized EndoButton CL chosen. The goal is to have at least 25 mm of graft within the tunnel. Should the tunnel be short and not accommodate the additional tunnel depth needed to "flip" a traditional EndoButton CL, an EndoButton Direct (Smith and Nephew, Andover, Massachusetts) is used. The AM tunnel is not created at this time as a transtibial trajectory is occasionally usable and avoids the lateral femoral condyle.

Attention is now directed toward creation of the tibial tunnels (Fig. 30.9). With the arthroscope placed in the AL portal, the previously identified AM and PL footprint is viewed. The PL tibial tunnel is created first. A 4-cm incision is made centered on the medial surface of the tibia and extended distally from the level of the tibial tubercle. Careful elevation of the periosteum and posterior exposure to the superficial MCL insertion reveals the underlying tibial surface. An Acufex ACL drill guide (Smith and Nephew, Andover, Massachusetts) is set at 45 degrees with the tip centered in the PL insertion. A 3.2-mm guidewire is started on the posterior portion of the tibial surface and drilled to the level of joint. The ACL guide is then set at 45 degrees and centered in the AM footprint. It is necessary to have at least a 1-mm bone bridge between the tunnels and this should be considered during guide pin placement. The 3.2-mm guidepin is started 1 cm anterior to the PL guidepin on the medial tibial surface and advanced to the level of the joint. For trajectory verification and to ensure adequate bone stock for reaming, a lateral view under fluoroscopy can be performed. Radiographs may be taken should the mini c-arm not be available. Reaming is then performed on each guidepin, again under-reamed by 1 to 2 mm and then dilated to fit the premeasured graft diameter.

The AM femoral tunnel is created last as on rare occasion the optimal trajectory is from a transtibial approach. The arthroscope is switched to the AM portal for viewing the notch. Within the University of Pittsburgh experience, this tunnel may be approached via the AAM portal in 99% of cases, via the PL tibial tunnel in 60%, and from the AM tibial tunnel in 10%. Each approach is checked with a guidepin in the previously placed pilot hole. With the knee flexed approximately 110 degrees, a 3.2-mm wire is advanced to the lateral femoral cortex with a mallet (Fig. 30.10). Undersized cannulated reaming (usually 6–7 mm) is then performed to a depth of at least 30 mm, and dilators are placed to match the graft diameter (Fig. 30.11). Again, a 4.5-mm reamer is used



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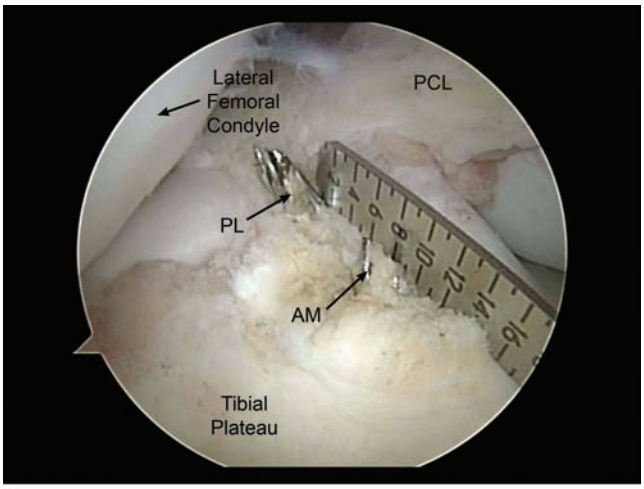

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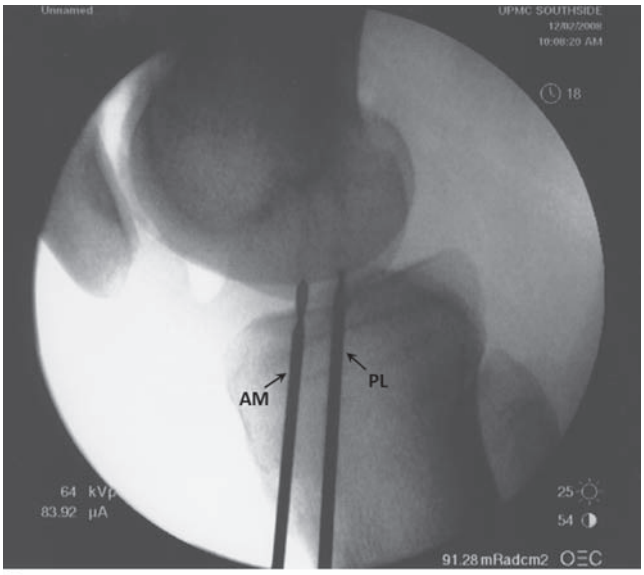

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FIGURE 30.9

Preparation of tibial tunnels. View from AL portal. Instrumentation placed through AM portal. **A:** The PL tunnel guidepin has been placed and the ACL guide tip is centered in the AM tibial footprint. **B:** Both the PL and the AM guidepins are in place. **C:** Lateral radiograph verifying guidepin placement and trajectory.

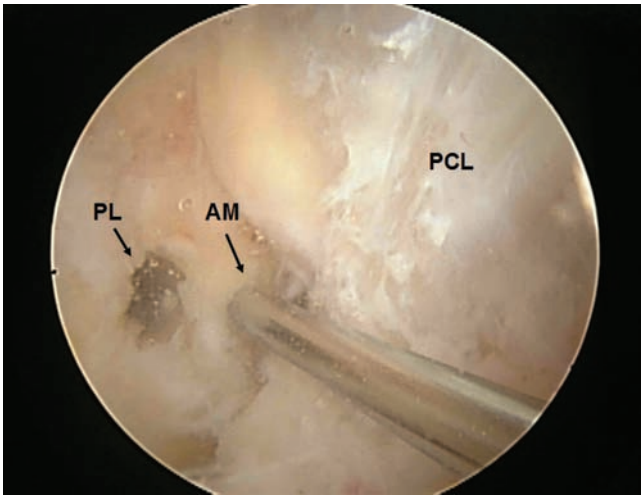


FIGURE 30.10

The AM tunnel is created last using the optimal trajectory through either the AM and the PL transtibial tunnels, or via the AAM portal. The guidepin, in this case, is through the AAM portal into the AM footprint on the lateral femoral condyle.

to perforate the lateral femoral cortex with total tunnel depth and values calculated for EndoButton CL graft insertion.

In cases where the quadriceps autograft has been the chosen graft, tunnel creation is modified. The construct remains consistent with the principles of anatomic ACL reconstruction. The tibial tunnels remain the same, but a single femoral tunnel is created via the AAM portal. Arthroscopic visualization is from the AM portal.

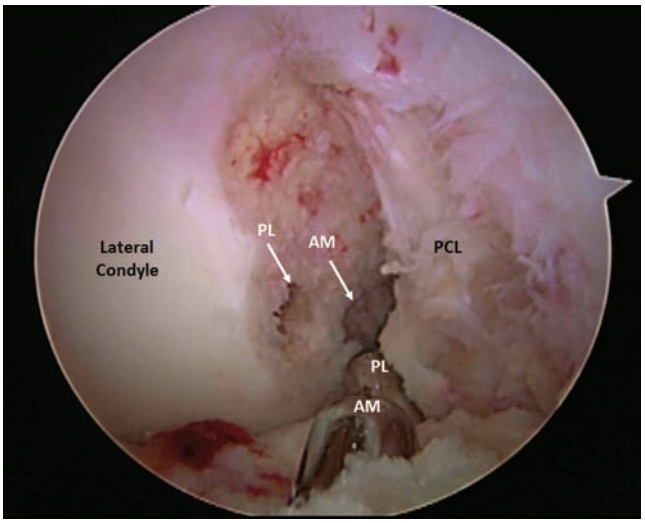
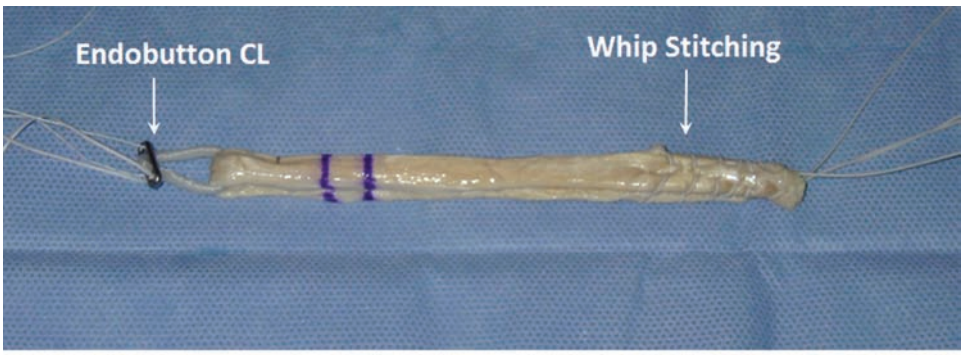


FIGURE 30.11

Both the femoral and the tibial tunnels have been created and are now ready for graft placement. Dilators are present in the tibial tunnels.

A 3.2-mm guidepin is placed from the AAM portal into a pilot hole created just posterior to the bifurcate ridge. It is then advanced to the lateral femoral cortex, avoiding the medial femoral condyle. A reamer is drilled to a depth of 28 mm to accommodate a 20-mm bone plug on an EndoButton. The 4.5-mm cannulated reamer is then used to perforate the lateral femoral cortex and the total tunnel depth measured and appropriate EndoButton chosen.



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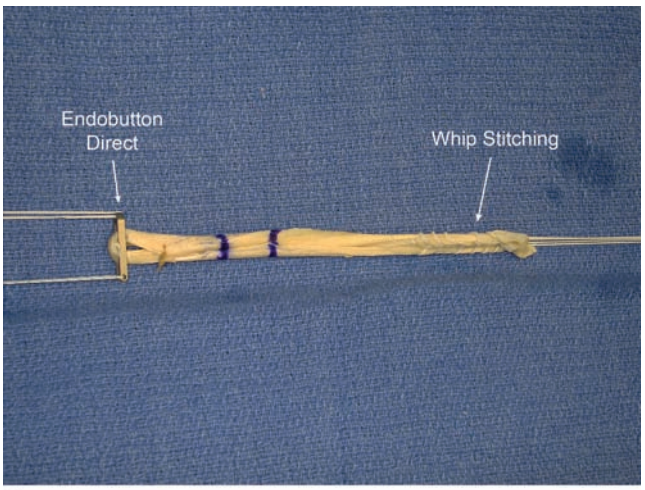

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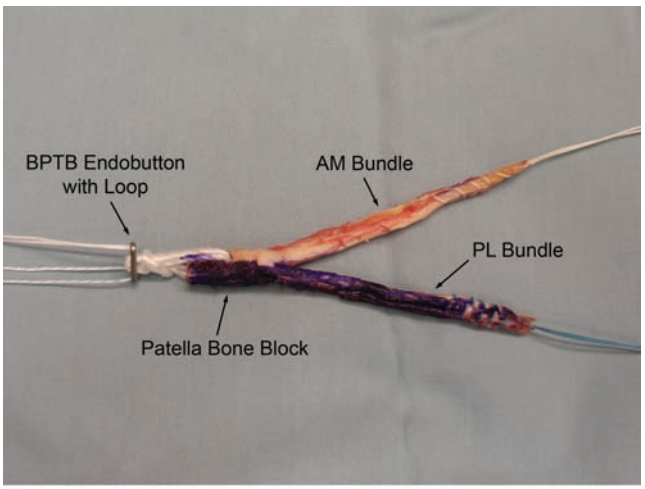

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FIGURE 30.12

Graft preparation. A whipstitch is placed within the ends of the graft. Tunnel depth and additional "flip distance" are marked. **A:** EndoButton CL (Smith and Nephew, Andover, Massachusetts). Tibialis anterior allograft. **B:** EndoButton Direct (Smith and Nephew, Andover, Massachusetts). Tibialis anterior allograft. **C:** Quadriceps Tendon Autograft.

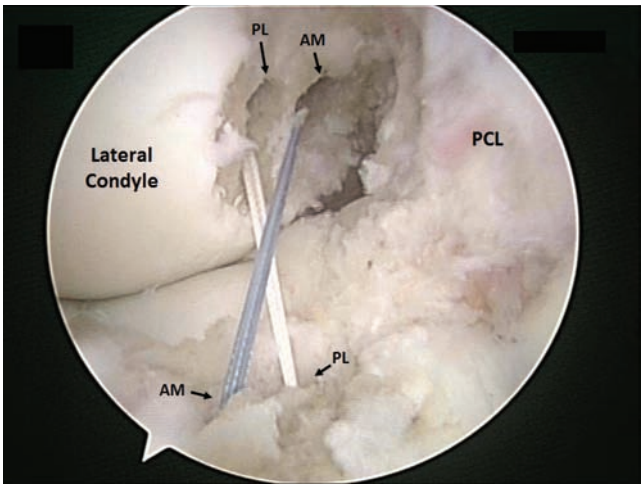

FIGURE 30.13

The tunnels are loaded with shuttle suture for graft placement. Both tunnels should be loaded with suture prior to individual graft placement in order to avoid interference.

GRAFT PASSAGE/FIXATION

Once the graft dimensions are determined during the footprint identification phase of the procedure, preparation of the graft is performed simultaneously for tourniquet safety purposes. For soft tissue grafts, an EndoButton CL technique is employed. The grafts are usually 15 cm long, with the AM diameter 6 to 8 mm, and the PL diameter 5 to 7 mm (Fig. 30.12). A whipstitch is placed in the ends of the graft using a 2 Ticron (Covidien, Mansfield, MA). An EndoButton Direct is used in situations where the femoral tunnel may be short and cannot accommodate at least 25 mm of soft tissue within the tunnel and the additional distance needed for the EndoButton CL.

A Beath pin is placed through the AAM portal and into the PL tunnel on the femur. An arthroscopic grabber, or ice tong, is placed within the tibial PL tunnel and used to load the suture from the Beath pin into the tibial tunnel. The EndoButton sutures (leading and trailing) are then loaded into shuttle suture loop and brought retrograde into the femoral tunnel through the skin on the lateral thigh (Fig. 30.13). The leading suture is then pulled, loading the graft first in the tibial tunnel, then into the joint, and finally in the PL femoral tunnel (Fig. 30.14). The EndoButton is "flipped" and antegrade tensioned applied to the graft ends to maintain the apposition of the metal on the lateral femoral cortex. Similarly, the AM graft is loaded into the AM tibial and femoral tunnels.

The knee is then cycled 20 times from 0 to 120 degrees and the graft secured in the respective tibial tunnels. The PL graft is tensioned with the leg in full extension and the AM graft tensioned with the knee flexed to 45 degrees. Interferences screws are used within the tibial tunnels (Fig. 30.15). The diameter of screw is usually the size of the tunnel and the length typically 20 to 25 mm. Other methods such as tying over a post may be employed primarily or to augment the fixation.

FIBRIN CLOT

Recently, we have started employing a fibrin clot that is made from patient's own blood to augment the healing of soft tissue grafts. 50 mL of blood is drawn by anesthesia and placed into a beaker on the field. Using a glass

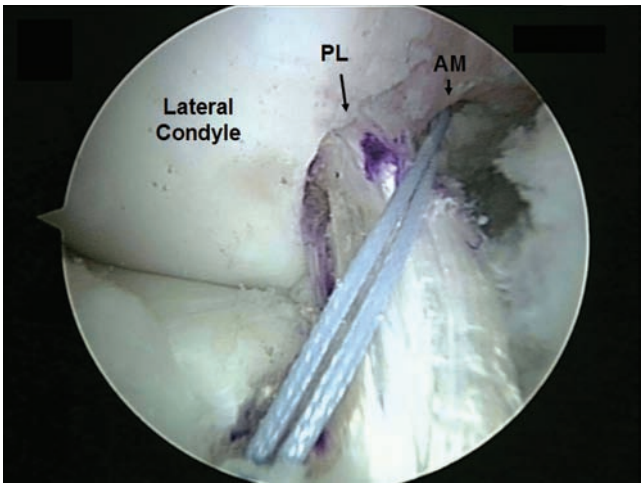

FIGURE 30.14

The PL graft is advanced into the femoral tunnel.

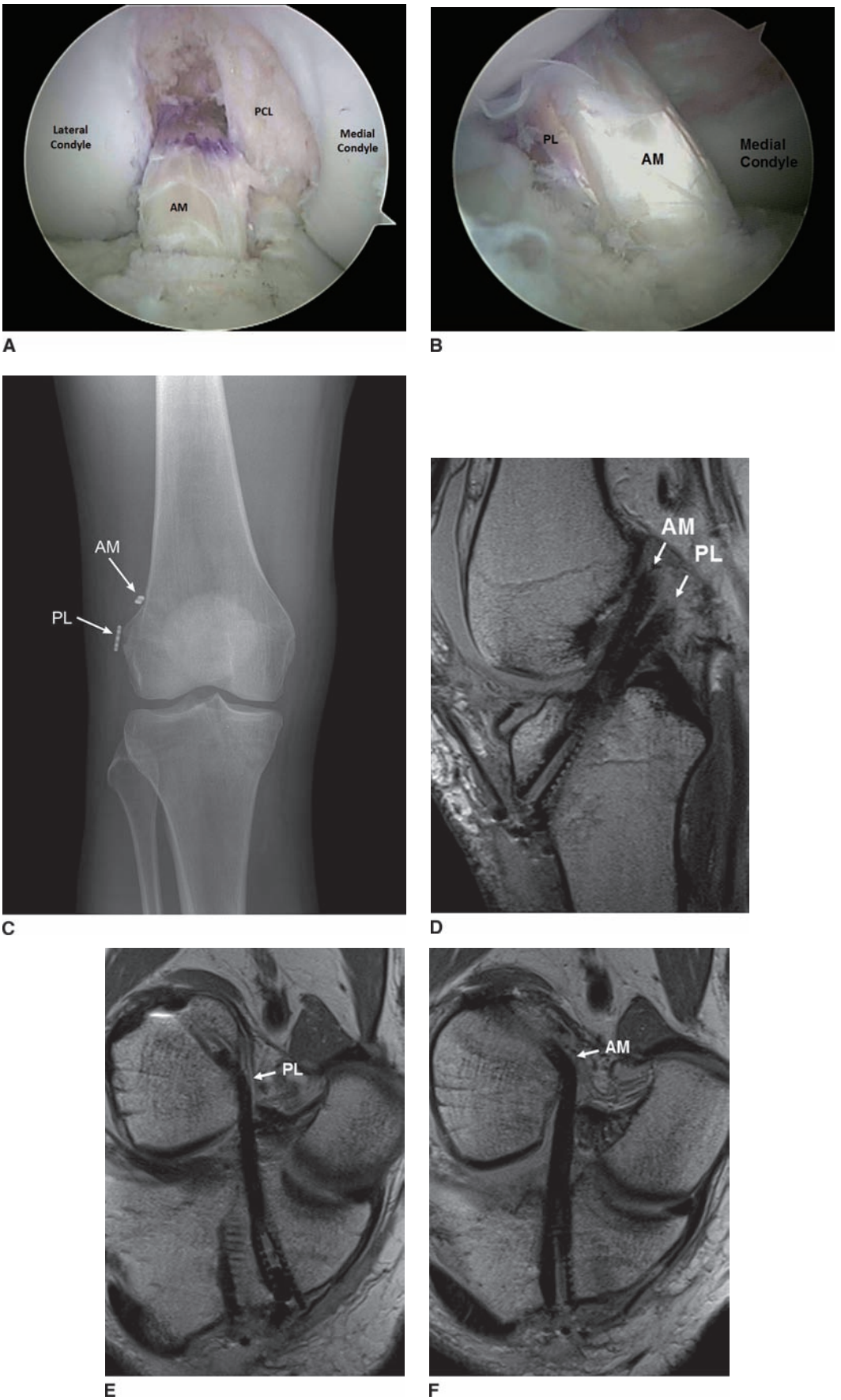

FIGURE 30.15

Final Graft Appearance. **A:** View from AM portal. **B:** View from AL portal. **C:** Radiographic (AP view). **D:** Postoperative sagittal MRI. **E:** Postoperative coronal MRI of PL bundle. **F:** Postoperative coronal MRI of AM bundle.

stirring rod, the blood is gently swirled for approximately 10 to 15 minutes until a clot forms. The clot is usually divided into three pieces, two of which are enclosed in the femoral portion of the doubled soft tissue grafts and secured with the standard stitching. The third section is sandwiched between the AM and the PL grafts intra-articularly to aid in the healing of the two bundles together, theoretically recreating the septum between the bundles.

To place the fibrin clot between the two grafts, a looped suture is inserted through the AAM portal around the AM Beath pin suture loop and grasped back through the same portal immediately prior to any graft passage. The PL bundle is passed and fixation performed at full extension. Then, the AM bundle is passed over the PL bundle and looped suture, applying slight pressure through the looped suture to ensure that it is not caught into the femoral tunnel during the passage. The EndoButton of the AM bundle is flipped, but prior to tibial fixation, gentle tension is applied through the additional looped suture at the AAM portal to tug the AM bundle anteriorly in order to open a space between the two bundles. The remaining fibrin clot is inserted into this space through the AM portal via a clear cannula and dilator, then full tension is applied on the AM graft to sandwich the clot between the two bundles. The looped suture from the AAM portal is removed, and then the tibial fixation of the AM bundle is done at the standard 45 degrees of knee flexion.

CLOSURE

The knee is irrigated arthroscopically, ensuring removal of all bony and soft tissue debris. The portal sites are closed with 3-0 nonabsorbable monofilament. The tibial incision is irrigated and the deep tissue reapproximated using 0 or 2-0 absorbable suture. The subcutaneous layer is closed with a 2-0 absorbable suture and skin closed per surgeon preference. Gauze, sterile Webril, bias wrap, and knee immobilizer locked in extension are serially applied. The vascular status is assessed prior to leaving the operating room.

POSTOPERATIVE MANAGEMENT

Rehabilitation

Postoperative rehabilitative therapy is an essential component toward maximizing the outcome of double-bundle ACL reconstruction. Our protocol consists of five phases with total duration of approximately 9 months. Each phase contains goals that must be obtained prior to advancement to the next phase.

Phase I (0–6 weeks) begins the day of surgery and initially focuses on modalities to control joint effusion, inflammation, and range of motion while protecting the graft during its incorporation. A knee immobilized locked-in extension is applied in the operating room. Weight bearing as tolerated with crutch assistance is permitted the day of surgery. Continuous passive motion is often used for first 2 to 3 weeks. Initial settings are 0 to 45 degrees for 2 hours, twice a day. Increases of 10 degrees are permitted daily as tolerated to a maximum of 120 degrees. Particular attention is given toward the quadriceps as quad sets and straight leg raises in the locked brace are encouraged, as are heel slides with the brace unlocked. Quadriceps isometrics are performed from 60 to 90 degrees. Full, symmetric knee extension is expected 1 week after surgery. Crutches are usually discontinued around 4 weeks as the extensor mechanism develops and the brace may be removed once the extensor lag has resolved. If fibrin clot was utilized during the reconstruction, the knee stays locked in extension in the brace for the first week, then the remainder of the protocol is the same afterward.

Phase II (6–8 weeks) focuses on gait training and includes the introduction of closed-kinetic chain exercises. Range of motion is encouraged. Therapeutic modalities include hamstring curls, wall slides, and stretching. Controlled, low-impact exercises such as high seat stationary bicycling are started.

Phase III (8 weeks to 6 months) continues gait training, focuses on proprioception, encourages full range of motion, and develops strength with advancing closed-kinetic chain exercises. Additional low-impact activities such as treadmill walking and elliptical exercises are added, with light jogging once quadriceps strength has recovered to >90%.

Phase IV (6–9 months) continues the development of strength, flexibility, and endurance. Full-speed running is achieved during this phase and sport-specific training is started later.

Phase V (>9 months) focuses on return to play and functional activities. Strength, flexibility, range of motion should continue to improve. Quadriceps strength is expected to be >90% for competitive sports. Objective measurements such as KT-2000 arthrometer testing (MEDmetric Corporation, San Diego, California), range of motion, strength, and balance may be used to document progress. A functional brace is often prescribed for individuals who wish to continue with competitive activities.

COMPLICATIONS

Complications shared with other arthroscopic procedures include infection of both the joint and the soft tissues. Deep vein thrombosis, nerve damage, and general medical sequelae related to anesthesia are also of concern. As with single-bundle techniques, ACL reconstructions are susceptible to graft rerupture and arthrofibrosis.

SUMMARY

Double-bundle ACL reconstruction has been the evolutionary product of improved understanding of the anterior cruciate ligament anatomy and function. Short-term, prospective studies are beginning to validate this approach (14). Furthermore, the principles of the anatomic double-bundle reconstruction are applicable to single-bundle techniques with the continued goal of improving clinical outcomes.

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31 Anterior Cruciate Ligament Reconstruction in Children and Adolescents

Craig Finlayson, Adam Nasreddine, and Mininder S. Kocher

The knee is the most common site of injury in the skeletally immature athlete (1). The incidence of anterior cruciate ligament (ACL) tears appears to be on the rise. The treatment of these injuries is controversial. Nonoperative management can lead to functional instability and difficulty with cutting and pivoting sports. Additionally, the pathologic shear forces are associated with meniscal and chondral damage over time. ACL reconstruction in children and adolescents risks iatrogenic injury to the physis. This chapter reviews the historical perspective of ACL injuries in the young patient, clinical and diagnostic findings in children, treatment options, and results of treatment.

HISTORICAL PROSPECTIVE

The ACL is the principal intra-articular stabilizer of the knee. As in adults, an ACL injury in a child or an adolescent is usually a noncontact valgus injury. Prior to the 1980s, these injuries were thought to be rare in the pediatric athlete. Advances in diagnostic imaging and improved clinical acumen have allowed physicians to identify midsubstance ACL tears in patients with open physis (2–5). A Finnish population-based cohort of 46,472 adolescents was followed for 9 years, and the incidence of ACL tears was reported to be 60.9 per 100,000 person years. Gender and activity level were identified as risk factors for ACL injuries. The relative risk of ACL injury for a young athlete participating in sports four times per week was 4 for males and 8.5 for females (6).

The results of nonoperative management in children are consistently associated with poor outcomes (7–17). Aichroth et al. reported on 23 children who were treated nonoperatively between 1980 and 1990. At final follow-up, meniscal tears were present in 15 knees, three osteochondral fractures occurred, and osteoarthritic changes developed in ten knees (11). From 1980 to 1985, McCarroll followed 16 patients under the age of 14 with open physes and midsubstance tears of the ACL treated without reconstruction. Six patients underwent arthroscopy for meniscal tears. Only seven patients returned to sports, all experiencing recurrent episodes of giving way, effusions, and pain (14).

Early attempts at primary repair of the ligament in children were unsuccessful (9,18–20). Engebretsen et al. presented eight adolescents who were followed 3 to 8 years after primary suture of a mid substance rupture of the ACL. Only three patients had good function, and five were functionally unstable. DeLee et al. examined three children <14 years old treated by primary surgical repair at 21 months postoperatively. All three patients had clinical evidence of ACL laxity. Two of the three had recurrent giving way. Failure of primary repair has led to the development of a variety of procedures to stabilize the knee. Surgical options include transphyseal, partial transphyseal, and physeal-sparing reconstructions.

TIBIAL SPINE FRACTURES AND PARTIAL ANTERIOR CRUCIATE LIGAMENT TEARS

It is important to understand the different types of injuries that can occur in the skeletally immature patient. Partial ACL tears and avulsion fractures of the tibial spine are more common in the pediatric population (21). Excellent functional results have been reported following arthroscopic reduction and internal fixation of tibial spine fractures, although long-term follow-up does demonstrate some residual laxity, indicative of associated intrasubstance injury to the ACL (2,22,23). Many partial tears can be treated nonoperatively (24). Based on a prospective study of arthroscopically confirmed partial ACL tears, failure of nonreconstructive treatment has been associated with tears >50%, tears of the posterolateral bundle, older skeletal age, and presence of a pivot shift.

HISTORY AND PHYSICAL EXAM FINDINGS

Important history questions include

1. How did the injury occur?
   a. Was there contact with another athlete?
   b. Was there a fixed position of the foot and rotation or twisting movement?
2. Were you able to continue to compete?
3. Was there significant swelling directly after the injury?
4. Have there been previous injuries to the knee?

Our understanding of ACL tears in the setting of younger athletes has changed considerably. The tibial spine fracture was once thought to be the pediatric equivalent of an ACL tear. Midsubstance ACL ruptures are now diagnosed more frequently in pediatric athletes participating in cutting and contact sports. The typical presentation is a young athlete who has a decelerating, twisting injury. Approximately two thirds of ACL injuries occur by noncontact mechanisms (25). The patient will often report a "pop" and the inability to return to the field. A large amount of swelling due to hemarthrosis is expected. The presentation is less dramatic in athletes who have had a prior partial tear of the ACL.

The findings on physical exam are dependent on the timing in relation to the injury. Directly after the injury, the stability of the knee can be tested on the sideline. The Lachman and pivot shift are positive before swelling and guarding occurs. When the patient presents for evaluation in the emergency department or clinic, the knee is typically swollen, compromising the ability to perform an accurate physical exam. Rates of ACL injury are reported between 10% and 65% in pediatric patients presenting with traumatic hemarthrosis of the knee; therefore, young athletes presenting with a hemarthrosis of the knee should raise suspicion for an ACL tear (26–30). The differential diagnosis of hemarthrosis of the knee includes patellar dislocation, meniscal tear, osteochondral fracture, tibial spine fracture, and epiphyseal fracture of the femur or tibia.

A thorough examination of the knee must be performed to rule out concomitant injuries. Associated injuries include meniscal tears, posterior cruciate, and/or collateral ligament tears, osteochondral fractures, and physeal fractures of the distal femur or proximal tibia. Given the higher prevalence of generalized ligamentous laxity in skeletally immature patients, a direct comparison to the contralateral knee should also be made.

IMAGING

Evaluation of the knee by magnetic resonance imaging (MRI) is an important part of the assessment, particularly in children. The MRI is useful to distinguish between partial tears, avulsions, and midsubstance tears of the ACL. Secondary findings in an acute injury include hemarthrosis and the presence of a bone contusion at the posterior lateral tibial plateau and anterior lateral femoral condyle. The MRI is useful for confirming the diagnosis of ACL tear, ruling out associated injuries, and assisting in preoperative planning (Fig. 31.1).

INDICATIONS AND TIMING OF SURGERY

Indications for ACL reconstruction in a skeletally immature patient include complete ACL tear with functional instability, partial ACL tear that has failed nonoperative treatment, and ACL injury with associated repairable meniscal or chondral injury. Due to higher rates of postoperative stiffness, acute ACL reconstruction is not recommended for isolated ACL tears (31). Surgery is typically delayed 3 weeks from the time of injury or until adequate range of motion has been achieved. Patients must be mature enough to participate in the extensive rehabilitation process following ACL reconstruction.

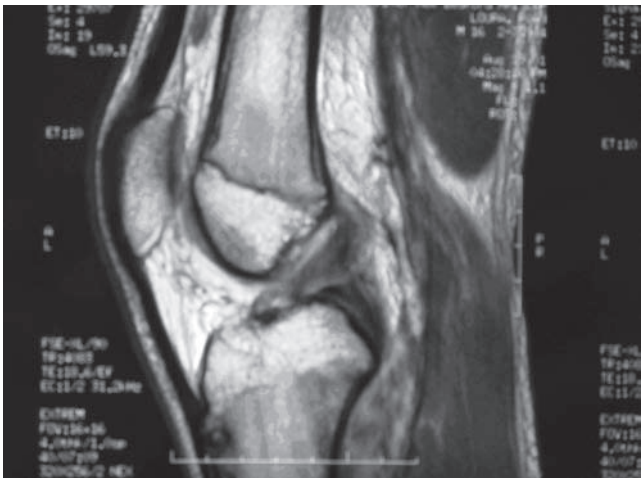


FIGURE 31.1

MRI demonstrating midsubstance ACL tear.

TREATMENT OPTIONS

The choice of surgical technique is dependent on the physiologic age of the patient and the amount of growth remaining. For prepubescent children, violation of the tibial and femoral physis presents a risk of significant growth disturbance that would require limb lengthening or osteotomy. Animal studies have demonstrated a risk of physeal arrest with transphyseal ACL reconstruction (32–34). A number of clinical reports have documented growth disturbances following ACL reconstruction in this age group (35–37). Radiographs and developmental findings are used to determine the physiologic age. Referencing radiographs of the left wrist to the atlas of Greulich and Pyle (38) provides an efficient means to determine skeletal age. Roche et al. (39) referenced radiographic patterns of maturation of the knee to develop a formula for knee-specific estimates of skeletal age, but this system is less widely used. The physiologic age is based on the Tanner staging system (40) (Fig. 31.2; Table 31.1).

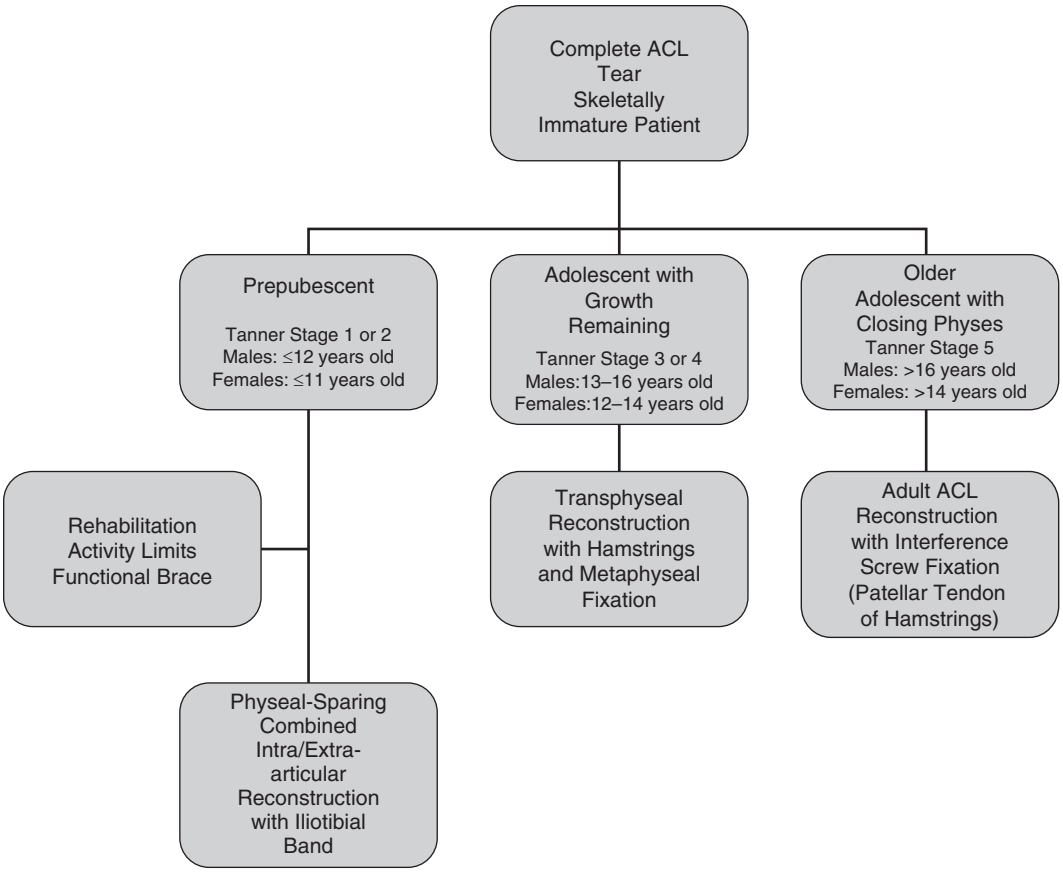


FIGURE 31.2

Algorithm for management of complete ACL injuries in skeletally immature patient.

TABLE 31.1 Tanner Staging Classification of Secondary Sexual Characteristics

Tanner Stage		Male	Female
Stage 1 (Prepubertal)	Growth	5–6 cm/y	5–6 cm/y
	Development	Testes <4 mL or <2.5 cm	No breast development
		No pubic hair	No pubic hair
Stage 2	Growth	5–6 cm/y	7–8 cm/y
	Development	Testes 4 mL or 2.5–3.2 cm	Breast buds
		Minimal pubic hair at base of penis	Minimal pubic hair on labia
Stage 3	Growth	7–8 cm/y	8 cm/y
	Development	Testes 12 mL or 3.6 cm	Elevation of breast; areolae enlarge
		Pubic hair over pubis	Pubic hair of mons pubis
		Voice changes	Axillary hair
		Muscle mass increases	Acne
Stage 4	Growth	10 cm/y	7 cm/y
	Development	Testes 4.1–4.5 cm	Areolae enlarge
		Pubic hair as adult	Pubic hair as adult
		Axillary hair	
		Acne	
Stage 5	Growth	No growth	No growth
	Development	Testes as adult	Adult breast contour
		Pubic hair as adult	Pubic hair as adult
Other		Facial hair as adult	Adrenarche: 6–8 y
		Mature physique	Menarche: 12.7 y
		Peak height velocity: 13.5 y	Peak height velocity: 11.5 y

The prepubescent child (Tanner stage 1 or 2) with a midsubstance ACL tear presents a difficult problem. Because of the large amount of growth remaining, the consequences of iatrogenic physeal arrest are severe. Unfortunately, activity modification such as refraining from cutting sports is difficult in this age group, and nonreconstructive treatment has been associated with meniscal and chondral injury (41–44).

Surgical techniques include physeal-sparing, transphyseal, and partial transphyseal reconstructions. In theory, the extra-articular reconstruction provides a method to restore stability and avoid risk of growth disturbance. Isolated extra-articular reconstructions in children have had variable long-term results. Nakhostine (45) reported on five patients with open growth plates who underwent anterior cruciate reconstruction with a strip of iliotibial (IT) band placed over the top of the lateral femoral condyle in a MacIntosh-type repair. At 4.4-year follow-up, the patients reported subjective satisfaction and ability to return to sport. Clinically, three of the five had ≥3-mm side-to-side difference on KT2000 testing and all the patients had a +2 Lachman test.

At our institution, we use a modification of the MacIntosh ACL reconstruction to perform a physeal-sparing reconstruction with an extra-articular and intra-articular component. A portion of the IT band is harvested from the lateral thigh. The IT band remains attached to the proximal tibia at Gerdy tubercle. The band is fixed to the proximal femur constituting the extra-articular portion of the reconstruction. The proximal portion of the IT band is then passed from the posterior aspect of the lateral femoral condyle through the intercondylar notch, under the intermeniscal ligament and fixed at the proximal tibial metaphysis to provide an intra-articular reconstruction. The results of 44 patients with a mean follow up of 5.3 years were examined. There were two failures at 4.7 and 8.3 years and no episodes of growth disturbance. The mean IKDC subjective knee score and the Lysholm score were 96.7 and 95.7 (47).

Surgical treatment with conventional transphyseal tunnels has been described (46,47). Liddle et al. describe the results of 17 patients treated with transphyseal ACL reconstruction with four-strand hamstring autograft. Eight Tanner stage 1 and nine Tanner stage 2 patients were followed for a mean of 44 months. The mean Lysholm score at follow up was 97.5. There was one failure due to an additional injury. One child was noted to have a 5-degree valgus deformity.

An alternative physeal-sparing technique using epiphyseal tunnels has been described by Anderson (49) (Fig. 31.3). A trans-epiphyseal technique using fluoroscopy was performed in 12 patients. The mean IKDC subjective score was 96.4 at 4.1 years with no graft failures or growth arrests noted.

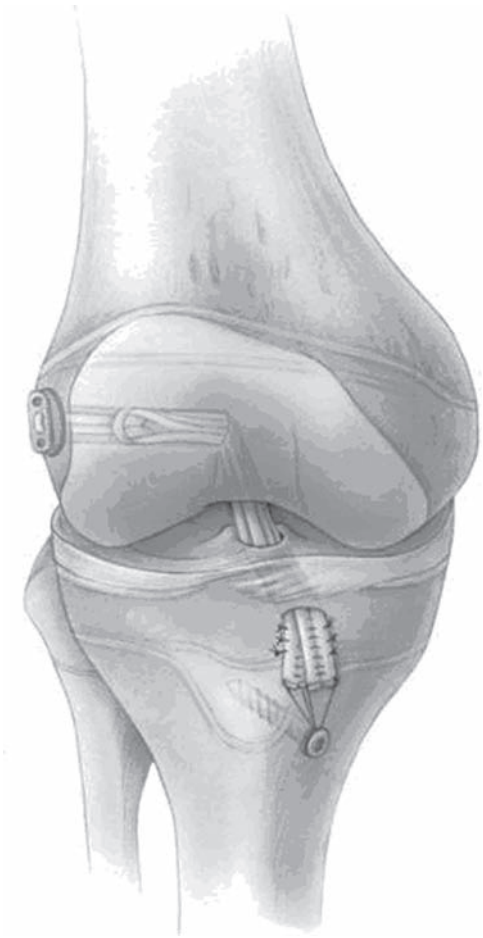


FIGURE 31.3
Physeal-sparing intra-articular ACL reconstruction with epiphyseal tunnels.

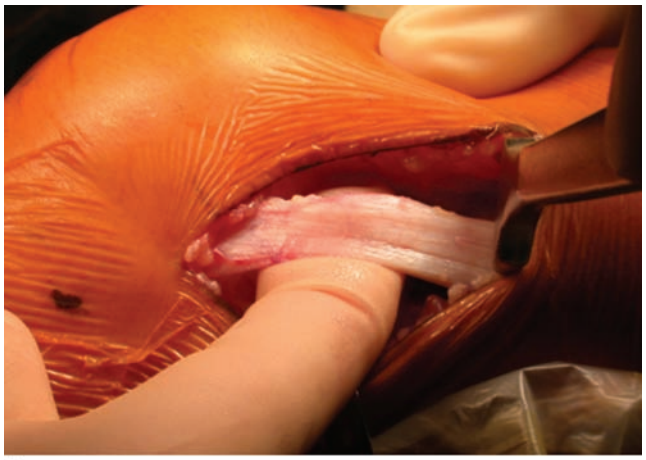
SURGICAL TECHNIQUE

Anterior Cruciate Ligament Reconstruction with the Iliotibial Band

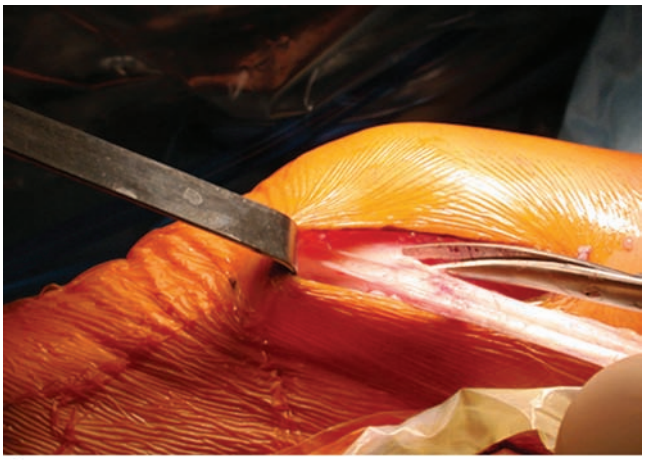
For prepubescent children, Tanner 1 or 2, a physeal-sparing reconstruction is recommended (48). Skeletal age is usually <14 in males and <13 in females. The patient is placed supine on the operating room table. Examination under anesthesia is performed to confirm Tanner staging and verify ACL insufficiency. The operative extremity is prepped and draped from the level of the foot to the level of a tourniquet placed at the thigh. It is important to place the tourniquet as proximally as possible in case a counterincision is necessary to assist in harvesting the IT band proximally. The insertion of the IT band on the tibia is palpated at Gerdy tubercle. The incision runs obliquely from the lateral joint line to the superior border of the IT band. The tourniquet is not routinely inflated in order to prevent tethering of the IT band. The incision is then made, and self-retaining retractors are placed. Dissection is carried down to the level of the IT band. In young, thin patients the IT band may be quite superficial. The anterior and posterior borders of the IT band are defined (Fig. 31.4A). Posteriorly, the IT band blends with the lateral hamstrings, and harvesting too posteriorly risks injury to the common peroneal nerve. A Cobb elevator is used to dissect the subcutaneous tissue away from the IT band along its course.

In order to harvest the IT tendon, a NO. 15 blade is used to make an incision at the anterior border, starting 2 cm above Gerdy tubercle. A Kelly clamp is placed in this incision and pushed posteriorly until the intramuscular septum is palpated. The clamp is then passed through the posterior border of the IT band just above the intramuscular septum. The clamp is then spread in line with the fibers of the tendon to start the posterior split in the tendon. Adhesions to the underlying tissue are often present and should be released. A meniscotome is used to extend the two incisions proximally. Two parallel cuts are made with the meniscotome in line with the fibers of the tendon and continued as proximally as possible. The angled meniscotome is then used to transect the graft proximally (Fig. 31.4B). If there is difficulty releasing the graft with the curved meniscotome a counterincision is made near the tourniquet.

The graft is tubularized and a whip stitch is placed at its proximal end with 5 ethibond. The tendon is separated from the underlying joint capsule and lateral femoral condyle. The capsule in this area is thin, but an effort should be made to maintain the integrity of the capsule to prevent fluid extravasation during later arthroscopy. The graft is left attached to Gerdy tubercle distally and tucked under the skin for the arthroscopic portion of the case.



A



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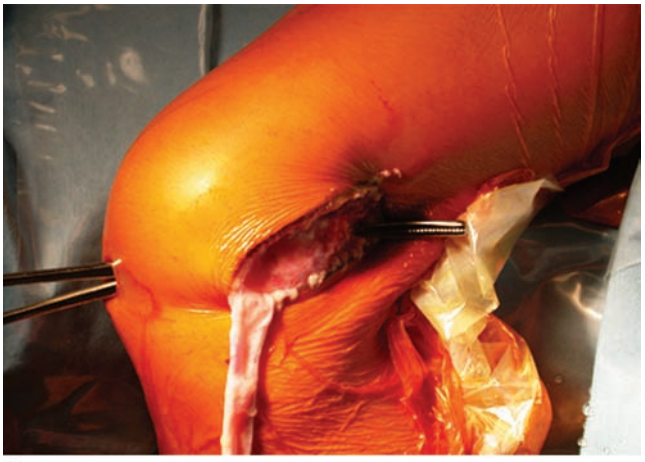

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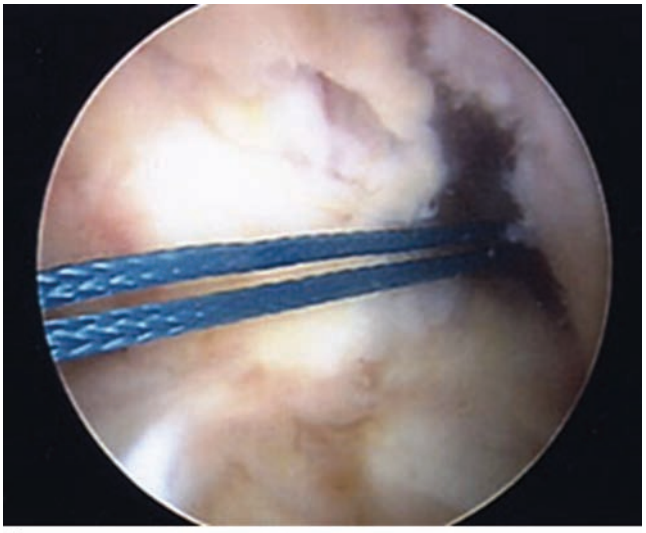

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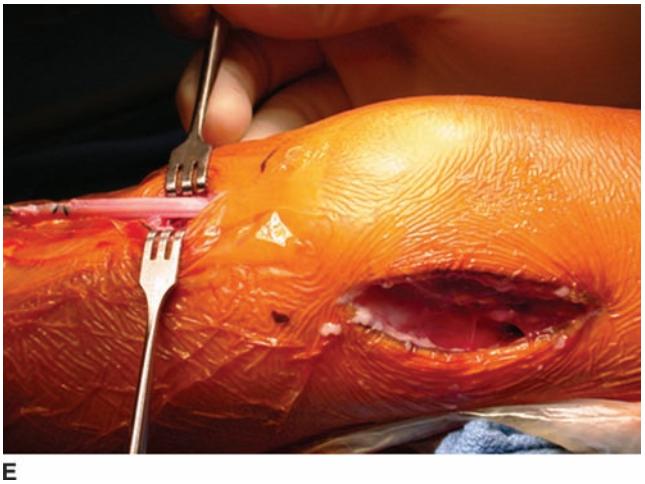

E

FIGURE 31.4

A–E: Physeal-sparing ACL reconstruction with autogenous IT band. **A:** The anterior and posterior borders of the IT band are identified through a lateral incision. **B:** The IT band graft is amputated proximally and released from the lateral condyle. **C:** A full-length clamp is placed into the over-the-top position arthroscopically and pushed through the posterior capsule. **D:** The graft is pulled into the over-the-top position. **E:** The graft is pulled under the intermeniscal ligament and delivered into the distal incision.

The leg is elevated and the tourniquet is inflated. The anterolateral viewing portal is established, and the arthroscope is inserted. An anteromedial portal is established under arthroscopic visualization. Diagnostic arthroscopy is performed and any associated injuries are treated. A limited notchplasty is performed to aid in visualization and identification of the over-the-top position on the distal femur. Excessive dissection should be avoided to prevent injury to the perichondral ring of the distal femoral physis during notchplasty. The distance from the femoral footprint of the ACL to the physis is typically 3 to 5 mm (50,51). Because there is no femoral tunnel, retaining a portion of the native ACL can help to maintain the position of the graft in the over-the-top position by acting as a sling.

Now it is necessary to pass the IT band into the over-the-top position. A full-length clamp is placed through the anteromedial portal and into the over-the-top position. The clamp is then passed through the joint capsule along the posterolateral femur and into the site of the IT band harvest (Fig. 41.4C). The clamp is then spread open to dilate a passage for the graft. The ethibond sutures at the free end of the graft are placed into the clamp, and the graft is passed into the knee joint (Fig. 31.4D).

The distal insertion of the graft is then prepared. An additional 3-cm incision is made on the anteromedial aspect of the proximal tibial. The incision must be distal to the tibial physis and medial to the tibial tubercle apophysis. Dissection is carried down to the periosteum. Under arthroscopic visualization, a rasp is then passed along the periosteum and into the knee joint proximally. The rasp must enter the joint underneath the intermeniscal ligament. Using the rasp, a groove is then made in the tibial epiphysis in order to translate the graft posteriorly and achieve a more anatomic position. A clamp is placed through this groove, and the graft pulled under the intermeniscal ligament and delivered into the distal incision (Fig. 31.4E).

Graft fixation proceeds from proximal to distal. With the knee in 90 degrees of flexion, tension is applied to the graft, and the proximal aspect of the graft is sutured to the periosteum of lateral femoral condyle. This forms the extra-articular component of the reconstruction and helps to limit rotation of the tibia. Distally, an incision is made in the periosteum of the tibia. Periosteal flaps are raised medially and laterally in order to accommodate the diameter of the graft. Care is taken to avoid excessive medial dissection as this risks injury to the tibial tubercle apophysis. A trough is then created in the tibia using a burr. With the knee in 20 to 30 degrees of flexion, distal tension is applied to the graft. 5 ethibond sutures are then placed through the medial periosteum, the graft and then the lateral periosteum. At least three sutures should be placed proximally in the femur and distally in the tibia (Fig. 31.5). Tibial fixation may be supplemented with a post if necessary.

Wounds are closed in layered fashion with absorbable suture. A sterile dressing and a cryotherapy unit are applied to the knee. A hinged knee brace is placed over the cryotherapy unit.

Postoperative range of motion is limited from 0 to 30 degrees for 2 weeks. A continuous passive motion unit is used for 2 weeks. Flexion is increased to 90 degrees from weeks 2 to 6, after which motion is unrestricted. Touchdown weight bearing in full extension is recommended for 6 weeks postoperatively. The patient may be placed into a simple hinge brace at 6 weeks. Jogging is instituted at 3 months with return to cutting sports at 6 months pending clearance. An ACL brace is worn for high-risk activities for the first 1 to 2 years after return to sport. Radiographs are obtained at 6 months to evaluate for physeal arrest (Fig. 31.6). Clinical follow-up with assessment for leg length discrepancy or angular deformity is done yearly for at least 2 years. Additional radiographs are obtained as indicated by clinical exam.

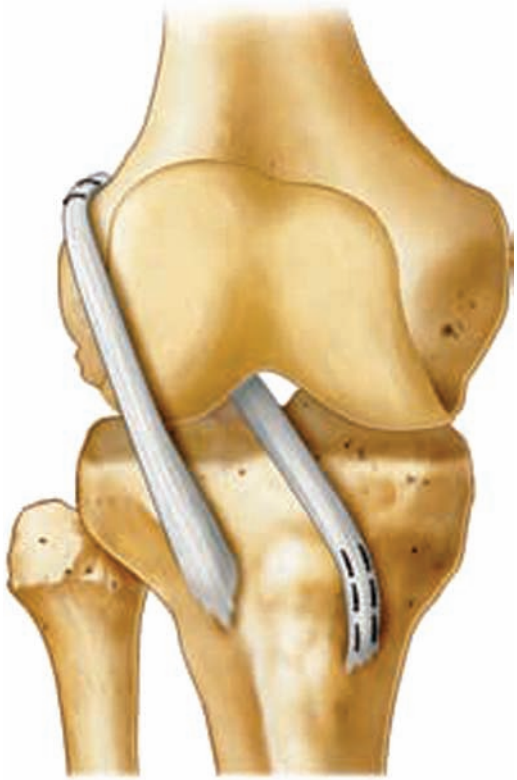

FIGURE 31.5

Combined intra-articular/extra-articular physeal-sparing ACL reconstruction.

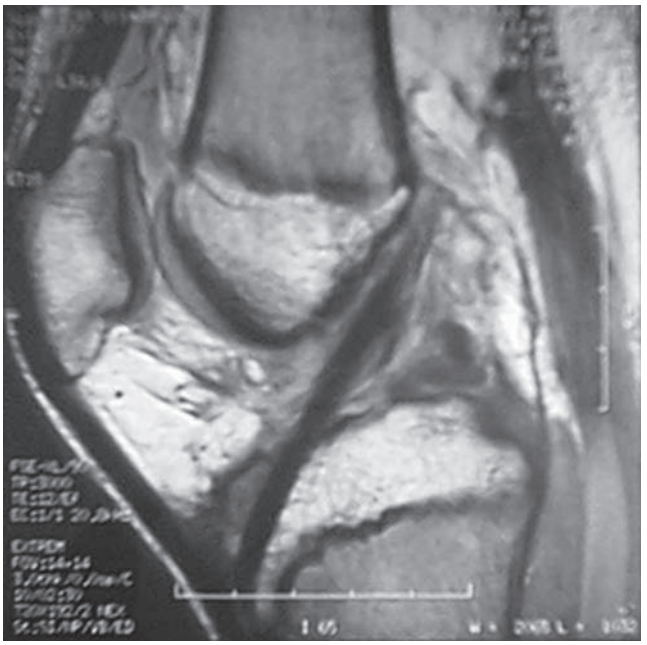

FIGURE 31.6
MRI s/p physeal-sparing ACL reconstruction.

Modified Transphyseal Anterior Cruciate Ligament Reconstruction with Hamstrings Autograft

The modified ACL reconstruction is indicated in the adolescent with significant growth remaining. These patients are typically Tanner stage III with pigmented axilla and pubic hair for boys. The females at this stage are typically postmenarchal. Another sign that the patient is nearing skeletal maturity is the lack of change in shoe size. For males the bone age is from 14 years until skeletal maturity and for females 13 years until skeletal maturity. Adolescents nearing skeletal maturity (Tanner IV and V) can be treated as adults with conventional bone tunnels.

Factors associated with growth arrest in transphyseal ACL reconstruction include placing hardware across the lateral distal femoral physis or tibial tubercle apophysis, bone plugs across the physis, large tunnels, and vigorous over-the-top dissection.

The patient is placed supine on the operating table. It can be useful to palpate the insertion of the hamstrings prior to prepping and draping the patient. A tourniquet is placed at the proximal thigh. The exam under anesthesia is performed. If the pivot shift is present, the hamstrings autograft is harvested initially. If the diagnosis is in doubt, diagnostic arthroscopy is performed first.

The leg is prepped and draped sterilely. The limb is exsanguinated and tourniquet inflated. The leg is placed in the figure of four position. Typically, the superior border of the medial hamstrings is 3 cm below the joint line. The superior and inferior borders of the hamstrings are marked 3 cm medial to the tibial tubercle (Fig. 31.7). A vertical incision is made, and dissection is carried down to the Sartorius fascia. Blunt dissection can be used to separate the Sartorius fascia from the subcutaneous tissue. The gracilis and semitendinosus should be palpated just below the Sartorius fascia. The thin layer of Sartorius fascia is carefully incised. A right angled clamp or

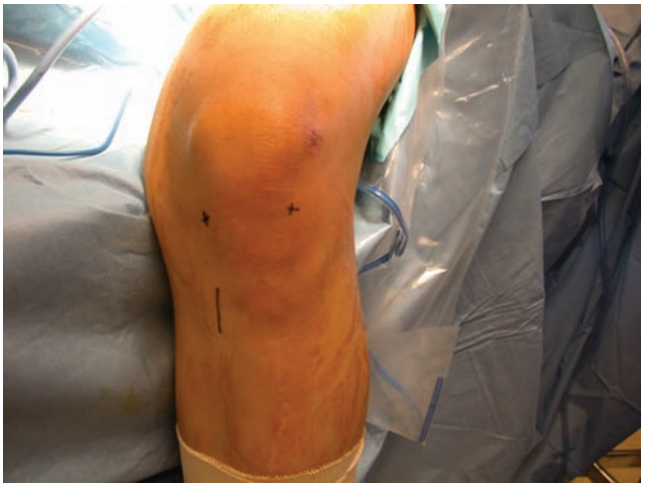

FIGURE 31.7
Incisions for transphyseal ACL reconstruction with hamstring.

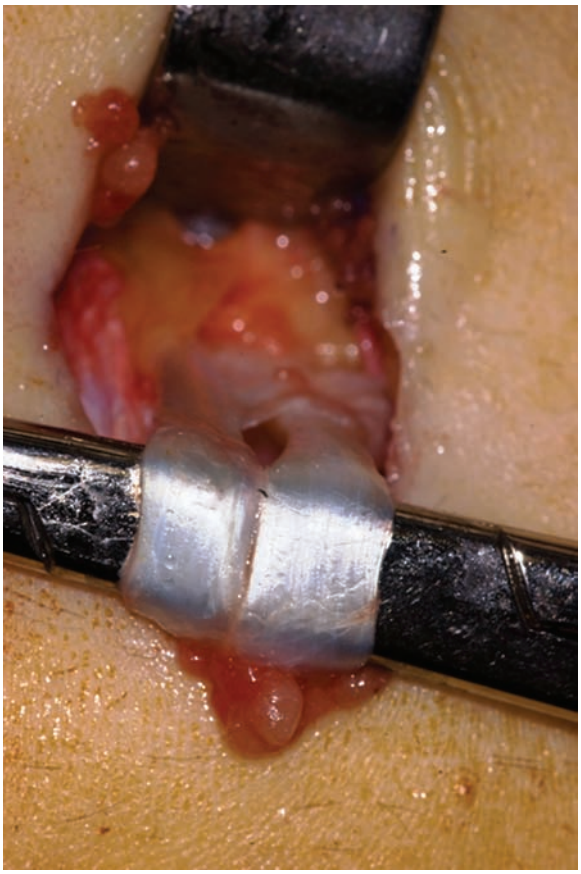

FIGURE 31.8
Gracilis and semitendinosus tendons identified.

Metzenbaum scissors are used to define the superior and inferior borders of the hamstrings tendons. The gracilis and semitendinosus are then isolated individually with vessel loops placed around each tendon (Fig. 31.8). A clamp may be passed deep to the tendons in order to apply distal traction on the tendons which will help free the tendons from the Sartorius fascia. The gracilis tendon is then dissected distally and released from its insertion on the tibia. Care should be taken to maintain a pick-up or clamp on the tendon to prevent proximal retraction after release. A whip-stitch is then placed in the free end of the tendon with 5 ethibond suture. This is repeated for the semitendinosus (Fig. 31.9). Distal traction is again applied to the tendons individually and any adhesions are released. Special attention should be paid to adhesions from the semitendinosus to the medial head of the gastrocnemius adhesions. Such adhesions can be quite fibrous and risk diverting the tendon stripper, which will result in premature graft amputation. The tendons are then harvested with a closed-loop tendon stripper and taken to the back table for preparation (Fig. 31.10). Excess muscle is removed from the proximal ends of the tendons and whipstitches are placed. The tendons are then folded over a closed-loop EndoButton to form a quadrupled graft, placed under tension, and covered with a moist sponge. Graft diameter is measured at this time.

A diagnostic arthroscopy is performed using standard and anteromedial and anterolateral portals. The menisci are carefully evaluated as there should be a low threshold for meniscal repair in this patient population. The soft tissue is cleared from the notch with a shaver. A limited notchplasty is performed if necessary for visualization or to avoid impingement (Fig. 31.11). The tibial guide is set at 55 degrees. With the leg hanging over the side of the table, the tibial guide is placed through the anterior medial portal. In order to avoid the tibial tubercle apophysis, the guide wire entry point on the tibia should be medial through the same incision used to harvest the hamstrings. The guide is typically at 20 degrees to the knee in the sagittal plane. The entrance for the tip of the guide is 5 mm in front of the PCL. It should be in line with the posterior portion of the anterior horn of the lateral meniscus and slightly more medial than lateral in the joint. The tibial tunnel is then drilled based on the width of the harvested graft (Figs. 31.12–31.13).

A bump is placed under the thigh to keep the knee at 90 degrees. A long guide pin is placed through the tibial tunnel to the over the top position on the femur. The pin is drilled through the proximal femur. The 4.5-mm EndoButton drill is then advanced through the lateral cortex. The pin and the drill are then removed from the knee. A depth gauge is used to determine the total tunnel length. The depth of the femoral tunnel is determined by subtracting the length of the EndoButton loop from the total length. An additional 8 mm are required to flip the EndoButton. For example, if the total tunnel length is 60 mm and a standard EndoButton length of 15 mm is used, the necessary femoral tunnel depth would be 45 mm. An additional 8 mm is added in order to flip the EndoButton, making the total drill depth 53 mm.

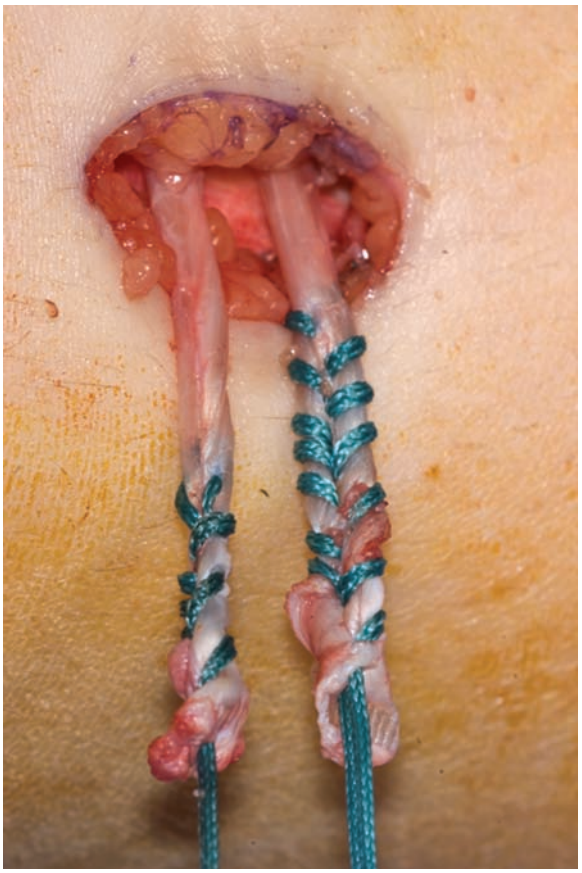

FIGURE 31.9

Tendons isolated, released distally and whip stitched.

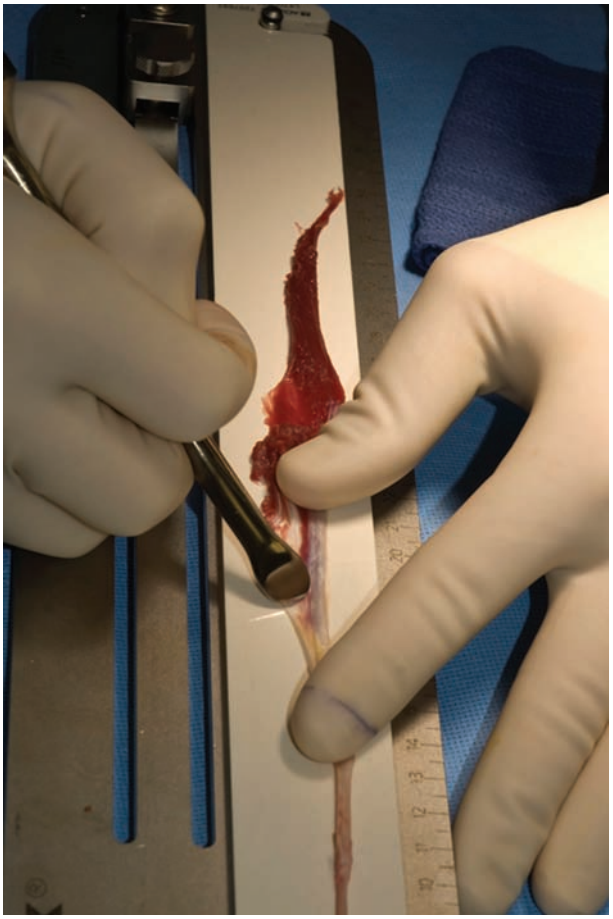

FIGURE 31.10

Graft preparation with removal of excess muscle.

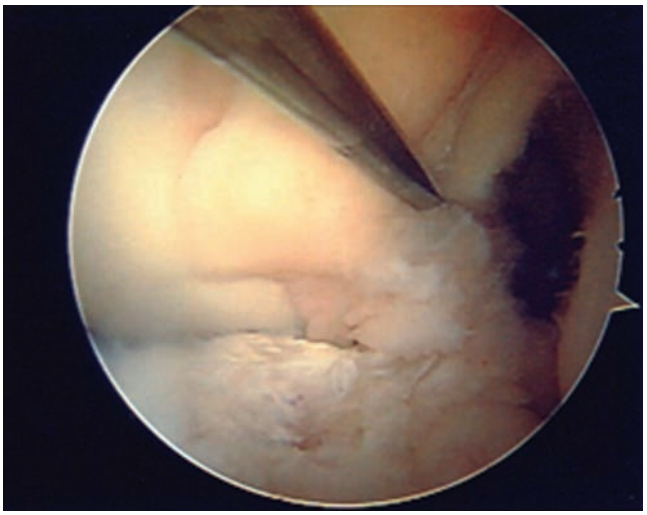

FIGURE 31.11
The ACL stump is debrided and the over-the-top position is visualized.

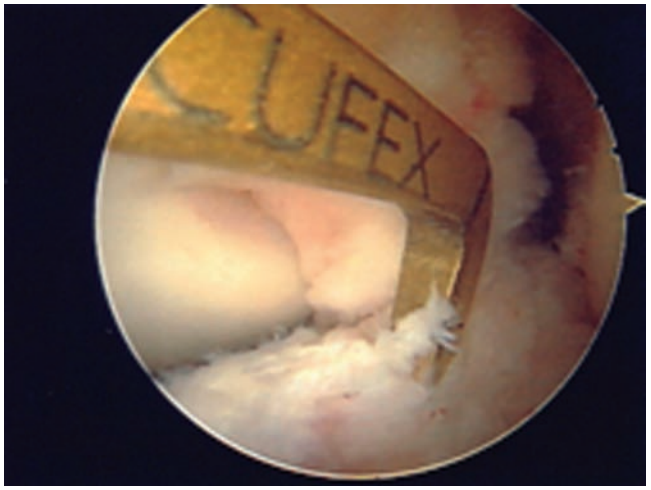

FIGURE 31.12
A tibial guide is used to make the tibial tunnel.

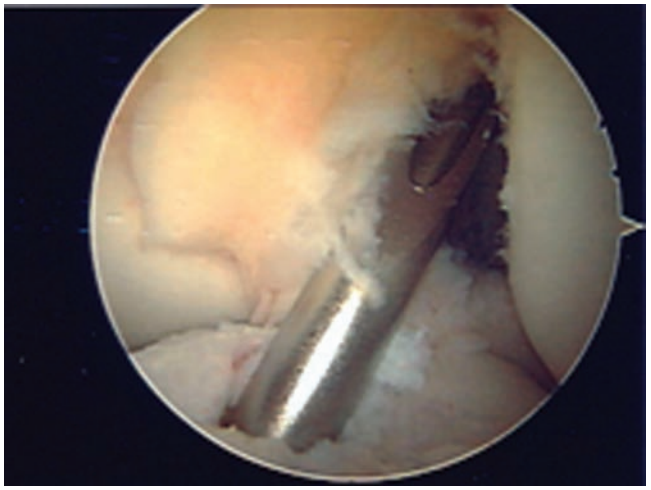

FIGURE 31.13
A transtibial femoral offset guide is used to make the femoral tunnel. Alternatively, the femoral tunnel can be drilled through a medial portal.

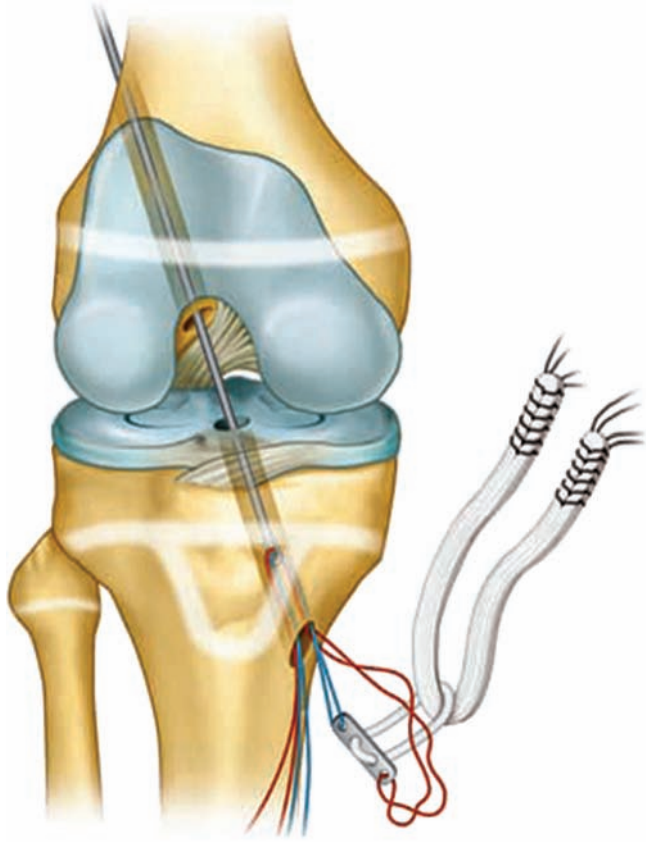

FIGURE 31.14
The leading sutures of the EndoButton are passed through the tibial and femoral tunnels.

The pin is then placed back into the femoral tunnel transtibially. The acorn drill corresponding to the width of the graft is then drilled to the calculated femoral depth. Excess bone should be removed with the shaver. A 5 ethibond suture is then placed at the end of the guide pin and pulled through the knee. If there is any question of the adequacy of the tunnels, the arthroscope can be placed through the tibial tunnel to visualize the femoral tunnel. The two passing EndoButton sutures are then secured to the number 5 ethibond and pulled through the knee. The two EndoButton sutures are then used to pass the graft through the tibial and femoral tunnels (Fig. 31.14). The EndoButton is flipped on the far cortex and fixation confirmed by pulling on the tibial end (Fig. 31.15). The arthroscope is placed back into the knee to evaluate the ACL graft. Additional notchplasty may be performed if there is evidence of graft impingement in extension. The length of the tibial tunnel should also be evaluated. The tibial physis can be visualized by placing the scope into the tibial tunnel. A gross measurement of the metaphyseal portion of the tibial tunnel can be made by bringing the scope up to the level of the physis and measuring the length of the scope within the tunnel. If this distance is <25 mm, an interference screw should not be used for fixation. A post, spike washer or staple may be used alternatively (Fig. 31.16).

If the tibial tunnel is of sufficient length, the graft is then fixed on the tibial side with a bioabsorbable interference crew (Fig. 31.17). Tension is applied to the graft at all time, and the knee is held in 20 to 30 degrees of flexion. Generally, the screw size matches the tibial tunnel diameter. The EndoButton sutures are removed from the femur. The wounds are irrigated and closed in layered fashion with absorbable suture. Sterile dressings, a cryotherapy unit, and a hinged knee brace are applied. Range of motion is limited from 0 to 90 degrees for the first 6 weeks postoperatively. Touchdown weightbearing with the knee in extension is maintained for 2 weeks. Home CPM is used for 2 weeks starting at 0 to 30 degrees immediately after surgery and advancing up to 90 degrees. After 6 weeks, rehabilitation and clinical follow-up are identical to physeal-sparing reconstruction (Figs. 31.18–31.20).

Sixty-one ACL reconstructions were reviewed in skeletally immature pubescent adolescents. Two patients underwent revision ACL reconstruction because of graft failure at 14 and 21 months postoperatively. For the remaining 59 knees, then mean IKDC subjective knee the score was 89.5 and the mean Lysholm knee score was 91.2 (52).

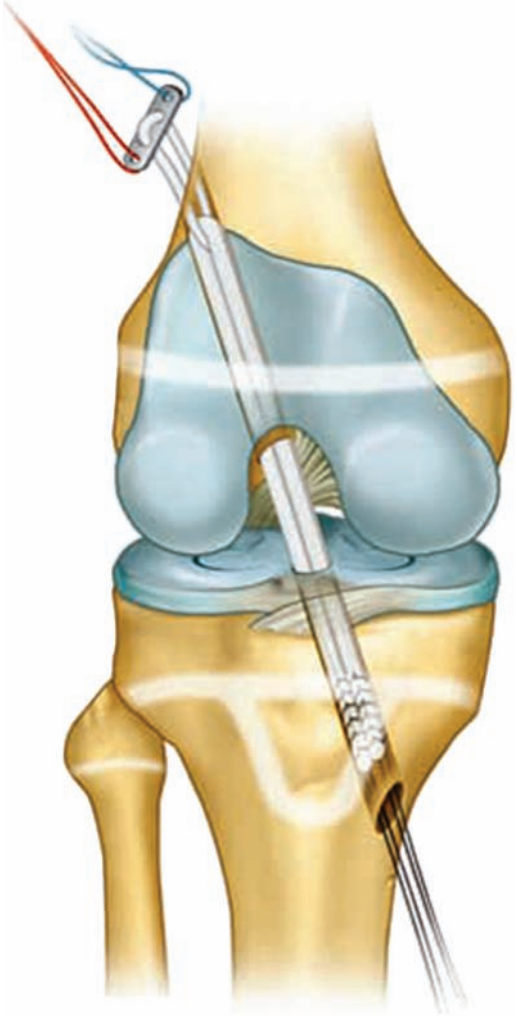

FIGURE 31.15
The graft is passed, and the EndoButton is flipped on the femoral cortex.

FIGURE 31.16
Alternative tibial fixation with a post.

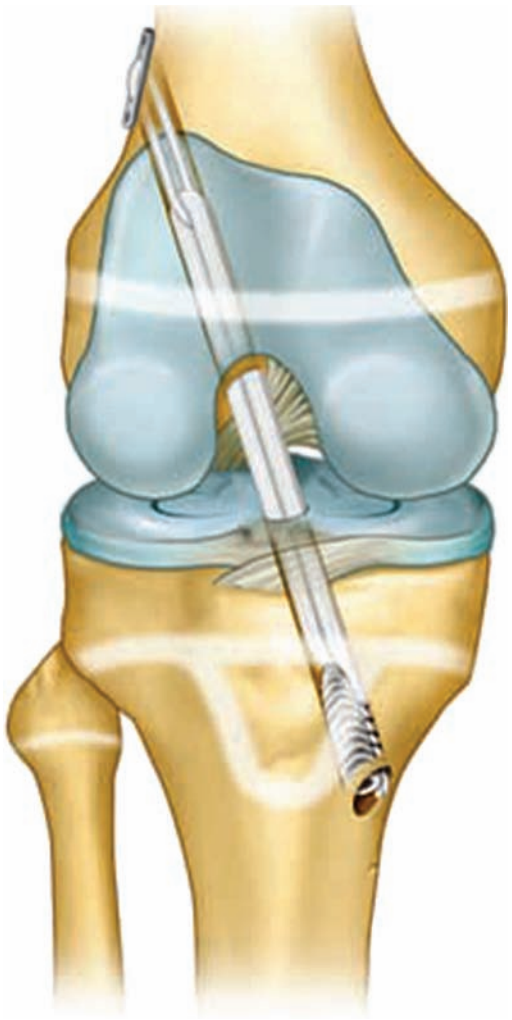

FIGURE 31.17
The graft is fixed distally using an absorbable interference screw.

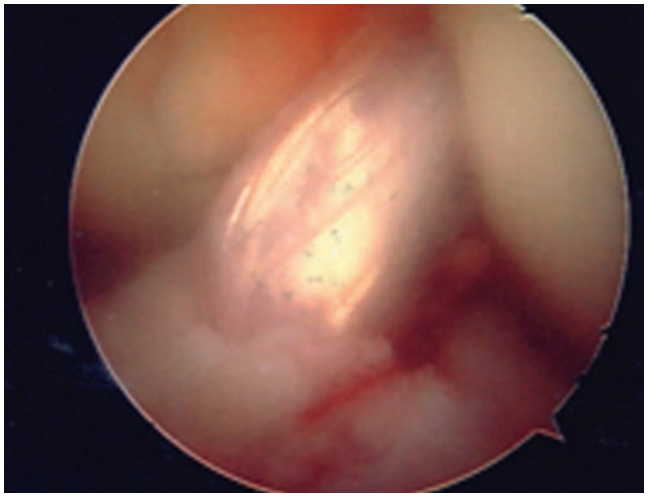

FIGURE 31.18
ACL reconstruction.

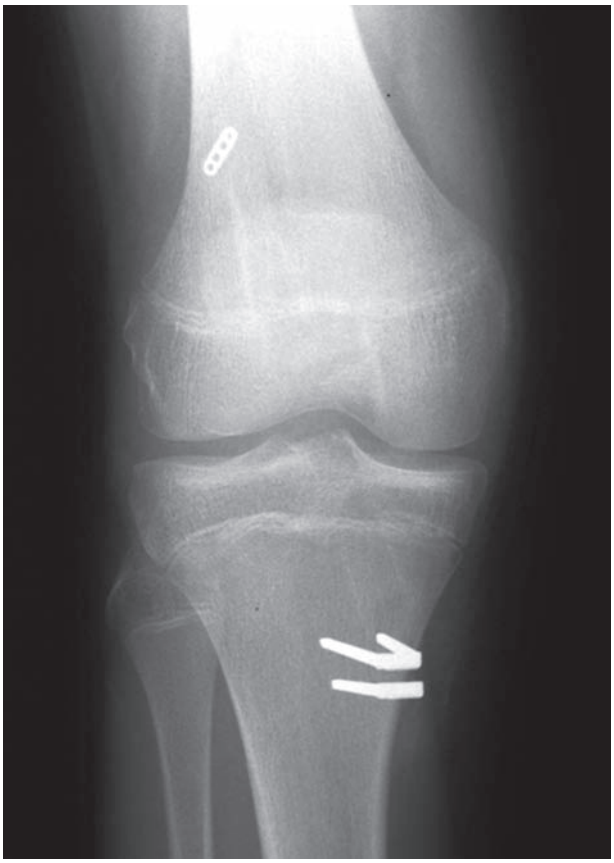

FIGURE 31.19
One month postoperative x-ray.

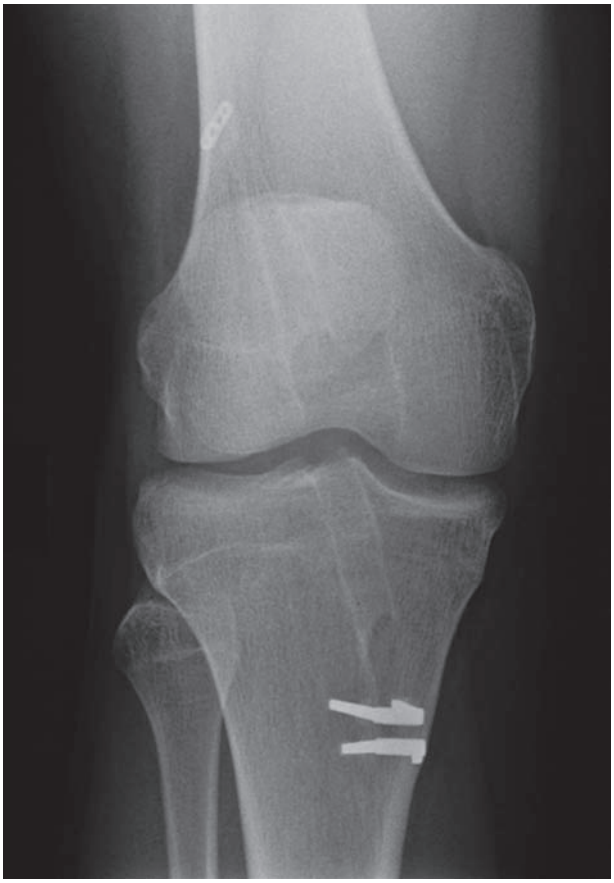

FIGURE 31.20
Four years postoperative x-ray.

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32 Revision Anatomic Anterior Cruciate Ligament Surgery

Todd M. Swenson and Darren L. Johnson

Over the past 3 decades, the incidence of anterior cruciate ligament (ACL) reconstruction has increased to a significant degree. This increase has likely occurred for a variety of reasons: an enlarging population base participating in competitive and recreational sporting activities; the explosive increase in the numbers of female athletes participating in ACL-dependent, high-velocity sports; improved means of diagnostic assessment and increased awareness on behalf of physicians; amplified exposure of orthopaedic surgeons, during their training and thereafter, to the surgical management of the ACL-deficient knee; and heightened knowledge and expectations from the ACL injured patient/athlete in our information-age society.

Performing ACL reconstructive surgery has become a very common component of many orthopaedic surgeons' practices (1). Incident to a larger number of primary ACL reconstructions being performed on an annual basis is an increasing need for revision procedures to address those reconstructions where failure has occurred. At present, we see this trend continuing and therefore anticipate that the number of revision ACL procedures will continue to rise.

A renewed appreciation, understanding, and study of native ACL bony insertion site anatomy and kinematic function have been rekindled in recent years (2–7); from this has grown the concept of "anatomic ACL surgery." Concerns exist that the popular transtibial arthroscopic technique will frequently not allow for complete anatomic placement of the femoral tunnel, often resulting in a vertically oriented ACL graft (8,9). When utilizing the transtibial technique, the placement and positioning of the femoral tunnel is limited and dictated by the position of the tibial tunnel; a nonanatomic location of the femoral tunnel will commonly result. This has led the authors and a growing number of other surgeons to modify their technique for primary ACL reconstruction. As an alternative to the transtibial technique, a variety of methods exist for creation of bone tunnels that match the native ACL femoral origin and tibial bony insertions; the use of these techniques can be employed during an anatomic single-bundle or double-bundle ACL reconstruction, depending upon surgeon preference and patient-specific anatomy. We carry these same principles forth in our approach to revision ACL surgery. Our goal is to provide the patient the means by which we may most effectively eliminate pathologic ligament laxity and restore anterior translational as well as rotatory stability with normal Kinematics; in our opinion, we feel this is best accomplished via a double-bundle anatomic ACL reconstruction. The procedure involves placement of two distinct and separate grafts representing the anteromedial (AM) and posterolateral (PL) components of the native ACL. Femoral tunnels are not drilled via the tibial tunnel, and greater flexibility exists to accommodate for patient-specific anatomy. Independent tensioning and fixation of the two grafts is performed in an attempt to maximally replicate the normal contribution each functional bundle has to knee stability throughout the arc of knee flexion.

Having familiarity with a variety of techniques for creation of bone tunnels and graft fixation as well as comfort working with several graft materials and configurations are important surgeon attributes for those performing revision ACL surgery. The ultimate function and success of a reconstructed ACL is dependent upon a combination of mechanical and biologic factors. Optimal interplay between a technically sound surgical procedure, a proper healing response, and a well-constructed rehabilitation process is needed in order to realize the best potential outcome. The goal of a primary ACL reconstruction is to replicate the anatomic position and kinematic function of the native ACL as closely as possible so as to allow the patient to return to their preinjury

state of comfort and function; these same goals, although proven more difficult to attain, are also sought in the revision setting.

The major focus of this chapter will center on the revision procedure performed for the patient who presents with recurrent instability after a failed previous ACL reconstruction; we will present and outline the details of our "optimal" revision technique. When appropriate, treatment of concomitant limb malalignment, acquired loss of motion, early degenerative changes, or compromise of secondary stabilizing constraints will serve to allow the most favorable outcome following the revision ACL procedure. Thorough discussion of the details surrounding the means by which each of these associated conditions would also be addressed, although important and not to be neglected is beyond the scope of this chapter.

INDICATIONS/CONTRAINDICATIONS

Surgical "failure" following an ACL reconstruction may be defined as loss of knee motion, persistent pain, dysfunction of the extensor mechanism, residual laxity (anterior translation and/or rotatory), recurrent functional instability, or a combination of factors. The true incidence of "failure" or "success" following reconstruction of the ACL is impossible to ascertain given the lack of broad-based acceptance regarding how each is defined. In high-demand athletes who perform at maximal performance levels, their subjective evaluation of their postsurgical knee may not match your objective evaluation. With respect to postsurgical ligament laxity and functional status, many objective measurements of our surgical results appear to inaccurately reflect patients' satisfaction and functional stability following reconstruction of their ACL (10,11). The presence or the absence of a pivot shift appears to be a better measure of functional stability than instrumented knee laxity (i.e., KT-1000 arthrometer) or Lachman examination and has a strong correlation with patients' perception of satisfaction, stability, and outcome (10–12).

From a structural standpoint, recurrent instability can lead to an overburdening and compromise of the secondary static restraints of the knee. Damage to the menisci, chondral surfaces, and possible progressive degenerative changes may also occur. Functionally, the patient may be unable to resume desired recreational or competitive sports participation and, at times, have difficulty with certain aspects of normal daily activities. Determining the nature and extent of the patient's presenting disability will allow an appropriate approach for treatment to be formulated and a realistic discussion of anticipated outcomes and expectations to follow.

Graft failure resulting in persistent increased knee laxity and/or recurrent functional instability may occur on the basis of technical, biological, or mechanical factors; a combination of etiologies is not atypical (13). Recognizing the possible cause(s) of graft failure is helpful prior to proceeding with a revision ACL reconstruction if the repetition of preventable errors is to be avoided. In our revision experience, errors in prior surgical technique are often the most common identifiable cause found contributing to failure of the previous surgical procedure. A nonanatomic, malpositioned femoral tunnel represents the technical error we most frequently encounter (followed by a posterior tibial tunnel); these tunnels are often vertical and/or excessively anterior in position.

Graft failures can be seen in the presence of prior well-positioned bone tunnels; this has not been a common occurrence in our revision experience. A traumatic event is often described and may represent the sole cause for graft failure; however, the astute clinician must seek other potential causative factors before ascribing "trauma" as the single explanation for loss of graft integrity, particularly when the failure presents <1 year from the index reconstruction. In patients found fitting this particular scenario, one should consider the following as possible contributing etiologies: overly aggressive rehabilitation protocol and/or a too early return to ACL-dependent activities, patient noncompliance, failure of graft fixation, or failure of graft incorporation. Even an optimally performed ACL reconstruction followed by appropriate patient compliance and rehabilitation may fail secondary to a lack of an adequate biologic healing response to the surgery; fortunately, this is not frequently seen. Traumatic failure should only be considered after verification of anatomic graft placement and the patient had truly returned to Level 1 sports at the same level before their primary ACL injury event.

Addressing all ACL revision cases through a single, regimented surgical technique will neither be possible nor necessarily appropriate. When technically feasible, the authors plan for the use of an anatomic, double-bundle ACL reconstruction for our revision ACL procedures. Independently tensioned grafts with abundant collagen tissue within the knee for control of both anterior translation and rotatory stability are sought. At times, patient-specific anatomy will not permit for a double-bundle reconstruction and an anatomic single-bundle technique is performed instead; this occurs infrequently and is not our preference except as mandated by anatomic or technical constraints.

Although this chapter outlines our thought processes with respect to approaching revision ACL surgery, these are simply concepts with accompanying technical suggestions. No single "recipe" will suffice for each patient as each revision procedure is truly unique and presents its own particular technical challenges. An ability to adapt one's technique to the patient's anatomy rather than taking a "rigid" approach of making the technique fit the patient is our recommendation.

PREOPERATIVE PREPARATION

A thoughtful and thorough preoperative assessment precedes and directs development of an appropriate surgical plan; both are imperative for achieving a successful outcome. A detailed history, physical examination, and radiographic evaluation are the essential components of the preoperative assessment. The patient is interviewed and a comprehensive history is obtained. It is of critical importance to ascertain the patient's primary presenting complaint. Limited range of motion or pain, even when found in association with abnormal ligament laxity, is not likely to be resolved through revision reconstruction alone.

Details surrounding any recent acute injury as well as symptoms and functional status of the knee since the time of the index reconstructive procedure are sought. The greater length of time that has transpired since recurrent instability began increases the likelihood of compromise to the secondary static restraints of the knee (posterior horn medial meniscus, collateral ligaments, PL complex). Any documentation from the prior surgery (i.e., operative report, arthroscopic pictures) that can be attained may be extremely useful. Information regarding the type of graft tissue that was used, nature and type of graft fixation utilized, associated procedures performed, and the status of the menisci and articular surfaces can be of significant assistance to the current assessment of the patient and subsequent planning of the revision procedure, as well as expectations the surgeon and patient can discuss.

Physical Examination

The patient is first evaluated in the standing position. Limb alignment and any asymmetry relative to the contralateral extremity are noted. Alterations in normal gait mechanics are sought, with the presence of a bent-knee gait or varus thrust being of particular concern. The location of prior surgical incisions, the condition of the skin, and the presence of any muscle atrophy are carefully assessed and documented. An examination of the neurovascular status of the limb is also completed.

With the limb in a resting, supported position, an evaluation for the presence of an effusion is performed. If an effusion is present, an arthrocentesis showing a hemarthrosis will indicate a new structural injury has likely occurred. If loss of motion is also present as a "new" problem for their usual laxity, one must be concerned about the presence of a large bucket-handle meniscal injury. Synovial fluid without bloody characteristics can be submitted for analysis including cell count and culture. Knee range of motion is assessed and compared to the opposite extremity. The prone position for assessing both passive extension and active and passive knee flexion is the most accurate means by which to document loss of motion relative to the opposite extremity. Loss of motion may be secondary to pain and swelling related to a recent acute event or may be more chronic in nature. When diminished range of motion is related to a recent traumatic event, a period of physical therapy followed by a repeat physical examination is warranted before a more definitive assessment of the knee and subsequent treatment plan are formulated.

Long-standing loss of knee motion can occur secondary to several possible etiologies; these include swelling in or about the joint, reflex sympathetic dystrophy, infection, arthrofibrosis, the presence of a mechanical block (i.e., Cyclops lesion, graft impingement, displaced meniscal tear), or capturing of the knee related to nonanatomic tunnel positions. In the presence of residual diminished motion resulting from a prior operative procedure, particularly lack of full extension, a treatment protocol (surgical and/or nonsurgical) aimed at restoring knee motion takes precedence over performing a revision ACL reconstruction. The revision procedure can be entertained after a functional range of motion has been reestablished.

To evaluate the nature of the abnormal laxity pattern found as a result of an incompetent ACL, the amount of anterior translation (Lachman test) and anterolateral rotatory instability (pivot-shift test) is documented. The ability to elicit a pivot shift in the office and grade its magnitude is inconsistent and variable, depending upon on a multitude of factors. Careful assessment for combined instabilities is sought through critical evaluation of the collateral ligaments (varus/valgus stress at 30 and 90 degrees of flexion) and PL/posteromedial structures (dial test at 30 and 90 degree flexion, PL drawer test, PL external rotation test, Slocum test).

Imaging Studies

Radiographic evaluation begins with standing full-length anterior-posterior (AP), 45-degree flexed weight-bearing posterior-anterior, lateral, and patellar view (i.e., Merchant, sunrise, infrapatellar) roentgenograms. Important information can be gleaned from these films including limb and patellar alignment, the size and location of prior bone tunnels, nature and location of associated graft fixation devices, geometry of the intercondylar notch, and the presence or absence of degenerative changes. If limb malalignment exists, correction via an osteotomy may be necessary, depending upon the clinical scenario. The combination of osteotomy and ACL reconstruction can be carried out as a two-stage procedure, with the osteotomy being done prior to the ligament reconstruction. If the two procedures are accomplished simultaneously, the osteotomy should be completed initially followed by creation of bone tunnels, graft passage, and finally, graft tensioning and fixation. If osteotomy is done, decreasing the slope of the tibia is done concurrently to aid in decreasing anterior pathology translations.

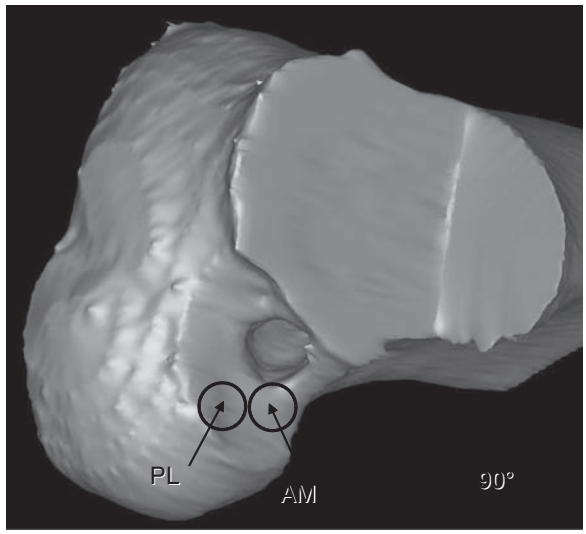

FIGURE 32.1
3D-CT SCAN shows nonanatomic high femoral tunnel with new anatomic PL and AM tunnels.

Computed tomography (CT) or three-dimensional CT scans (Fig. 32.1) can be extremely helpful in supplying a more detailed and accurate assessment of prior bone tunnel locations as well as the extent of any tunnel expansion or osteolysis that may be present. Magnetic resonance imaging (MRI) will provide abundant details regarding the integrity of the prior ACL graft, any injury or abnormality of the secondary supporting structures as well as the status of the menisci and articular cartilage; this information can assist the surgeon in planning for any additional procedures that may be performed in conjunction with the revision ACL reconstruction.

SURGERY

Performing a revision ACL surgery necessitates availability of all instrumentation typically utilized by the surgeon for a primary reconstruction. In addition, equipment that may be needed for removal of prior hardware, graft fixation, and possible alternative options for femoral tunnel creation should be present. Hardware removal may or may not be necessary, depending upon the position of the prior femoral and tibial tunnels. We recommend leaving previous hardware in place if it does not impede or obstruct creation of the revision bone tunnels in their desired locations. If removal of a prior fixation device is necessary, it may be accomplished with ease or at times, with great difficulty and significant bone loss. Having a variety of instruments on hand to assist with this task can be of enormous benefit; this should include osteotomes, curettes, trephines, end cutting reamers, and a universal screwdriver system. If "bioabsorbable" material was used for fixation during the prior ACL reconstruction, it does not preclude the possibility of encountering similar potential difficulties to those found in the presence of metal fixation devices. These materials often remain wholly or partially intact and may require removal depending upon their location. At times, these devices have begun to degrade and the process creates bone voids in their place; this may or may not have been appreciated on the presurgical radiographic assessment. We have found this to be problematic because of the poor bone quality around these "biodegradable" implants. The surgeon should be aware of this possibility and its potential implications.

When feasible, secondary incisions required for harvesting graft tissue, creation of bone tunnels, or to perform additional complementary procedures should be accomplished through the utilization or extension of prior skin incisions. When this is not possible, the surgeon should attempt to make any new incisions parallel to the previous incisions and with maximal skin bridges to minimize potential compromise of the vascular supply to the intervening skin.

Examination Under Anesthesia

A general anesthesia is used for all procedures. Preoperative intravenous antibiotics are administered. A padded pneumatic tourniquet is placed about the proximal thigh of the operative extremity. An examination under anesthesia is performed and always compared to the "normal" knee. Range of motion and laxity patterns of the operative and nonoperative extremities are assessed and compared. In the anesthetized state, void of muscular control, grading of ligament laxity, and the quality of endpoints may be different, and frequently underestimated, relative to that which was found during examination in the office setting. If the presence of concomitant ligamentous laxity is not recognized and properly addressed, repeat failure of the reconstructed ACL will likely result. When a combined pattern of ligamentous laxity is identified, options include: (a) staging the surgical procedure, with the secondary restraints addressed initially followed by a later reconstruction of the ACL; or (b) attending to all pathologic laxity through simultaneous surgical correction.

Patient Positioning

A successful surgical procedure begins with proper patient positioning. An arthroscopic leg holder is placed upon the proximal thigh of the operative extremity and secured to the surgical table at the break point of the bed. This leg holder is then positioned such that it is slightly elevated from the surgical table and angled toward the patient's head, placing the hip of the operative extremity between 30 and 45 degrees of flexion. The foot of the bed is then removed or maximally flexed. This combination of details for surgical limb positioning is necessary to allow for maximal hyperflexion of the knee, a position that is required during the method of medial portal drilling for creation of the femoral tunnels (Fig. 32.2). The nonoperative extremity is placed in a lithotomy-type position with the leg resting upon a well-padded support in a position of hip and knee flexion (each ~90 degrees) in addition to hip abduction and external rotation (Fig. 32.3). This position allows the surgeon or an assistant unobstructed access to the medial aspect of the operative extremity should any accessory procedures (i.e., inside-out meniscal repair, MCL/posteromedial capsular plication) be necessary.

Arthroscopy

Following sterile preparation and draping of the operative extremity, the surgical procedure is initiated. We attempt to perform as much of the arthroscopic procedure as is as possible without inflation of the tourniquet. Monitoring and control of the patient's blood pressure and use of an arthroscopic electrocautery device are beneficial in maintaining a clear field of visualization.

The importance of appropriately placed arthroscopic portals cannot be overemphasized. Poorly positioned portals may obscure adequate visualization and compromise the use of instrumentation during the procedure. We routinely utilize three anterior portals for visualization and instrumentation during all ACL reconstructions (14). These portals are each created with an 11-blade with the knee in a 90-degree flexed position. Depending upon surgeon preference, an additional superior-medial or superior-lateral portal for either inflow or outflow may also be employed. The anterolateral portal, familiar to all arthroscopists, is used solely for visualization during an ACL reconstruction. We place this portal tight to the lateral border of the patellar tendon, just beneath the inferior pole of the patella; this position will typically avoid penetration of the infrapatellar fat pad and

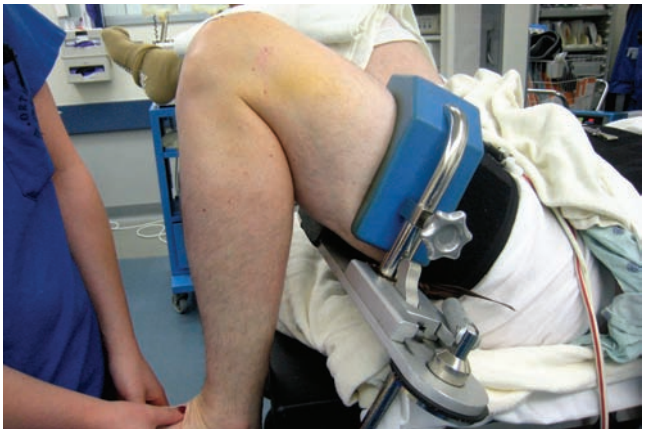

FIGURE 32.2
Arthroscopic leg holder positioned on the operative extremity to allow for maximal knee hyperflexion.

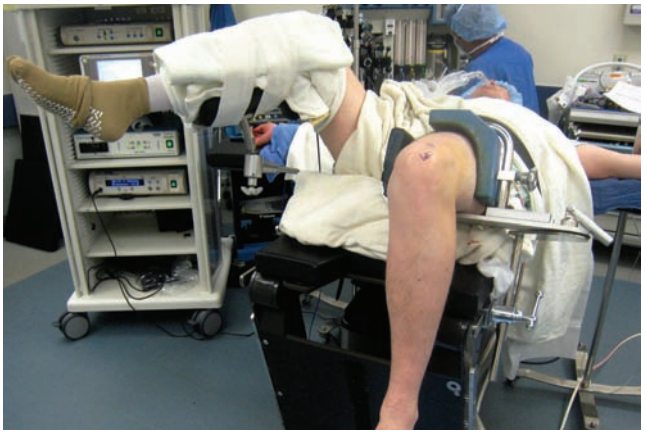

FIGURE 32.3
Patient positioning for a revision ACL reconstruction.

provides excellent access to all three compartments of the knee during diagnostic assessment. This portal also permits the surgeon to look down upon the anatomic location of the ACL tibial insertion, an important view during creation of the tibial tunnel(s). Making this portal to low will not allow one to see the entire ACL tibial footprint in the AP direction.

The central medial portal is established with the assistance of spinal needle localization. The position of this portal is immediately adjacent to the medial border of the patellar tendon and above the medial meniscus directly in line with the ACL tibial footprint. Debridement of a portion of the infrapatellar fat pad may be necessary to improve the ease of using instrumentation entering through this portal. When visualizing through the central medial portal, the surgeon is provided an unobstructed view of the entire lateral intercondylar wall and posterior aspect of the notch. Visualization of the posterior portion of the lateral intercondylar wall and adjacent over-the-top position can be difficult and less than optimal while viewing only through the anterolateral arthroscopic portal. The central medial portal serves as both a working portal and a viewing portal at points during the revision ACL procedure.

The third anterior portal is the accessory AM portal; its location is more medial and slightly inferior relative to the adjacent central medial portal (Fig. 32.4). This portal is created under direct visualization with the arthroscope in the anterolateral portal and viewing in a medial direction. A spinal needle is placed just above the medial meniscus with a superior and laterally directed trajectory; the needle will pass just in front of the medial femoral condyle (Fig. 32.5). This portal will be utilized for drilling of the femoral bone tunnels. The location of this portal is critical; before creating the skin incision, the spinal needle position is adjusted in anticipation of allowing passage of an appropriate diameter single fluted annulated reamer to the lateral intercondylar wall without causing iatrogenic damage to the articular cartilage of the medial femoral condyle.

Following creation of the standard arthroscopic portals, a systematic diagnostic assessment of the entire intra-articular aspect knee is undertaken. Any identified chondral or meniscal abnormalities are addressed accordingly. Attention is then focused upon the revision ACL reconstruction. All remaining previous graft material is carefully resected. Identifying and visualizing the over-the-top position in the posterior aspect of the notch is critical. The intra-articular locations of the prior bone tunnels and the fixation hardware are sought (Fig. 32.6). We recommend that a nonaggressive, methodical debridement be performed so as to minimize bone

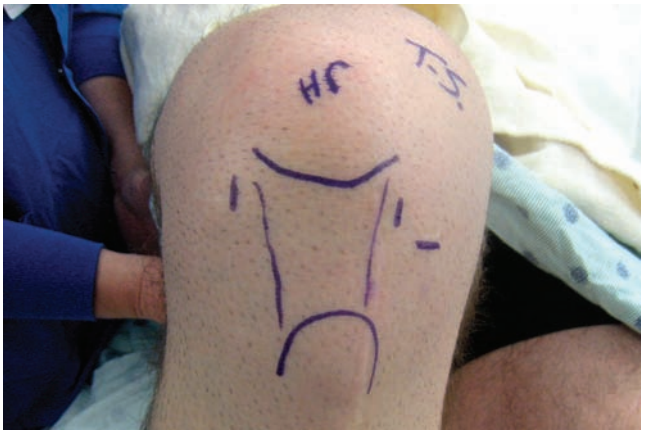

FIGURE 32.4

Landmarks are drawn on the skin of this right knee. In this photo, the approximate positions of the three anterior arthroscopic portal sites are marked (from left to right: anterolateral, central medial, and accessory AM). Also depicted are the inferior pole of the patella superiorly, the tibial tubercle inferiorly, and the borders of the intervening patellar tendon. The surgical scar from the previous ACL reconstruction runs along the medial border of the patellar tendon.

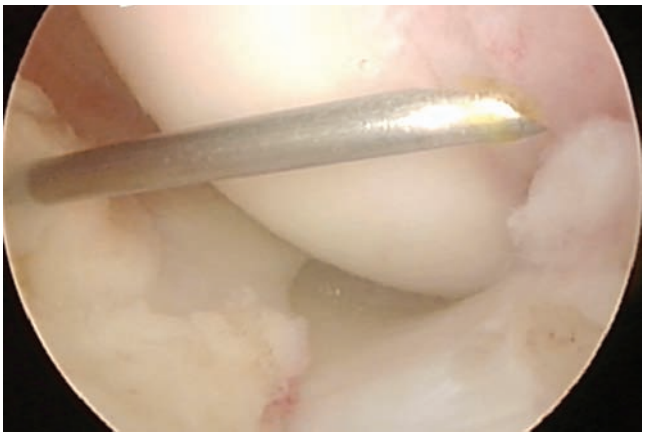

FIGURE 32.5

Arthroscopic view from anterolateral portal looking medially, showing a spinal needle localizing the position of the accessory AM portal. This portal will be used for drilling of the femoral bone tunnels.

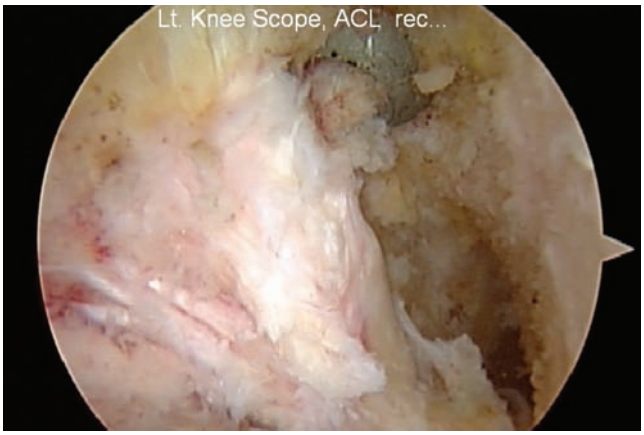

FIGURE 32.6

Retained femoral interference screw high in the notch (anterior, vertical position) after removal of residual graft tissue and minimal notch debridement. The PCL is seen in the foreground to the left.

removal and any associated further distortion of anatomy. The traditional notchplasty removes bone to allow improved visualization from the anterolateral portal, but this will not be necessary when viewing occurs from the central medial portal. As little bone as possible should be removed during the notchplasty, particularly at the native anatomic attachment site. When any overgrowth of osteophytes creating stenosis of the notch is present, they should be resected; these are typically present only at the anterior aspect of the notch. In all circumstances, the surgeon should try to avoid removal of bone posterior to the aperture of the intercondylar notch so as not to lateralize the position of the femoral tunnel(s), changing the normal length of the individuals ACL.

Tunnel Location and Preparation

The most important technical aspect of a revision ACL procedure is the location and creation of the new bone tunnels. In a primary ACL reconstruction, the native ACL remnants and associated intact topical landmarks allow the surgeon to ascertain that particular patient's insertion site anatomy; drilling of proper anatomically positioned femoral and tibial tunnels is guided by the patient's unique anatomy, not by the guides themselves. In the revision setting, this important native anatomy has often been distorted or removed as a consequence of the prior surgical procedure. By clarifying the positions of the previously placed bone tunnels and having knowledge of ACL insertion site anatomy (3,5–7,15) the surgeon is able to begin the process of establishing new tunnels for the revision reconstruction. Our approach to a revision surgery applies the same anatomic concepts that we employ during a primary ACL reconstruction; however, in the revision setting, the characteristics and positions of the prior tunnels will dictate the specifics of our surgical technique.

We address the femoral tunnels initially and subsequently proceed with creation of our tibial tunnels. Our femoral tunnel sizes will dictate the corresponding dimensions of our tibial tunnels. Before proceeding with creation of the new bone tunnels, a thorough assessment of the patient's unique intercondylar anatomy as well as prior tunnel locations and characteristics is of paramount importance. Evaluating the tibial anatomy before drilling the femoral tunnels is necessary to assure that there are no specific findings present that may prohibit or impact upon the ability to perform anatomic double-bundle reconstruction. If the depth of either the lateral wall of the intercondylar notch measured with the knee at 90 degrees of flexion or the ACL tibial insertion site is ≤14 mm in length, a double-tunnel double-bundle reconstruction will not be feasible. In such a circumstance, an anatomically positioned matched single-bundle graft should be placed.

Comfort and familiarity with multiple techniques for creation of the femoral tunnel(s) is recommended. Possessing these skills will arm the revision surgeon with the means by which to address the many planned as well as unplanned details that may arise during this aspect of the procedure. We have found that in the majority of our revisions, use of the medial portal drilling technique for making our femoral tunnels is optimal. When the surgeon uses an outside-in or medial portal drilling technique for creation of the femoral tunnel(s), greater freedom in selecting a starting point is permitted. Although not frequently necessary, the use of a two-incision technique with a rear-entry guide or employment of the over-the-top graft position for the AM bundle may be warranted; having the appropriate equipment available and awareness of its proper use should not be overlooked. The revision ACL surgeon must be comfortable with transtibial, medical portal, two-incision outside in, and over-the-top femoral-sided techniques.

When a revision double-bundle ACL technique is performed, any problems with creation of the new femoral tunnels will usually involve the AM tunnel; this is based upon its possible proximity to the prior femoral tunnel. Establishment of the PL tunnel is typically in a "virgin" portion of the lateral intercondylar wall, located in a position unaffected by the prior surgery. This situation may change if more surgeons begin to convert to the double-bundle procedure. Our current experience has found that the vast majority of revisions are done with the index procedure having been accomplished via a transtibial drilling technique. In most of these situations, the femoral tunnel was placed vertical and/or anterior in location (Fig. 32.7). Even when the prior femoral

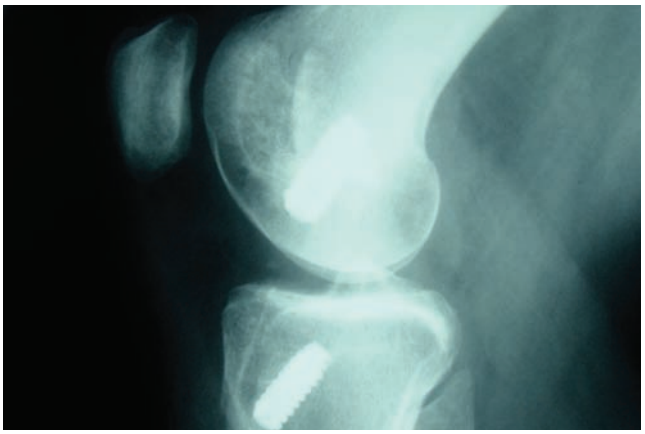

FIGURE 32.7

Lateral radiograph from a patient with a failed primary ACL reconstruction showing a femoral tunnel located in an extremely anterior position.

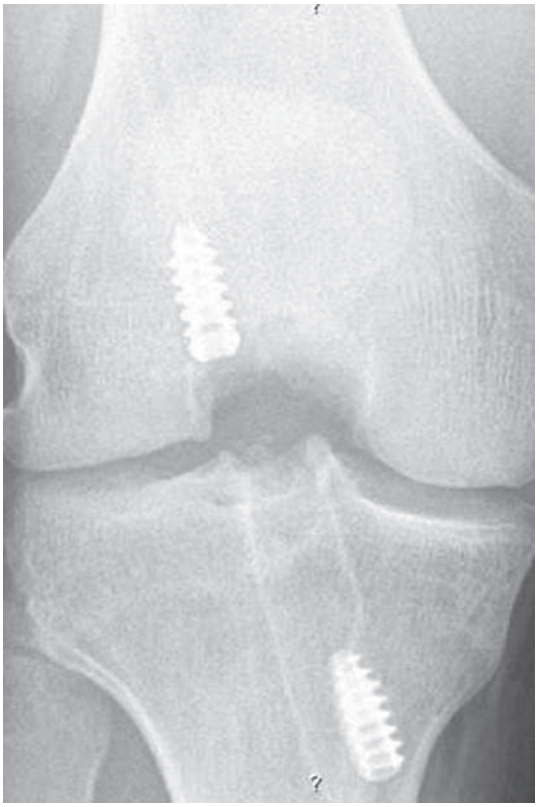

FIGURE 32.8

Radiograph of a patient with a failed previous ACL reconstruction done via a transtibial technique. This image shows a vertical position of the prior graft.

tunnel has been placed sufficiently posterior in location, it is usually "high" in the notch (vertical graft orientation) and not positioned in the anatomic location of the AM bundle (Fig. 32.8A and B). When this situation is encountered, we proceed with creation of our AM and PL femoral tunnels in a manner identical to that used for a primary anatomic double-bundle ACL reconstruction.

Starting points for the intended central positions of both AM and PL tunnels are made with a sharp pointed awl prior to guide wire placement. With the knee in 90 degrees of flexion, the approximate center of the PL bundle would be located along a vertical line projecting perpendicular to the horizontal axis and beginning from the point of contact made by the cam of the lateral femoral condyle with the tibial plateau (15). The vertical distance from this contact point should be half of the intended diameter of the PL tunnel (i.e., 3 mm for a 6-mm tunnel) plus an additional 2 mm to leave a cortical margin above the articular cartilage. The center of the AM tunnel will be located along a line extended posteriorly from the PL center point and along an axis angling superiorly approximately 25 to 30 degrees relative to the horizontal axis (again referencing with the knee in a position of 90 degrees of flexion). The distance posterior from the PL starting point is adjusted to allow maintenance of a posterior cortical rim after AM tunnel drilling, to allow a 2-mm bridge between AM and PL tunnels, and to create the desired AM tunnel diameter (Fig. 32.9).

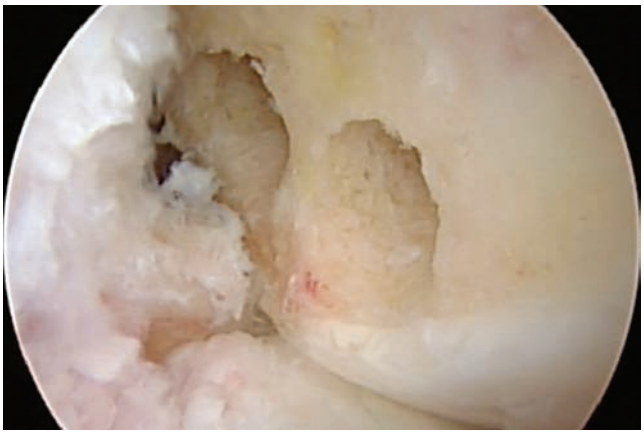

FIGURE 32.9

Revision femoral AM and PL tunnels in a left knee, viewed from the central medial portal with the knee at 90 degrees of flexion. Note the relationship of the tunnels to the articular cartilage and to one another. Refer to text for further description.

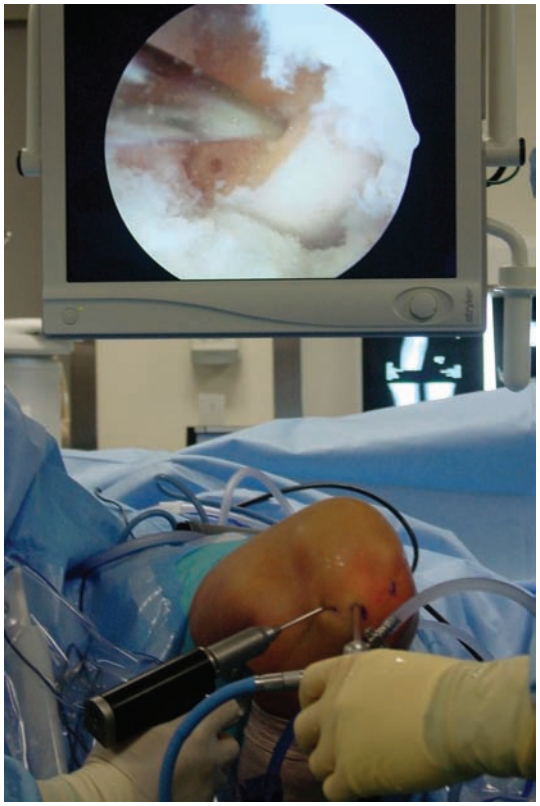

FIGURE 32.10

Arthroscopic drilling of the PL tunnel in a right knee, external view. Arthroscope is in the central medial portal and drill in the accessory medial portal. Arthroscopic image is seen on the monitor in the background. Note the hyperflexed position of the knee.

A guide wire is placed through the accessory AM portal and inserted into the selected starting point for the PL tunnel. A single flute cannulated reamer of appropriate diameter (5–7 mm) is placed over the guide wire and advanced to the lateral wall of the intercondylar notch. Care is taken to avoid iatrogenic injury to the articular cartilage of the medial femoral condyle while advancing the reamer. The tunnel is created while viewing through the central medial portal and with the knee held in 110 degrees of flexion (Fig. 32.10). The AM tunnel is created in an identical fashion although with the knee held in a greater degree of flexion, typically 130 degrees. Visualizing through either of the two medial portals provides an excellent view of both tunnels and allows the surgeon to assess their positions and integrity (Fig. 32.11). If applicable, either tunnel can be expanded incrementally with the use of tunnel dilators.

If concern exists that the creation of the AM tunnel will extend into a portion of the previous AM tunnel and thereby compromise the integrity of the new tunnel, the surgeon has several options. The first option would be to utilize the selected anatomic starting point but drill the new tunnel divergent from the old tunnel, either through the accessory medial portal (if possible) or via a two-incision outside-in technique. The two tunnels may have a small area of coalescence at their origin but diverge from one another more proximally, thereby maintaining integrity of the new tunnel over the majority of its length. When this situation arises, use of suspensory fixation or fixation distant from the tunnel entrance into the knee would be recommended. A second option would be to

place the AM graft in the over-the-top position. This would again necessitate use of a two-incision approach, a technique that may not be familiar to many recently trained surgeons. This is also an excellent option when, during the course of drilling the AM tunnel, the posterior cortical integrity is compromised or tunnel length is too short because of inadequate flexion during drilling. The final option that may be considered, one that we have not frequently employed, would be to bone graft the prior femoral tunnel and stage the reconstruction. In the few instances when this situation has arisen, significant tunnel expansion or osteolysis was present and conflicted with the other available options for creation of the new AM femoral tunnel.

The size, characteristics (prior soft tissue graft vs. bone plug, type of previous fixation device), and location of the previous tibial tunnel will dictate the options available for creation of the revision AM and PL tunnels. Options include creation of two new tunnels, use of the previous tunnel with creation of a second new tunnel, or expanding the previous single tunnel so that it will accommodate both grafts, which is not recommended. In the presence of significant tunnel expansion or associated osteolysis involving the previous tibial tunnel, a fourth option would be to bone graft the prior tunnel and stage the reconstruction. The preoperative assessment will often alert the surgeon to the presence of this latter possibility; however, it may arise unexpectedly based upon intraoperative findings, and this potential option should be discussed with the patient prior to surgery.

To initiate establishment of the AM and PL tibial tunnels, a commercially available guide is employed for placement of the guide wires. The proximal arm of the guide is positioned through the central medial portal while viewing through the anterolateral portal. The tibial tunnels are created with an effort to maximize divergence of the two tunnels distal to their respective entrances into the knee. Ideally, the AM tunnel is initiated medial to the tibial tubercle with the guide set at 55 to 60 degrees; the PL tunnel is placed more posteromedial in location relative to the AM tunnel and with the guide set at 45 degrees. The distance between the starting points of the two guide wires should be a minimum of 2 cm to allow for a 1-cm cortical bridge after drilling of the tunnels. The guide tip is placed within the center of the anticipated AM tunnel location using the anterior horn of the lateral meniscus as landmarks to assist with positioning; the PL guide wire enters the knee more posterior and lateral, with the posterior root of the lateral meniscus serving as a point of reference. Guide wire positions and spacing within the tibial ACL footprint are assessed prior to tunnel drilling (Fig. 32.11); if desired, a lateral fluoroscopic image with the knee in full extension can be obtained to confirm anatomic positioning. The diameter of each tibial tunnel is made to match its respective femoral tunnel dimension. The AM tibial tunnel is created with a cannulated reamer whose size is 1 mm smaller than the intended diameter of the tunnel. The tunnel is then expanded to its ultimate diameter with tunnel dilators of 0.5-mm increments. By so doing, the metaphyseal bone within the tunnel is compacted, improving its structural characteristics. The PL tunnel is next created in an identical fashion. Because the anatomic position of the PL tunnel is located immediately anterior to the bony insertion site of the posterior root of the lateral meniscus, caution should be utilized as this reamer emerges into the knee. In situations where the tibial metaphyseal bone is of poor quality, a tunnel dilator can be left within the AM tunnel while establishing the PL tunnel in order to minimize errant drilling. After both tunnels have been created, appropriately sized dilators are positioned within each tunnel so that 5 to 10 mm is emerging into the knee (Fig. 32.12). The knee can then be brought into full extension and assessed for any impingement. If the tunnels are anatomically positioned, no impingement should be noted unless bony overgrowth of the notch is present. If necessary, bone can be resected from the roof of the notch using a high-speed burr.

At their entrance into the knee joint, the two tibial tunnels may coalesce into one another; this is *not* a detrimental occurrence and will not preclude separate tensioning or fixation of the two grafts because of their divergent paths distal from their respective entry points into the knee. The amount of tunnel length that is "shared" proximally by the adjacent tunnels may preclude aperture fixation or use of an interference screw whose length corresponds to the full length of the tunnel. When interference fixation is sought, use of a shorter screw confined to the distal aspect of the respective tunnels may be necessary.

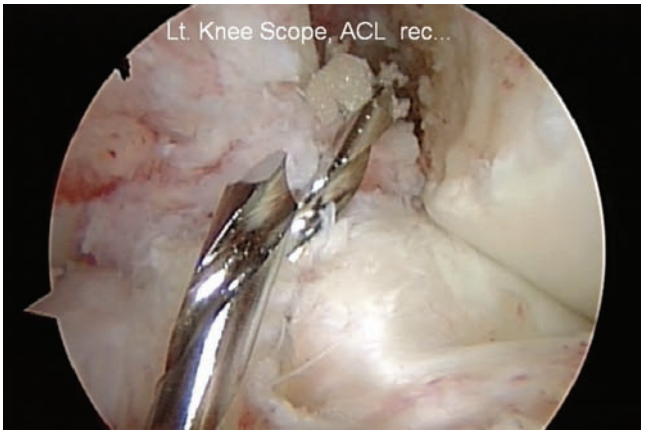

FIGURE 32.11

Arthroscopic view of left knee from anterolateral portal showing position of AM and PL tibial guide wires prior to tunnel drilling.

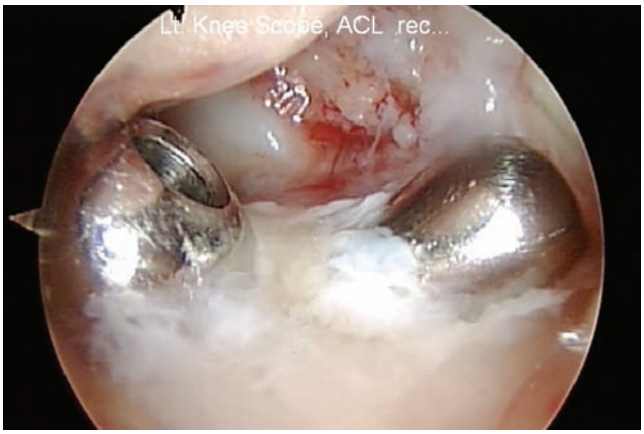

FIGURE 32.12

Tunnel dilators in position after creation of the revision AM and PL tibial tunnels in a left knee, viewed from the anterolateral portal. Dilator in the PL tunnel is to the right, AM tunnel dilator to the left.

In certain instances, the previous tibial tunnel can be utilized for one of the two revision tunnels. This will be possible if its entry point into the knee corresponds to the appropriate anatomic site for either the AM or the PL tunnels. A guide wire can typically be passed into the previous tunnel in a retrograde fashion and its entrance site into the knee visualized. If beneficial, a fluoroscopic image may also be employed at this point. A determination can be made accordingly as to whether this tunnel position would be acceptable for either the AM or PL graft. In our experience, when the index procedure was performed using a transtibial technique, the tibial tunnel is typically posterior in location and can potentially be used for the PL tunnel. Any prior graft soft tissue in this tunnel should be removed. The tunnel is reamed to assure exposed bone throughout the circumference of the tunnel. If the tunnel size is larger in diameter than what will be used for the PL graft, fixation within the tunnel can be accomplished with a large-diameter interference screw. Alternatively, if an Achilles Tendon Bone allograft is being used for the AM graft, a portion of its excess bone can be fashioned into a free bone dowel. This bone can then be positioned in the tibial tunnel adjacent to the revision graft with subsequent insertion of an interference screw placed so as to compress the free bone graft into the soft tissue graft.

If the prior tibial tunnel position is central within the anatomic footprint of the native ACL tibial insertion, it may preclude creation of two new, distinct tibial tunnels. One option in this scenario would be to revise the ACL with a single-bundle graft positioned in an anatomic fashion. If allograft tissue is used, a large graft (~12 mm) can be placed in the central position for both tibial and femoral tunnels. Alternatively, two femoral sockets can be created along with a single, large tibial tunnel. The tibial tunnel is expanded to an appropriate size to accommodate both AM and PL grafts. The prior tibial tunnel can be expanded either symmetrically or eccentrically so as to occupy an appropriate amount of both AM and PL tibial insertion sites. With the AM graft typically being 8 to 10 mm in size and the PL graft being 5 to 7 mm in size, the tibial tunnel should be skewed in a slightly more anterior rather than central position to maximally mimic the position and contribution of each bundle. The grafts can still be tensioned and fixated separate from one another (see "Graft Fixation" section), but this will require the initial fixation to be done outside of the tibial tunnel. After each graft is fixed along the tibial metaphysis, an interference screw can be placed within the tibial tunnel for additional fixation strength.

After all four bone tunnels have been created, two passing sutures are placed in preparation for graft passage, one each for the AM and PL grafts. When the medial portal drilling technique has been employed, a passing pin with the free ends of a looped suture threaded through the eyelet is directed through the medial portal, retrograde through the PL femoral tunnel, and out the skin of the distal lateral thigh. This maneuver is performed with same knee flexion angle used during drilling of the tunnel. The loop of suture is slowly brought into the knee through the accessory AM portal as the passing pin is withdrawn laterally. A grasping instrument is introduced through the corresponding tibial tunnel and retrieves the loop of suture from within the knee and out the PL tibial tunnel. The process is then repeated for the AM tunnel (Fig. 32.13).

Graft Selection/Graft Preparation

As opposed to a primary ACL reconstruction, we recommend that bone tunnels be drilled *prior* to graft preparation during a revision procedure. The dimensions of the tibial and femoral bone tunnels that have been created will dictate the specific graft sizes that are to be prepared. This order of proceeding avoids the possibility of having initially harvested or prepared grafts and then encountering unanticipated circumstances that necessitate altering the surgical plans or the size of grafts needed. Graft preparation is accomplished once it is determined whether single or dual grafts are to be employed and their respective sizes are known. A separate sterile back table with all anticipated necessary equipment (standard instruments, graft preparation board, variety of suture material, power drill, oscillating saw) is utilized for preparation of the graft(s).

The choice of potential graft material for a revision ACL reconstruction includes autograft or allograft tissue. A variety of factors play a role in selecting the specific type of graft to be utilized for a particular revision ACL

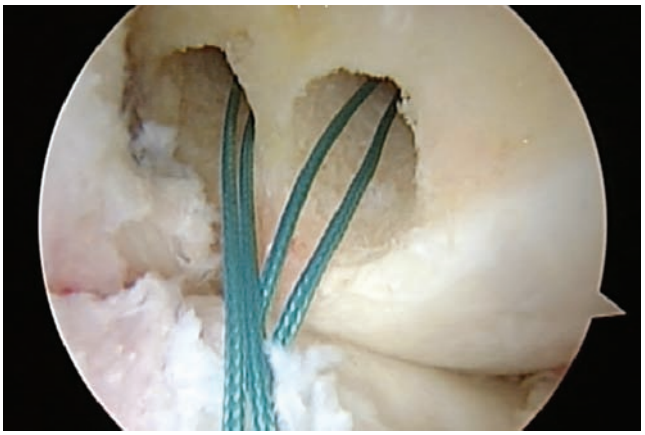

FIGURE 32.13

Passing sutures in place for delivery of the AM and PL grafts into their respective bone tunnels, viewed from the central medial portal.

reconstruction; these include, but are not limited to type of prior graft usage, amount and size of revision graft material needed, patient and surgeon preference, as well as cost. Autograft tissue can be obtained from either the ipsilateral or the contralateral knee. Graft options include bone-patellar tendon-bone, hamstring tendons, and quadriceps tendon with or without attached patellar bone plug. The advantages of autograft tissue include lack of potential disease transmission, lack of additional cost, and improved healing potential within bone tunnels. Disadvantages consist of increased operative time, potential graft harvest site morbidity, limitation of graft size, in addition to the possibility of limited graft choice based upon prior graft harvest.

The advantages and disadvantages surrounding the use of allograft tissue are reciprocal to those involving use of an autograft. Allograft tissue may have prolonged incorporation time in bone tunnels, does carry the possibility of disease transmission, and has an associated cost. At the same time, use of allograft tissue has no associated harvest site morbidity, does not have a limited supply, and can be customized with respect to graft size and type. Achilles tendon-calcaneus and bone-patellar-tendon bone are the most common allograft tissues that are utilized; semitendinosus and anterior tibialis all soft tissue grafts are also frequently employed.

When available and appropriate based upon preoperative preparation, we prefer the use of autograft tissue for at least one of our dual revision grafts. If patient-specific details and anatomy permit, a bone-patellar tendon-bone autograft for the AM portion of our double-bundle reconstruction is utilized; this is particularly true if the failed primary reconstruction was done with allograft tissue. Hamstring tendon size is quite unpredictable prior to its harvest and may not be of insufficient diameter for the AM bundle. The PL bundle is often reconstructed with the use of an all soft tissue graft; hamstring autograft or a soft tissue allograft can be used. If autograft hamstring tissue is to be used, one tendon (gracilis or semitendinosus) is harvested initially. The tendon is doubled (or tripled if of sufficient length) and its diameter assessed. The PL tunnel need to be only 5 to 7 mm in size, and if a single tendon suffices, the second tendon need not be harvested.

Even when the presurgical plan is for use of only autogenous tissue, the surgeon must discuss with the patient the *possibility* of allograft utilization. The need for allograft tissue may occur because of intraoperative anatomic findings or unforeseen circumstances that arise during the procedure serving to preclude the use graft tissue comprised solely of autogenous origin. When such a scenario is encountered, a hybrid reconstruction should be considered (autograft + allograft) if at all possible. In other instances, the surgeon may know based upon preoperative findings that allograft tissue alone will suffice for the revision reconstruction. Each case is inherently unique and requires thoughtful discussion between surgeon and patient regarding the multitude of possible graft options and why plans may need to be altered in order to optimize outcome.

Graft Fixation

Graft passage and fixation is performed in a specific sequence. Initially, the PL graft is passed retrograde through the tibial tunnel and seated in its femoral socket by use of the previously placed passing suture (Fig. 32.14). A variety of fixation methods can be utilized depending upon tunnel length, tunnel diameter as well as the type of graft tissue. We typically employ suspensory fixation with the use of a 15-mm EndoButton (Smith & Nephew Endoscopy, Andover, Massachusetts) for fixation of our PL graft; this is a soft tissue graft and fixation outside of the tunnel will allow maximal tendon-to-bone contact about the entire circumference of the tunnel, an important variable for optimizing graft incorporation.

In a similar fashion, the AM graft is next passed and its femoral fixation performed. For our ACL revisions, the AM graft will typically have a bone plug on its femoral aspect (i.e., bone-patellar tendon-bone, quadriceps tendon-bone, Achilles tendon-calcaneus) and its passage may be somewhat more difficult, often requiring some assistance via an instrument introduced into the knee to help maneuver and seat the bone plug within the femoral tunnel. For a double-bundle procedure, we recommend a femoral bone plug length of no more than 20 mm. When the femoral tunnel bone is of good quality, interference screw fixation is an option. If bone

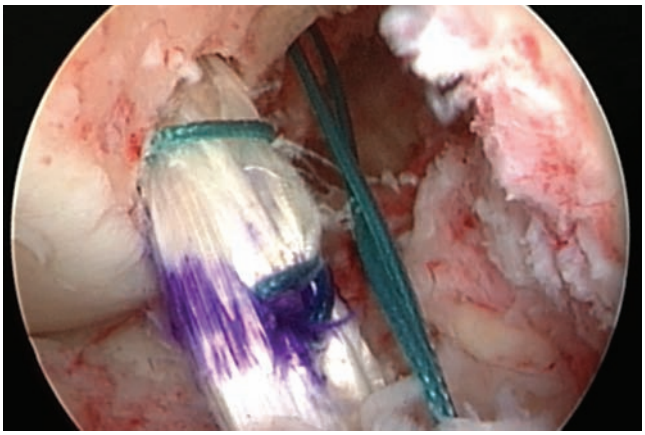

FIGURE 32.14
The PL graft is passed initially and its femoral fixation secured by use of an EndoButton.

quality is marginal, or if concern exists regarding the integrity of the tunnel's posterior wall, distant fixation should be considered; this can be achieved either through use of a suspensory device such as an EndoButton, or by tying the sutures attached to the graft around a bicortical screw and washer placed across the distal femur via a lateral incision. At this point, the grafts are pretensioned by taking the knee through 25 repetitions of full motion, while holding the tibial sutures taut. This maneuver will also permit a relative check of femoral fixation stability. The arthroscope is introduced into the knee and the grafts are assessed visually while taking the knee through a full arc of motion; this is done to assure that no graft impingement upon the PCL or notch is noted. However, it is perfectly normal for the grafts to load the bony outlines of the notch and PCL. Any adjustments deemed necessary can be made at this time, prior to committing to final graft fixation.

Tibial fixation is the final step in the procedure. Interference screw fixation within both tibial tunnels is preferred unless precluded by bone quality, which is not uncommon. Because early fixation compromise or graft slippage usually occurs on the tibial side, we routinely utilize both primary and back-up tibial fixation. The PL graft is fixed with the knee in a position of full extension. An assistant applies a slight posterior force to the anterior tibia while the surgeon fully advances the interference screw while maintaining tension on the graft sutures. The AM graft is fixed in an identical manner although with the knee positioned in 45 degrees of flexion. Supplemental fixation distal and external to the tibial tunnel(s) can be accomplished through a variety of means depending upon graft type and graft length (i.e., sutures tied over a fixation post and washer, soft tissue screw and washer, fixation staple). Following completion of the fixation process, knee range of motion is assessed to assure that no impediment to either full flexion or extension is present. The arthroscope is reintroduced into the knee and a final inspection of the grafts is undertaken. The grafts are probed to assure stability and appropriate tension in varying degrees of knee flexion.

Closure

Arthroscopic portal incisions are reapproximated with skin sutures. Incisions utilized for graft harvest or tunnel placement are closed in layers. A well-padded sterile dressing and a cold therapy unit are applied to the operative extremity. The leg is wrapped from the groin to the toes with an Ace bandage followed by application of a postoperative double-upright brace, locked in full extension.

Pearls and Pitfalls

- Expect the unexpected; challenges will frequently arise. The ability to accept and compensate for the unforeseen is often necessary, even in the face of optimal presurgical preparation.
- Identify the likely contributing cause(s) of prior graft failure and use that information to avoid the same errors during the revision procedure.
- Patient positioning is the initial prerequisite component to a technically successful revision ACL reconstruction.
- Assure necessary equipment availability for both planned and unplanned intraoperative findings and occurrences.
- Proper arthroscopic portal placement cannot be overemphasized.
- Knowledge and comfort with several techniques for creation of femoral tunnels (i.e., two-incision outside-in technique; the use of a rear-entry guide; the use of the over-the-top graft position) can be invaluable and will allow the revision surgeon an array of means by which to deal with patient-specific anatomy and obstacles presented as a result of the prior surgical procedure(s).
- Bone grafting a tunnel from the previous surgery and staging the revision reconstruction is preferable to accepting less than optimal anatomic tunnel positioning as a consequence of the anatomic alterations created

from prior bone tunnel positions and/or osteolysis. Anatomic tunnel placement is critically important to overall outcome.

- Primary *and* supplemental tibial-sided graft fixation is recommended for soft tissue grafts or other situations where impaired graft fixation is present.
- Intraoperative fluoroscopic images can be beneficial for confirming positions of bone tunnels whether or not uncertainty exists. It is particularly helpful in the early learning curve of those performing DB ACL surgery.
- An overly accelerated and aggressive rehabilitation protocol is *not* appropriate following a revision ACL reconstruction.
- Failure to identify and address laxity of the static secondary restraints will commonly lead to suboptimal restoration of knee stability and probable compromise or failure of the revision ACL graft.

POSTOPERATIVE MANAGEMENT

The historical development and promotion of an accelerated rehabilitation program following primary ACL reconstruction allowed for improved functional outcomes while diminishing associated complications resulting from prolonged immobilization and a delay in initiation of strengthening exercises. Until biologic incorporation of the graft into host bone occurs, graft fixation must be capable of withstanding normal cyclical forces during rehabilitation without graft slippage or pullout occurring (16). Animal studies have provided timelines with respect to graft incorporation, healing, and remodeling following an ACL reconstruction (17–19) and have served as guidelines for structuring the early phases of postsurgical rehabilitation protocols; knowledge of the native ACL strain behavior during various exercises (20) has been of additional benefit in guiding development of these protocols.

Two concerns have led to our use of a less aggressive, more prolonged rehabilitation protocol following a revision ACL reconstruction. First, we believe the revision patient may provide a "compromised" host environment, and as such, the biology of graft healing/incorporation could be impaired and lengthier relative to a primary ACL reconstruction. In addition, although graft revascularization may be complete at 6 months, further remodeling and development of increased tensile strength continues up until 12 months following placement of an intra-articular graft (18,19). It is our belief that an overly accelerated rehabilitation protocol, even in its latter phases, may have as a consequence, a negative impact upon graft maturation; the functional implications could be detrimental, particularly to the patient who strives to return to participation in ACL-dependent sporting activities. Principles outlined in a postsurgical rehabilitation protocol developed for patients recovering from a primary ACL reconstruction serve as a template to which we adhere following a revision procedure (21). In our revision patients, the timeline of progression through the protocol is, however, slower. When concomitant secondary procedures have been performed, adapting certain aspects of the rehabilitation protocol accordingly may be necessary.

Following an isolated revision ACL reconstruction, the surgical extremity is protected with a postoperative long leg hinged brace for 8 weeks. The patient is permitted crutch-assisted weight bearing as tolerated with the brace locked in full extension for the initial 6 weeks and unlocked during ambulation for an additional 2 weeks. The brace may be unlocked for range of motion exercises (i.e., continuous passive motion [CPM], seated knee flexion, heel slides) immediately following surgery. Early restoration of symmetric knee extension is of primary importance. Swelling is controlled through cold therapy, use of a compression stocking, and limitation of prolonged weight-bearing activity. During the period of protected weight bearing, physical therapy exercises are focused on achieving full range of motion, improving patellar mobilization while also initiating quadriceps isometric and closed kinetic chain strengthening. If available, aquatherapy can be utilized after the surgical incisions have healed. When in a pool, brace-free gait mechanics can be employed. As gait mechanics normalize and quadriceps strength improves, proprioception training and resistive exercises of increased intensity are begun. Initiation of plyometric exercises, introduction of running, and progression to functional training exercises are all delayed relative to a primary ACL reconstruction. The patient is fit with a functional knee brace prior to beginning their functional training regimen. A return to unrestricted activity, including sports, is typically delayed until 9 to 12 months following surgery.

ILLUSTRATIVE CASE

A 25-year-old male presented after incurring an injury to his right knee when he landed awkwardly after jumping to the ground from a modest height. He reported that his knee "buckled" upon impact with the ground followed by pain and a rapid onset of swelling. His past history was significant for a basketball injury 3 years prior that was treated with an autogenous bone-patellar tendon-bone ACL reconstruction performed using a transtibial drilling technique. The operative note from that procedure indicated no presence of any associated meniscal or chondral injury. Prior to his current injury but following his index ACL reconstruction, the patient indicated he had experienced occasional feelings of insecurity with recreational sports but denied any frank episodes of instability, periods of appreciable swelling, mechanical episodes of catching or locking, or any symptoms of pain.

Physical examination of the patient's injured right knee was notable for a 2+ Lachman test with an absent endpoint. Pain and guarding did not permit adequate testing for the presence of a pivot shift. No additional ligamentous abnormalities were present. Radiographic evaluation did not demonstrate the presence of any fractures, limb malalignment, joint space narrowing, loose bodies, or degenerative changes. The femoral tunnel from the prior ACL reconstruction was vertical and anterior in orientation with evidence of metal interference fixation of the previous ACL graft. No tunnel osteolysis was seen involving the prior femoral or tibial tunnels. MRI confirmed disruption of the ACL graft tissue, the presence of a vertical longitudinal tear involving the posterior horn of the medial meniscus, and a chondral injury of the weight-bearing portion of the medial femoral condyle. Characteristic bone bruises were also noted on the MRI images.

Given the combination of intra-articular injuries, the amount of pathologic laxity noted on exam, and the nature of the patient's lifestyle, a decision was made to proceed with a revision anatomic ACL reconstruction. A plan to simultaneously address the associated meniscal and chondral abnormalities was discussed with and accepted by the patient. After a period of rehabilitation to allow for resolution of swelling, to restore knee range of motion, and to allow for improved quadriceps function, the surgical procedure was undertaken.

Arthroscopic evaluation showed a midsubstance tear of the prior ACL graft; the graft tissue appeared to be poorly vascularized (Fig. 32.15). Within the medial compartment, an unstable vertical longitudinal tear of the posterior horn of the medial meniscus and a full thickness area of chondral injury involving the weight-bearing portion of the medial femoral condyle were confirmed (Fig. 32.16). After performing an all-inside medial meniscal repair (Fig. 32.17) and microfracture procedure of the medial femoral condyle (Fig. 32.18), we proceeded with a double-bundle revision ACL reconstruction. The location of the prior femoral tunnel and metallic interference screw was sufficiently distant from the anatomic positions of the AM and PL femoral tunnels so as not to necessitate screw removal nor alteration of our intended means of creating the new femoral tunnels through an accessory medial portal drilling technique (Figs. 32.19 and 32.20). Allograft bone-patellar tendon-bone tissue was utilized for the AM graft and autogenous gracilis tendon for the PL graft (Fig. 32.21). Femoral fixation for both grafts was accomplished with the use of an EndoButton. Fixation within the tibial tunnel for both grafts was achieved via a bioabsorbable interference screw. Supplemental metaphyseal fixation for the PL soft tissue graft was additionally utilized.

The early rehabilitation phase included 6 weeks of toe-touch weight bearing with a postoperative brace locked in extension. The use of a CPM machine was begun immediately postoperatively and continued for

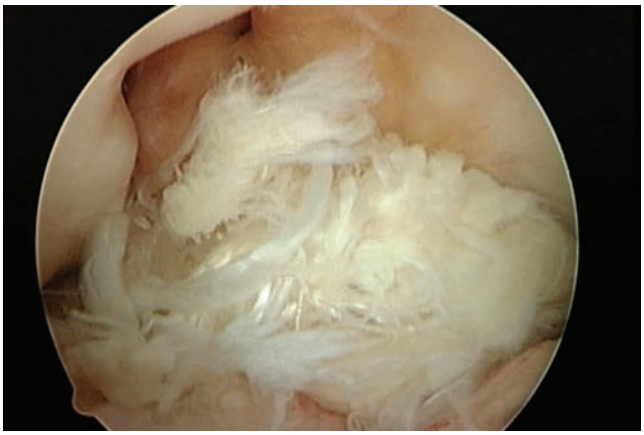

FIGURE 32.15

Arthroscopic view of a failed ACL graft following a traumatic event. Note the avascular appearance of the graft tissue.

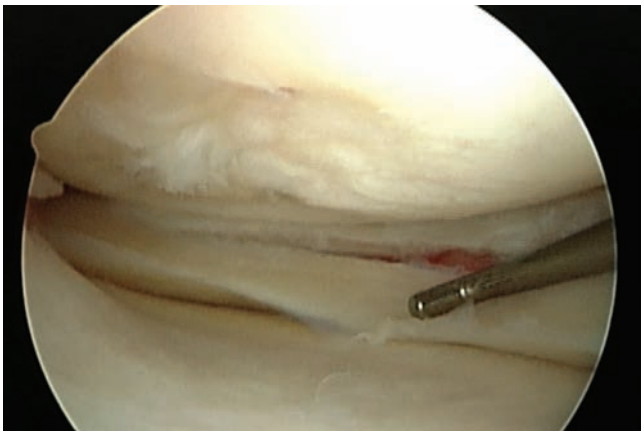

FIGURE 32.16

Arthroscopic view of the medial compartment showing a tear in the red-white zone of the medial meniscus and significant chondral injury involving the weight-bearing portion of the medial femoral condyle.

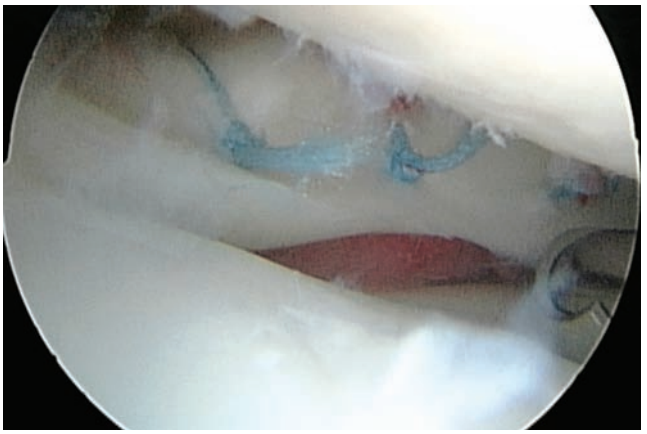

FIGURE 32.17

All-inside suture repair of a posterior horn medial meniscal tear.

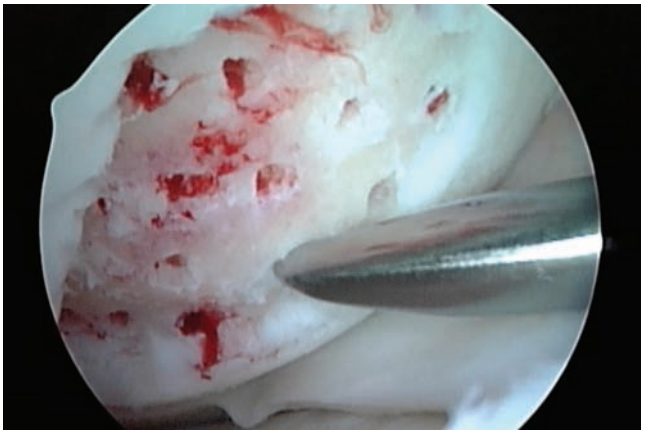

FIGURE 32.18

Completing a marrow stimulation microfracture procedure of the medial femoral condyle.

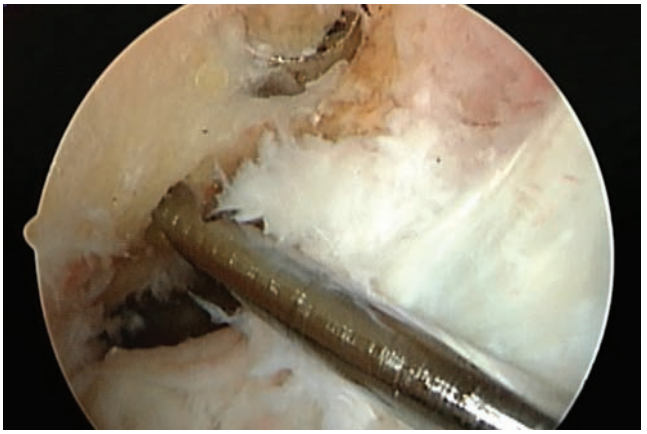

FIGURE 32.19

Guide wire entering from the accessory AM portal and placed into the center of the femoral AM bundle location. The anterior and vertical position of the prior femoral tunnel and associated interference screw did not inhibit placement of the new AM tunnel in its anatomic position.

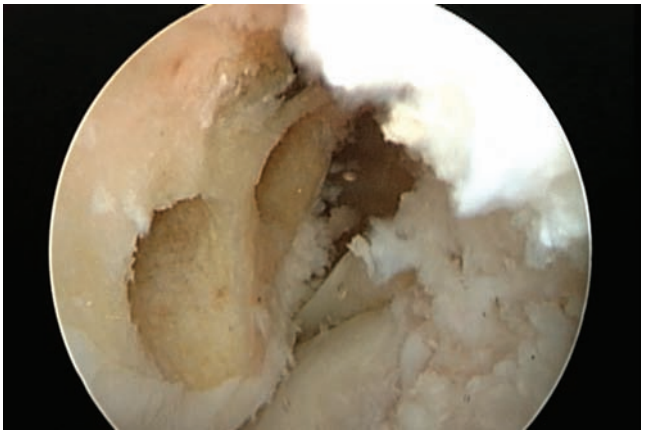

FIGURE 32.20

Arthroscopic view from the central medial portal showing the position of the AM and PL revision femoral tunnels with the knee at 90 degrees of flexion.

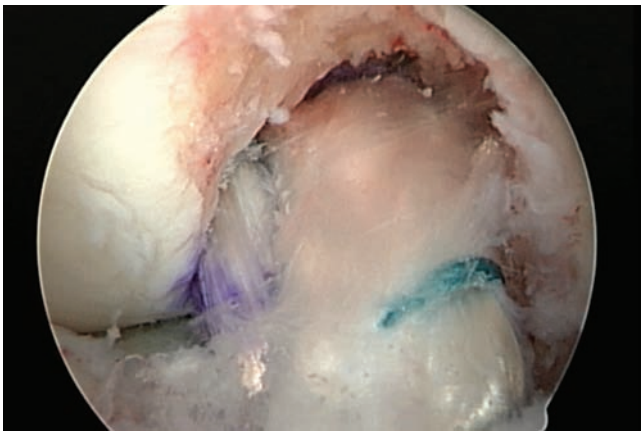

FIGURE 32.21
Final appearance of the revision double-bundle grafts, viewed here from the central medial portal.

a minimum of 6 to 8 h/d for the first 6 postsurgical weeks. After the initial 6 weeks, protected weight bearing with crutches and a hinged brace not restricting motion continued until gait mechanics were normalized. A supervised physical therapy regimen including use of a stationary bicycle, lower extremity muscle strengthening exercises, proprioception exercises, and aquatherapy was also utilized. A progressive running program and plyometric exercises began during the fifth postsurgical month. Functional training was initiated at 7 months following surgery. One year after undergoing his reconstructive procedure, the patient was reporting no pain, swelling, mechanical symptoms or episodes of instability. At this point in his recovery, he was permitted to return to unrestricted activities including sports.

COMPLICATIONS

Complications and untoward outcomes do not differ inherently from those that may be seen following a primary ACL reconstruction. There is nothing intrinsic to the revision procedure itself, which creates or exposes the patient to specific defined risks or potential complications not seen in the setting of a primary reconstruction. Infection, deep vein thrombosis, neurovascular compromise, risks associated with the use of allograft tissue, loss of motion, persistent effusion, failure of graft incorporation, loss of graft fixation, recurrent development of graft laxity or instability, progressive degenerative changes, etc. all may occur following a revision ACL reconstruction and warrant appropriate discussion with the patient as part of the standard preoperative dialogue and consent process.

RESULTS

A revision surgical procedure for a failed ACL reconstruction can provide for a gratifying outcome to both patient and surgeon. The necessary elements for this mutually positive result include the implementation of proper preoperative planning followed by critical attention to technical details during performance of the surgery. Specific presurgical consultation with the patient regarding motivation, expectations, and compliance with rehabilitation is another critical component of the presurgical preparation serving to maximize potential outcomes. Realistic expectations following revision ACL surgery have proven not to be equivalent to that of primary ACL surgery; this certainly should be the goal toward which we strive; however, reported results in the literature for revision ACL reconstructions bear out the inferior outcomes relative to those seen subsequent to primary ACL reconstructions (22–26).

The authors have adopted the use of an anatomic double-bundle technique as our preferred approach to the revision of a failed prior ACL reconstruction. Short-term outcomes are encouraging and warrant our continued interest and investigation. At present, the lack of appropriate long-term level I and II clinical studies limits our ability to ascertain whether the long-term functional outcomes will differ from those reported in the literature following single-bundle revision procedures.

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33 Computer-Assisted ACL Reconstruction

Stefano Zaffagnini, Simone Bignozzi, Nicola Lopomo, Danilo Bruni, Giulio Marcheggiani, Alessandro Russo, and Maurilo Marcacci

COMPUTER-ASSISTED ACL RECONSTRUCTION: RATIONALE

In the 19th century, Lord Kelvin Thompson stated, "*I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind*" (63), which can be summarized in "If it can be measured, it can be improved." This philosophy fully adapts to the concept of computer-assisted surgery (CAS). With the help of this technology, in the last years, the knowledge about anatomy and kinematics of the anterior cruciate ligament (ACL) has improved dramatically.

CAS in ACL reconstruction has now reached 15 years of research. First publications started in the second half of the 1990s (62). The main goal of the navigated procedures was to improve the correct position of the graft, using anatomical references and graft isometry during the range of motion, considering that 70% to 80% of the complications were due to malpositioned tunnels (16).

The purpose of these first systems was to augment the information given to the surgeon, in order to better identify the anatomical landmarks that were difficult to be recognized in an arthroscopic setup. The efficacy of these enhanced information given by computer-based ACL reconstruction was evaluated in the clinical use by Dessenne et al. (1,16) who demonstrated the feasibility of navigation in routine clinical setup. In addition, Klos et al. (28) in 1998 concluded that simple visual enhancements were useful to improve the repeatability of arthroscopic ACL reconstruction using radiographic tunnel position measurements as a comparison.

These studies, however, did not increase the interest of the orthopaedic community in this field for several years. The reason for this scarce interest in navigation was probably due to the unclear goal in tunnel placement and orientation during the ACL reconstruction. Also the isometry concept has been shown to be insufficient and the correct positioning of graft insertions is still a matter of debate (11,17,41,57,59). In addition, the costs and the time-consuming problems related to the use of this device were the major obstacles to the wide spreading in clinical practice.

More recently, thanks to more surgeon-friendly systems and to the evolution of software for computer-based ACL surgery, there has been an increased interest in this field. This development includes the possibility to perform stability testing, including rotational and translational measurements, or decomposition of complex clinical test such as pivot shift (6), allowing to better evaluate the effect of different surgical procedures to the stability of the knee and to better describe patients' specific laxity (46). The augmented performance of navigation systems allows to use this methodology to assess the performance of new and more complex reconstructive surgical techniques, such as double bundle. In fact, starting from 2005, there has been a big number of articles on navigated ACL and on anatomical double-bundle reconstruction techniques (Fig. 33.1).

The possibility to better understand and describe different surgeries and to characterize patients' specific laxity has moved the trend of navigation to a new concept: the "on demand" surgery, where kinematics and anatomy can be compared to a database of different surgical workflow, in order to better address the pathology for the specific patients.

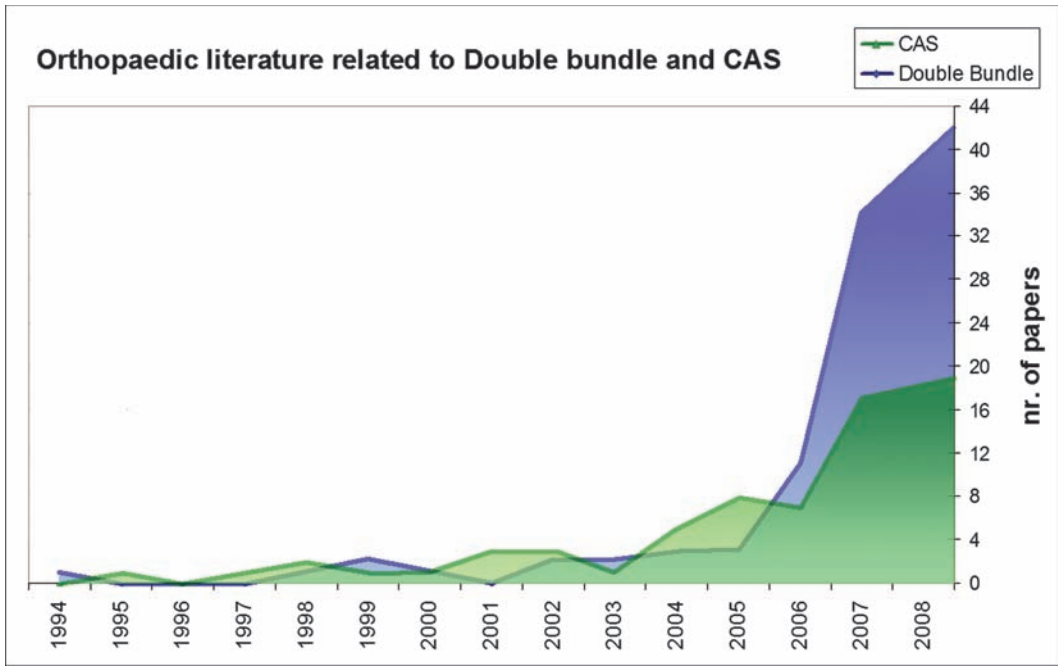

FIGURE 33.1
Publications about double-bundle and CAS ACL reconstruction in the last 15 years.

At present, instrumental evaluation during surgery, with the use of navigation systems, remains the more accurate procedure; therefore, several clinical studies have evaluated the effect of different surgical techniques to joint kinematics at time zero.

NAVIGATION TYPES

There are two types of navigation systems used clinically. Image-based systems that utilize anatomical data derived from different imaging methods, such as computer tomography (e.g., Navitrack [Orthosoft, Montreal, Canada]), intraoperative fluoroscopy (e.g., Vector Vision [BrainLAB, Muenchen, Germany], Fig. 33.2), or standard x-rays (e.g., SurgiGATE [Medvision Houston, Texas]).

Image-free systems rely on the acquisition of anatomical references during surgery and require no preoperative imaging. The anatomical data registration allows to create the virtual bone model of the patient. Most of the image-free systems are based on bone morphing (e.g., Praxim [Medvision, La Tronche, France], Fig. 33.3), which requires large numbers of data points to match the individual knee morphology to be modeled, increasing surgical times.

Some systems do not perform bone morphing (e.g., Orthopilot [Aesculap, Tuttlingen, Germany], Fig. 33.4) and BLU-IGS, [Orthokey, Lewes, Delaware], Fig. 33.11). The registration is used to define bones' reference systems and reference points used for surgical planning or by kinematic acquisitions. Limb position and orientation are shown in Figure 33.4 with image templates that are derived from the acquired data.

Hardware for tracking the surgical scenario also differs. There are mainly two types of systems: optoelectronic and electromagnetic. Most of optoelectronic systems utilize sterilizable markers that reflect the infrared light emitted by the cameras. These markers do not require power supply but are generally disposable, increasing the cost for single surgery.

Electromagnetic systems use a receiver to track the position of transmitters mounted on the bones. This technology has the advantage of not suffering from the "line of sight" problems, causing potential problems in the setup of the operative room. The critical point of electromagnetic technology, at present, consists in magnetic interferences caused by ferromagnetic objects, such as surgical tools, that may cause limitation in its accuracy.

TUNNEL PLACEMENT USING CAS

One of the most critical factors for successful clinical outcome of ACL reconstruction is proper intra-articular positioning of the graft. There is general agreement that long-term results are significantly influenced by correct tunnel placement (5,14,20,31).

Clinical validation of the navigation was focused on the evaluation of tunnel placement. CAS systems for ACL reconstruction have focused on isometry and graft elongation (4,13,25,37,49–51,53) or on impingement-free placement (16,21,23,40,49,53,54). Most of the papers highlighted the versatility of the systems for different surgical techniques, indicating the CAS as useful tool in reducing surgical errors (15,51,53).

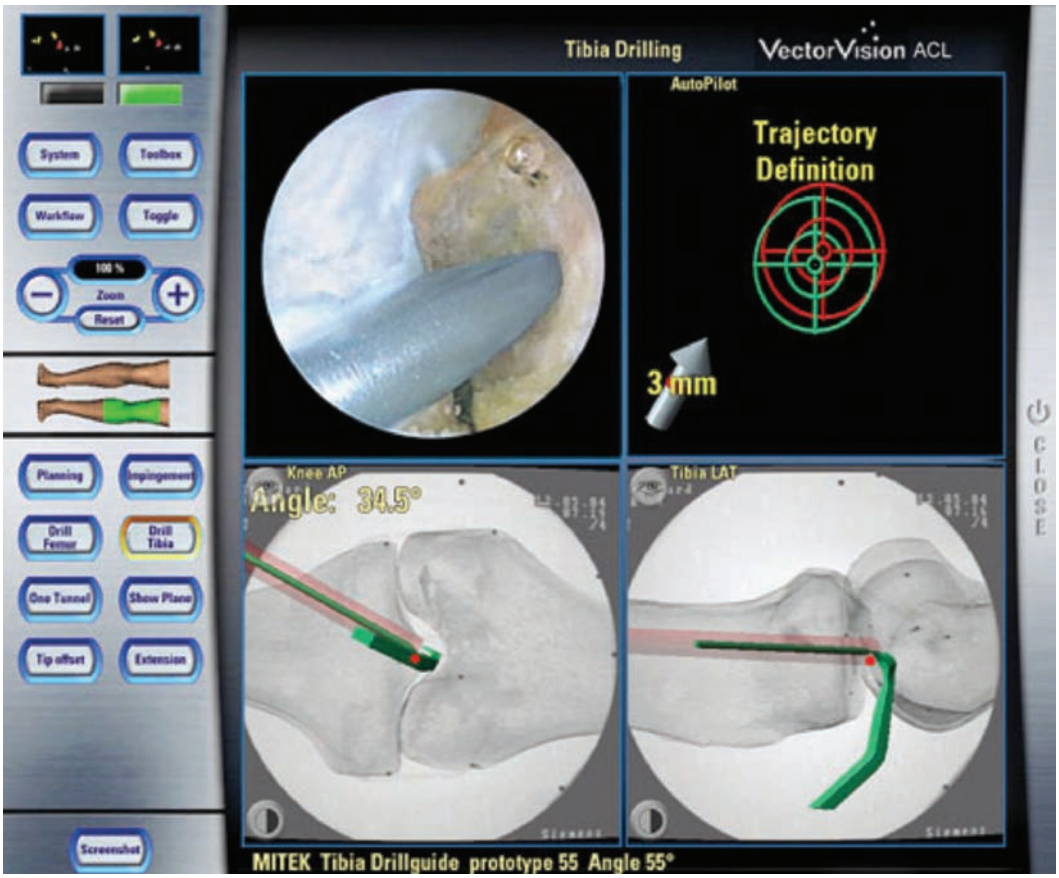

FIGURE 33.2

Interface of fluoroscopy-based navigation system (Vector Vision, BrainLAB).

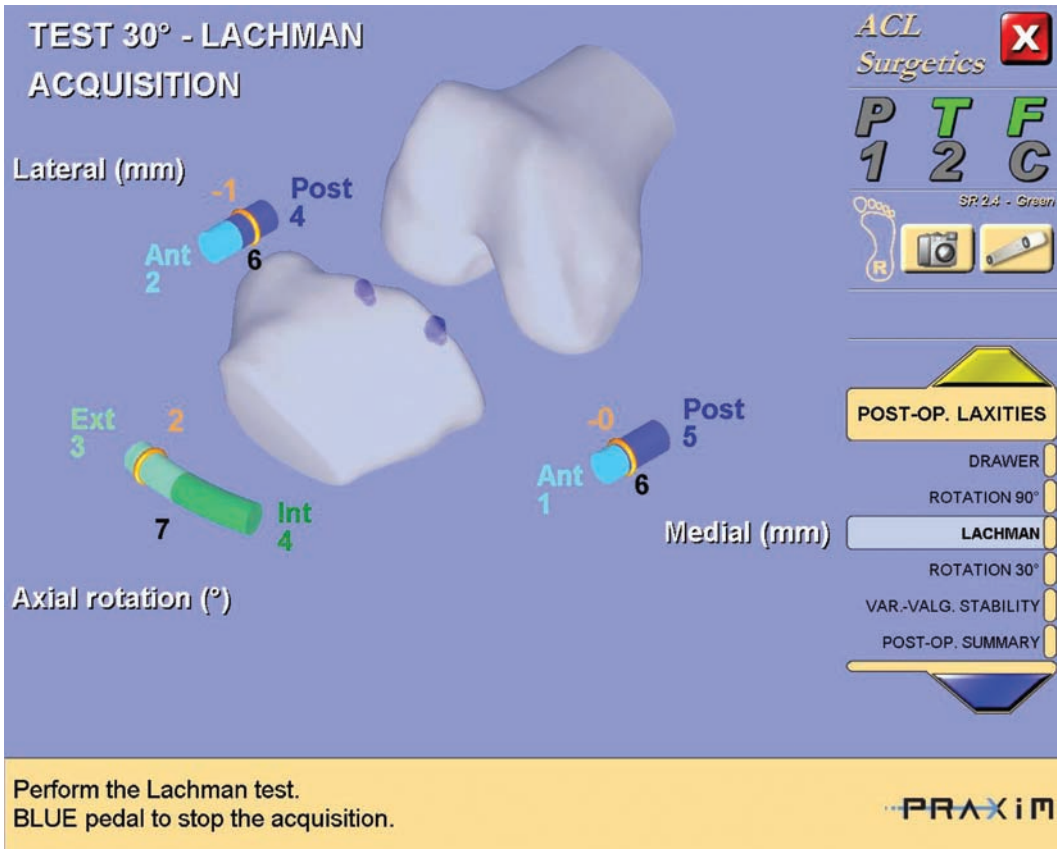

FIGURE 33.3

Interface of morphing-based navigation system (Praxim).

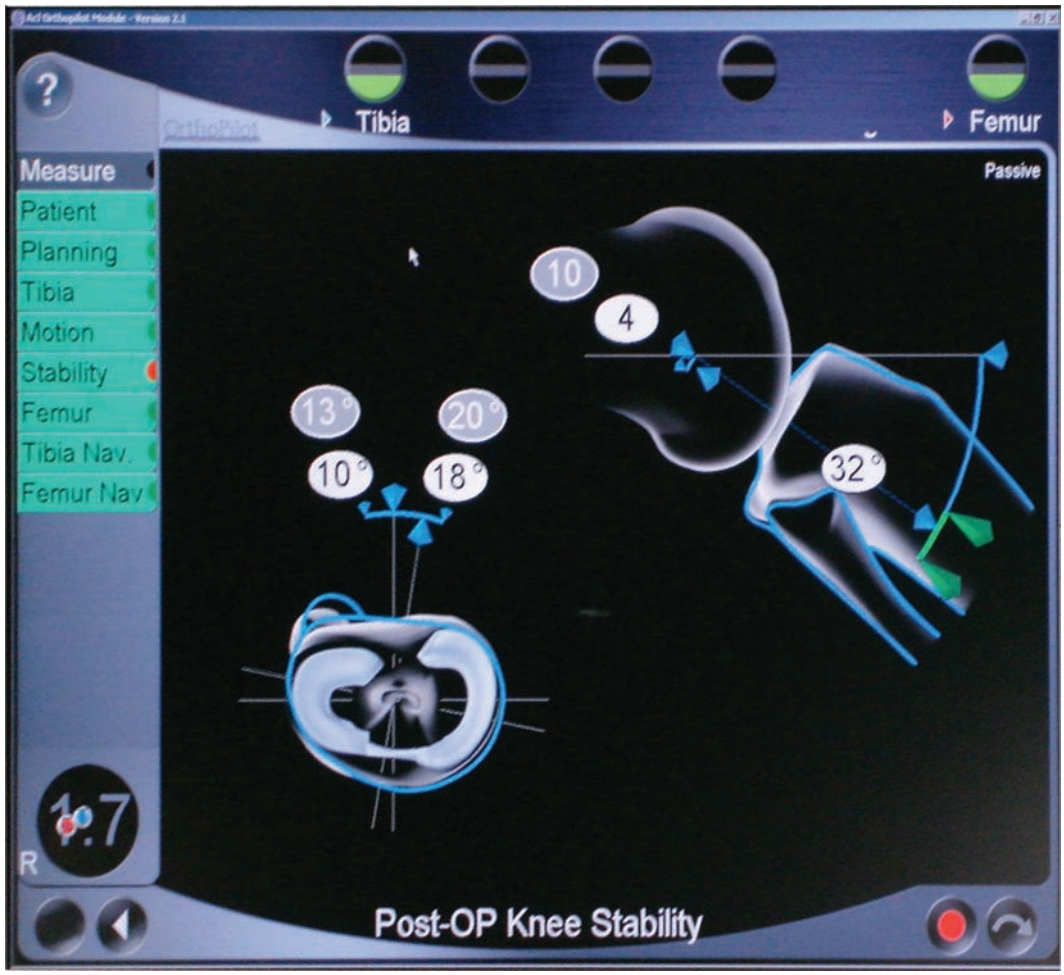

FIGURE 33.4
Template-based navigation system (Orthopilot).

The evaluation was made analyzing the repeatability of tunnel placement with respect to femoral and tibial anatomical references and comparing it with patients operated with conventional technique (1,22,28,29,40,41,44,48,54,60). Some surgeons (8,40,54) found no significant differences between CAS surgery and manual placement by an experienced surgeon. While in contrast, others (15,28,61) found improved accuracy with a computer-assisted system based on radiographs and computer animation.

In tibial placement, the mean position of tunnels is not altered by the use of navigated systems, but the deviation is significantly decreased (8,28,53,54,61). Nevertheless studies from several centers have shown to improve most significantly femoral placement, most studies (28,48,53) showed improved positioning in navigated ACL reconstruction using radiographic data. Because many studies are still defining the position of ACL at the femoral site (17), there is no clear optimal aiming point. The position in the femur is also related to kinematic outcome found during in vitro laboratory experiments (33,42,45,64). The navigation system makes it possible to obtain time zero data on the table even if these data are still influenced by other factors such as meniscal damage or removal and collateral damage on extra-articular structures (3,58).

KINEMATIC EVALUATION USING CAS

The use of navigation for kinematic evaluation has been evaluated since 2000, but the interest of this feature of navigation grew up after 2005 in conjunction with the evaluation of double-bundle technique. In vitro and in vivo studies confirmed its repeatability (39,65) and reliability(47). Correlation with kinematic acquisition and clinical classification of complex tests such as the pivot shift was also demonstrated (2,7,12,30).

Pearle et al. (47) in 2007 on a controlled laboratory setup, with the help of a robotic system, demonstrated the reliability of an image-free navigation system and concluded that surgical navigation is a precise intraoperative tool to quantify knee stability examination and may help delineate pathologic multiplanar or coupled knee motions, particularly in the setting of complex rotatory instability patterns. But repeatability of load application during clinical stability testing remains problematic.

The same results were found by Kendoff et al. in (27) 2007 on a cadaver setup with intact and dissected ACL reconstruction. In addition to comparing KT1000 and navigation, they also compared a mechanical goniometer with navigated measurements for tibial rotation, founding no differences in the two methodologies.

While in a laboratory setup navigation technology has been demonstrated to be reliable, understanding the usability of instrumented CAS manual test in the operating room remained fundamental to comprehend the usability of navigation technology in assessing knee laxity intraoperatively. In fact, in vivo results of navigated kinematic test during surgery are affected not only by the nominal accuracy of localizing technology or the experimental setup but also by other external factors, such as surgeon-subjective and manually applied loads, limb positioning during test, and patients' specific laxity.

Our first research works were aimed at characterizing the intraoperative acquisition protocol (38,65), in order to be aware of all possible pitfalls and errors that could jeopardize the results of kinematic studies; therefore, a more accurate evaluation of the in vivo kinematic evaluation was performed. We assessed the reliability of navigation technology to quantify knee laxities in in vivo setup, evaluating intraobserver reliability and interobserver repeatability and correlation with manual instrumental evaluation, where possible, used in clinical routine.

First clinical application of kinematic ACL evaluation was performed in our institute in 2005 (65). The purpose of our research was to optimize the intraoperative setup for the kinematic evaluation of knee at time zero, trying to define a system that could be used routinely and that could give a global description of the joint laxities. The study was performed on 15 patients in order to analyze the capability of this new CAS procedure. The capability of the protocol was studied, by analyzing the accuracy and repeatability of the tests, the ergonomics of the setup, time taken, and interaction with the surgical steps.

The repeatability of laxity computed from manual tests, at maximum forces, showed an average standard deviation of 0.78 degrees for varus-valgus (VV) rotation, 1.83 degrees for internal-external (IE) rotation, and 0.88 mm for anteroposterior (AP) translation. Repeatability tests of the neutral position used during kinematic tests were lower than 1 mm for all flexion angles. Average standard deviation in tibia orientation was lower than 3 degrees for tests at 0 and 30 degrees of flexion and lower than 4 degrees for tests at 90 degrees of flexion. Navigation resulted practicable and reliable, also in clinical setup, also for kinematic evaluation of ACL reconstruction.

DESCRIPTION OF NAVIGATED SURGERY

The computer-assisted operation is performed with a standard approach and equipment; typically, surgery is performed under general or spinal anesthesia, with the patient placed in a supine position on the operating table. Arthroscopic portals are created and evaluation of the ACL lesion can be performed.

At this point, tibial and femoral navigated references can be fixed with surgical wires. There is no indication for the positioning of the reference tool, whether they can be inserted within the skin incision or percutaneously. Care must be taken in order to allow a complete visibility of the tools during the navigated steps of surgery without interfering with the surgical procedure. Typically, the tibial reference array is fixed in the approach for tendon harvesting or on distal tibia, oriented distally with respect to the knee, while the femoral array is inserted above the end of the medial condyle, distally oriented with respect to the knee (Fig. 33.5).

After reference fixation, the registration of the patient's anatomy is performed with a navigated pointer. The registration phase consists of the acquisition of anatomical landmarks, percutaneously and arthroscopically, in order to identify anatomical coordinate systems. Typically, on the tibia, the following points are digitized: medial and lateral malleoli, most medial and lateral point on plateaus, external tunnel exit holes, percutaneously; internal tunnel holes, ACL insertions, and most distal points on medial and lateral plateaus, arthroscopically. On the femur, the following points are digitized: femoral head, by leg pivoting; medial and lateral epicondyles, lateral tunnel exit hole, percutaneously; and most distal points on medial and lateral condyles, ACL insertions, and internal tunnel exit hole, arthroscopically.

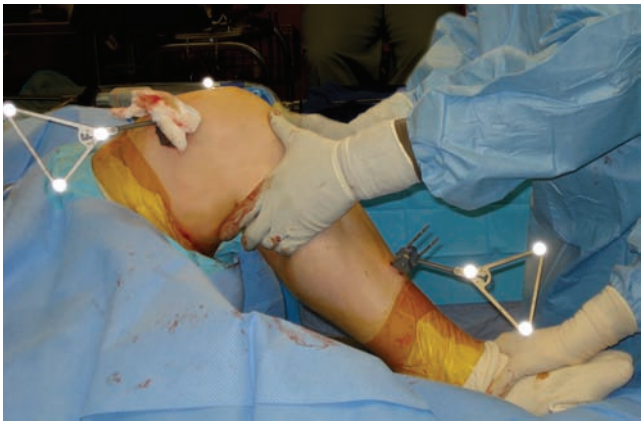

FIGURE 33.5

Execution of drawer preoperative test with a navigation system. Tibial and femoral reference arrays are positioned medially, far from the surgical area.

After registration, it is possible to perform the preoperative kinematic tests (Fig. 33.5). During tests, the leg is flexed with the foot laid on the operating table, and the thigh is held by an assistant. Kinematic acquisitions are performed according to clinical practice and may include passive range of motion (PROM); VV rotation at 0 and 30 degrees of flexion, at maximum force; IE rotation at 30 and 90 degrees of flexion, at maximum force; AP at 30 and 90 degrees of flexion, at maximum force; and pivot shift test.

OUR CLINICAL EXPERIENCE

To evaluate the joint laxity and kinematics, we used an optical navigation system (BLU-IGS, Orthokey, Delaware) with a software focused in kinematic acquisitions (KLEE, Orthokey, Delaware). This system applied to or allowed to perform different studies. Nearly, 200 cases have been performed since 2004, with different reconstructive techniques.

Clinical studies included the evaluation of knee laxity before and after ACL reconstruction with two different surgical techniques utilized at our institute: The first technique is a hamstring double bundle with one tibial tunnel, over-the-top passage for the PL bundle and femoral tunnel passage for the AM bundle (34) (Fig. 33.6A). The second technique is an intra-articular hamstring single bundle (SB) with over-the-top passage and additional extra-articular (EA) lateral plasty (35) (Fig. 33.6B).

Comparison of AP, VV, and IE laxities between the two techniques was performed, and we found no statistical difference ($p > 0.05$) for all laxity tests (Fig. 33.7).

Anteromedial Instabilities

More interesting results were obtained evaluating patients, operated with both techniques, with different preoperative conditions. We wondered whether it was possible to identify some residual laxity in patients with combined chronic ACL and Medial collateral ligament (MCL) lesions when compared to patients with pure ACL lesion (66). Patients were prospectively classified in two groups: patients with isolated ACL lesion, used as control group, (Group I) and patients with grade II injury of the medial collateral ligament combined with ACL lesion used as studied group (Group II).

Clinical evaluation was performed using the International Knee Documentation Committee (IKDC) knee ligament standard evaluation form. Fifty-seven patients were included in the study; thirty-seven patients were put in Group I and twenty patients in Group II. Age, gender distribution, and time from injury to surgery were similar in the two groups (Table 33.1). Preoperative laxities were different in both groups for VV and AP tests (Fig. 33.8).

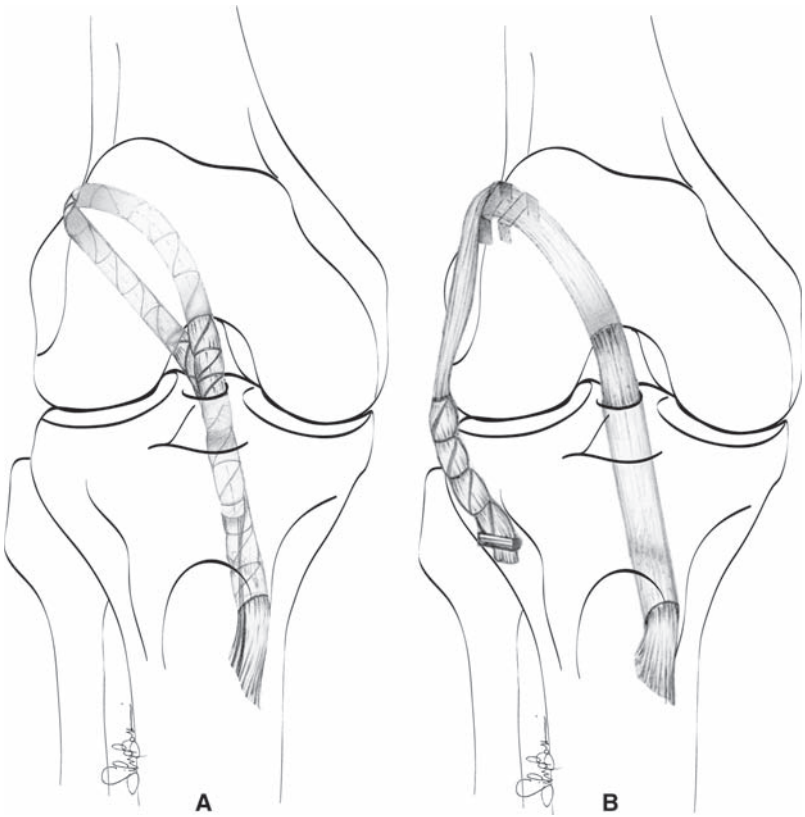

FIGURE 33.6

Double-bundle over-the-top hamstring reconstruction **(A)** and SB over-the-top plus EA plasty **(B)**.

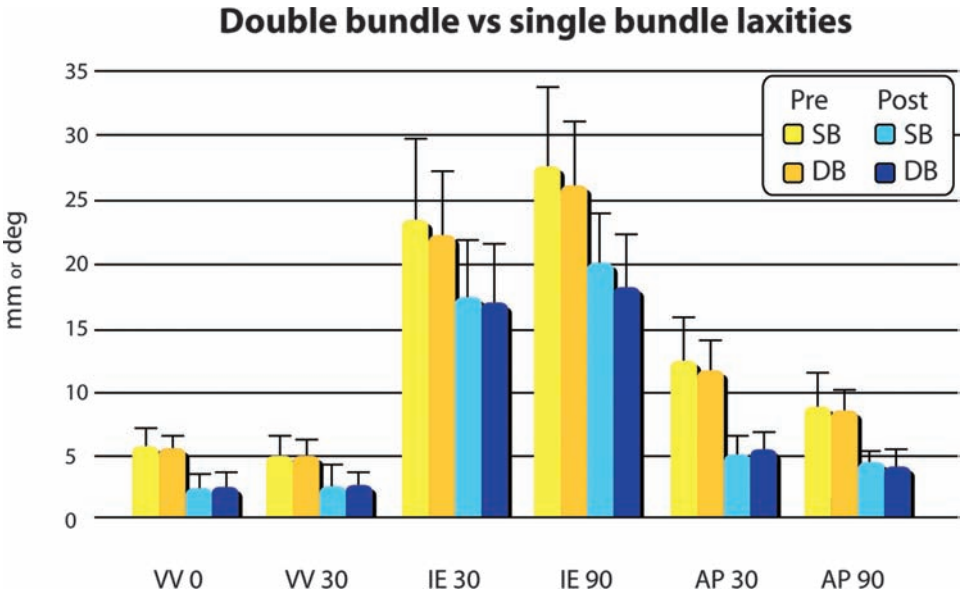

FIGURE 33.7
Results of laxity tests for hamstring over-the-top double bundle and SB plus lateral plasty.

TABLE 33.1 Demographic Data of Patients with Isolated ACL Lesion and Combined MCL Strain.

	Group I	Group II
Age, y	30 ± 9.5	34 ± 15.4
Sex, (no. of subjects) male/female	34/3	19/1
Time from injury to surgery	12 ± 12.8	9 ± 4.7

I, group with pure ACL injury; II, group with ACL injury with associated grade II MCL tear.

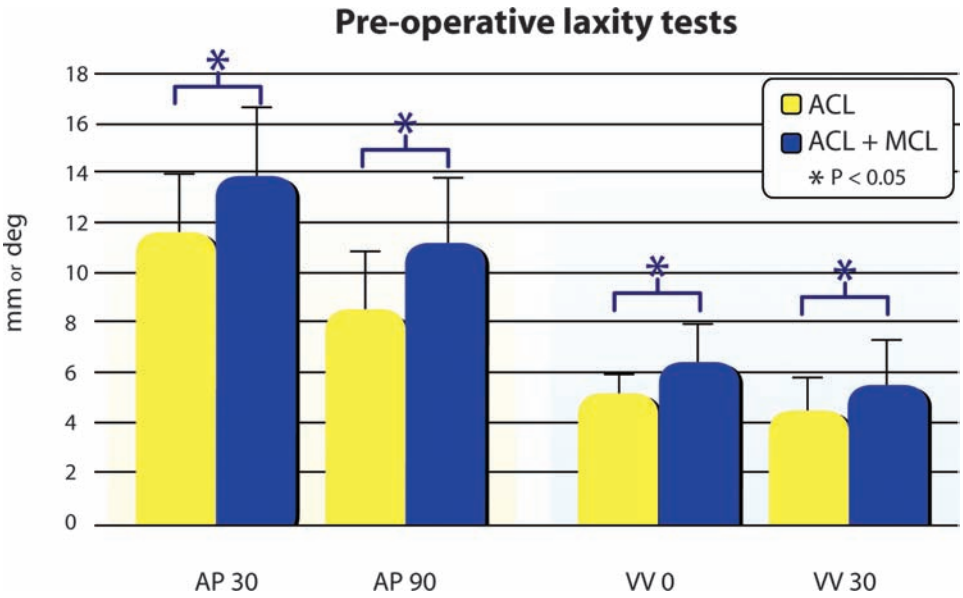

FIGURE 33.8
Preoperative laxities in patients with pure ACL lesion and patients with combined ACL and MCL strain.

Postoperative AP comparison has shown that, at 90 degrees of flexion, some residual laxity remained in patients with combined injuries with respect to patients with isolated ACL lesion. On the other hand, at 30 degrees of flexion, the postoperative laxities were not statistically different even if the power of our sample for AP test at 30 degrees of flexion was low (power 0.67) and, therefore, we were not able to claim the groups were equivalent (Fig. 33.9).

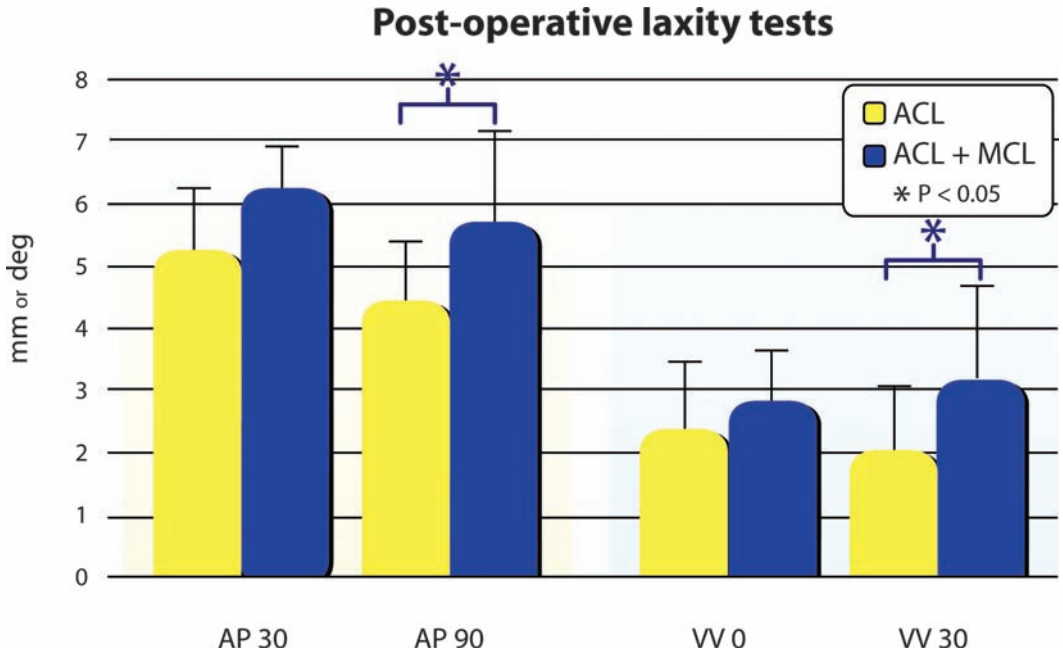

FIGURE 33.9

Postoperative laxities in patients with pure ACL lesion and patients with combined ACL and MCL strain.

Our findings agree with those of Sakane et al. (52) and Shapiro et al. (56) who reported that, in vitro, the role of the MCL during AP loading was minimal toward extension but became clinically more important when the knee was flexed.

Similar patterns of results also were found for VV tests: residual laxity remained for patients with ACL lesion with MCL sprain, compared with patients with pure ACL lesions, at 30 degrees of flexion, while in extension, the graft was able to control the rotation, since no statistical difference between the two groups was found. Our results agree with the findings of Seering et al. (55) who reported that, in vitro, the MCL created a larger resistive moment when the specimens were at 30 degrees of flexion than it did when they were at full extension. The reduction of knee laxity was slightly greater for Group II, where the initial laxity was statistically higher, thereby confirming the importance of the ACL in controlling AP and VV laxities. Patients with MCL grade II sprains have an additional 1.3-mm laxity in AP displacement at 90 degrees of flexion and 1 degree in VV rotation at 30 degrees in comparison with patients with ACL injury only, which was detectable with the navigated kinematic evaluation.

Extra-Articular Lateral Plasty

Not only is navigation able to evaluate with high accuracy uniplanar laxities, such as AP translations or VV and IE rotations, but it can also be used for more detailed kinematic analyses such as the evaluation of AP translation in medial and lateral compartments or the decomposition of rotations and translations during the pivot shift test. Evaluation of translation in the two tibial compartments resulted useful in the evaluation of the effect of the EA lateral plasty in controlling joint laxity (3). In vivo and in vitro studies, there was no general consensus about the effect of the additional EA procedure to knee laxity. These studies were in agreement only in indicating that there was a load sharing between the intra-articular and extra-articular portions and, in particular, that the load on the ACL graft diminished with knee extension (9,18,19,32,43). Anyway the effect of this load sharing remained a matter of debate. We wanted to measure the effect of additional EA procedure, added to single-bundle hamstring over-the-top ACL reconstruction, evaluating coupled tibial translation during Lachman and drawer test.

We evaluated 28 patients with a computer-assisted kinematic evaluation protocol, excluding from the study patients with associated ligament tears or meniscal damages.

After tibial bone tunnel drilling, but before graft insertion, the operating surgeon performed standard clinical tests at maximum force to evaluate the AP joint laxities, during Lachman and drawer tests, in the ACL-deficient knee. SB graft was inserted into tibial tunnel, fixed with two staples on the femur in the over-the-top position, and laxity tests were repeated. After this step, the additional EA procedure was executed passing the remaining part of the graft under the fascia lata to reach the Gerdy tubercle where it was fixed with another staple. Laxity tests were repeated again.

In order to quantify the effect of the SB graft and of the EA procedure, we compared the knee laxity of the ACL-deficient knee with laxity obtained after SB (Δ_SB) fixation and EA (Δ_SB+EA) fixation, respectively (Fig. 33.10).

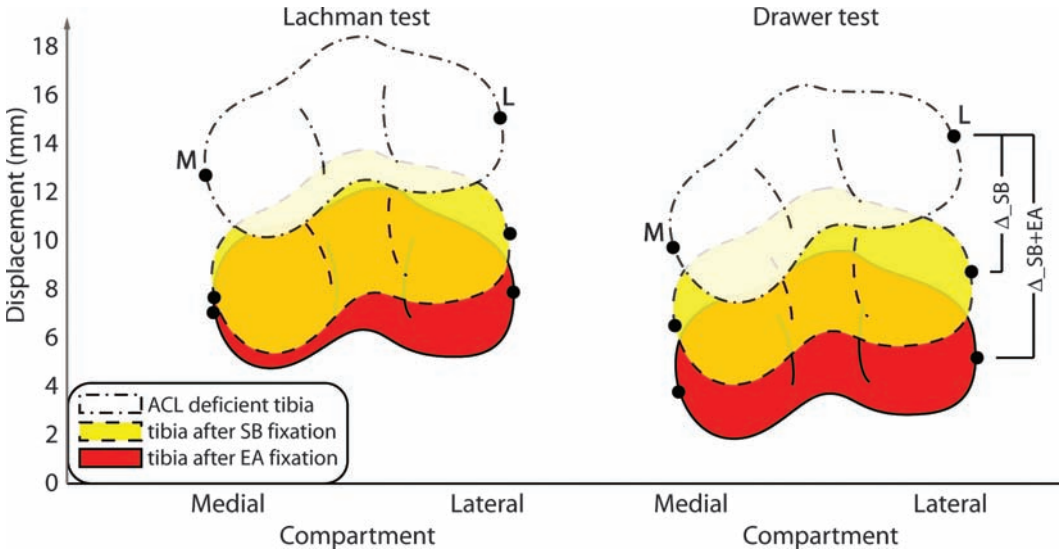

FIGURE 33.10
Tibia displacement during Lachman and drawer tests. M, AP displacement on medial plateaus; L, AP displacement on lateral plateaus; Δ_SB, difference between ACL-deficient knee and knee after SB graft fixation; Δ_SB + EA, difference between ACL-deficient knee and knee after EA procedure on medial compartment.

At 30 degrees of flexion, SB graft reduced tibial displacement in both compartments (5 mm). Laxity on medial plateaus was not reduced using the EA procedure ($p = 0.741$), while on the lateral plateaus, the reduction was of about 2 mm ($p = 0.015$).

At 90 degrees of flexion, laxity on medial plateaus was slightly reduced by SB graft (2 mm), while on the lateral plateaus, the reduction was greater (5 mm). The additional EA procedure caused a further significant reduction of knee laxity of about 1 mm ($p < 0.05$) in both compartments.

We have found that, despite the SB hamstring graft having a primary role in reducing the knee laxity, an EA procedure, added to the graft, is effective in further controlling the laxity: Near extension, the SB graft reduces AP translation, while the EA procedure controls internal rotation, reducing by 1.6 mm the translation of lateral tibial compartment. This result shows that the coupled tibial translation, which is not controlled by SB graft, is reduced by the EA procedure. In contrast, in flexion, the SB graft reduces coupled AP translation in both compartments, while the EA procedure contributes in controlling tibial translation, reducing laxity by 1 mm in both compartments.

Our results confirm the in vitro studies of Engebresten et al. (19) about subluxation of lateral plateaus prevention performed by the EA procedure. Moreover, the control of the lateral compartment at 30 degrees may explain the reduction of "giving away" sensation reported by Jensen et al. (26) and the good clinical outcome, observed in clinical studies, using this combined procedure (36).

Anatomical Double Bundle

Between September 2007 and April 2008, 18 patients, with isolated ACL injury, were operated with anatomical double-bundle hamstring technique as described by Chhabra et al. (10). Of all patients included in the study, 11 had preoperative IKDC C score and 7 D score.

The operating surgeon performed manually clinical tests at maximum force, before and after the reconstruction. Tests consisted of VV stress at 0 and 30 degrees of flexion, IE stress at 30 and 90 degrees of flexion, Lachman test (AP 30), drawer test (AP 90), and pivot shift test.

For what concerns pivot shift test, we analyzed laxity of the joint as the decomposition of two different parameters with respect to flexion angle: AP translation and IE rotation. For each decomposition, we evaluated the areas included by the curves obtained during the test (the "hysteresis" of the joint due to positive pivot shift) as dynamic joint laxity. Within those curves, we also identified the highest or lowest peaks obtained and at which angle they occur, to describe static laxity during the test. A typical result of pivot shift kinematic decomposition in AP translation, with BLU-IGS software, is shown in Figure 33.11.

All laxities were significantly reduced by the reconstruction. In particular, anterior laxity showed a great reduction, which resulted highly significant ($p < 0.0001$) during Lachman test and drawer tests. Also VV rotation showed a highly significant reduction ($p < 0.0001$) both in extension and at 30 degrees of flexion. The reduction of IE rotation even if significant ($p < 0.01$) was less compared to the other tests (Fig. 33.12).

These results are in agreement with results reported by Bull et al. (6) and Colombet et al. (13), which indicates this test as more discriminating of the effect of the two bundles in controlling the dynamic instability of the knee. Peaks analysis showed that maximum laxity is always reached, between 20 and 30 degrees of flexion. Both AP translations and IE rotation peaks were significantly reduced ($p < 0.0001$, Fig. 33.13).

The comparison between preoperative and postoperative laxity areas (Fig. 33.14) highlighted a huge recovery of the dynamic stability of the joint. Both AP and IE areas showed a high reduction ($p < 0.0001$). In our results, pivot shift AP and IE areas not only showed a high statistical difference between preoperative and

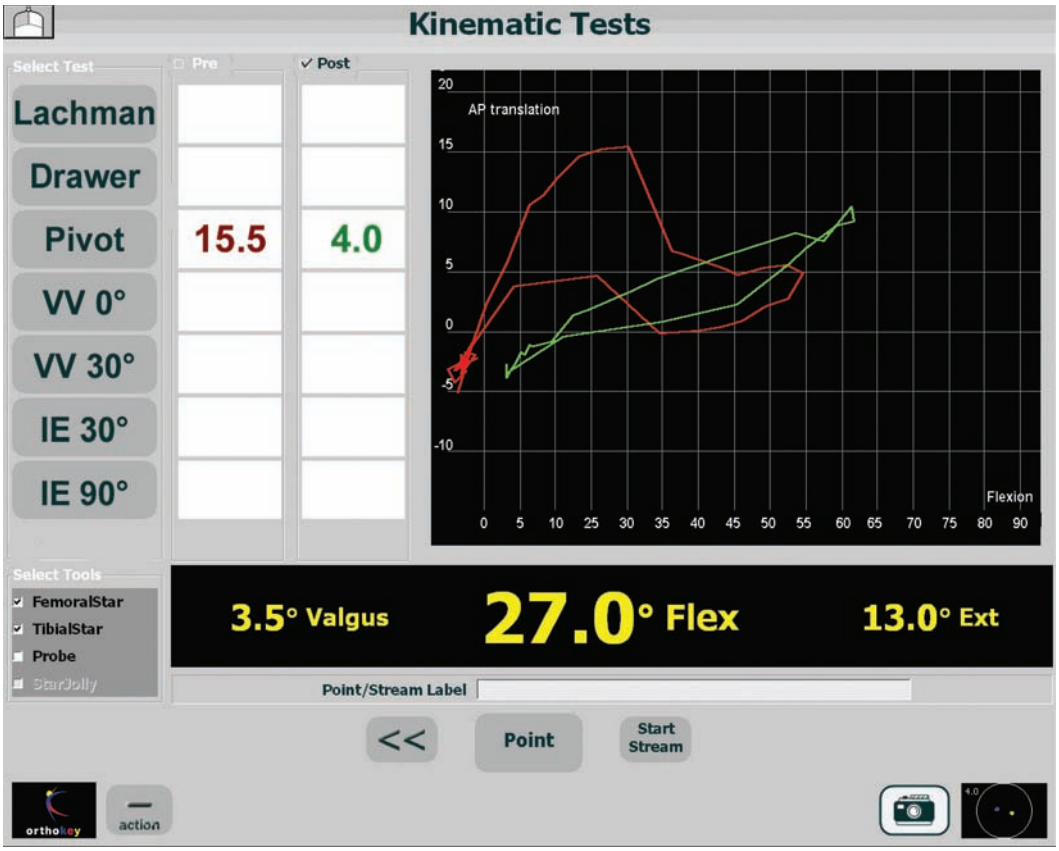

FIGURE 33.11

Result of pivot shift test with BLU-IGS system (Orthokey, Lewes, Delaware). Screen shows AP translation during pivot shift maneuvre. On the left, it is possible to read the value of laxity peak around 30 degrees (15.5 pre-op and 4.0 post-op); in the graph, it is possible to evaluate the envelope of passive motion of tibia (red pre-op, green post-op).

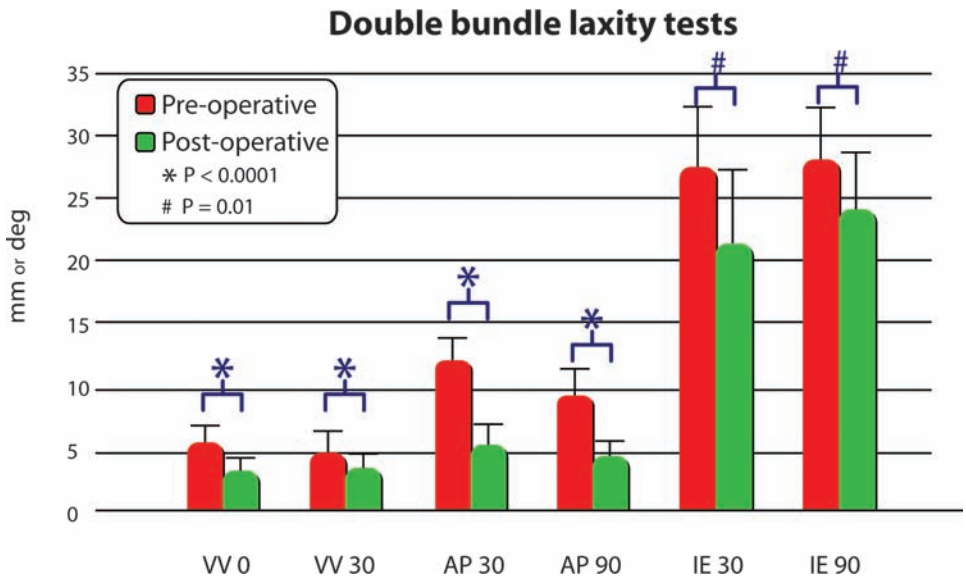

FIGURE 33.12

Results of static laxity test before and after reconstruction for anatomical double-bundle reconstruction.

postoperative laxities but also correlated with the preoperative IKDC score, as reported also by Hoshino et al. (24) with a large number of patients. In patients with IKDC grade C, the area during pivot shift was significantly larger, in ACL deficient knees, with respect to patients graded D (Figs. 33.15 and 33.16). This difference was not found after reconstruction.

This type of measurement can reflect more the feeling reported by the surgeon during manual clinical test, quantifying and summarizing joint laxity in all range of flexion during pivot shift, and therefore, it can be used to clinically quantify associated or constitutional rotatory instabilities of the knee.

We found no correlation between the laxities obtained during static tests and pivot shift test. This may explain the contradictory results found in literature analyzing joint laxity with different methods. Primary or coupled IE rotations may not be sufficient in describing the effect of two grafts in reducing knee laxity.

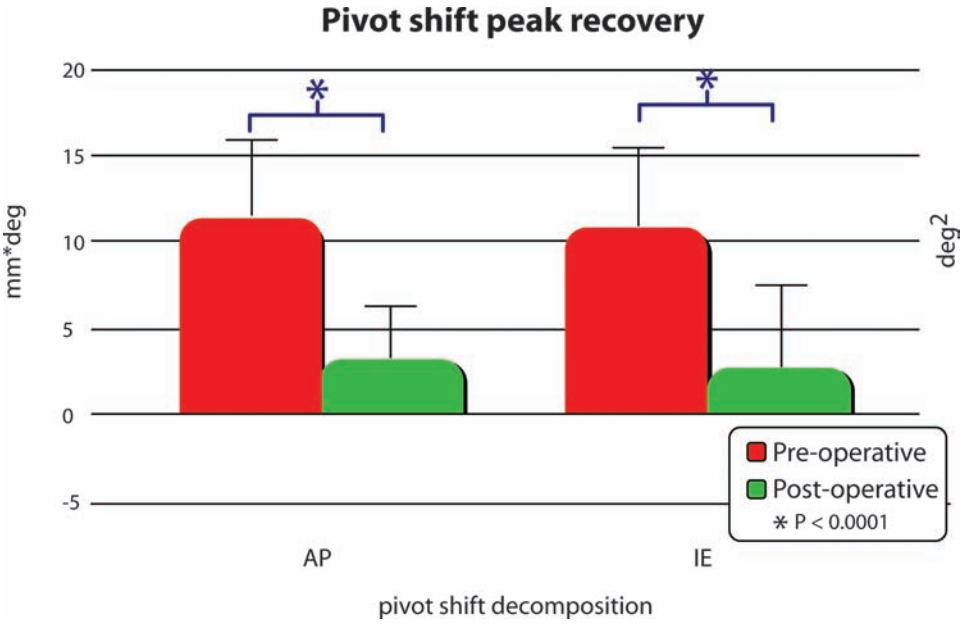

FIGURE 33.13
Average peaks of laxity during pivot shift test.

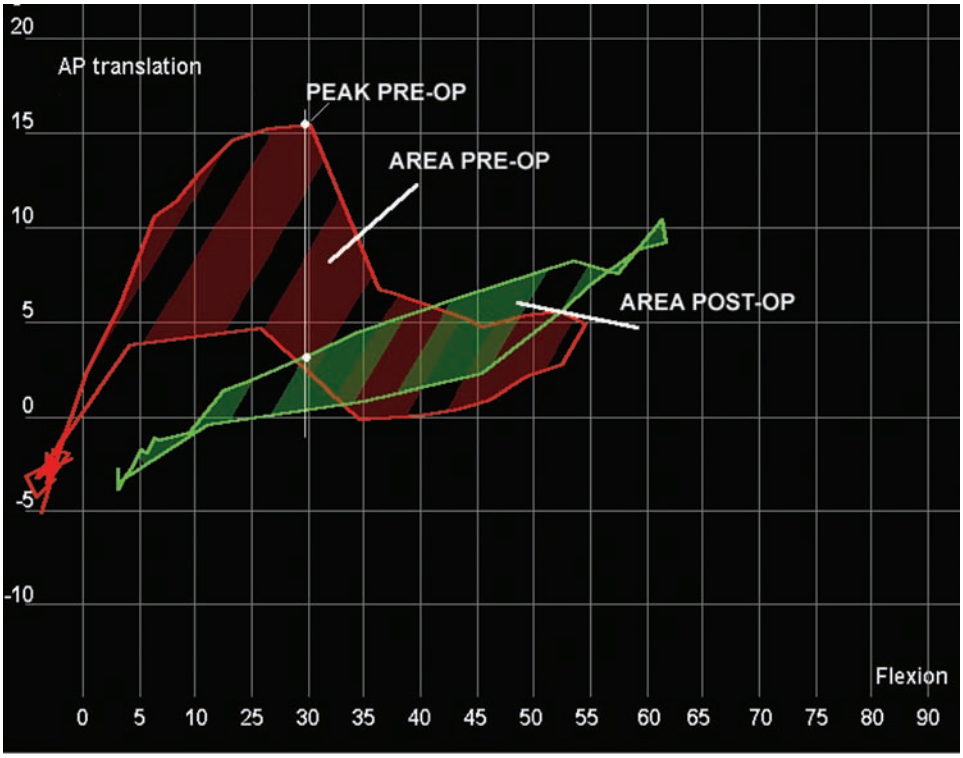

FIGURE 33.14
Description of area obtained from the AP tibial translation during the pivot shift test.

From an anatomical point of view, the evaluation of graft positioning, shown in Figure 33.17, clearly illustrates how reconstructive grafts, if correctly positioned, have similar position pattern as the native ACL bundles as defined in previous anatomical studies (10,50,67), being parallel in extension and crossed in flexion. The analysis of bundle elongation during PROM has shown that there are little variations in AM bundle length, while PL bundles shortened during flexion (Fig. 33.18).

CONCLUSIONS

With the help of less invasive and image-free systems in the last 15 years, the knowledge about anatomy and kinematics of the ACL has improved dramatically. The possibility to describe with high precision insertion areas of the different bundles of the ACL and to measure correct tunnel positioning intraoperatively can lead to a reduced numbers of outliers during surgery, improving the final surgical outcome.

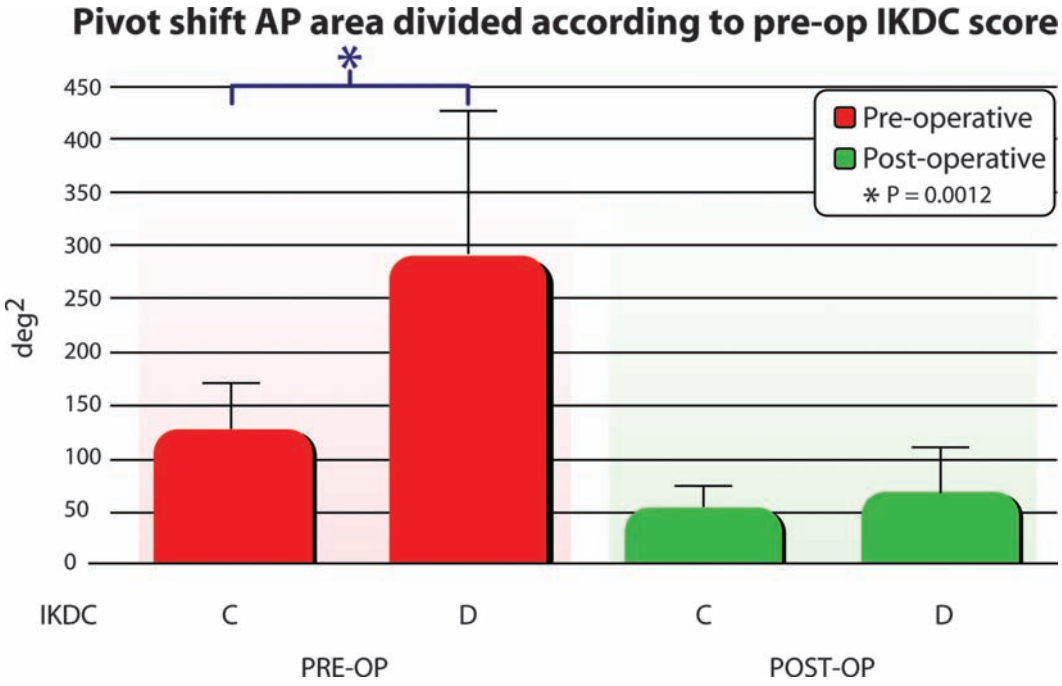

FIGURE 33.15

Area of dynamic laxity in AP direction during pivot shift test, in patients divided according to IKDC score (mean ± standard error).

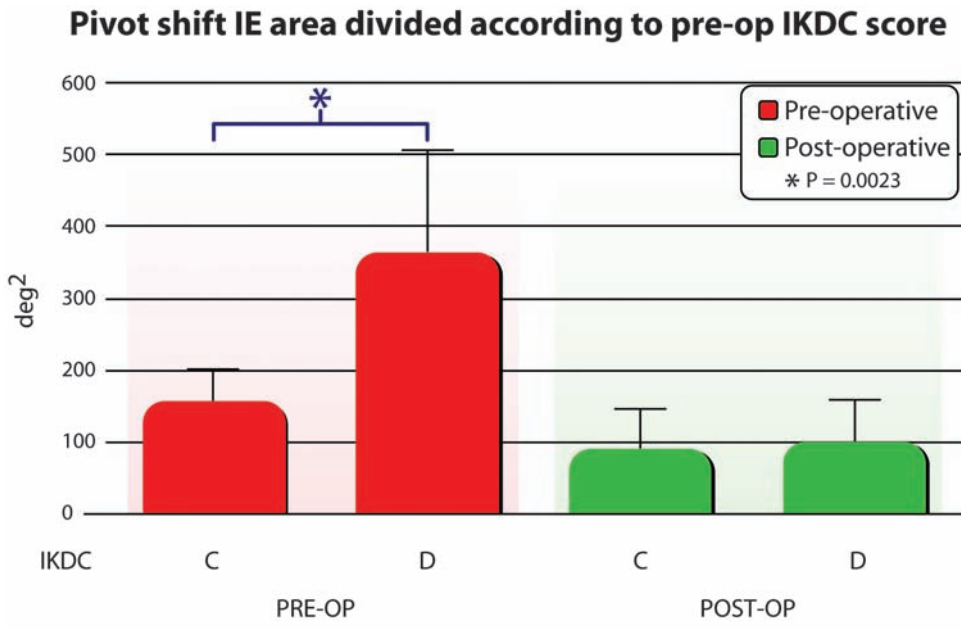

FIGURE 33.16

Area of dynamic laxity of IE rotation during pivot shift test, in patients divided according to IKDC score (mean ± standard error).

However, the use of surgical navigation for tunnel placement remained limited because the targets and tolerances for this optimal graft positioning are still poorly understood. With the introduction of kinematic evaluation, it became possible to quantify at time zero the effect of the surgery in controlling knee laxity.

Initial navigated knee-stability measurements included standard uniplanar tests such as the Lachman test, the anterior drawer test, and maximal internal and external rotation at various flexion angles. More recent iterations of the navigated stability examination have included more complex pathologic movements, such as those that occur in the pivot shift phenomenon, leading to a complete quantification of clinical laxity.

These data begin to define surgical parameters for various ACL reconstruction techniques. With this information available intraoperatively, it is now possible to think at the "on demand" surgery, where quantitative data can help to refine the surgical outcome. The principles for the "on demand" surgery require description of the pathology that needs to move outside the operating room. Therefore, more recently, some efforts have been made in order to quantify, also in an office setup, the joint laxity (24).

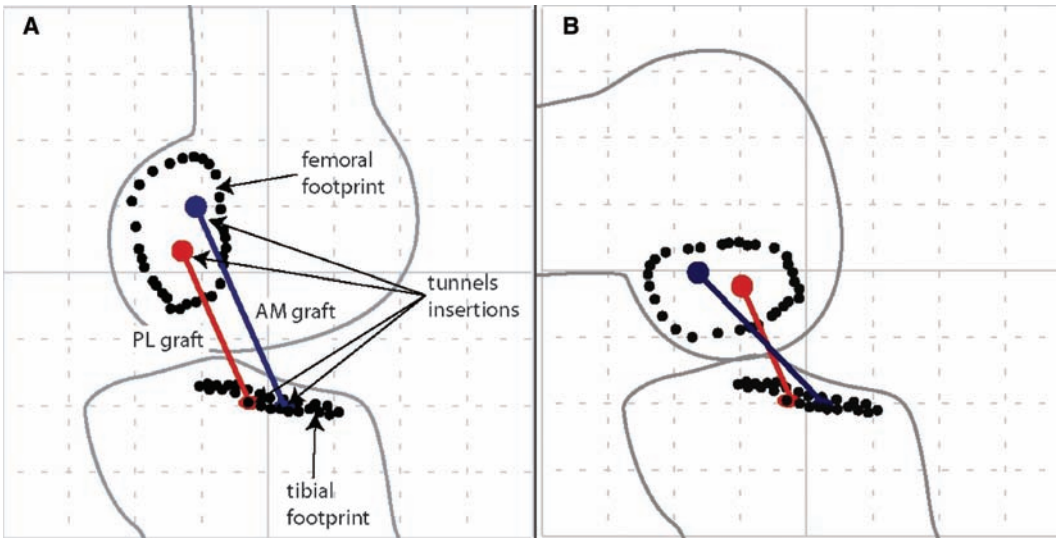

FIGURE 33.17

Acquired points on ACL insertions showed on sagittal view, with leg in extension **(A)** and in flexion **(B)**. Dots represent the acquisitions done on the patient. Tibial and femoral shapes have been superimposed for clarification.

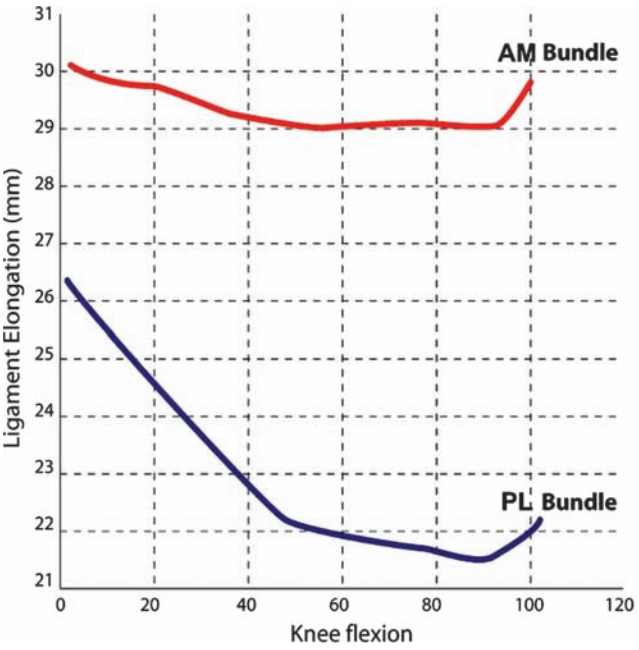

FIGURE 33.18

AM bundle and PL bundle elongations during passive range of motion.

The biggest challenge, however, of CAS remains the tracking technology: Accurate tracking of knee motion is based on rigid osseous fixation of trackers, so comparative examinations of the contralateral limb or follow-up is difficult. Furthermore, application of standardized loads during stability testing in vivo remains a challenge.

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34 Single-Bundle Posterior Cruciate Ligament Reconstruction: Transtibial Technique

Peter David Longino, Robin Martin, and J. Robert Giffin

In the past 2 decades, there has been an increase in both basic science research detailing the anatomy and biomechanics of the native posterior cruciate ligament (PCL) and outcome studies evaluating management of the ruptured PCL. While the methodology of the latter continues to improve, results based on the current level of evidence must be interpreted cautiously (18). The focus of many recent studies has been double-bundle versus single-bundle reconstruction techniques. The theoretical advantage goes to double-bundle techniques, but a clinical difference in outcome has not been consistently demonstrated (8,17). Some biomechanical studies have reported improved control of posterior laxity with double-bundle reconstruction; however, results appear to be more dependent on tunnel position and graft tensioning (13).

In acute isolated symptomatic PCL injuries in which the posteromedial bundle and the meniscofemoral ligament remain intact, a single-bundle augmentation procedure may be the preferred surgical technique. In more complex PCL ruptures with associated injuries involving the posterolateral structures (PLS) or medial collateral ligament, more benefit may be derived from double-bundle reconstruction. Again, cadaveric testing of double-bundle PCL reconstruction has not consistently outperformed single-bundle techniques in combined PCL/PLS injury (3). Multi-ligamentous injuries are commonly associated with PCL rupture (15), and their management should be considered carefully in the decision to reconstruct one or both of the functionally distinct PCL bundles. However, the technical complexity of double-bundle reconstruction, the longer surgical time required, as well as the inconclusive clinical outcome are all factors that must be weighed carefully.

INDICATIONS/CONTRAINDICATIONS

The goal of PCL reconstruction regardless of technique is to restore normal knee biomechanics (2) by addressing the various components, the anterolateral and posteromedial bundles and the meniscofemoral ligaments, of the complex anatomy of the PCL. Typical single-bundle reconstruction aims to reproduce the anterolateral bundle of the PCL. In the isolated PCL injury, which occurs much less frequently, absolute indications for surgical treatment include persistent symptoms of knee instability following a Grade III (complete) PCL rupture or a bony PCL avulsion. Contraindications include traumatic knee arthrotomy, active infection, or significant knee stiffness

PREOPERATIVE PLANNING

A complete PCL rupture can be accurately diagnosed by means of a thorough history and physical examination. In light of the known association between PCL rupture and multiligament knee injuries; however, the neurovascular status of the leg must be carefully assessed and documented. Furthermore, careful evaluation of the integrity of the PLS is of paramount importance given the high incidence of associated injury to these structures. Failure to recognize and treat associated PLS instability and/or injury to other secondary restraints will compromise the success of a PCL reconstruction.

Preoperative imaging includes bilateral standing AP radiographs with the knees in both full extension and in 30 degrees of flexion (tunnel view), a lateral radiograph with the knee in 30 degrees of flexion, and a skyline view of the patellofemoral joint. If any clinical or radiographic concerns exist regarding varus or valgus alignment of the lower extremity, three-foot standing views are obtained to determine if a concurrent or staged tibial osteotomy may be required.

Magnetic resonance imaging (MRI) can be helpful prior to PCL reconstruction to identify additional ligamentous injuries. One must keep in mind, however, that while the sensitivity and specificity of MRI in detecting acute PCL rupture have been reported to be 99% and 100% respectively (6,12), the accuracy in the chronic setting is much reduced (16). Associated meniscal injuries occur much less frequently than in ACL rupture (15) and should be managed at the time of arthroscopic PCL reconstruction.

SURGERY

Patients routinely receive one gram of cefazolin intravenously 30 minutes prior to surgery. Those with allergies to cefazolin are given vancomycin or clindamycin.

Patient Positioning

The patient is positioned supine on the operating table. A comprehensive examination under anaesthesia is routinely performed. A tourniquet is applied proximally on the thigh and set at 300 mm Hg and not inflated unless poor visualization secondary to bleeding is encountered. A lateral post is placed at the level of the tourniquet, and a foot rest is used to maintain the knee in a self-supported position of 70 to 80 degrees of flexion (Fig. 34.1). This is the working position for notch preparation, tibial tunnel drilling, and autologous graft harvest. The knee is shaved with electric clippers 5 cm above the proximal pole of the patella to 5 cm distal to the tibial tubercle. Care is taken to incorporate areas of incisions for potential meniscal repairs. Arthroscopy portals are marked, as well as the incision planned for graft harvest and tibial tunnel drilling. The leg is washed and the incision sites are preinjected with 20 mL of 0.25% sensorcaine with 1:200,000 (5 μg/mL) epinephrine. Intraarticular injection is avoided. The leg is prepped with a chlorhexidine solution and allowed to dry before sterile drapes and an iodophor impregnated adhesive drape are applied.

Arthroscopy

Given that no conclusive difference in clinical outcome has been demonstrated in studies comparing tibial inlay techniques to transtibial techniques for tibial fixation (10,14), we currently use an all arthroscopic technique.

Inferomedial and inferolateral parapatellar working portals and a superomedial outflow portal are created vertically with a No. 11 blade. The inferolateral portal is placed slightly more lateral than in routine knee

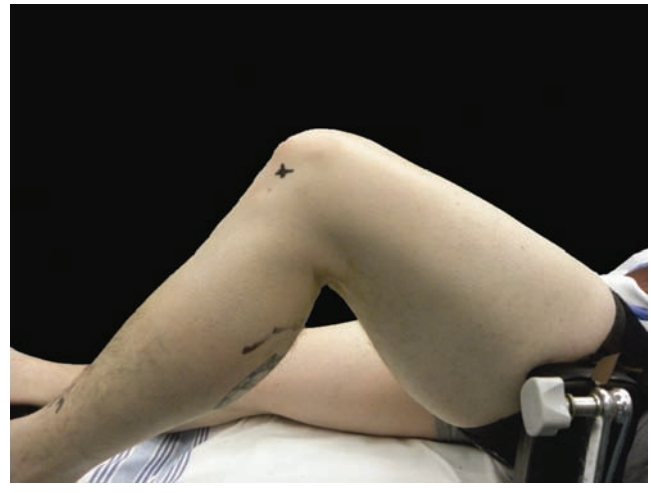

FIGURE 34.1

Knee is placed in a self-supported position of 70 to 80 degrees of flexion with a lateral side post. A tourniquet is applied.

arthroscopy in order to improve the visualization of the medial femoral condyle when drilling the femoral tunnel. The inferomedial portal is placed medial to the medial border of the patellar tendon and proximal to the medial meniscus. A diagnostic arthroscopy is performed and any meniscal pathology addressed.

Two additional posteromedial portals are created for visualization and preparation of the tibial insertion of the PCL. The safety of posteromedial portals and the value of utilizing dual portals to assist with medial meniscal repair have been well documented (1,11). A 30 degrees arthroscope is inserted into the inferolateral portal and directed posteriorly through the femoral notch just lateral to the medial femoral condyle. This allows the surgeon to directly visualize the placement of portals in the posteromedial joint capsule. An 18-gauge spinal needle is inserted through the skin into the knee joint at the location of the first posteromedial portal. Portals should be positioned proximal and posterior to the medial femoral condyle, approximately a two-finger breadth proximal to the medial joint line (Fig. 34.2). The second posteromedial portal is placed just proximal to the first (Fig. 34.3). Two small separate or one common larger skin incision may be used for the placement of the two posteromedial portals. A frequent error is to place the portals too anterior and distal causing the medial femoral condyle to become an obstacle to instrument maneuverability.

A No. 11 blade is advanced into the knee joint directly in line with the previously placed spinal needle. This path is subsequently dilated with a haemostat. An arthroscopic cannula is placed through each of the posteromedial portals to accommodate the mechanical shaver through as 5-mm cannula and the arthroscope through an 8-mm cannula. The large cannulas minimize fluid extravasation during preparation of the tibia.

The order of tunnel preparation depends on the chronicity of the injury. In the chronic PCL injury, either the tibial or femoral tunnel can be prepared first. In more acute cases, extravasation of arthroscopic fluid from

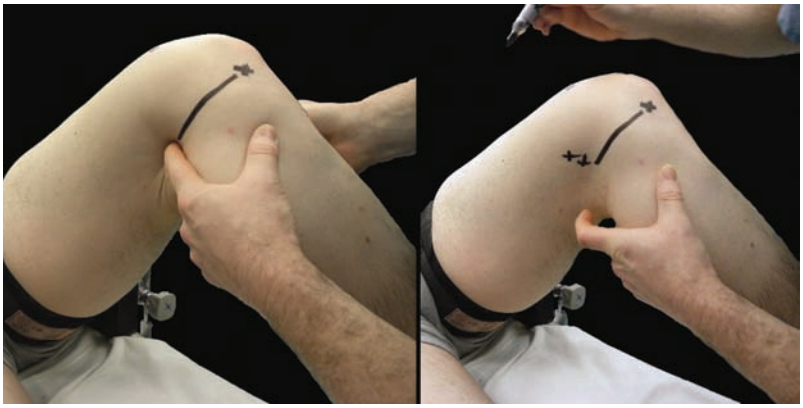

FIGURE 34.2

Arthroscopic portals are marked. Two posteromedial are positioned proximal and posterior to the medial femoral condyle, approximately a two-finger breadth proximal to the medial joint line.

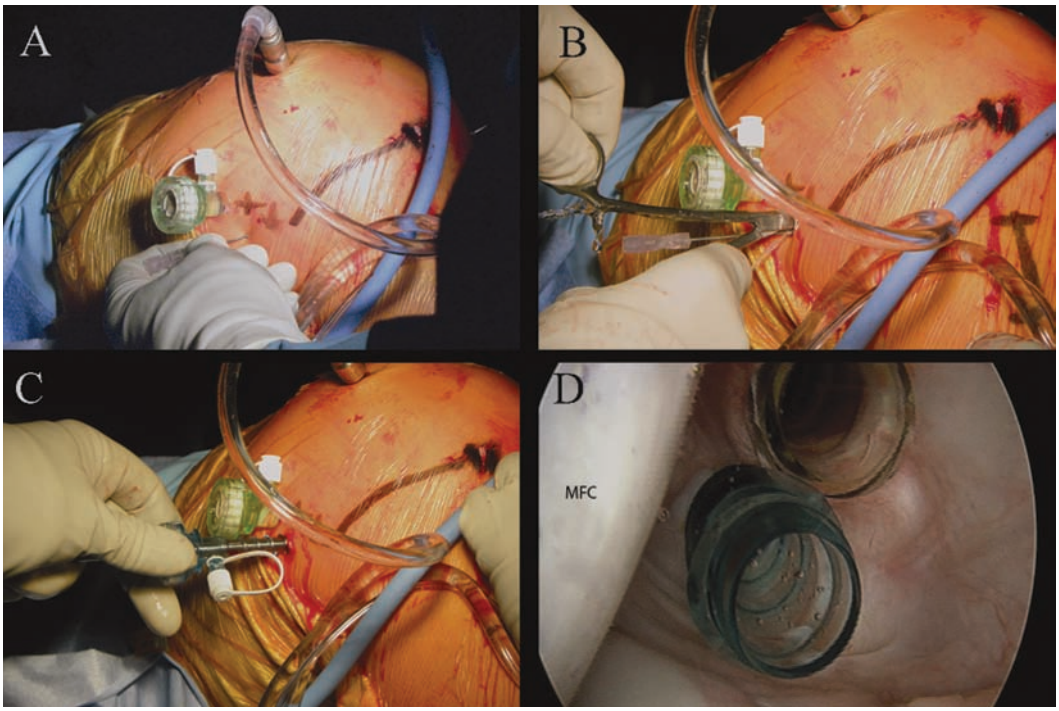

FIGURE 34.3

Posteromedial portal placement is demonstrated. **A:** Under arthroscopic guidance, a spinal needle is introduced into the knee to ensure accurate portal placement. **B:** Once a portal has been created with a No. 11 blade, it is dilated with a haemostat. **C:** Insertion of the 5 mm arthroscopic cannula. **D:** Arthrosocpic view of the 5-mm and 8-mm cannula placement.

the knee can quickly distort surrounding soft tissue planes, complicate ligament repair or reconstruction of collateral restraints, and increase the risk of compartment syndrome. Because it is more difficult to convert arthroscopic tibial tunnel preparation to an open technique, than it is to convert femoral tunnel preparation, we prioritize tibial tunnel preparation in acute (<3 weeks from injury) PCL reconstruction, especially if additional ligamentous or capsular compromise is present.

Tunnel Location and Preparation

Tibial Tunnel The PCL tibial insertion site is prepared using the 30 degree arthroscope and mechanical shaver through the superior and inferior posteromedial portals, respectively (Figs. 34.4–34.8). Often the tibial insertion of the PCL is intact and can serve as a reference point. Débridement of the inferior aspect of the posterior septum of the knee (below the level of the middle geniculate artery) is carried out posterior to the PCL insertion. This technique preserves the native tibial insertion and any remaining intact fibres, which is very important for PCL injuries where the posteromedial bundle and meniscofemoral ligament remain intact. The débridement is continued until the most distal and lateral borders of the PCL insertion are visualized.

The calibrated tibial PCL guide is set at a 55-degree angle and inserted through the inferomedial portal and the notch medial to any preserved PCL fibres. Under direct visualization and with the arthroscope in the posteromedial portal, the tip of the guide is placed 1.5 to 2 cm distal to the top of the tibial plateau in the lateral most aspect of the PCL footprint. A small incision is made along the anteromedial border of the tibia, and the guide sleeve is seated against bone.

A nonthreaded guide wire on power is advanced to the posterior tibial cortex through the guide parallel to the orientation of the proximal tibiofibular joint, as viewed on lateral fluoroscopy. Under direct visualization with the arthroscope in the posteromedial portal, the guide wire is advanced by hand through the posterior tibial cortex to exit posteriorly in the lower one third of the PCL insertion. The same process is repeated with a reamer that corresponds to the graft in diameter. A curette can be placed through the second posteromedial portal over the guide wire to ensure it is not inadvertently advanced during reaming. The tunnel is cleared of any debris with a shaver and rasped superiorly at the posterior cortex to smooth any sharp edges to protect the graft where it will make its abrupt turn.

A pediatric feeding tube is inserted retrograde into the tibial tunnel and its exit from the posterior cortex of the tibia visualized arthroscopically. A grasper through the inferolateral portal is used to retrieve the feeding tube medial to any preserved PCL fibres. A polydioxanone monofilament 0 suture is shuttled through the tibial

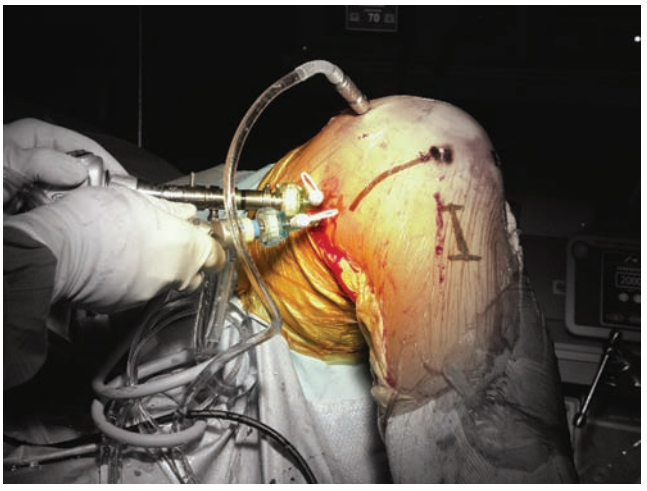

FIGURE 34.4
During preparation of the tibial insertion site, the surgeon works from the opposite side of the operating table through the two posteromedial portals.

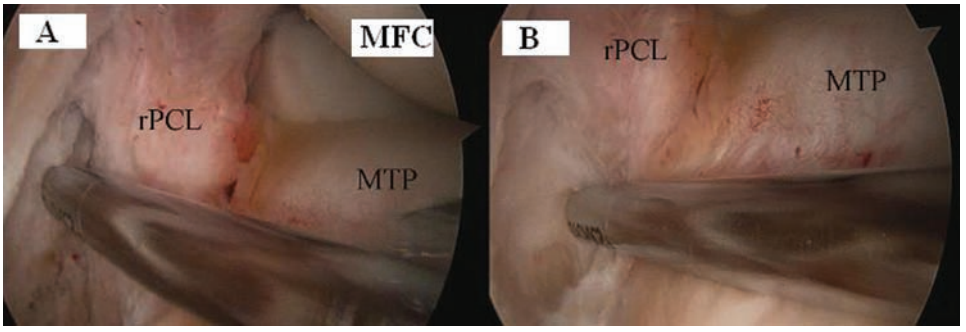

FIGURE 34.5
Preparation of the tibial insertion site is demonstrated. **A, B:** Débridement of the inferior aspect of the posterior septum of the knee, posterior to the PCL insertion. This technique preserves the remaining intact PCL fibres (rPCL). The medial femoral condyle (MFC) and medial tibial plateau (MTP) are shown.

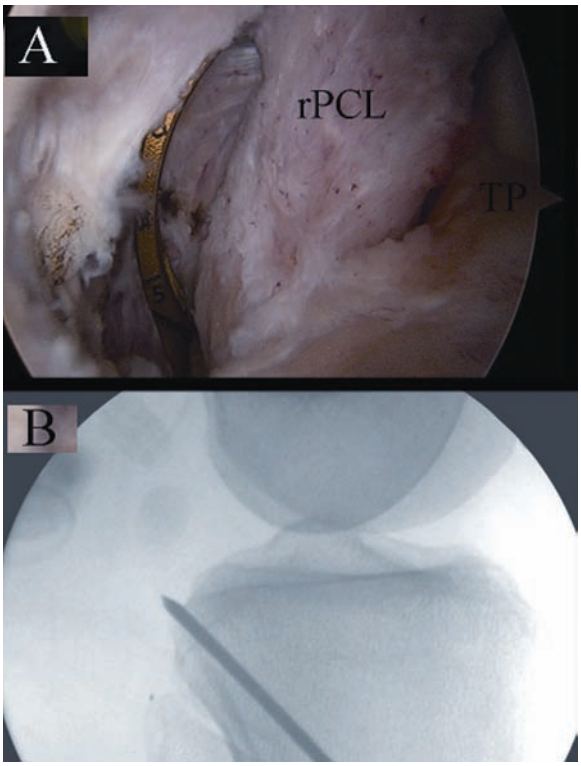

FIGURE 34.6

The tibial tunnel is created. **A:** Under direct visualization, the tip of the guide is placed 1.5 to 2 cm distal to the top of the tibial plateau. **B:** Fluoroscopy is used to confirm the position of the wire. The remaining PCL (rPCL) is indicated.

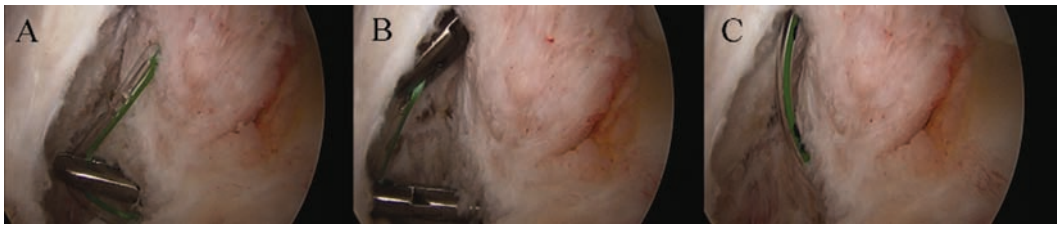

FIGURE 34.7

A: A paediatric feeding tube is inserted retrograde into the tibial tunnel. **B, C:** It curves superiorly and can be easily retrieved using a grasper through the inferolateral portal. The tube is used to pull the traction sutures anterograde into the tibial tunnel.

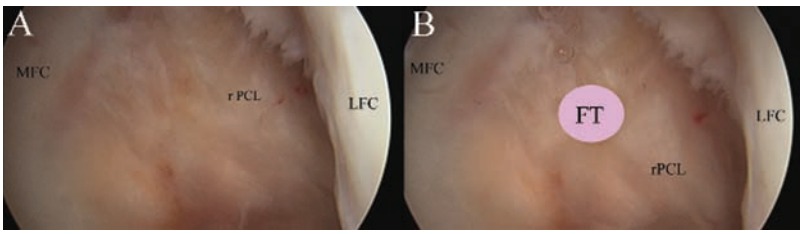

FIGURE 34.8

The femoral tunnel is prepared. **A:** The PCL femoral footprint that often remains intact is shown. **B:** The center of the proposed femoral tunnel (FT) is shown within the footprint of the anterolateral bundle on the medial femoral condyle. The remaining PCL (rPCL), medial femoral condyle (MFC), and lateral femoral condyle (LFC) are indicated.

tunnel with the feeding tube. A looped nonabsorbable 5 suture is tied to the polydioxanone strand at its tibial end and retrieved through the inferolateral portal.

Femoral Tunnel Studies suggest that the majority of the anterior and middle portions of the PCL are likely nonisometric with respect to length (4) (Fig. 34.9). Isometric single-bundle PCL reconstruction may therefore not only prove challenging but also be less effective than anatomical PCL reconstruction in restoring posterior tibial translation (13).

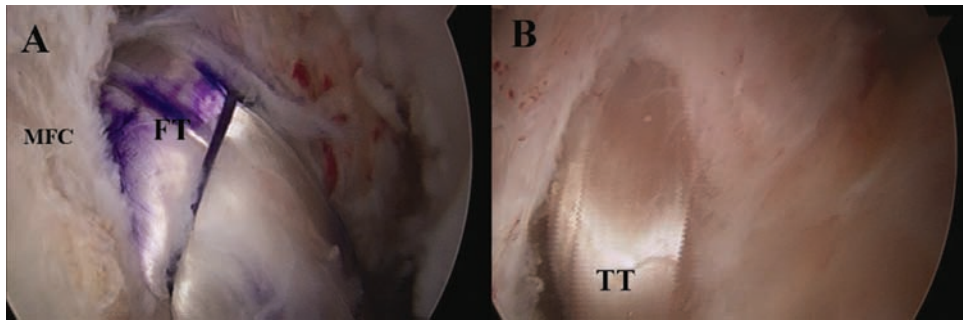

FIGURE 34.9

Final graft position is shown. **A:** Demonstrates the femoral tunnel (FT) insertion. **B:** The tibial tunnel (TT) insertion is shown. The medial femoral condyle (MFC) is indicated as well.

A 30-degree arthroscope is placed through the inferolateral portal. A hooked cautery tip in the inferomedial portal is used to mark the centre of the proposed femoral tunnel within the footprint of the anterolateral bundle on the medial femoral condyle. Fortunately, the PCL footprint on the femur often remains intact. Using cautery to remove any synovium from the insertion site of the PCL, care is taken to leave any underlying fibres undisturbed. If no intact PCL fibres remain, a Steadman awl is used to mark the starting point on the medial femoral condyle.

A Beath pin loaded through the appropriate diameter cannulated reamer (sized for graft) is inserted through the inferolateral portal. The tip of the Beath pin is gently impacted into the medial femoral condyle at the centre of the proposed femoral tunnel drilling site. The cannulated reamer is advanced by hand over the Beath pin to a depth of approximately 1 to 2 mm into the medial femoral condyle and then removed. The location of the reamer etching is viewed with either a 30- or 70-degree scope through the inferomedial portal to ensure it is acceptable and does not compromise the articular cartilage of the medial femoral condyle. Occasionally, an accessory inferolateral portal is required to bring the angle of the Beath pin as close to the face of the lateral femoral condyle as possible. This serves to reduce the acuity of the angle the graft encounters at its insertion into the femur.

With the knee positioned in 110 to 120 degrees of flexion, the Beath pin is reinserted and advanced through the medial femoral cortex. The 4.5-mm cannulated EndoButton drill is advanced over the Beath pin and through the medial femoral cortex. Care must be taken to ensure that the anterior aspect of the lateral femoral condyle is not damaged during reaming. The femoral tunnel length is measured, and an EndoButton of a size that will allow placement of a minimum of 20 mm of graft within the femoral tunnel is slelected. A cannulated reamer is used by hand to create the femoral tunnel. The Beath pin is pulled through the medial femoral cortex shuttling an absorbable polydioxanone monofilament suture size 0 through the femoral tunnel from the inferolateral portal. The femoral tunnel can alternatively be drilled with an outside-in technique and interference screw fixation utlilized.

Graft Passage

The inferolateral portal is enlarged sufficiently to allow unimpeded insertion of the PCL graft into the knee. It is critical to have both the tibial and femoral shuttling sutures free of any interposed soft tissue when exiting the inferolateral portal. The sutures attached to the EndoButton are shuttled through the medial femoral condyle. The EndoButton and attached graft are inserted through the inferolateral portal and pulled out of the femoral tunnel. The EndoButton is flipped. The sutures on the remaining end of the PCL graft are shuttled antegrade through the tibial tunnel using the previously placed nonabsorbable shuttling suture. The free end of the PCL graft is inserted into the inferolateral portal and retrieved from the tibial tunnel distally.

Graft Fixation As described, EndoButton fixation is used on the femoral side. Tibial fixation is accomplished with either staples or interference screws. The graft is secured with the knee in 90 degrees of flexion while applying an anterior load to the tibia in order to recreate both normal knee kinematics and in situ forces previously described in the PCL reconstruction utilizing a single anterolateral bundle technique (7).

Pearls and Pitfalls

Arthroscopic Fluid Extravasation In arthroscopic reconstruction, care must be taken to avoid excess arthroscopic fluid extravasation from the knee when associated ligamentous and capsular damage exist. Using a large diameter shaver for tibial and femoral tunnel preparation will save time and as well facilitate the evacuation of a greater quantity of arthroscopic fluid from the knee than a smaller diameter shaver. The outflow cannula must be constantly monitored to ensure that it does not become blocked.

Graft Contamination While extremely uncommon, graft contamination during ligament reconstruction can occur, and to date, no clear consensus has been reached regarding appropriate management (9). Our current protocol recommends that the contaminated graft be soaked for 30 minutes in a solution of 500 mL 0.9% normal saline containing Penicillin G (2 million units), Bacitracin (50,000 units), and Gentamycin (80 mg).

This is followed by serial dilution baths in normal saline to cleanse the graft of the antibiotic solution. Bacterial swabs are then taken prior to implantation.

Medial Femoral Cortex Breach The exit point for the femoral tunnel in PCL reconstruction is often situated in the softer metaphyseal cortex of the femur. If the medial femoral cortex is breached, fixation may be accomplished with the Xtendobutton (XtendoButton, Smith and Nephew, Corp., Andover, Massachusetts), a femoral interference screw, or by securing the sutures around a femoral post using a two incision technique.

Short Graft To avoid premature amputation of the graft during harvest, an extra 2 to 2.5 cm of graft can be obtained by releasing the common insertion site of the two tendons on the anterior tibia with a large sleeve of periosteum attached. This may provide enough length to proceed with the reconstruction as planned. However, if staple fixation cannot be utilized due to insufficient graft, an interference screw may be used.

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35 Single-Bundle PCL Reconstruction: Inlay Technique

Luke Choi, Chealon D. Miller, and Mark D. Miller

HISTORY OF THE TECHNIQUE

The posterior cruciate ligament (PCL) is infrequently injured with an estimated incidence of 3% to 16% of all knee injuries (1). There has been less investigation of the mechanics and function of the PCL when compared with the anterior cruciate ligament (ACL). In recent years, a better understanding of the short- and long-term consequences of PCL deficiency has spurred research to find the optimal method for reconstructing this ligament. There have been several techniques of PCL reconstruction developed; however, no single operation has emerged as the gold standard to predictably restore posterior stability and PCL function. We believe that, as with other procedures in orthopaedic surgery, the best results stem from procedures that recreate normal anatomy.

The PCL originates at the posterolateral aspect of the medial femoral condyle, inserting extra synovialy in a central sulcus located 1 cm distal to the posterior edge of the tibial plateau. The ligament consists of a large anterolateral portion and a smaller posteromedial portion, each of which has distinct and consistent insertions, in addition to variable meniscofemoral ligaments. These ligaments originate from the lateral meniscus and insert anterior and posterior to the PCL on the medial femoral condyle. The meniscofemoral ligaments (ligaments of Humphrey and Wrisberg) commonly remain intact following PCL rerupture and provide some posterior stability to the knee. The smaller posteromedial portion of the PCL consists of shorter fibers that are taut in knee extension. The anterolateral bundle is thickest in diameter, contains the longest fivers, and is taut with knee flexion. This is the portion of the PCL that provides the greatest tensile strength and resists posterior tibial translation beginning at 30 degrees of flexion (2,3).

Historically, most PCL reconstructions have emphasized an anterior-to-posterior approach to recreate the anterolateral bundle. This has been performed through a long oblique interosseous tunnel that creates difficulty with graft passage. These reconstructions require the graft to bend around a large angle at the back of the tibia, which has been dubbed the "killer turn," and has been implicated as a cause of graft failure (4).

The tibial inlay technique was originally developed in Europe and introduced to the United States by Berg (5) in 1995. This method processes a more anatomic reconstruction of the PCL by placing the distal portion of the graft directly in the PCL sulcus, in the posterior aspect of the tibia. Thus, the tibial inlay method avoids creating the "killer turn" of the graft associated with other reconstruction techniques.

This chapter describes the combined original concept of the tibial inlay with a posterior approach to the tibia s described by Burks and Schaffer (6). Additional refinements have been added, leading to the technique discussed herein.

INDICATION AND CONTRADINCATIONS

Diagnosis

A thorough history of the events of the injury is needed to make the diagnosis of a PCL injury. Common mechanisms of PCL injury include "dashboard injuries" during motor vehicle accidents or overloading of the knee and quadriceps in hyperflexion during athletic events. Isolated PCL injuries are more likely to be associated with athletic injury than any other mechanism. Acute, isolated PCL rupture is often associated with a smaller hemarthrosis than with ACL injury. Problems with knee instability with cutting or rapid deceleration movements are less common than with ACL-injured patients, although they may give a history of an instability sensation especially when on uneven ground. Many athletes will continue to play on a PCL-injured knee and will not seek medical attention until they develop a pain or aching the following days. Patients with PCL injuries may complain that the knee is just "not right" or have other subjective complaints such as a generalized "aching." Chronic PCL-injured patients will report pain (medial and patellofemoral) with ambulation or descending stairs.

PCL tears frequently occur with concomitant ligamentous, bony, or capsular injuries to the knee. In the trauma setting, these associated injuries can occur up to 60% of the time (7). Following medial or lateral collateral ligament damage, varus or valgus stress to the tibia may result in PCL injury. A hyperextension mechanism of PCL rupture can occur after the ACL is torn and is also associated with a posterior capsular injury. The most common combination is the combined PCL and posterolateral corner injury, which is reported to occur in up to 60% of all combined injuries.

The physical exam is critical to making the correct diagnosis of PCL injury. The posterior drawer test is 90% sensitive and 99% specific for PCL pathology and should be considered the gold standard for diagnosis (8). The posterior sag test, the Godfrey test, the prone drawer, the quadriceps active test, and the dynamic posterior shift test may all be used to confirm a PCL injury. An isolated grade III must be sought when looking for any additional instability. Knee dislocation must be ruled out any time there is the possibility of a multifilament injury. A careful hip and ankle exam as well as a neurovascular exam should be performed, especially if associated with high-energy trauma or a potential knee dislocation. Posterolateral instability is commonly associated with PCL injury and may be diagnosed with external rotation asymmetry, the external rotation recurvatum test, posterolateral and posteromedial drawer test, or the reverse pivot shift test. External rotation asymmetry has been proven to be the most reliable indicator of posterolateral instability.

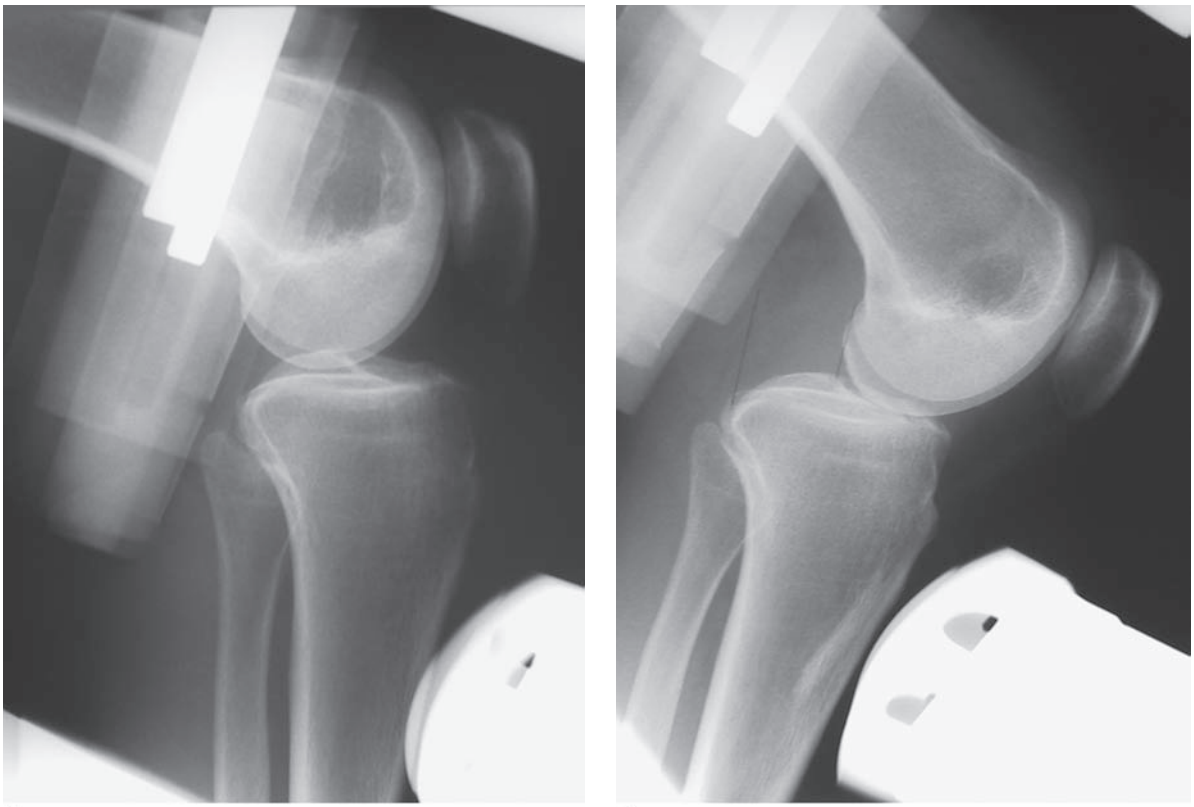
Radiographic studies, including plain films, stress radiography, and magnetic resonance imaging (MRI), are used to confirm clinical suspicion for a PCL injury. Plain films can be used to assess for any bony avulsion, tibial plateau fracture, or fibular head fracture suggesting possible posterolateral corner injury. Stress films are used to quantify posterior instability and can confirm clinical suspicions. It is a noninvasive, reproducible, and reliable method for determining the amount of posterior tibial translation (Fig. 35.1).

Historically, the management of PCL injuries has been nonoperative. Conservative management usually involves early brace treatment with progressive range of motion (ROM) exercise, followed by a quadriceps strengthening program early in the postinjury period. Protecting the knee from posterior tibial translation is crucial. Patients are typically restricted from athletics until 90% of contralateral quadriceps and hamstring strength is obtained. Recently, the accepted management of complete PCL tears has become more aggressive, with a lower threshold for operative treatment. This is the result of long-term follow-up studies that demonstrate worse results with nonoperative treatment. These studies also show radiographic deterioration with tie, especially in the medial patellofemoral compartments (9). The rate of arthrosis severity and progression depends upon the degree of posterior instability, quadriceps weakness, and the presence of additional ligamentous or meniscal damage. Nonoperative treatment is now reserved for asymptomatic, acute isolated PCL tears with mild posteriorly laxity (grades I and II), or chronic isolated PCL injuries that are asymptomatic.

The development of pain and degenerative arthritis is more common in patients with combined PCL injuries. Thus, patients who suffer PCL injuries in combination with bony avulsion injuries, posterolateral corner injuries, concomitant ligamentous injuries (grade III medial collateral ligament [MCL] or ACL rupture) require operative reconstruction of the PCL. Combined MCL-PCL and posterolateral corner injuries are an indication for operative treatment because the posterolateral corner is a secondary stabilizer to posterior displacement. Posterolateral corner injuries should be reconstructed within 2 weeks of injury. Isolated PCL injuries with grade III posterior laxity/instability are also an indication for operative management. Finally, active, young patients who demonstrate <10 mm of posterior laxity on displacement testing (grade II) but with symptomatic complaints of instability or pain should also have the PCL reconstructed.

Another relative indication for the use of the tibial inlay technique involves the revision setting. The tibial inlay technique is useful when a previous nonanatomic reconstruction has been performed. This avoids complications associated with previous tibial tunnels that are too wide in diameter or too proximal on the tibia. Patients with tibial osteopenia, previous fracture, or previous osteotomy may benefit from the tibial inlay technique to prevent proximal graft migration (10).

When operative management is indicated, the type and site of injury is critical in choosing the correct surgical procedure. Bony avulsion injuries involving the PCL insertion at the posterior tibia are treated with primary



A B

FIGURE 35.1

Stress radiography. **A:** Normal stress radiograph. Note that there is no posterior displacement of the tibia as the drawer test is applies. **B:** Abnormal stress radiograph. Note the posterior displacement of the tibia suggesting PCL injury.

repair using lag screws or suture fixation. Midsubstance tears of the PCL require ligament reconstruction, which attempts to reproduce normal anatomy. We believe that the tibial inlay technique procedures have the most anatomic PCL reconstruction.

The tibial inlay technique is contraindicated in patients who have had prior vascular procedures, especially those who have had remote vascular repairs.

SURGICAL TECHNIQUE

Preoperative Planning

Prior to surgery, it is necessary to diagnose concomitant knee pathology and to quantify the degree of posterior instability. With the assistance of stress radiography (Fig. 35.1A and B) or instrumented ligament testing using the KT-1000/2000 (MedMetric, San Diego, California), PCL instability may be quantified (11,12). (Fig. 35.2) Plain radiographs are used to exclude associated bony injury and to assess radiographic signs of arthrosis. MRI is also used as an adjunct in diagnosis and development of treatment plan. MRI is nearly 100% sensitive and specific for diagnosing PCL tears (13). In addition, MRI may be used to diagnose meniscal injuries, which should be addressed at the time of surgery. The arthroscopic exam is used as the final confirmation of intracapsular pathology (14). At the time of surgery, arthroscopy provides direct visualization, looking for the presence of complete versus partial PCL tears, bony avulsions, ACL pseudolaxity, and degenerative changes.

Anesthesia, Positioning, and Setup

For anesthesia, we prefer the use of a general anesthetic to allow for proper positioning and control during the procedure. Often, we will employ the use of a femoral or sciatic nerve block that is placed prior to surgery for use in postoperative pain control. Epidural catheter placement is also an option for use in postoperative pain control.

Once adequate anesthesia obtained, an exam under anesthesia is performed prior to final positioning and preparation of the patient. This is useful for confirmation of ligamentous laxity associated with PCL rupture and

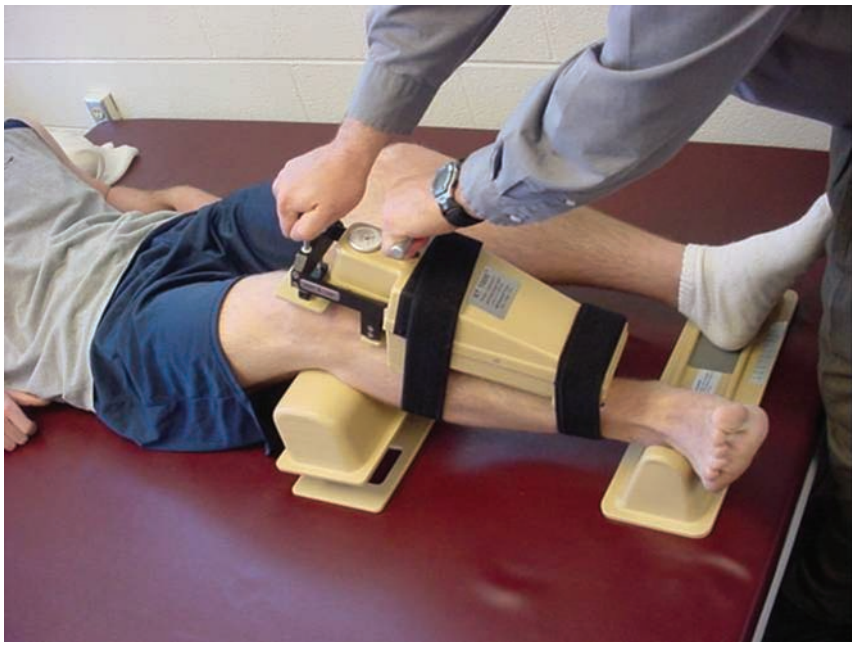


FIGURE 35.2

KT-1000. KT-1000-developed to provide objective measurements of sagittal plane motions of the tibia relative to the femur.

for ruling out previously unrecognized combined knee injuries. A broad-spectrum cephalosporin antibiotic or a suitable alternative is given preoperatively. Following examination, the patient is placed in the lateral decubitus position with the injured leg up. The contralateral leg remains extended, with padding placed around the fibular head in order to protect the common peroneal nerve (Fig. 35.3). The injured leg is abducted and externally rotated at the hip, flexed at the knee, and locked in place with a commercially available leg holder. From this position, graft harvest, arthroscopy, and drilling of the femoral tunnel are easily accomplished (Fig. 35.4). The posterior approach and the tibial inlay are performed with leg positioned in extension, neutral rotation, and resting on a Mayo stand. Finally, a tourniquet is placed on the proximal thigh, and the patient is prepped and draped in the usual sterile fashion.

Patellar Graft Harvest

Following preparation and draping, an 8-cm longitudinal incision is extended from the inferior pole of the patella to the tibial tubercle centered on the medial aspect of the patellar tendon. Care is taken to preserve saphenous nerve branches. The dissection is taken down to the paratenon and skin flaps are raised. The paratenon is carefully dissected off the patellar tendon both proximally and distally for use in the later closure. A central third 11 to 12 mm patellar tendon graft with 20 mm bone-patellar tendon-bone blocks is harvested, taking special care to make parallel incisions. A shorter graft is typically obtained and it can better negotiate the needed angle for entry in the femoral tunnel.

The tibial bone plug is trimmed to achieve a trapezoidal shape with a flattened surface, and a 3.2-mm hole is drilled centrally. This hole is then tapped in preparation for tibial inlay fixation using a 4.5-mm bicortical screw

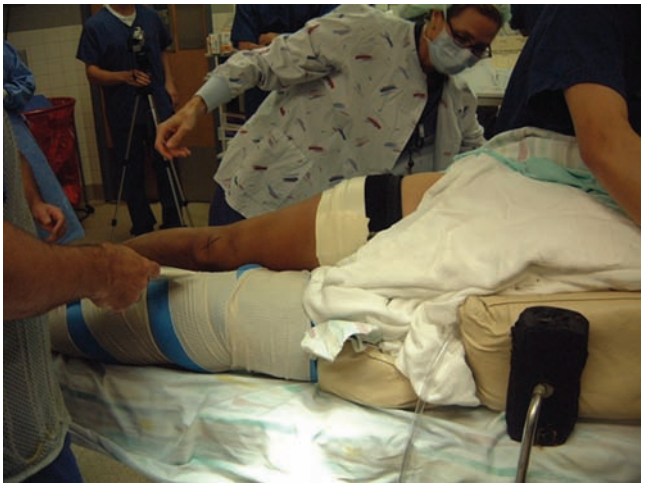


FIGURE 35.3

Preoperative positioning. The patient is placed in the lateral decubitus position with the contralateral leg padded.

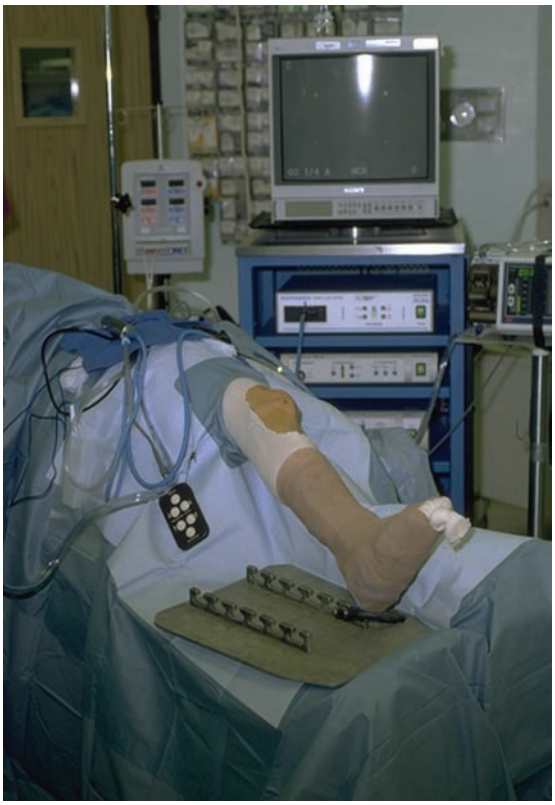


FIGURE 35.4
External rotation and abduction of the leg allow for graft harvest and arthroscopy.

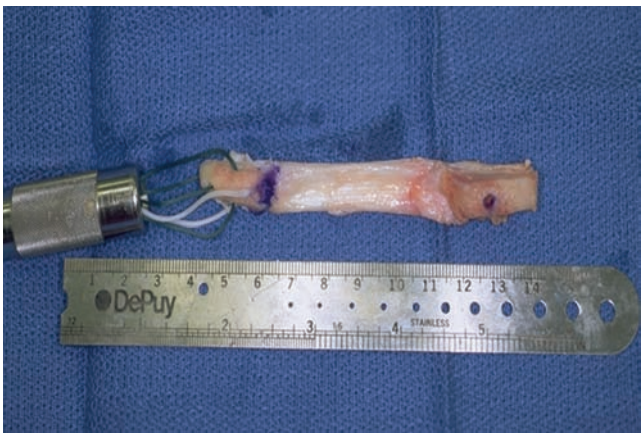


FIGURE 35.5
PCL patellar tendon graft. Note the preparation of the tibial plug for passage of a 4.5-mm bicortical screw. Patellar side with tapered bone plug and perpendicular sutures for femoral graft passage.

(Fig. 35.5). The patellar bone plug is sized so as to be able to fit through a 10 to 12 mm tunnel. The patellar bone plug is cylindrically contoured, tapering the leading edge such that it is bullet shaped for ease at insertion. Two perpendicularly oriented drill holes are placed approximately 5 mm and 10 mm from the distal tip of the patellar end of the graft. Two 5 nonabsorbable sutures are placed through the leading edge of the bone plug a the drill hole sites. These sutures will lateral be used to manipulate the patellar bone plug into the femoral tunnel. A 2 Ethibond or Ticron suture is also placed at the patella-bone-tendon junction and will be used laterally to toggle the graft, permitting easier entry into the femoral tunnel. Finally, all bone plug trimmings should be saved and used later as bone grafts.

Arthroscopy and Femoral Tunnel Placement

The affected limb is held in abduction, external rotation, and flexion by the leg holder. Standard anterolateral and medial arthroscopic portals are created. A thorough diagnostic arthroscopy is performed to confirm PCL deficiency, identify comorbid intra-articular pathology, and identify landmarks for reconstruction. Special attention should be directed to the lateral joint space of patients who have excessive opening with varus stress. These patients should be evaluated with a high index of suspicion for posterolateral corner injuries (15). Following

PCL débridement, all meniscal and cartilage work should be performed, and uninjured meniscofemoral ligaments should be left intact. After débridement of the PCL femoral footprint, a standard PCL femoral guide is placed into the knee via the anteromedial portal. This guide will be used to place the guide pin for the femoral tunnel. The drill guide is placed in the anterior portion of the PCL femoral insertion site, located 8 to 10 mm behind the medial femoral condyle articular surface at the 1 o'clock position in the notch for a right knee, and 11 o'clock for a left knee. A small 2 to 3 cm incision is made at the superior and the medial borders of the patella. The vastus medialis oblique muscle fibers are split or retracted, and the external tunnel guide is positioned on the cortical surface of the femur away from the articular surface of the medial femoral condyle (Fig. 35.6A). A guide pin is inserted from outside in and identified on the intra-articular medial femoral condyle (Fig. 35.6B). After confirming the guide pin to be in the anterolateral PCL bundle footprint, the tunnel is overdrilled from outside in with a cannulated drill bit reamer-sized appropriately for the graft. A small curette is placed into the joint to prevent the guide pin from injuring any intra-articular structures. Bone graft should be saved from the flutes of the closure. Following drilling, the posterior aspect of the tunnel is rasped, or smoothed, with a reverse cutting reamer to decrease abrasive forces on the graft. Once the femoral tunnel is fully prepared for graft placement, a looped 18-gauge wire is introduced in the tunnel from outside to inside. The guide wire is passed into the posterior aspect of the knee joint and will be used later to initiate and facilitate graft passage (Fig. 35.7). At this time, the pump/inflow is turned off, and the arthroscope and the equipment are removed from the knee. Attention is directed to the inlay portion of the case.

Posterior Approach and Inlay

The patient is repositioned, placing the injured leg on the padded Mayo stand in full extension and neutral rotation (Fig. 35.8). A transverse incision is made in the flexion crease. The medial head of the gastrocnemius

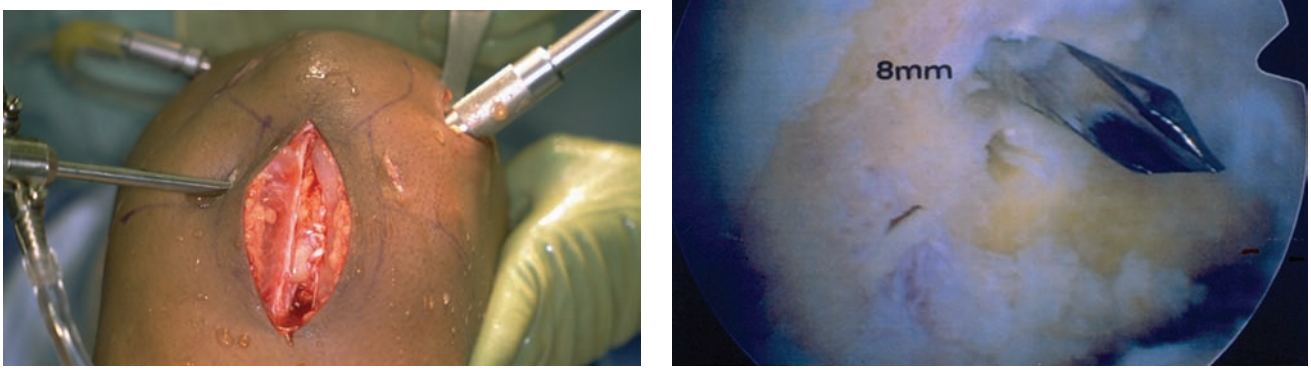


FIGURE 35.6

Femoral tunnel placement. **A:** The vasus medialis oblique muscle fibers are split and the external tunnel guide is positioned on the cortical surface of the femur away from the articular surface of the medial femoral condyle. **B:** A guide pin is inserted from outside in and identified on the intra-articular medial femoral condyle. Note that the guide pin to be in the anterolateral PCL bundle footprint approximately 8 mm behind the medial femoral condyle articular surface.

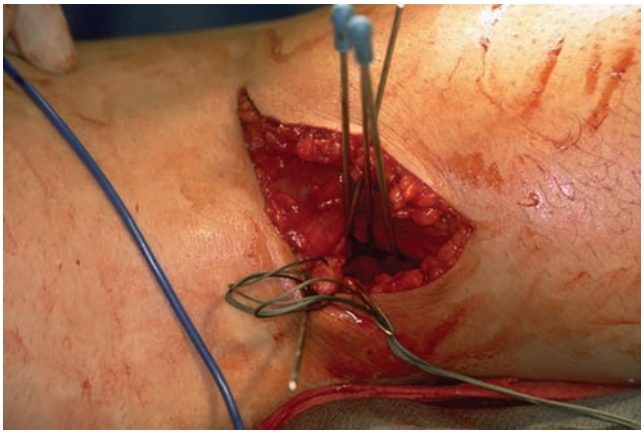


FIGURE 35.7

Positioning for the posterior approach to the knee.

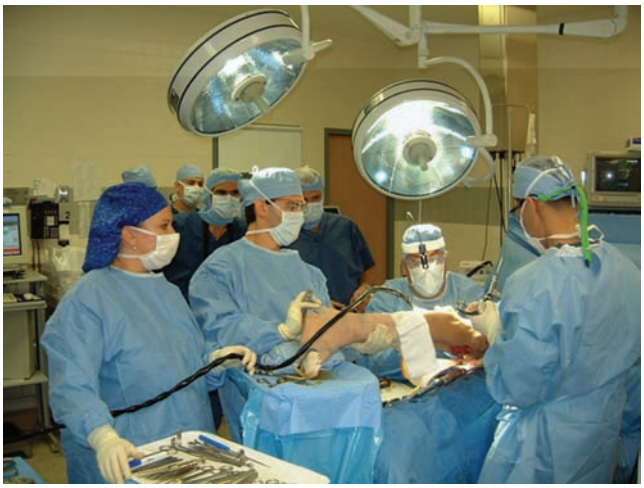


FIGURE 35.8

Looped 18-gauge wire used for passage of patella end through arthrotomy.

muscle is exposed by incising the medial aspect of the gastrocnemius fascia both transversely and distally on the medial side. Blunt dissection is used to develop an interval between the gastrocnemius and the semimembranosus muscles. The medial sural cutaneous nerve must be kept in mind at this point, although it usually perforates the deep fascia distal to the incision. Once the interval is developed, the medial head of the gastrocnemius muscle is laterally retracted, exposing the posterior knee capsule. The middle and the medial geniculate arteries may be encountered near the midposterior capsule and can be ligated if necessary. The medial head of the gastrocnemius is surprisingly mobile, but it is occasionally necessary to release a portion of its tedious origin medially in order to gain adequate exposure. Slight knee flexion will also allow for greater lateral retraction of the medial head of the gastrocnemius and increase exposure. A cadaveric study previously demonstrated that the gastrocnemius muscle protects the popliteal artery during lateral retraction, and this exposure is safe, although one must be aware of anatomic variations (16). Steinmann pins can be placed posteriorly into the tibia and bent laterally in order to assist with retraction of the medial head of the gastrocnemius.

Next, the PCL sulcus is palpated through the fibers of the popliteus muscle. The sulcus is defined by a large medial and a smaller lateral bump. Electrocautery and an elevator are used to dissect the popliteus muscle from its origin, exposing the posterior tibial cortex. The position of the PCL sulcus is reconfirmed at the central aspect of the posterior tibial. A generous capsular incision is made vertically, contiguous with the PCL sulcus. Any remaining scar tissue or PCL remnant is débrided at this time. At this point, the preplaced 18-gauge passing wire may be retrieved through the new posterior arthrotomy site (Fig. 35.7). The 18-gauge wire will later be used to pass the 5 nonabsorbable sutures and graft through the femoral notch and into the femoral tunnel. A trough is developed at the PCL insertion site using an osteotome, burr, and tamp. The inlay site is fashioned such that it matches the size and the shape of the tibial portion of the PCL graft. The graft is inlaid into the unicortical widow. The graft/bone plug is carefully adjusted such that it fits snugly within the trough, flush with the posterior tibia. Before securing the graft, a second 18-gauge looped guide wire is passed from the anteromedial arthroscopic Portland out of the posterior arthrotomy (Fig. 35.9). This looped guide wire is used to pull the 2 Ethibond suture out of the anteromedial portal. The patellar end of the graft is then passed into the knee joint and the femoral tunnel using the 18-gauge wire and 5 sutures.

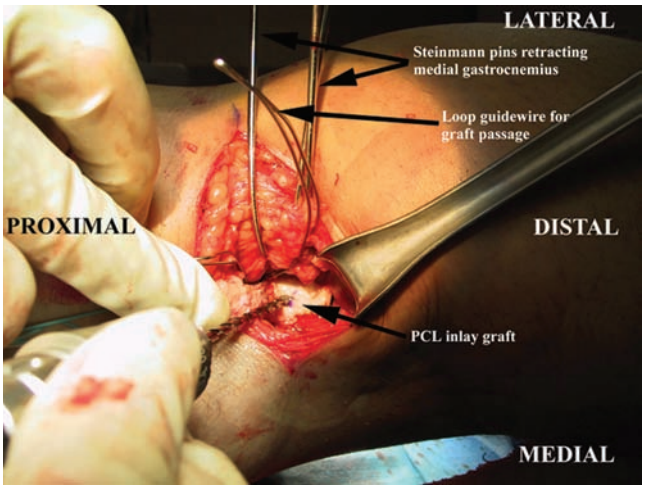


FIGURE 35.9

Tibial inlay. Note the Steinmann pins used for lateral retraction of the gastrocnemius and the looped guide wire for passage of the graft into the femoral tunnel. The tibial portion of the patellar tendon graft is placed into the unicortical window and drilled from posterior to anterior.

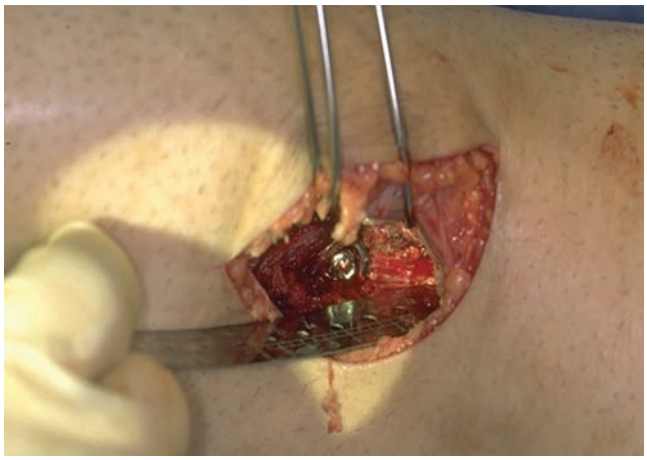


FIGURE 35.10
Inlay fixation. Tibial inlay following placement of a 4.5-mm posterior to anterior bicortical screw.

After all necessary sutures and the patellar end of the bone-patellar tendon-bone graft are passed into the knee joint, the tibial bone plug is secured by lagging 4.5-mm bicortical screw and washer through the predrilled tibial bone plug hole and into the anterior cortex of the tibia (Fig. 35.10). Additional fixation with a second screw or a staple is sometimes beneficial.

Graft Passage and Fixation

Using the original looped 18-gauge wire as a graft passer, the patellar end of the graft is passed through the posterior arthrotomy, into the notch, and then into the femoral tunnel. The knee is then passively taken through a full ROM cycles while palpating the tibial inlay site in order to ensure that there are no hang-ups at the posterior arthrotomy. The leg is then repositioned for arthroscopy and final graft placement. The 5 and 2 sutures should be pulled through the femoral tunnel and anteromedial arthroscopic portal, respectively, if this has not been already performed. The 5 suture is used to pull the patellar bone plug into the femoral tunnel, while the 2 suture is used to toggle the graft for easier passage. The graft is optimally positioned with the patellar-bone plug-tendon junction located at the articular margin of the femoral tunnel. This graft/tunnel angle is sometimes referred to as the "critical corner" because poor positioning can contribute to excessive sheer stress and early graft failure (17). While keeping moderate tension on the 5 suture, the knee is again passively cycled through full ROM cycles in order to rule out kinks in the graft and reconfirm a lack of impedance at the posterior arthrotomy site.

The graft is tensioned by placing an anterior drawer on a knee flexed to 70 to 80 degrees while maintaining the desired intra-articular position of the patellar-bone plug-tendon junction. Proximal fixation is achieved with a 9 mm by 20 mm interference screw. Additional fixation with a plastic button tied with the 5 nonabsorbable sutures over the cortex at the tunnel entrance is also utilized. Intraoperative radiographs should be obtained to ensure proper graft and hardware placement (Fig. 35.11A and B).

Wound Closure

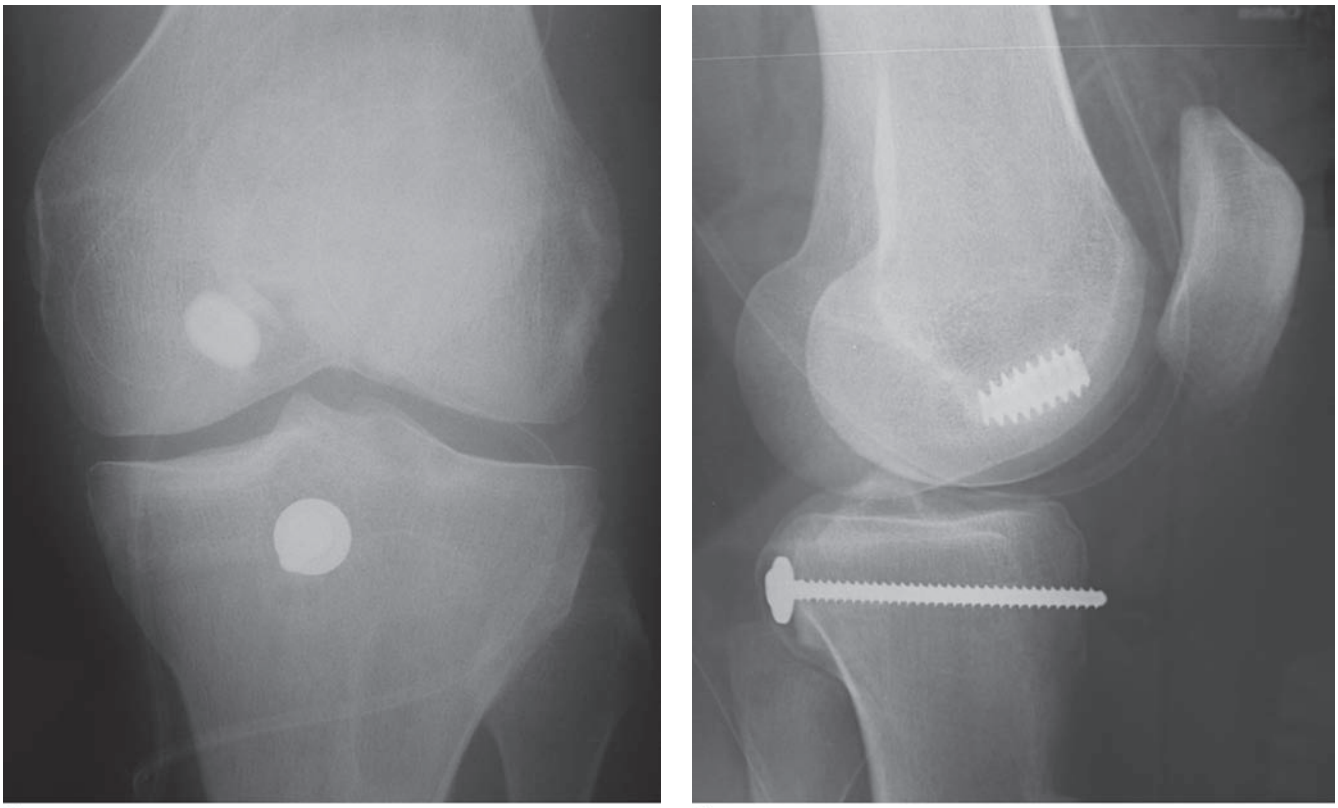
Prior to wound closure, all bone graft from femoral tunnel drilling and graft preparation should be packed into the patella and tibial tubercle harvest sites. Anteriorly, the paratenon is closed in an interrupted fashion using 0 Vicryl sutures over the patellar tendon and previous bone harvest sites. All subcutaneous tissue and skin layers are closed in standard fashion, and a sterile dressing is applied.

At the end of the procedure, the posterior capsule is closed and sutured with 0 absorbable suture. A one-eighth inch closed drain is placed deep to the medial head of the gastrocnemius muscle for Hematoma prevention. The medial gastrocnemius is allowed to fall into place, the subcutaneous layers are approximated, and the skin is closed in a routine fashion.

TECHNICAL ALTERNATIVES AND PITFALLS

The surgeon should be particularly vigilant during certain periods of the PCL reconstruction in order to prevent operative complications. One potential pitfall is the failure to recognize an associated injury. Isolated PCL injury is uncommon; thus, most injuries will involve other knee ligament or structure. This can lead to residual laxity on the posterior drawer test and present as recurrent symptomatic laxity following reconstruction.

Often, avascular necrosis (AVN) of the medial femoral condyle has been reported. Patients will usually present with medial knee pain and tenderness to palpation of the medial femoral condyle. To avoid this potential problem, care must be taken to start the femoral tunnel 8 to 10 mm posterior to the articular margin as the



A B

FIGURE 35.11

Postoperative films **(A)** AP and **(B)** lateral radiograph of a patient's knee after PCL tibial inlay technique.

etiology secondary to femoral drilling is too close to the articular surface or the extensive soft tissue dissection over the medial femoral condyle. AVN of the medial femoral condyle can present months to years after surgery and is thought to be caused by local trauma to the subchondral bone blood supply causing increased pressure in the area. By using a more proximal entry site, maximal subchondral bone is preserved, thereby reducing the risks of AVN. It is also critical to ensure that the graft does not kink or hang up during passage from the posterior arthrotomy, through the femoral notch, and into the femoral tunnel. This complication decreases the stability of the reconstruction, causing persistent posterior laxity, but can be easily avoided by palpating the PCL inlay site and using direct arthroscopic visualization of the graft while the knee is taken through passive full ROM cycles. Persistent laxity can also be caused by overly aggressive rehabilitation, poor graft fixation or placement, and a previously stated failure to recognize any associated injuries. In addition, particular care should be taken to ensure that the patellar bone tendon junction is located at the intra-articular margin of the femoral tunnel in order to decrease graft degradation at this "critical corner." Finally, we previously used a hockey stick–shaped incision for the posterior approach to the knee. This approach was associated with an increased incidence of wound breakdown superiorly. By using a transverse incision on the flexion crease of the posterior knee, we nearly eliminated the problem of wound breakdown, while providing a better cosmetic result (Fig. 35.12).

The most feared potential complication with any posterior exposure to the knee is vascular injury. Injury to the vascular structures is always a risk during posterior knee exposure, especially in the revision setting where normal anatomy can be altered secondary to previous scar formation. The surgeon should be aware of potential vascular anomalies during the exposure as even the superficial dissection in the semimembranosus-gastrocnemius interval can lead to inadvertent injury. Subperiosteal dissection of the popliteus provides additional soft tissue protection against any anatomic variants. The use of k-wires or Steinman pins allows for continuous retraction during posterior dissection, thus avoiding repetitive repositioning of retractors and further potential for injury.

REHABILITATION

In the immediate postoperative period, the extended leg is placed in a hinged knee brace. Special care is taken to support the tibia and prevent posterior translation. On postoperative day 1, the patient is permitted to bear weight as tolerated and ambulate with crutches. When bearing weight, the patient is always in the brace

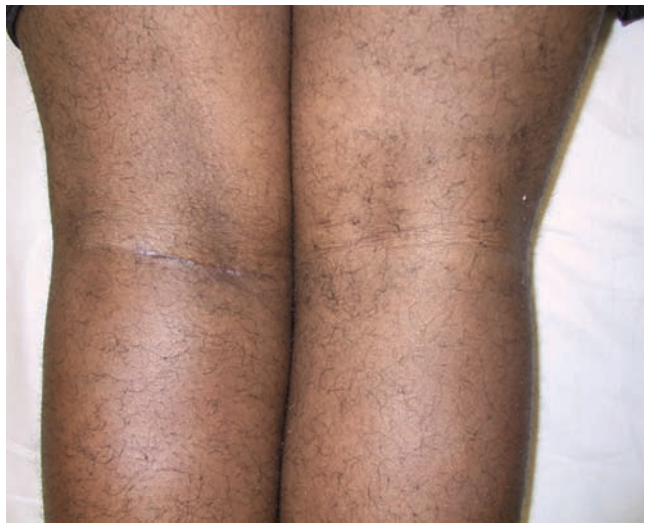


FIGURE 35.12

Using a transverse incision at the flexion crease of the posterior knee decreases problem of wound breakdown while providing a better cosmetic result.

locked at 0 degrees. Continuous passive motion, isometric quadriceps training, and straight leg raised should be implemented into the rehabilitation program as soon as the patient can tolerate such activity. Partner-assisted ROM exercises are also useful in the immediate postoperative period. These exercises are performed with the patient in the prone position in order to prevent posterior translation of the tibia. In the early postoperative period, weeks 0 to 4, gravity-assisted flexion exercises to 90 degrees and closed-chain exercises for quadriceps strengthening are important. At 1 month postop, the patient is allowed to transition to unlocking the brace for ambulation and activities under supervision of the therapist. The patient may start to wean off crutches as tolerated. When the patient exhibits independent quadriceps control, he or she may progress to open-chain extension exercise, minisquats, and isometric exercises. At 2 months, the patient may add in stationary bike or stairmaster activities as well as leg presses within available ROM. From months 3 to 9, the patient may progress within his or her level of function and symptoms. The patient should ideally be allowed to return to normal activities 9 to 12 months postoperatively if the knee is stable, with full ROM and quadriceps strength equal to the contralateral leg.

OUTCOMES AND FUTURE DIRECTIONS

Even among experts, PCL reconstruction is a relatively uncommon procedure, and there are a limited number of published reports in the literature. A growing body of data suggests that the tibial inlay technique is effective at decreasing posterior knee instability with good long-term results. A 2-year follow-up study performed by Jung et al. (18) in Korea demonstrated that the average posterior displacement on stress radiography decreased from 10.8 to 3.4 m, with 90% of patients reporting a satisfactory outcome. Likewise, Cooper (19,20) has presented two reports showing good results using the tibial inlay. The standard trans tibial tunnel technique of PCL reconstruction has been popular, but biomechanical studies raise concern about the long-term outcomes of this method. A cadaveric, matched pair comparison of the tibial inlay versus tibial tunnel techniques found that the tibial tunnel group had greater anterior-posterior laxity postoperatively. Upon evaluation of the grafts, the tibial tunnel group revealed greater evidence of mechanical degradation at the acute angle (21). These findings were confirmed by a second matched pair biomechanical comparison that demonstrated the tibial inlay method to be superior to the tibial tunnel technique with respect to graft failure, permanent graft lengthening, and graft thinning (22).

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36 Surgical Approach to PCL Injury

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INDICATIONS/CONTRAINDICATIONS

Posterior cruciate ligament (PCL) injuries are rare, may be partial or complete, and frequently occur with other ligamentous and soft tissue injuries. There is a relative lack of consensus regarding the optimal management of PCL injuries. Most authors advocate nonoperative management of isolated, partial PCL injuries (grades I and II). Our treatment protocol includes immobilization in full extension with protected weight bearing for 2 weeks. Range of motion exercises are advanced as tolerated and strengthening is focused on the quadriceps muscles through closed-chain exercises. Return to sport after isolated grade I and II PCL injuries is usually 4 to 6 weeks, paying special attention to protect the athlete from injury and potential progression to a grade III injury. We have found functional bracing to be of little benefit after return to sport.

Treatment of isolated grade III injuries is more controversial, as some authors dispute the existence of an isolated grade III injury. We recommend nonoperative treatment with immobilization in full extension for 2 weeks to prevent posterior tibial subluxation. Weight bearing is protected during these 2 weeks, then slowly advanced. Quadriceps sets and straight leg raises are encouraged, while hamstring loading is prohibited until later in the rehabilitation course. After 1 month, range of motion, full weight bearing, and progression to functional activities is instituted. Return to sport is usually delayed for 2 to 4 months in patients with grade III injuries.

Our indications for reconstruction of isolated PCL tears are displaced bony avulsions or chronic grade II/III injuries with persistent instability and pain. We also advocate PCL reconstruction in the setting of combined ligamentous injuries, especially those involving the posterolateral corner. Surgical treatment of isolated grade II or III injuries may be considered for higher-level athletes.

PREOPERATIVE PLANNING

Accurately diagnosing isolated PCL or combined ligamentous knee injuries through a complete history and thorough physical exam is the first step in injury management. Once identified, understanding PCL injuries with respect to their natural history, surgical indications, surgical technique, and postoperative rehabilitation is important in order to achieve a successful outcome. The timing of PCL reconstruction depends on the severity of the injury and the associated concomitant ligamentous injuries. Displaced bony avulsions and knees with multiligamentous injuries should be addressed within the first 3 weeks to provide the opportunity for anatomical repair (4).

The initial history should focus on the mechanism of injury, its severity, and associated injuries. With acute injuries, the patient will often not report feeling a "pop" or "tear," as is often described with ACL injuries. The history should also focus on assessing the chronicity of the injury, and the pain and instability the patient experiences. Acute injuries usually result from a history of a direct blow to the anterior lower leg. Motor-vehicle accidents and sports-related trauma are the most commonly cited causes of PCL injuries (2). In motor-vehicle trauma, the classic "dashboard injury" occurs when the proximal tibia strikes the dashboard, causing a posteriorly directed force to the proximal tibia with the knee in a flexed position. Athletic injuries usually involve a direct blow to the anterior tibia or a fall onto a flexed knee with the foot in plantar flexion. Noncontact

hyperflexion injuries have been reported to result in partial tearing of the PCL. Hyperextension injuries, which are often combined with varus or valgus forces, often result in combined ligamentous injuries.

A comprehensive knee examination, including inspection, palpation, range of motion testing, neurovascular examination, and special tests should be performed. Special tests to examine the PCL and posteriolateral corner include posterior drawer test (Fig. 36.1), posterior sag (Godfrey) test (Fig. 36.2), quadriceps active test, reverse pivot shift test, dial test, and posterolateral external rotation test. The posterior drawer test is the most sensitive test to detect a PCL injury. The quadriceps active test must be performed in the office setting as voluntary quadriceps contraction must occur. This test is generally only helpful for higher grade injuries, as the examiner must visualize the posteriorly subluxed tibia reduce anteriorly with quadriceps contraction. The reverse pivot shift test is performed with the patient supine and the knee flexed to 90 degrees. The knee is extended while the foot is externally rotated and a valgus stress is applied to the knee. A palpable reduction of the tibia occurs at 20 to 30 degrees during a positive test. As previously mentioned, PCL injuries frequently occur with other ligamentous and soft tissue injuries. They are most commonly associated with posterolateral corner injuries. A dial test may be performed in the office with the patient prone. The tibiae are externally rotated with the knees at 30 and 90 degrees. A positive test results in asymmetry of >10 degrees of external rotation. Another important test for diagnosing posterolateral corner injuries, especially during the exam under anesthesia, is the posterolateral external rotation test. With the patient supine, the knee is flexed to 90 degrees, and the foot is supported on the table. A posterior and external rotation stress is placed on the tibia. The tibia is palpated for posterolateral subluxation.

Standard AP and lateral radiographs of the knee are an essential part of the diagnostic evaluation. These films should be carefully scrutinized for subtle posterior tibial subluxation, which may be the only radiographic finding in isolated PCL injuries. An avulsion of the tibial insertion of the PCL may be identified on a lateral radiograph. Stress radiographs and contralateral views, although not routine, may be helpful in some situations (7). In the setting of a chronic injury, flexion weight-bearing and long cassette films are also essential to assess for medial and patellofemoral compartmental arthrosis and coronal malalignment. An MRI is important to confirm a PCL injury (Fig. 36.3), determine its location and completeness, and to assess for a concomitant injury, including meniscal and posterolateral corner pathology.

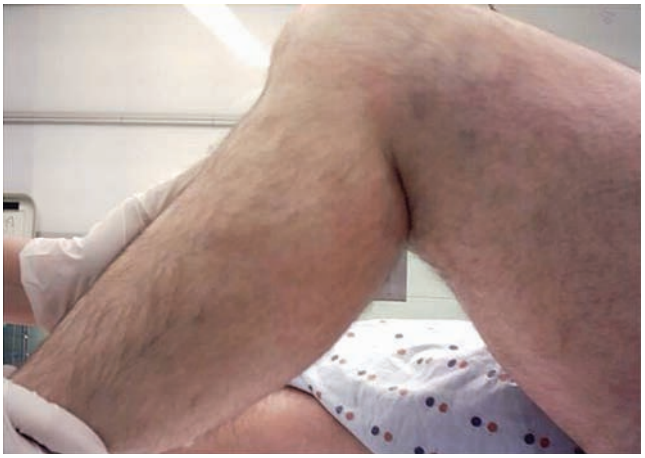

FIGURE 36.1

The posterior drawer exam is performed with the patient supine, the knee flexed to 90 degrees, and the foot supported on the table. The examiner's thumbs are placed on top of the medial and lateral tibial plateaus and a posterior force is applied to the proximal tibia. Posterior tibial translation compared to contralateral side results in a positive test. Grade I (0–5 mm), grade II (5–10 mm), grade III (>10 mm).

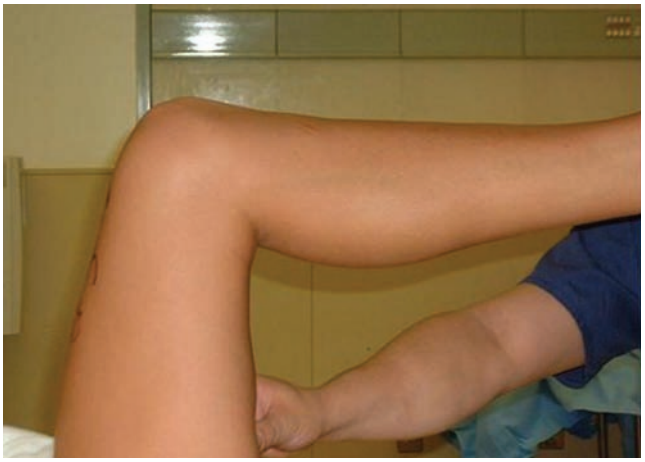

FIGURE 36.2

Godfrey test (posterior sag) is performed with the patient supine, the hip and knee flexed to 90 degrees, and the foot supported by the examiner. Abnormal posterior sag of the tibia relative to the femur results in positive test.

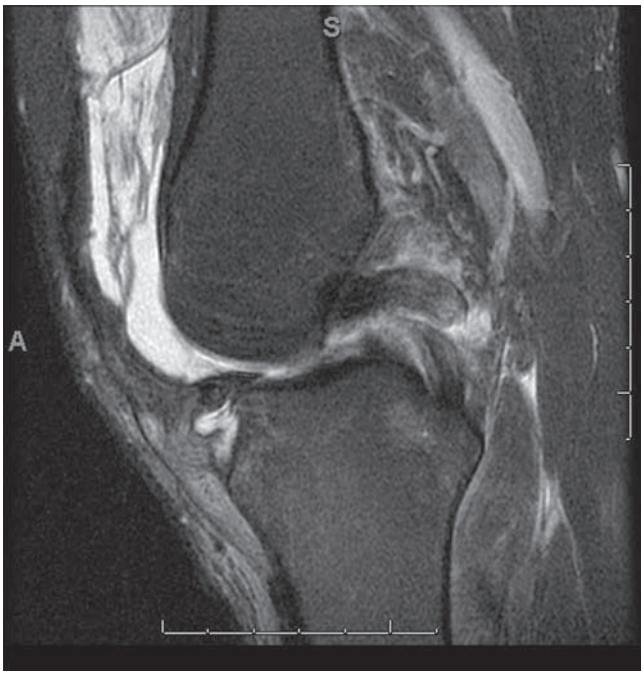

FIGURE 36.3
T2 weighted sagittal MRI demonstrating a midsubstance tear of the PCL.

SURGERY

Sciatic and femoral nerve blocks catheters may be placed prior to surgery. However, no anesthetic is introduced until neurologic assessment has occurred upon completion of the case. After induction, an examination under anesthesia (EUA) is performed on both the nonoperative and the operative knees. Data from the contralateral knee may be particularly helpful with combined injuries. A detailed exam to determine the direction and degree of laxity is recorded. Fluoroscopy may be used after the EUA to assess posterior tibial displacement.

Treatment Algorithm

For acute injuries, we employ the single-bundle technique. If there is some component of the native PCL remaining, we spare this tissue and utilize the augmentation technique. This technique can be time consuming and difficult, but preservation of PCL tissue may provide enhanced posterior stability of the knee and may promote graft healing. We perform the double-bundle technique most commonly in the chronic setting when any remaining structures are significantly incompetent. Although some authors advocate the tibial inlay technique for all settings, we typically do not utilize this technique. In the setting of a displaced tibial avulsion or a combined PCL and posterolateral corner injury, we use the techniques described below.

Single-Bundle Technique

The patient is positioned supine on a radiolucent operating room table. We do not use a tourniquet. A side post is placed on the operative side just distal to the greater trochanter to support the proximal leg with the knee in flexion. A padded bump is taped to the operating room table to hold the knee flexed to 90 degrees during the case. After prepping and draping the operative site, a hole is cut in the stockinette for access to the dorsalis pedis pulse throughout the case. A bump is placed between the post and the leg to stabilize the knee in a flexed position while the foot rests on the prepositioned sand bag (Fig. 36.4). The knee is flexed to 90 degrees and the vertical arthroscopy portals are delineated. The anterolateral portal is placed just lateral to the lateral border of the patellar tendon and adjacent to the inferior pole of the patella. The anteromedial portal is positioned 1 cm medial to the medial border of the superior aspect of the patellar tendon. A diagnostic arthroscopy is conducted to determine the extent of injury and evaluate for other cartilage or meniscal pathology. The notch is examined for any remaining intact PCL fibers. If there are remaining fibers, care is taken to preserve these fibers and an augmentation is performed (see Single-Bundle Augmentation technique). Using an arthroscopic electrocautery device and shaver, overlying synovium and ruptured PCL fibers are debrided and the superior interval between the ACL and PCL is defined. An accessory posteromedial portal is created just proximal to the joint line and posterior to the MCL. A 70-degree arthroscope is placed between the PCL remnants and the medial femoral condyle to assess the posterior horn of the medial meniscus and to localize the posteromedial portal with a spinal needle. A switching stick may be placed into the posteromedial portal to facilitate exchange of the arthroscope. The 30-degree arthroscope is used when viewing via the posteromedial portal. A trans-septal portal also

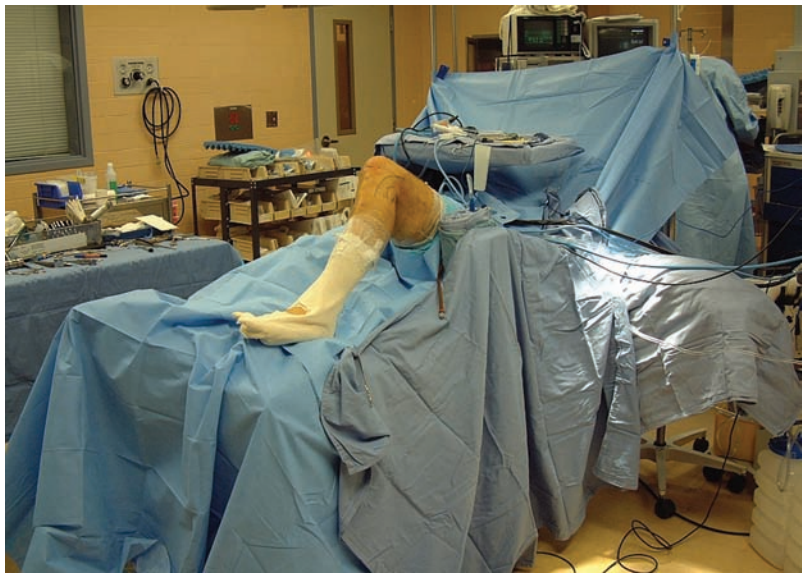

FIGURE 36.4
Operating room setup.

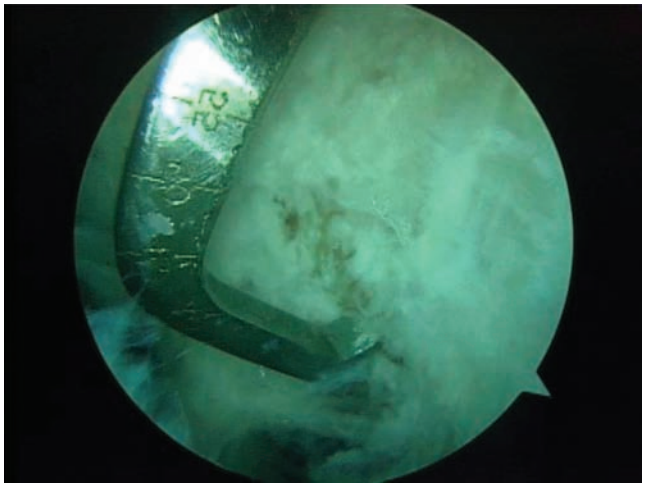

FIGURE 36.5
The PCL guide is positioned just distal and lateral to the PCL insertion site, 1.5 cm distal to the articular edge of the posterior plateau along the sloped face of the posterior tibial fossa.

may be created for better visualization of and access to the tibial PCL insertion (8). Preparation and exposure of the tibia is essential for drilling the tunnel safely in the appropriate position. First the 70-degree arthroscope is placed into the anterolateral portal and a commercially available PCL curette is introduced through the anteromedial portal. A lateral fluoroscopic image may be obtained to confirm its position. The 30-degree arthroscope is then introduced through the posteromedial portal. The soft tissue on the posterior aspect of the tibia is carefully elevated centrally and slightly laterally. A shaver may be placed through the anterolateral portal to debride some of the surrounding synovium. The 70-degree arthroscope is returned to the anterolateral portal and the shaver placed in the posteromedial portal to complete the exposure. A commercially available PCL tibial drill guide set to 55 degrees is advanced through the anteromedial portal and placed just distal and lateral to the PCL insertion site, 1.5 cm distal to the articular edge of the posterior plateau along the sloped face of the posterior tibial fossa. The position is checked fluoroscopically with a lateral view and arthroscopically via the posteromedial portal. An incision and dissection through periosteum to bone is made on the anteromedial aspect of the tibia in line with the guide. The PCL guide is set and its position is confirmed with fluoroscopy and arthroscopy (Fig. 36.5). A guide wire is drilled to but not through the posterior cortex. Fluoroscopy is used to confirm the path of the guide wire (Fig. 36.6). With the 30-degree arthroscope in the posteromedial portal, the PCL curette is introduced through the anteromedial portal and is used to protect the posterior knee structures as the guide wire is carefully advanced through the posterior cortex under arthroscopic visualization. A parallel pin guide can be used to make small pin placement corrections if necessary. A cannulated compaction reamer is used to drill the tibial tunnel. The tibial cortex is cautiously perforated by hand reaming under arthroscopic visualization (Fig. 36.7). The tunnel is irrigated and increasing serial dilators are used under arthroscopic visualization up to the graft size.

Attention is then turned to femoral tunnel preparation. An angled awl, via the anterolateral portal, is used to create a starting hole at the 1:00 or 11:00 position for right and left knees, respectively. The anteroposterior

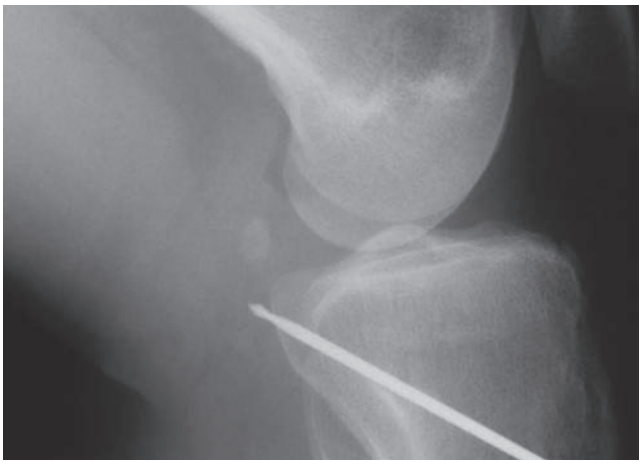

FIGURE 36.6
Fluoroscopy is used to confirm the path of the tibial guide wire.

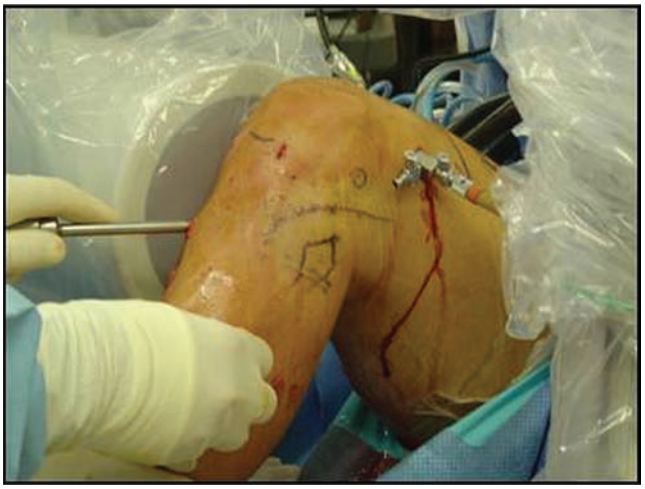

FIGURE 36.7
The tibial tunnel is completed by hand with fluoroscopic guidance.

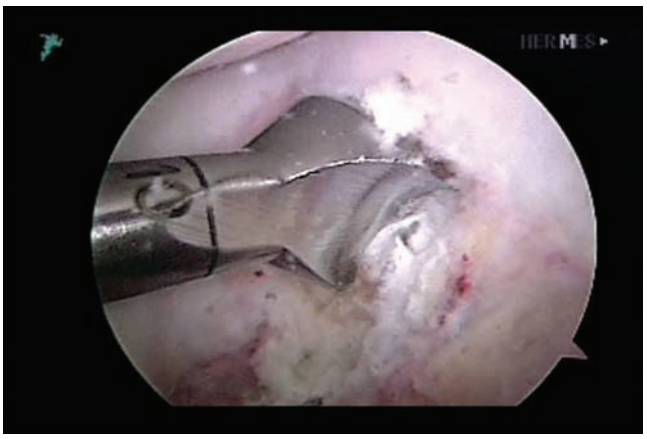

FIGURE 36.8
The femoral tunnel is drilled from lateral portal, so the tunnel edge is located at the junction with the articular cartilage.

position depends on the size of the graft, but the hole should be positioned so the tunnel edge is located at the junction with the articular cartilage. A guide wire is impacted into the starting hole via the anterolateral portal. An appropriately sized cannulated acorn reamer is carefully passed over the guide wire, given the close proximity of the patellar articular surface (Fig. 36.8). The tunnel is drilled to a depth of approximately 30 mm, taking care to avoid penetration of the outer cortex of the medial femoral condyle. Increasing serial dilators are passed to match the size of the graft. A smaller EndoButton drill is used to perforate the outer cortex of the medial femoral condyle, and a guide wire is inserted through the anterolateral portal into the femoral tunnel. An incision is made parallel to Langer lines over the anteromedial aspect of the distal medial femoral condyle, at the estimated exit of the guide wire from the bone. The vastus medialis obliquus fascia and muscle is split in line

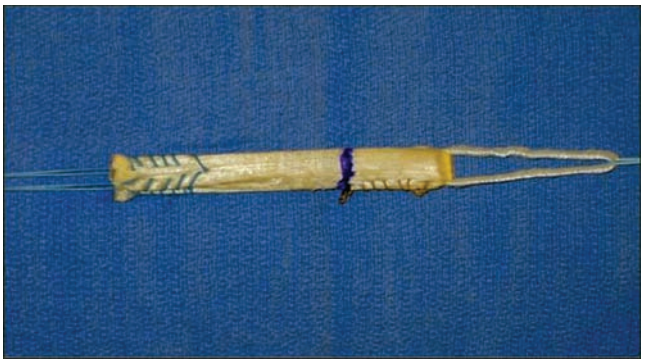

FIGURE 36.9

The tibialis anterior allograft is prepared with an Endoloop on one end and free sutures at the other end.

with its fibers and the muscle and periosteum are elevated off the anteromedial distal femur. The drill hole is exposed and guide wire is removed.

Attention is turned to passage of the graft. A tibialis anterior allograft is prepared with an Endoloop at one end and free sutures in a whip stitch fashion at the other end (Fig. 36.9). Passage of the graft may require enlarging the anterolateral portal. The 30-degree arthroscope is placed in the posteromedial portal, and a long 18-gauge bent wire loop is passed with the loop bent upward from anterior and distal to posterior and proximal through the tibial tunnel. A tonsil is introduced through the anterolateral portal and through the notch to retrieve the bent wire loop. Leading sutures from the free ends (tibial side) of the graft are placed through the wire loop. The wire and sutures are pulled back through the tibial tunnel in an anterograde fashion. A small scooped malleable is introduced through the anterolateral portal and placed just posterior to the AL tunnel to retract the fat pad and provide an unobstructed path for a Beath pin. A Beath pin is then passed through the anterolateral portal and through the femoral tunnel. The lead suture limbs from the Endoloop side of the graft are threaded through the eye of the Beath pin. The pin with the suture limbs is pulled proximally. Traction on the suture limbs pulls the graft into the femoral tunnel to the marked line, while traction of the tibial suture limbs pulls the graft into the femoral tunnel. The position of the graft is confirmed arthroscopically.

Graft fixation is achieved by placing the Endoloop along the medial femur with a tonsil to estimate its most proximal extent. A 3.2-mm drill bit is used to drill a unicortical hole at the most proximal extent of the Endoloop. After the hole is measured and tapped, a 6.5-mm cancellous screw and a washer are placed through the Endoloop into the femur. The screw is tightened as the graft is pulled tight distally. The fixation is palpated to ensure the Endoloop limbs are tight distal to the screw and washer. An anterior tibial force is applied to reduce the tibia prior to and during final tibial fixation. A cortical 4.5-mm screw and a washer are placed from anteromedial to posterolateral within the proximal tibia. The graft is fixed at 90 degrees flexion. Before the screw advances to the second cortex, the suture limbs from the tibial side of the graft are tied with tension over the post. The screw is then tightened (Fig. 36.10). The arthroscope is inserted to confirm adequate position, tension, and fixation of the graft. The incisions are irrigated, and the fascia in the anterolateral femoral incision is closed with 0 Vicryl suture. The subcutaneous layer is approximated with interrupted, inverted 3-0 Vicryl suture and the skin is closed with a running 4-0 absorbable suture. The portals are closed with 3-0 nylon suture. The dorsalis pedis and posterior tibialis pulses are assessed by palpation and a doppler if necessary. The incisions are covered with adaptic gauze and sterile gauze then wrapped in cast padding and bias wrap.

Single-Bundle Augmentation

For single-bundle augmentation, much of the technique is identical to the single-bundle technique described. Frequently, the AL bundle is ruptured and the PM bundle remains intact. Consequently, for the purposes of this chapter, the AL bundle augmentation will be described. The diagnostic arthroscopy is performed. If the AL bundle is noted to be intact, special care is taken to preserve this bundle while the overlying synovium and ruptured PCL fibers are debrided. Also, when preparing the posterior aspect of the tibia, preservation of the PCL origin is essential. Tibial tunnel preparation is performed similar to the single-bundle technique. The exit point for the guide pin along the sloped face of the posterior tibial fossa is just distal and lateral to the intact PCL insertion site. When preparing the medial femoral condyle for tunnel drilling, care is again taken to preserve the intact PCL bundle. The starting hole is placed at the 1:00 or 11:00 position for right and left knees, respectively. The hole should be positioned in the anteroposterior plane, so the tunnel edge is located at the junction with the articular cartilage. This location depends on the size of the graft and the distance from the intact PM bundle. The graft is passed around the intact bundle, which is the final augmentation consideration (Fig. 36.11). Fixation and closure are then performed.

Double-Bundle Technique

For double-bundle PCL reconstruction, the initial aspects of the technique are identical to single-bundle reconstruction, including portal placement, arthroscopy, and preparation for drilling. The tibial side is addressed first. Throughout this process, care must be taken to avoid tunnel convergence and ensure an adequate bony

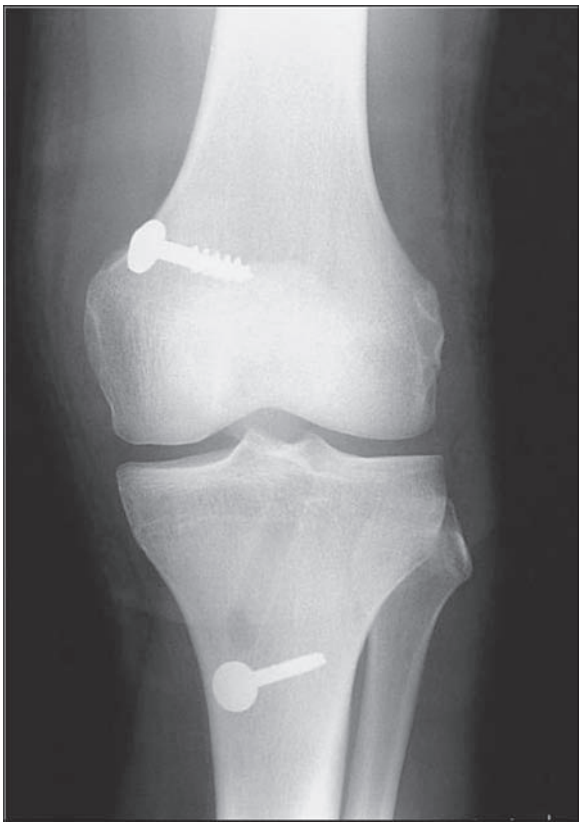

FIGURE 36.10

Postoperative radiograph demonstrating the position of the femoral and tibial screws used to fix the graft.

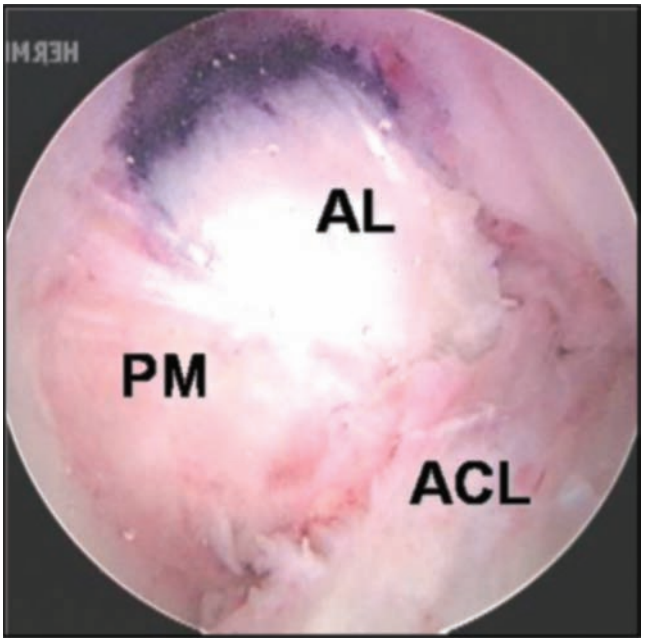

FIGURE 36.11

Final position of the single-bundle augmentation reconstruction, demonstrating an intact native PM bundle and a reconstructed AL bundle.

bridge between the two tibial tunnels. First, the guide pin for the AL tunnel is positioned using the same technique as with single-bundle reconstruction. It exits the tibia just distal and lateral to the PCL insertion site, 1.5 cm distal to the articular edge of the posterior plateau. The PCL guide is then reintroduced into the joint. The same steps and precautions are repeated for placement of the PM tibial guide wire. The PM tibial guide wire enters the tibia on the anteromedial aspect of the tibia slightly more proximal and medial than the AL guide wire. Conversely, the PM guide wire may be introduced through the anterolateral tibia, crossing the AL guide wire on the coronal view, but remaining proximal to the AL guide wire throughout its course on the sagittal view. It exits the tibia in the footprint more medial and slightly proximal to the AL tibial guide wire (Fig. 36.12). It is important to ensure that adequate separation between the two guide pins exists

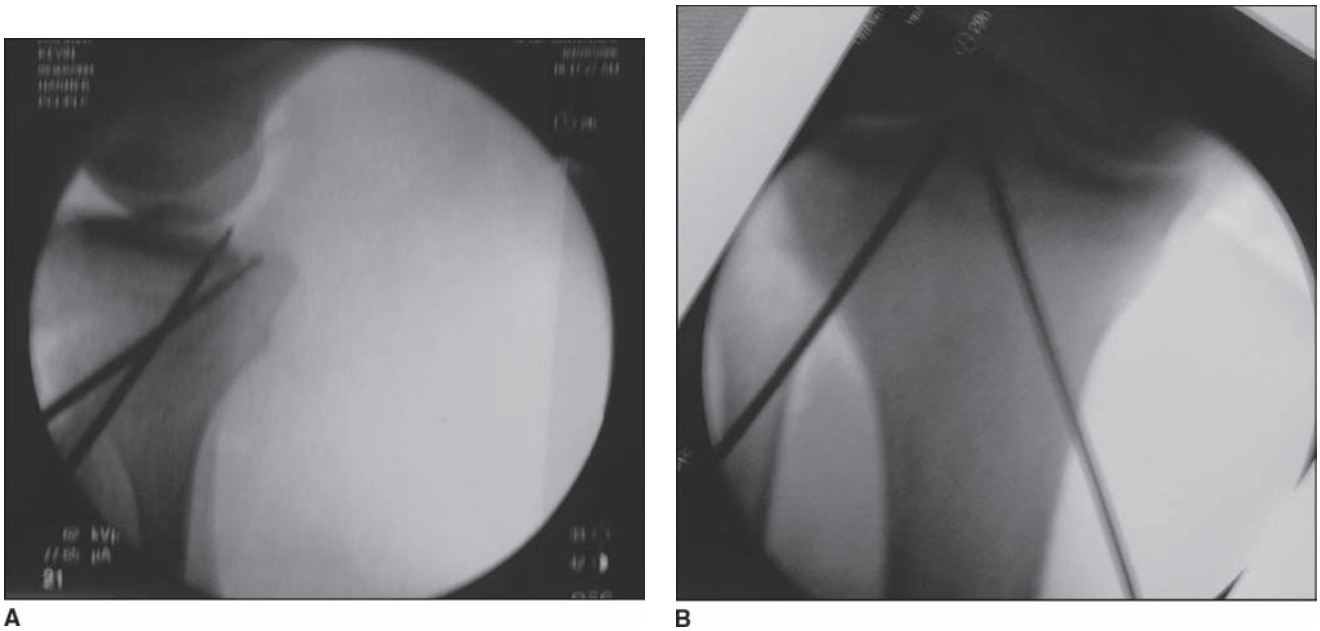

FIGURE 36.12

The PM guide enters the tibia through the anterolateral tibia, crossing the AL guide wire on the coronal view **(A)**, but remaining proximal to the AL guide wire throughout its course on the sagittal view **(B)**. It exits the tibia in the footprint more medial and slightly proximal to the AL tibial guide wire.

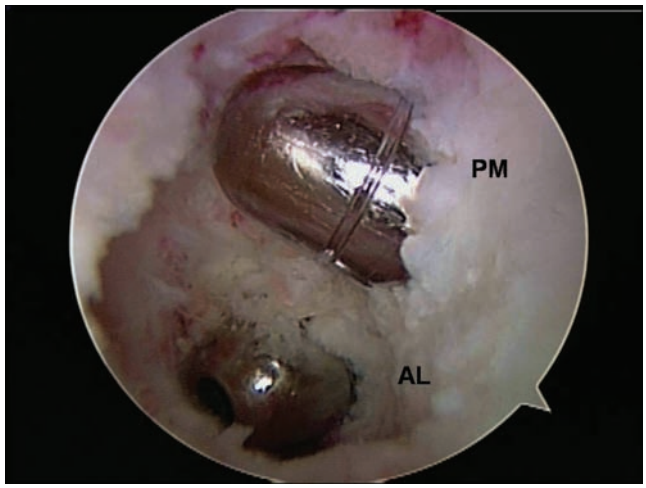

FIGURE 36.13

The position of the tibial tunnels at the PCL footprint in the double-bundle technique.

to accommodate both tunnels with a bony bridge separation. Once the guide wire positions are satisfactory, a cannulated compaction reamer is used to first drill the AL tibial tunnel. Drill advancement is performed under fluoroscopic guidance. The posterior tibial cortex is cautiously perforated by hand reaming under arthroscopic visualization. The tunnel is irrigated and increasing serial dilators are used under arthroscopic visualization. The steps are repeated for drilling the PM tibial tunnel with a 7-mm cannulated compaction reamer (Fig. 36.13).

Attention is then turned to drilling the femoral tunnels. An angled awl is used to create the starting holes. For the AL bundle, the starting hole is placed at the 1:00 or 11:00 position for right and left knees, respectively. The hole should be positioned in the anteriorposterior plane, so the tunnel edge is located at the junction with the articular cartilage. The guide wire is passed via the anterolateral portal and impacted into the starting hole. The appropriately sized cannulated acorn reamer is passed over the guide wire. The reamer should be passed carefully given the close proximity of the patellar articular surface. The tunnel is drilled to a depth of approximately 30 mm with care taken to avoid penetration of the outer cortex of the medial femoral condyle. Increasing serial dilators are passed to match the size of the graft. A smaller EndoButton drill is used to perforate the outer cortex of the medial femoral condyle. This inside-out femoral tunnel preparation technique is then repeated for the PM tunnel. The angled awl is used to create the starting hole at the 3:00 or 9:00 position for right and left knees, respectively. The PM tunnel is placed parallel or slightly posterior to the AL tunnel. The guide pin is then

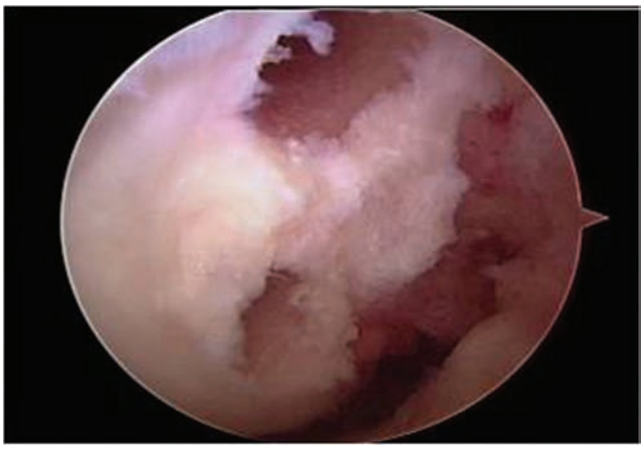

FIGURE 36.14
The position of the femoral tunnels in the double-bundle technique.

placed via the anterolateral portal and impacted into the starting hole. A 7-mm acorn reamer is passed over the guide wire and drilled to a depth of approximately 30 mm (Fig. 36.14). The medial femoral condylar cortex is perforated with the EndoButton drill.

A tibialis anterior allograft is used for each bundle, with the AL graft typically sized to 9 mm and the PM graft sized to 8 mm. The AL graft is passed first using the same technique as with single-bundle reconstruction. This process is then repeated for the PM graft. It is helpful to keep tension on the AL graft suture ends when passing the PM graft to ensure that the AL graft does not get pulled into the joint. Graft fixation is performed first on the femoral side. The AL bundle is secured as previously described. This process is repeated for the PM bundle, ensuring enough separation exists between the two screws and washers to prevent overlap. An anterior tibial force is applied to reduce the tibia prior to and during final tibial fixation. Two 4.5-mm cortical screws and washers are placed from anteromedial to posterolateral within the proximal tibia, just distal to the respective tunnels. As with the single-bundle technique, before the screw advances to the second cortex, the suture limbs from the tibial side of the graft are tied with tension over the post, and then the screw is tightened. The AL graft is secured first at 90 degrees of flexion and the PM bundle is then secured at 15 degrees of flexion. The arthroscope is inserted to confirm adequate position, tension, and fixation of the grafts (Fig. 36.15).

Tibial Avulsion Technique

The patient is positioned supine to facilitate arthroscopic examination. The leg is brought into a figure-four position, with the knee flexed to 90 degrees and the bump repositioned under the lateral ankle. A 6-cm incision is made over the posterior border of the tibia from the crease of the popliteal fossa and curving distally along the posteromedial border of the tibia. The dissection is continued through the subcutaneous fat to the sartorius fascia and the fascia overlying the medial head of the gastrocnemius. The fascia is incised along the palpable posteromedial tibial border. The semimembranosus and pes anserinus tendons are retracted anteriorly and proximally. The medial head of the gastrocnemius is elevated from the tibial cortex and retracted posteriorly. The medial border of the gastrocnemius is followed distally along the posterior tibia and the proximal border of the popliteus muscle is identified. The popliteus muscle is elevated subperiosteally off the posteromedial surface of the tibia and mobilized laterally and distally. A vertical arthrotomy is made and the avulsed fragment

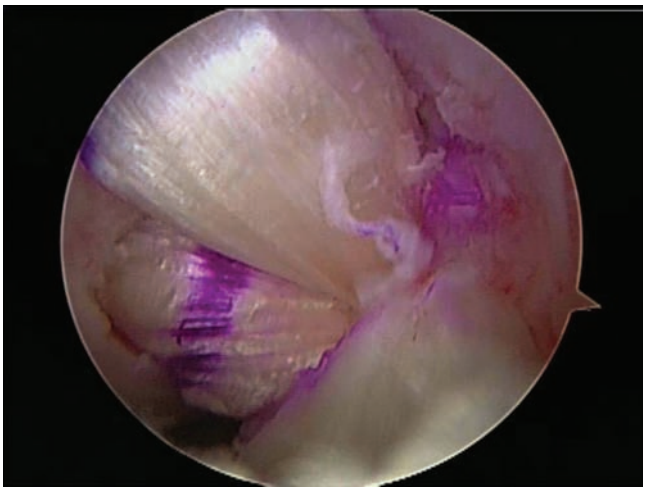

FIGURE 36.15
Final position of the grafts in the double-bundle technique.

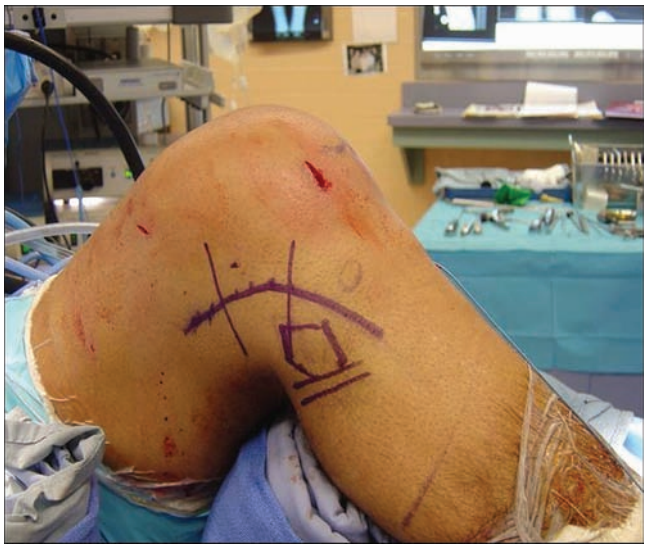

FIGURE 36.16

The posterolateral corner is approached through a lateral hockey stick incision that parallels the posterior edge of the iliotibial band.

of the tibia with the attached PCL is identified. The bone fragment and PCL are reduced and secured with a 4-mm cortical or a 6.5-mm cancellous screw and spiked washer, depending on the size of the fragment. The reduction is confirmed with fluoroscopy or a radiograph.

PCL/Posterolateral Corner

For a combined PCL/posterolateral corner reconstruction, the PCL injury is addressed first in either a single-bundle or a double-bundle fashion as outlined above. After the PCL graft(s) is passed and fixed on the femoral side, the posterolateral corner is addressed. A lateral hockey stick incision is made, paralleling the posterior edge of the IT band (Fig. 36.16). The iliotibial band is split parallel to its fibers, exposing the deep structures of the lateral collateral ligament (LCL) distally and anteriorly. The lateral head of the gastrocnemius muscle and the underlying popliteus complex are exposed more proximally and posteriorly. An alternative technique is to make multiple deep intervals or windows. One window is created at the anterior aspect of the iliotibial band to expose the femoral insertions of the posterolateral corner; a second is made between the iliotibial band and the biceps tendons to expose the fibular insertions. If the peroneal nerve is going to be released, then a third window is created proximally below the biceps and carried distally, as the nerve is decompressed, around the fibular neck.

In many situations, the LCL is intact and only a rotational deformity exists. Thus, only a popliteofibular ligament (PFL) reconstruction and popliteus tendon repair are necessary. If the LCL is deficient, however, an LCL reconstruction is performed first with a 7- or 8-mm Achilles tendon allograft and imbrication of the native LCL. First, the tendinous portion of the Achilles allograft is secured to the femoral LCL insertion through drill holes or suture anchors. A whip stitch is then used to imbricate the native remaining LCL to the tendinous portion of the allograft. The injured LCL is then dissected free from its distal insertion on the fibular head. A tunnel is drilled along the longitudinal axis of the fibula and the allograft calcaneal bone plug is tensioned and secured in the tunnel with use of a metal interference screw.

Our graft choice for reconstructing the PFL is a tibialis anterior allograft or an ipsilateral semitendinosus autograft. The graft is prepared with a 2 braided nonabsorbable suture whip-stitch on both ends to fit into a 7-mm bone tunnel. The torn, native popliteus tendon is mobilized from its femoral insertion and the end is prepared in the same fashion. A 7-mm femoral tunnel is created at the anatomic insertion site of the popliteus tendon, just distal and anterior to the femoral epicondyle. Next, an oblique anterior-to-posterior fibular tunnel for the PFL reconstruction is created. The PFL tunnel rests more medial and closer to the proximal tibiofibular joint than does the previously drilled LCL tunnel. Using a Hewson suture passer, the PFL graft is passed from posterior to anterior through the fibular tunnel (Fig. 36.17). It is not fixed to the fibula until after it has been fixed on the femoral side. The graft is then passed under the LCL into the previously drilled femoral tunnel. A Beath pin is used to pass the PFL graft and the native popliteus tendon into the tunnel. Approximately, 10 mm of the popliteus tendon and 25 mm of the PFL allograft should end up in the femoral tunnel (Fig. 36.18). The PFL graft and the popliteus tendon are tied over a 4.5-mm cortical screw and a washer on the anteromedial aspect of the distal part of the femur. Before the PFL graft is secured to the fibula, final PCL graft fixation to the tibia (as described above) is performed. As the final step in the combined reconstruction, the PFL graft is fixed to the fibula with a bioabsorbable interference screw with the knee in 30 degrees of flexion and mild internal rotation.

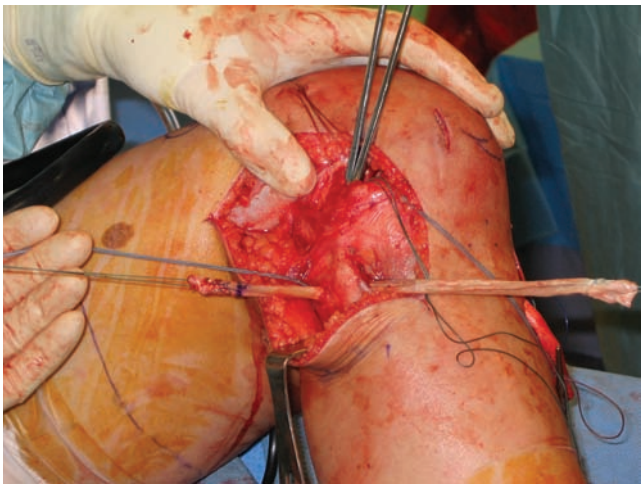

FIGURE 36.17

The PFL graft is passed from posterior to anterior through the fibular tunnel.

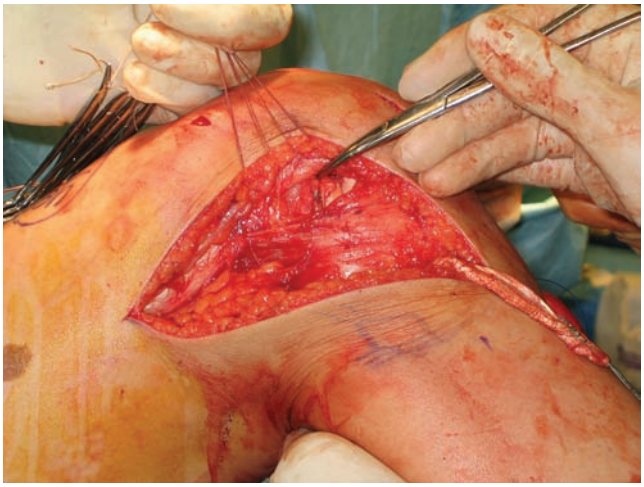

FIGURE 36.18

The PFL graft and the native popliteus tendon are passed into the femoral tunnel.

POSTOPERATIVE MANAGEMENT

Postoperatively, a hinged knee brace locked in extension is applied to the affected extremity. Cryotherapy is utilized to assist with management of postoperative pain and swelling. Neurovascular examinations are performed in the recovery room as well as in the patient's hospital room that night and the next morning. Most patients are discharged on postoperative day one when their pain is under control and have a normal neurovascular exam for 24 hours. All dressing changes are performed while an anterior tibial force is applied to prevent posterior translation and excessive stress on the graft. Patients are instructed to maintain touchdown weight bearing for 1 week and to perform quadriceps sets, straight leg raises, and calf pumps. Partial weight bearing (30%) is initiated after the first postoperative visit. Patients are started in physical therapy during the first month to work on full knee extension, passive prone knee flexion, quadriceps sets, and patellar mobilization exercises. The brace is unlocked after 4 to 6 weeks and usually discontinued after 8 weeks. Minisquats are performed from 0 to 60 degrees after the first week and from 0 to 90 degrees after the third week. Once full, pain-free range of motion is achieved, strengthening is addressed. At 9 to 12 months, sport-specific functional training exercises are begun with gradual return to previous sport. The criteria to return to sport are (a) quadriceps and hamstring strength at least 90% of opposite leg, (b) one-leg hop test and vertical jump at least 90% of opposite leg, (c) full speed run, shuttle run, and figure-of-eight running without a limp, (d) squat and rise from a full squat, and (e) no effusion or quadriceps atrophy in conjunction with a satisfactory clinical examination.

RESULTS

Outcome studies suggest that patients with isolated grade I and II PCL injuries have good subjective outcomes but have a high incidence of degenerative changes, primarily involving the medial femoral condyle and patellofemoral joint and poor functional results (10,12,13). These findings are especially true in those patients with

grade III injuries or combined ligamentous injuries. Consequently, pain rather than instability may be the patient's primary symptom following a PCL injury treated nonoperatively. Although no randomized prospective clinical trials exist, multiple case series demonstrate excellent subjective outcomes with good objective improvements after PCL reconstruction (1,3,5,6,9,11,14).

COMPLICATIONS

Complications from PCL surgery are rare but do exist. Failure to carefully position the extremity with adequate padding may result in neuropraxia. Residual laxity can also occur as a result of graft positioning or failure to address concomitant ligamentous injury. Care must be taken to prevent overpenetration of the posterior tibial cortex, as injury to the popliteal vessels may be a serious complication. The thigh and calf should be routinely palpated to ensure no compartment syndrome develops from fluid extravasation into the soft tissues. Loss of motion (usually decreased flexion) can result from errors in graft positioning, excessive tensioning during graft fixation, or inadequate rehabilitation.

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37 Surgical Management of Medial Collateral Ligament Injuries

Bryson Patrick Lesniak, LCDR Scott T. King, and Christopher D. Harner

INTRODUCTION

The medial collateral ligament (MCL) is the most commonly injured ligament in the knee (3–5,8,10). It generally results from trauma to the knee following valgus with or without a rotational force applied. MCL injuries present as an isolated injury or commonly in combination with injury to the anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), or both. The MCL has a relative increased ability to heal primarily without surgical intervention compared to the other ligaments of the knee. There are certain MCL injuries, mostly in combination with concomitant ligamentous injuries that do not reliably heal nonoperatively and leave patients with significant joint instability. The purpose of this chapter is to delineate which patients are at risk and how they are treated.

ANATOMY

Warren et al. (13) described the medial side of the knee to be anatomically divided into three layers. Layer I includes the superficial sartorial fascia bordered anteriorly by the patella tendon and posteriorly by the popliteal fossa. Anteriorly layer I merges with layer II. The gracilis and semitendinosus tendons can be separated from layer I superficially and layer II deep to it. Layer II is composed of the superficial MCL, which merges with layer III at the posteromedial corner of the knee. Layer III is deep to the superficial MCL and consists of the capsule of the knee with a thickened portion termed the middle capsular ligament (Fig. 37.1).

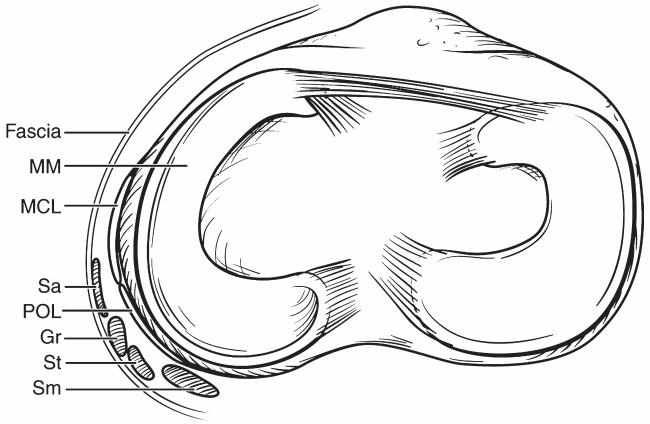


FIGURE 37.1

Cross section view of the medial layers of the knee. (Adapted from Muller.)

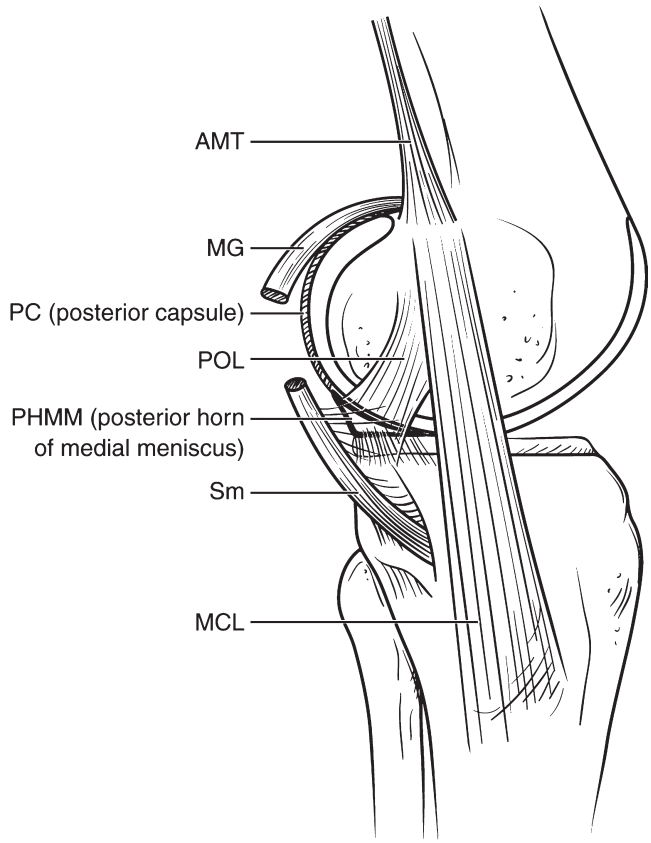


FIGURE 37.2
Sagittal view of the medial structures of the knee. (Adapted from Muller, 1983.)

The MCL, and more specifically the superficial MCL, is the primary resistance to valgus force applied to the knee (4,6,14). Studies have shown the MCL provides 57% of the total restraint at 5 degrees and 78% of the total restraint at 25 degrees of flexion. Near full extension, the posterior medial capsular structures provide increased medial stabilization. Based on cadaveric studies, Grood et al. (4) found that a 5 to 8 mm increase in medial laxity clinically is indicative of a complete MCL injury (4).

The superficial MCL is the largest structure in the medial aspect of the knee. It is between 10 and 12 cm long and 1.5 cm wide (2,9,11,14). The femoral attachment of the superficial MCL is an average of 3.2 mm proximal and 4.8 mm posterior to the medial epicondyle (9). There are two separate tibial attachments (1,9,12). The proximal tibial attachment is primarily to the semimembranosus tendon (9). The distal tibial attachment is approximately 6 cm distal to the joint line, just anterior to the posteromedial crest of the tibia (1,9,12). The deep MCL consists of the medial capsular, posterior oblique, meniscofemoral and meniscotibial ligaments (Fig. 37.2).

CLASSIFICATION

MCL injuries are classified according to chronicity, the extent of disruption of the ligament, the amount of joint laxity, and location of injury. An acute injury is defined as an injury that occurred within the past 3 weeks. Valgus stress testing at 0 and 30 degrees of knee flexion allows estimation of the amount of laxity. At 30 degrees of knee flexion, a grade 1 injury is <5 mm of medial joint opening, grade 2 is 5 to 10 mm of laxity, and grade 3 is >10 mm. Any laxity at 0 degree is an ominous sign as there are likely associated injuries such as a cruciate tear or a posteromedial capsular injury. Chronic MCL injuries typically occur when nonoperative management of a grade 3 MCL injury fails and is typically 6 weeks or greater from time of the injury.

Location of an MCL injury can be described as a femoral avulsion, tibial avulsion, or midsubstance tear. This is an important consideration because complete tibial sided MCL tears (tears that involve both the deep and the superficial components) often do not heal. The reason for this lack of healing is likely interruption of the tendon-bone interface by synovial fluid (15).

HISTORY/PRESENTATION

Injury to the MCL involves an isolated valgus force to the knee, or a valgus combined with a rotational force. It is usually the result of a sports-related impact injury or a twisting noncontact injury. When rotational

injury is suspected, concomitant injury to the posteromedial corner structures and/or the ACL should be considered. The patient will present with varying degrees of swelling, pain, instability, and loss of motion. Location of swelling can be variable. An isolated MCL tear may only have swelling at the medial aspect of the knee. A hemarthrosis may be present if there is injury to the deep MCL and capsule, or if there is other associated intra-articular pathology. Studies have found up to 80% of MCL injuries have additional ligamentous injury (3).

PHYSICAL EXAM

The injured knee should be examined completely and compared with the contralateral knee. This includes a thorough neurovascular examination. Although potentially difficult, the patient should be relaxed to achieve a useful physical exam. Tenderness along the MCL should be assessed by palpation and note made of whether pain can be localized to a specific region of the MCL. In order to isolate the MCL on exam, a valgus force in the coronal plane should be applied while avoiding any rotational component. The MCL should be tested at 0 and 30 degrees of flexion (Figs. 37.3 and 37.4). As previously stated, increased laxity to valgus stress in full extension is an ominous sign as it implies possible injury to a cruciate ligament and/or posteromedial capsular structures. Flexion of the knee reduces the secondary restraint of the posterior capsule and better isolates the MCL. The ACL and the PCL provide secondary restraint to varus and valgus stress, so the knee should remain stable with stress at zero degree if the cruciate ligaments are intact, even in the setting of MCL injury. The ACL, PCL, LCL, and posterolateral corner should all be examined to determine the severity and pattern or the injury (Figs. 37.5 and 37.6).

The endpoint of varus and valgus stress to the knee should be noted. A complete tear of the MCL may or may not have an endpoint detected with valgus stress. If there is any uncertainty, comparison to the contralateral knee can provide further confirmation of the injury.

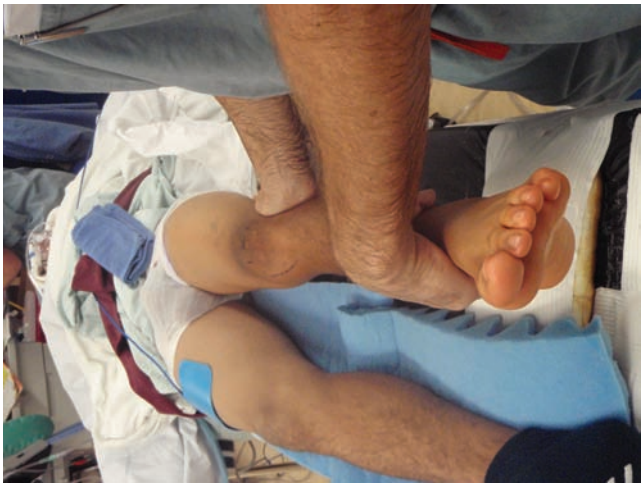


FIGURE 37.3
Valgus stress testing of the patient in full extension.

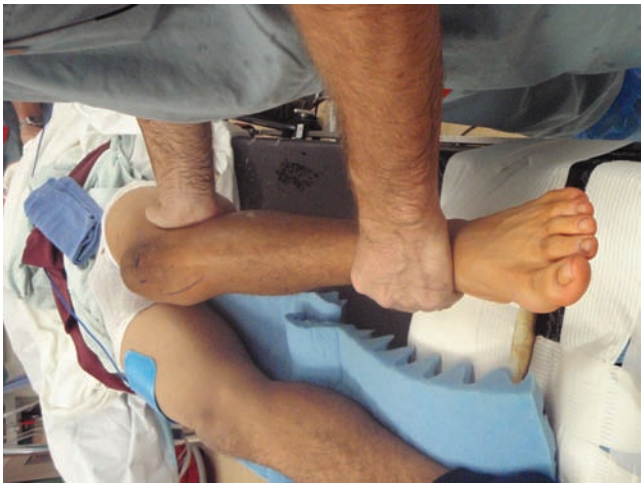


FIGURE 37.4
Valgus stress testing of the knee at 30 degrees of flexion.

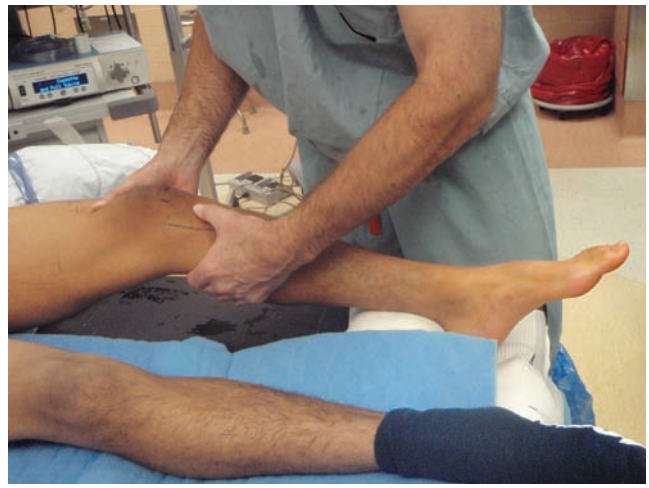


FIGURE 37.5
Lachman exam to assess the ACL.

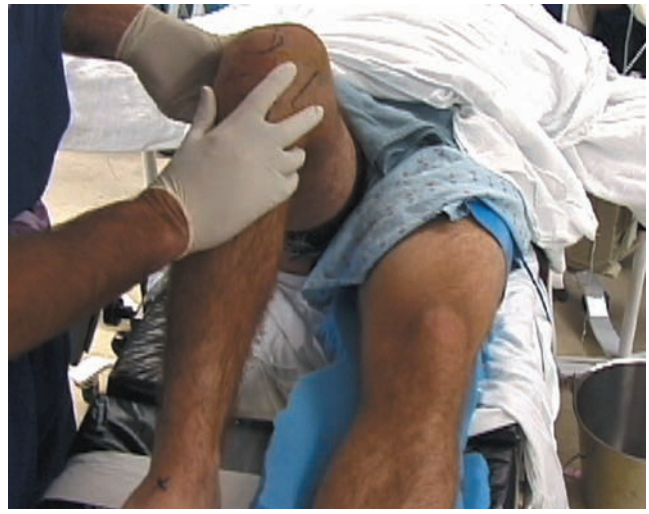


FIGURE 37.6
Posterior drawer exam to assess the PCL

IMAGING

When an MCL injury is suspected, radiographic evaluation begins with a standard knee series. This should include a 45 degree-flexion weight-bearing AP, lateral and merchant views. Plain radiographs usually provide limited information, but may show evidence of a bony avulsion or an osteochondral fragment that could alter the treatment plan. In skeletally immature patients, stress radiographs should be obtained to evaluate for physeal injury as the cause of valgus laxity as this is more common than an MCL tear. Stress radiographs may also be used to better confirm the extent of laxity of the medial knee. They should be compared to the contralateral knee and increased laxity >4 mm indicates MCL instability.

Magnetic resonance image (MRI) can provide significant data that can assist in treatment of an MCL injury. First and foremost, an MRI can assist in determining the severity of the MCL injury as well as any associated cruciate ligament, meniscal, or capsular damage. MRI can determine the location of the MCL tear that, as stated previously, can have therapeutic implications. Occasionally, a displaced MCL tear that becomes incarcerated in the knee joint is seen on MRI, thus obligating operative intervention (Fig. 37.7). Information from the MRI combined with physical exam findings allows for formulation of the appropriate treatment plan.

In cases of multiligament knee injuries, consideration must be made for a possible knee dislocation. In this clinical scenario, the vascular supply to the extremity should be examined by at least ankle-brachial-index testing and possibly an angiogram.

TREATMENT

Both surgical and nonsurgical treatment has been utilized in the past for treatment of MCL injuries. The treatment recommendations of MCL injuries are based on the severity, location, and chronicity of the injury as well as concomitant injuries in the knee. In general, isolated tears of the MCL regardless of severity are treated

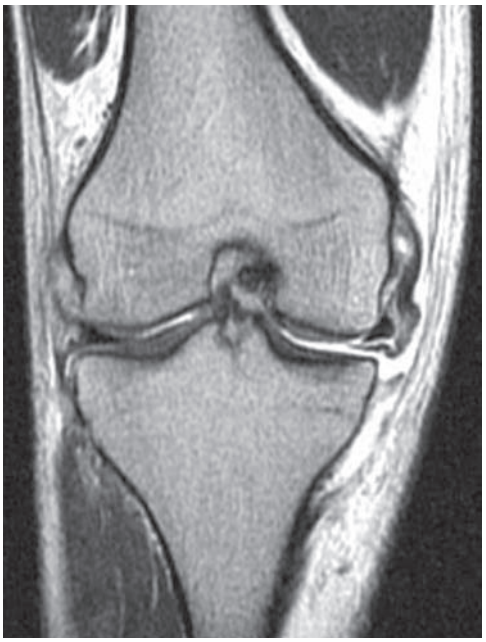


FIGURE 37.7

MRI demonstrating incarceration of the MCL into the medial compartment, mandating operative reduction of the MCL.

nonoperatively with predictable success. Primary repair should be considered if the MCL is entrapped in the joint. In addition, MCL instability in the valgus aligned knee is not well tolerated and potentially less likely to heal nonoperatively given the increased stress on the injured ligament when compared to a varus aligned patient. Operative reconstruction should be performed in a patient who presents with a chronic MCL injury and remains symptomatic and unstable after nonoperative treatment has failed.

NONOPERATIVE MANAGEMENT

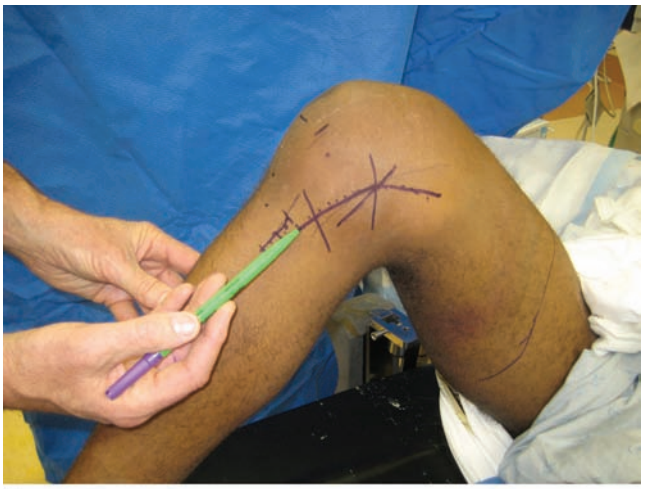
The typical treatment of isolated MCL injuries includes hinged bracing, protected weight bearing with crutches, and reestablishment of range of motion. For grade I injuries, most patients require 1 to 2 weeks to return to sport, 2 to 4 for type II, and up to 6 to 12 weeks for complete (type III) tears. Indelicato prospectively evaluated nonoperative and operative treatment of grade III MCL tears (7). He found no difference in the function and stability of the knee between the two groups. Other investigators have found equivalent results when comparing operative and nonoperative management and have found less complications, in particular postintervention athrofibrosis, with nonoperative management.

The treatment of MCL injuries with combined ACL or PCL injuries is more controversial than isolated MCL injuries. There have been studies completed that support nonoperative treatment on the MCL with the delayed treatment of the ACL once the MCL is healed. Studies have also supported the acute operative treatment of both the ACL and the MCL. It is our opinion is that each injury should be evaluated individually to determine the treatment plan.

In a grade I or II MCL injury, ACL reconstruction should be completed between 4 and 6 weeks after injury. This permits nonoperative healing of the MCL and reduces the risk of arthrofibrosis that often occurs with immediate surgery. Grade III MCL injuries with an ACL injury are more controversial. Determination of the location of the type III MCL injury may have prognostic value as femoral avulsion injuries tend to heal more reliably than tibial avulsion injuries. In our opinion, tibial sided MCL injuries need to be followed closely to assess healing and the need for operative repair. Operative repair should be considered if there is medial laxity still present after a trial of rehabilitation. Our current approach is to allow 4 weeks of rehabilitation to allow the MCL to heal and allow the patient to regain knee motion and reduce swelling. Our final determination of the operative procedure is not complete until after the examination under anesthesia. If valgus laxity with gentle stress persists after 4 weeks of nonoperative management, we will proceed with both the cruciate reconstruction and an MCL repair versus reconstruction. Again, valgus testing at 0 and 30 degree is helpful to assess overall joint stability and extent of the injury.

SURGICAL MANAGEMENT

The patient is placed in supine position after general or spinal anesthesia is administered. In our practice, we do not use a tourniquet, especially in the setting of a knee dislocation where an undiagnosed arterial injury may be exacerbated by tourniquet use. A complete examination under anesthesia is performed to confirm or



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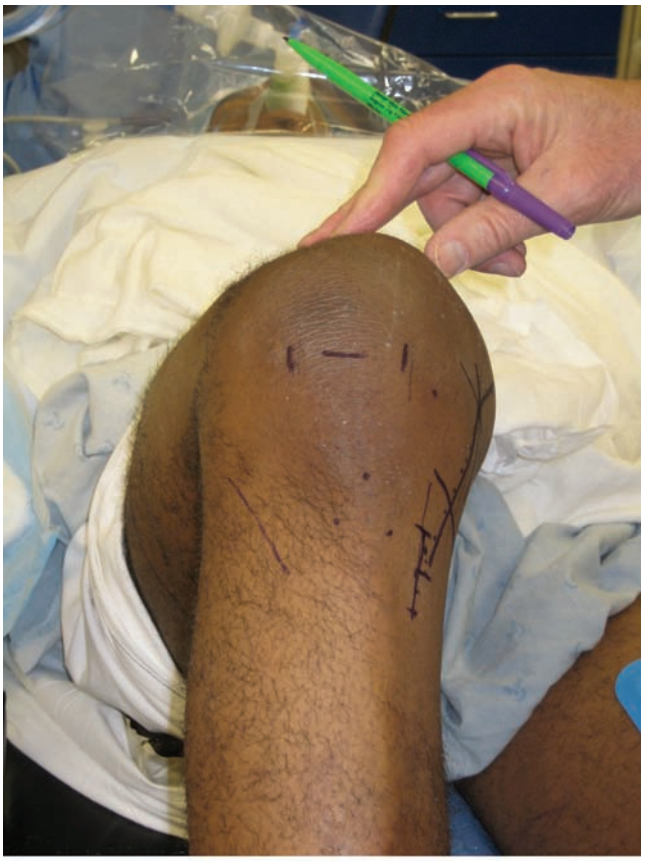


B

FIGURE 37.8

Planned surgical incision: the MCL and planned curvilinear incision are drawn on the medial knee.

refine the diagnosis made by the examination in the office and the imaging studies. All bony prominences are well padded and all relevant anatomic landmarks and incisions are drawn on the skin (Fig. 37.8). The planned incisions are then prepped with betadine and injected with epinephrine (1:100,000). Prophylactic intravenous antibiotics are given preoperatively.

A 5-lb sand bag is taped to the operative table to allow the knee to rest in 90 degree flexion and a side post is placed at the midthigh level to serve as an abduction block when the knee is in flexion and provide an abduction post when performing arthroscopy (Fig. 37.9). The entire limb is then prepped with alcohol and betadine and draped free. A sterile bolster is then made and placed between the thigh and the side post.

ACUTE REPAIRS

Injuries identified acutely (<3 weeks) are performed in conjunction with ACL reconstruction or occasionally as an isolated injury. To optimize the repair of the MCL, the cruciate ligament injuries must be addressed, as

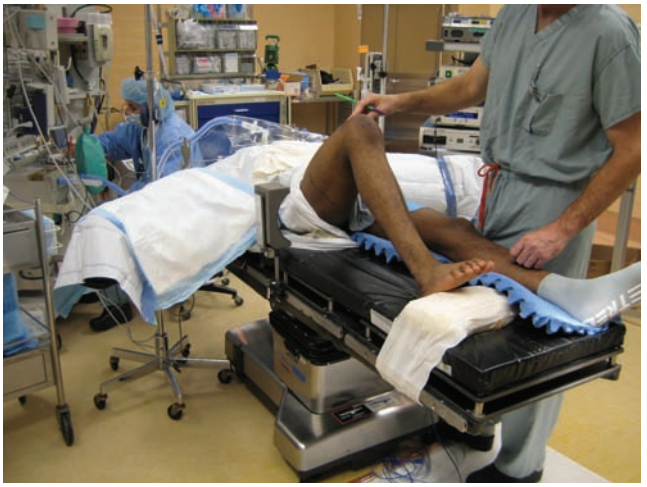


FIGURE 37.9

Operative set up: All boney prominences are well padded and a sandbag is placed to maintain 90 degrees of flexion for the operative leg. A post is placed at the midthigh level to allow for abduction during arthroscopy.

they are important secondary restraints to valgus stress. Our preference is to reconstruct the cruciate ligaments first. In the setting of a concomitant cruciate and MCL injury our preferred cruciate graft is an allograft- either tibialis anterior or a central- third bone- patella tendon- bone graft.

Arthroscopic examination of the knee can be performed before or after the medial dissection. We recommend performing the approach prior to the arthroscopic examination because the tissue planes are more readily identified making the dissection more straightforward. However, the difficulty of performing arthroscopy after an arthrotomy must be considered as well.

Most commonly when approaching the medial structures of the knee, a medial "hockey stick"–type incision is used that can allow for adequate exposure for cruciate reconstruction and MCL repair/reconstruction (Fig. 37.8). The landmarks for the medial incision are the adductor tubercle, the medial epicondyle, the joint line, and the medial facet of the patella. Often, the incision size can be adjusted and minimized by centralizing the incision over the location of the MCL injury (Fig. 37.10).

Skin and subcutaneous tissue is incised with a scalpel to the sartorial fascia. Care must be taken to identify and protect the infrapatellar branch of the saphenous nerve as it emerges from under the sartorius 1 cm above the joint line and travels anteriorly on the fascia (Fig. 37.11). The nerve should be identified and retracted gently with a vessel loop. Skin flaps are then made at the fascial layer using a lap sponge and finger dissection.

Sartorial fascia is then incised in line with the skin incision proximally from the medial epicondyle to the gracilis tendon distally. The hamstring tendons as well as the sartorius are retracted posteriorly. The pes bursa is removed thereby exposing the superficial MCL and the posterior oblique ligament (POL). Access to the joint is made by creating an arthrotomy between the posterior edge of the superficial MCL and the anterior border of the POL (Fig 37.12). An important note is to perform this arthrotomy with caution as transecting the medial meniscal is possible. With the medial structures of the knee now exposed, all structures should be identified and evaluated for any injury.

The sequence of repair should proceed from deep to superficial. First, any meniscal injuries that are accessible are addressed. Any peripheral meniscal injuries should be repaired using nonabsorbable suture. Care must be taken to reduce the capsule that the meniscus is being sewn to prior to passing any sutures to ensure proper reduction of the meniscal injury. We routinely place the knee in extension to avoid restricting motion

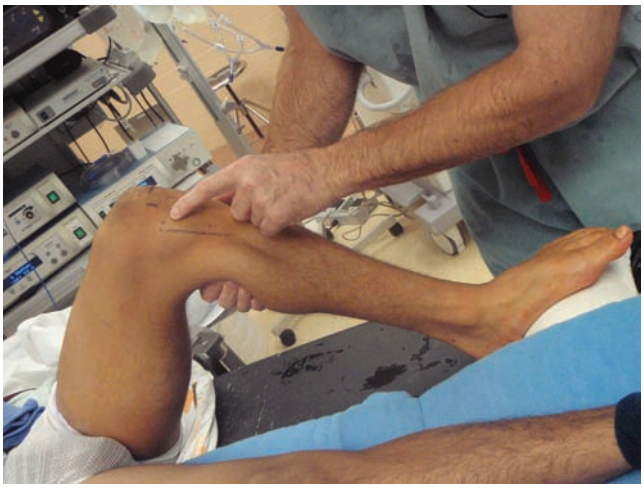


FIGURE 37.10

A minimized incision planned for a tibial sided MCL repair.

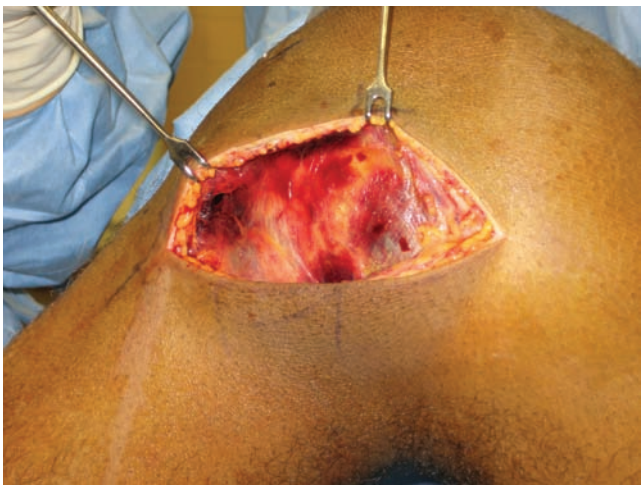
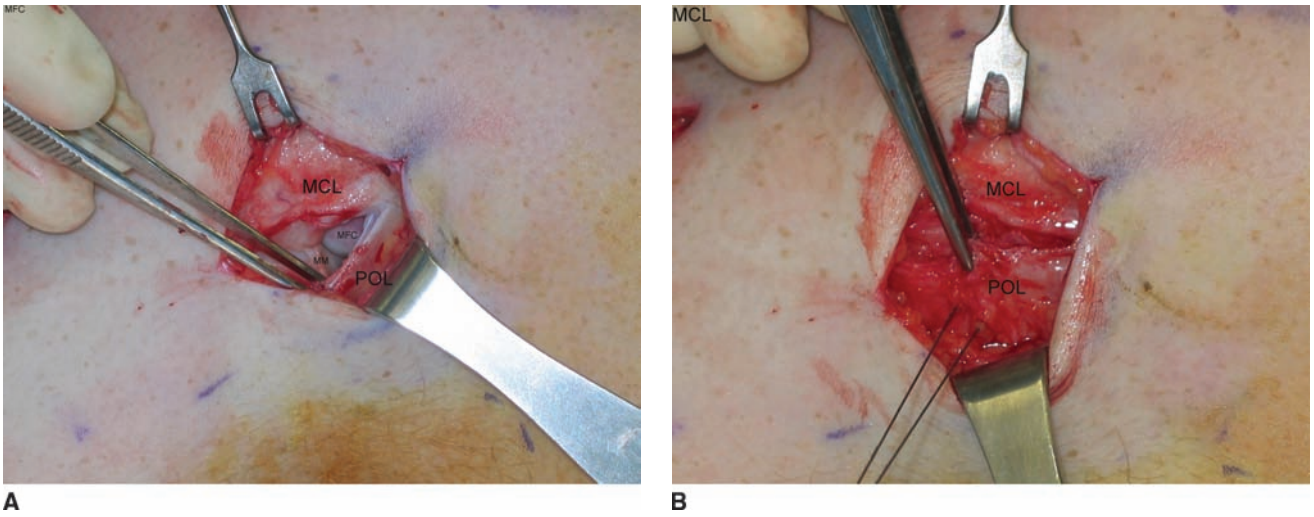


FIGURE 37.11

Dissection through subcutaneous tissue with the underlying exposed Layer I. Care is taken to avoid injury to the infrapatellar branch of the Saphenous nerve (not seen).



A B

FIGURE 37.12

A: The capsule is incised between the MCL and the POL, exposing the medial joint and meniscus. **B:** The medial meniscus is tagged (black suture) for eventual incorporation into the final repair.

by overconstraining the knee. When all sutures are passed, these are tagged until the remaining structures are repaired and then tied at the end of the reconstruction (Fig. 37.12).

The MCL is then addressed. For the MCL repair, the knee is kept in approximately 30 degrees of flexion by placing a soft bolster under the distal thigh. If the tibial insertion of the deep MCL is avulsed, this should be sutured to the tibial periosteum deep to the superficial MCL. If the superficial MCL is avulsed off of the tibia (most common MCL pattern requiring operative repair), this should be repaired with multiple suture anchors with mattress sutures or a screw with a soft tissue washer (Fig. 37.13). To ensure appropriate placement of the anchors or screw, we use intraoperative fluoroscopy to ensure all anchors are adequately distal from the joint line (Fig. 37.14). The goal is to reapproximate the MCL anatomically and prevent synovial fluid from being able to disrupt bone-ligament contact.

If the MCL is avulsed from its femoral insertion, the deep and superficial portions must be repaired directly back to the medial epicondyle (Fig. 37.15). The MCL can be either sutured to periosteum directly with a 0 or 1 nonabsorbable suture or with suture anchors. In cases of midsubstance tear patterns, the MCL is repaired anatomically with direct suturing. With femoral sided or midsubstance tears, the anterior edge of the POL is advanced to the level of the repair and used to reinforce the repair. This provides increased strength to the repair and assists with medial stability (Fig. 37.16).

If the patient has anteromedial rotary instability, and an isolated POL repair is planned, a more limited approach can be employed (Fig. 37.17). The medial joint line is identified, and an incision is marked along the posterior one third of the medial femoral condyle that is approximately 5 cm long with two thirds of the incision distal to the joint line and one third proximal. Again, layer one is identified and incised in similar manner to that described in the above paragraph describing MCL repair. Once layer 2 is identified, the anterior edge of the POL and posterior edge of the superficial MCL is found. If there is difficulty identifying the plane between these two structures, a valgus stress maneuver can be utilized. With a valgus stress, the MCL will become taught whereas the POL will remain relatively lax. The interval is then divided and the medial capsule deep to these structures is identified (Fig. 37.18). The MCL and the POL are dissected off of the capsule with an elevator. For imbrications, we use four horizontal mattress sutures (braided 2 nonabsorbable sutures) to advance the POL anteriorly and restore posteromedial tension. The POL is advanced underneath the MCL at the level of the MCL tear (midstance or femoral sided), thus reinforcing the area of injury. In addition to the proximal-distal level of advancement, the depth of advancement of the POL under the superficial MCL is determined by the severity of the MCL injury and subsequent laxity (Fig. 37.19). Once the appropriate imbrication is determined, the sutures are all tied in 15 degrees of knee flexion. Any meniscal repair sutures are included into the repair at this time as well. It is important to take the knee through a full range of motion after this repair to ensure no flexion contracture. After repair of the MCL, the cruciate ligament(s) are reconstructed in usual fashion with care taken not to stress the medial structures.

CHRONIC MEDIAL INSTABILITY

If surgery is indicated in a chronic situation, primary repair is attempted initially. The approach is similar to an acute repair as previously described. It is important to note that in chronic conditions, the medial structures can

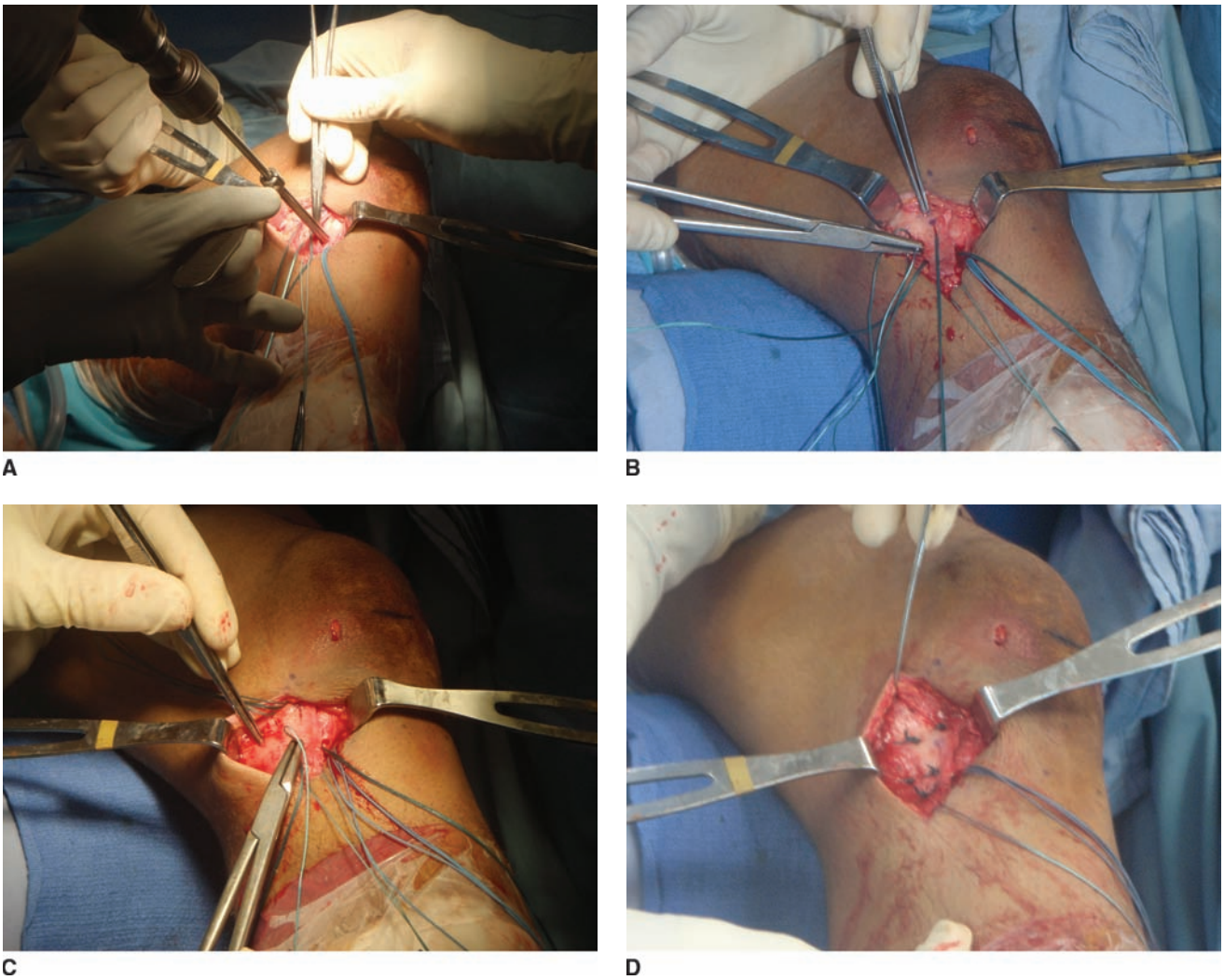


FIGURE 37.13

A: After preparation of the MCL and tibial surface, the suture anchors are drilled sequentially. **B,C:** Mattress sutures are then thrown to secure the MCL to the tibial surface. **D:** All mattress sutures tied sequentially.

be poorly defined and poorly identified making primary repair more difficult. Because of this, augmentation of primary repair with an anatomic reconstruction is often necessary.

The same principle of starting with MCL repair and reinforcing with the POL is employed. Numerous graft choices are available including hamstring autograft or multiple allografts. Our preference is tibialis anterior

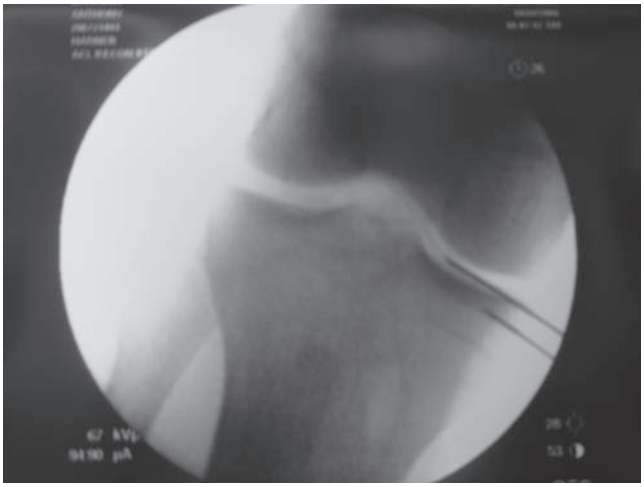


FIGURE 37.14

Fluoroscopic confirmation of anchor placement can be a helpful technique to ensure proper location (note one improper needle location in the medial joint space and one proper location in the medial tibia).

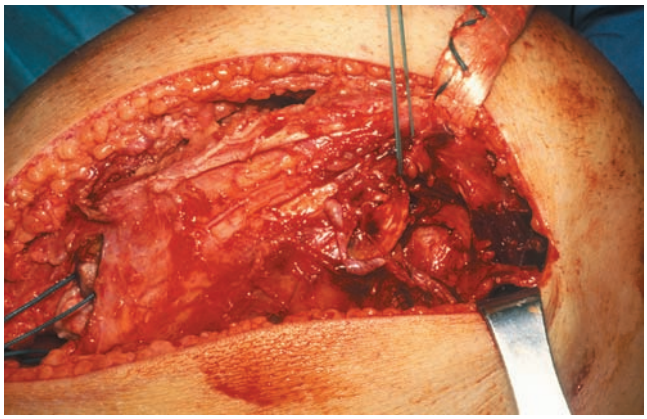
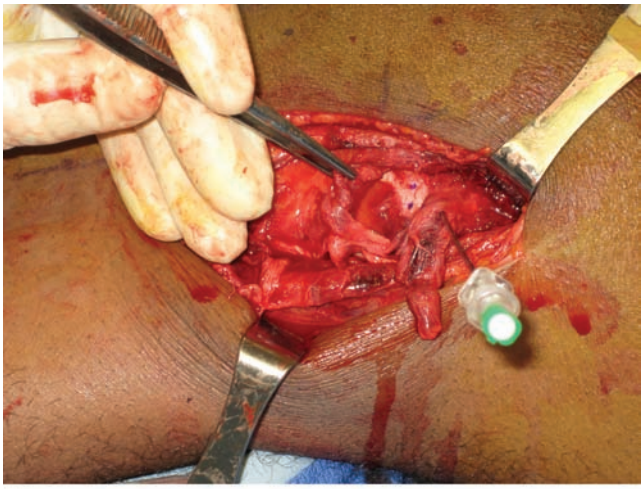


FIGURE 37.15

Direct fixation of a femoral sided MCL tear with suture anchors in the medial epicondyle.



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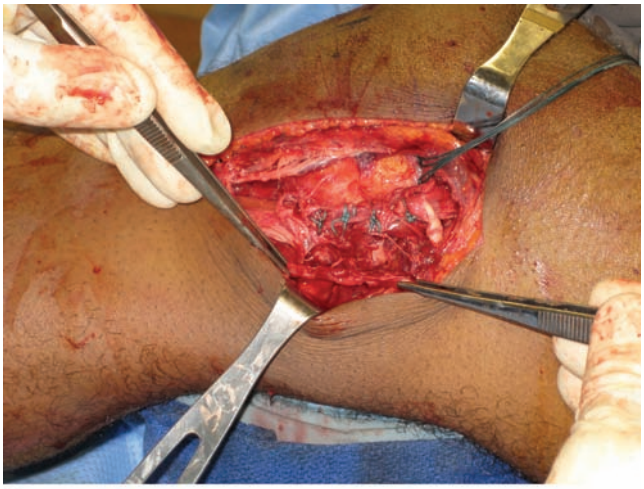

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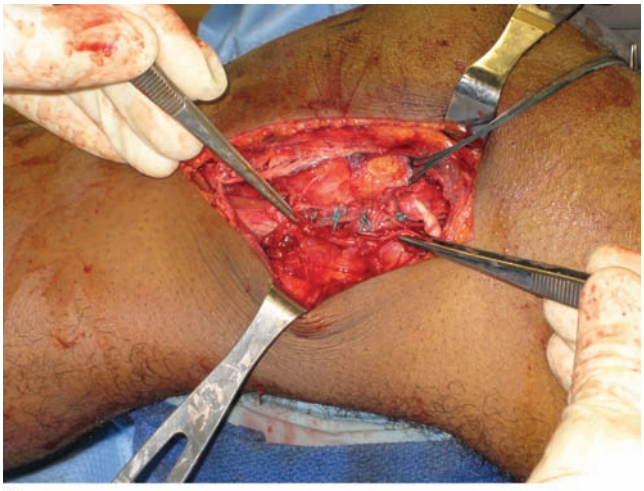

C

FIGURE 37.16

A: Dissection through layer I exposing the torn ends of the MCL. Note the 18-gauge needle in the medial epiconyle and the distal portion of the MCL in the forceps. **B:** MCL repaired with direct suturing. Note the POL held in the forceps posterior to the repaired MCL. **C:** Advancement of the POL to the posterior edge of the MCL.

allograft; however, given its proximity and ease of harvest, semitendonosis autograft is also reasonable. The soft tissue graft is whipstitches at each end and doubled over a 5 suture (Fig. 37.20).

For anatomic reconstruction, the medial epicondyle and the anteromedial tibia should be identified. The goal of the graft is to recreate the superficial MCL. Tibial fixation is easily achieved by using a screw with a soft tissue washer through the graft. The proximal end of the graft is then held (manually or with temporary K wire fixation) at the location of the medial epicondyle. The knee should be taken through a full range of motion to

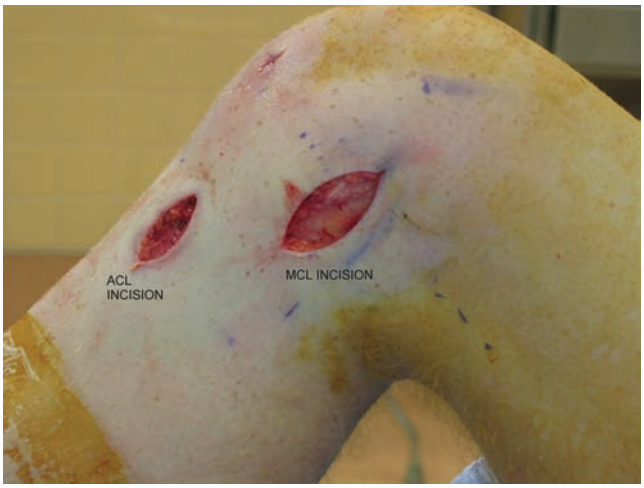

FIGURE 37.17

The limited incision through layer I to expose the POL and the MCL for POL advancement.

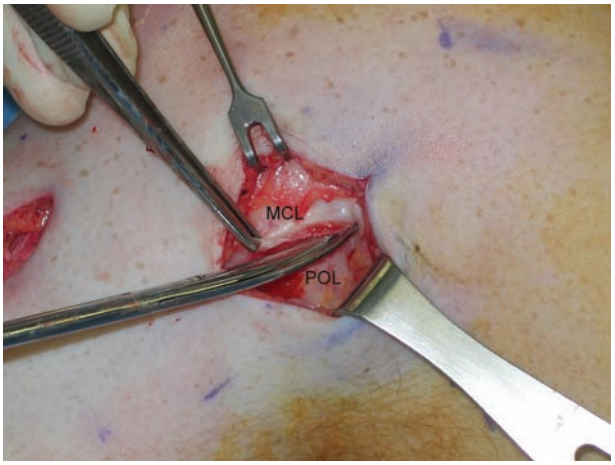

FIGURE 37.18

The demarcation between the MCL and the POL is split to allow for the imbrication.

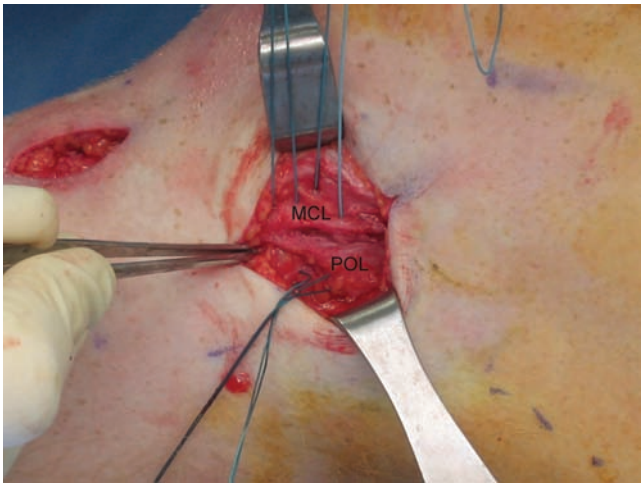

FIGURE 37.19

Sutures are passed through the POL and advanced through the MCL, thereby completing the imbrications.

ensure the MCL reconstruction is isometric. A pilot hole is drilled at the isometric point and the graft is fixed proximally with a screw and soft tissue washer with the knee in full extension. If needed, the POL is advanced in a similar fashion that was previously described for acute repairs. It is our opinion that chronic repairs tend to require POL advancement more often than acute repairs. Again, horizontal mattress sutures should be passed through the superficial MCL (and graft) and into the tibial periosteum (Fig. 37.21).

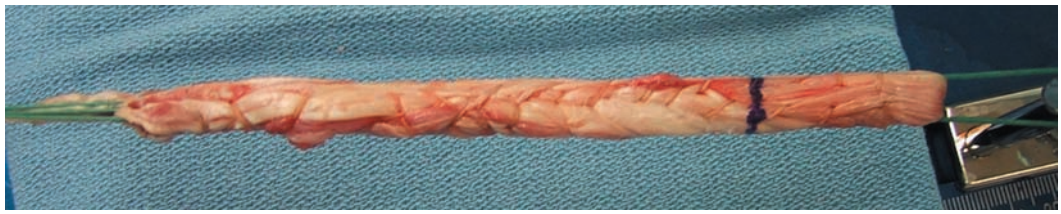

FIGURE 37.20
Tibialis anterior allograft whipped stitched prior to MCL reconstruction.

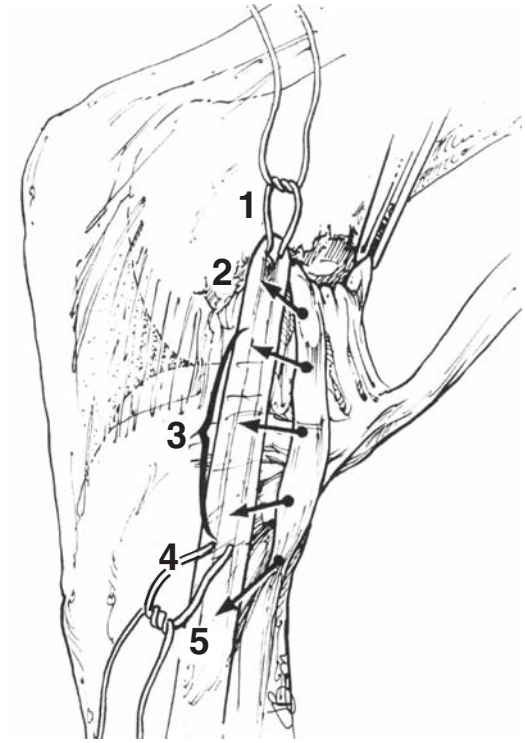

FIGURE 37.21
The graft is placed from the medial epicondyle to the anteromedial tibial surface. The POL can be advanced similar to the MCL repair to reinforce the reconstruction.

POSTOPERATIVE MANAGEMENT

With combined injuries, the postoperative protocol follows cruciate reconstruction rehabilitation regimen. Achieving full extension is the initial goal, in particular with combined ligamentous injury. Any decrease in range of motion or failure to progress in range of motion should be treated aggressively.

If a medial sided repair/reconstruction is performed in isolation, our postoperative protocol is to maintain the leg in full extension in a locked hinged brace for 2 to 4 weeks. A continuous passive range of motion machine is used twice daily. At 4 weeks, the brace is unlocked and motion exercises are begun. The patients are non–weight bearing with crutches for 2 weeks and then progressive weight bearing is allowed. Crutches are only discontinued when ambulation without a limp is achieved. Strengthening is initiated at 6 weeks post-op with closed-chain exercises. The brace is discontinued at 8 weeks from the date of surgery.

COMPLICATIONS

The primary complication of operative treatment of the MCL is arthrofibrosis. While this complication may occur with any knee ligament surgery, it is accepted that surgical treatment of the MCL is a risk factor for loss of motion. This risk can be minimized by careful dissection and an appropriate repair with care taken not to over tension the POL or MCL. As we stated earlier, after repairing the MCL the knee should be taken through a full range of motion prior to skin closure. If full range of motion is possible in the operating room, then motion should be able to be restored with aggressive physical therapy. Another important consideration is the preoperative range of motion. We routinely allow 1 to 2 weeks after injury to pass to allow reduction of swelling and restoration of motion prior to operative management.

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38 LCL/PLC Reconstruction

Christopher C. Dodson, Robert Parisien, and Scott A. Rodeo

INTRODUCTION

Interest in the posterolateral corner (PLC) of the knee joint has increased because recent biomechanical and anatomic studies have revealed its importance in knee stability (1). PLC injury of the knee is commonly associated with concomitant ligament disruptions (1). Although PLC injuries of the knee are uncommon, they can lead to chronic disability from persistent instability and resultant articular cartilage degeneration (2). The diagnosis of subtle lesions of the PLC can be elusive unless there is heightened clinical suspicion for possible injury of this region (3). Failure to diagnose and treat PLC injuries may increase the failure rates for both anterior and posterior cruciate ligament (PCL) reconstructions (1). However, early diagnosis may allow for immediate surgical repair of the PLC that has resulted in superior outcomes as compared to delayed reconstruction (1,2).

ANATOMY

The complex anatomy of the PLC of the knee is due largely to the evolutionary changes in the anatomic relationships of the fibular head, the popliteus tendon, and the biceps femoris muscle (3). Recent anatomic and biomechanical studies have more clearly defined the various anatomic structures composing the PLC of the knee. These structures include the iliotibial tract, lateral collateral ligament (LCL), popliteus tendon complex, popliteofibular ligament (PFL), and the posterolateral capsule (1,13). The LCL is the primary static restraint to varus opening of the knee (4–6). The femoral insertion is located proximal and posterior to the lateral epicondyle in a small depression between the lateral epicondyle and the supracondylar process. Distally, the LCL attaches to the fibular head a mean of 8.2 mm posterior to the most anterior aspect of the fibular head (7–9) (Fig. 38.1).

The popliteus tendon complex consists of the popliteus muscle-tendon unit and the ligamentous connections from the tendon to the proximal fibula, tibia, and meniscus (10). The popliteal muscle originates from the posteromedial aspect of the proximal tibia and gives rise to its tendon, which courses intra-articularly through the popliteal hiatus of the coronary ligament to insert on the popliteal saddle on the lateral femoral condyle (11). The femoral insertion site of the popliteus is consistently anterior and distal to the femoral attachment site of the LCL, according to LaPrade et al. (11). However, Brinkman et al. (12) found more variability in the popliteus tendon femoral insertion site as either anterior or posterior to the LCL. The three popliteomeniscal fascicles extend from the tendon to the lateral meniscus and assist in providing dynamic stability to the meniscus (13).

On the basis of their dissection studies, Sudasna and Harnsiriwattanagit (14) identified a fibular origin of the popliteus (also known as the popliteofibular ligament or PFL) in 98% of the knees, a fabellofibular ligament in 68%, and a thin, membranous arcuate ligament in 24%. The PFL arises from the myotendinous junction of the popliteus and courses distally and laterally to insert on the fibular styloid process.

In addition, the iliotibial band (IT) is composed of multiple layers and blends with a confluence of the short head of the biceps to form an anterolateral sling about the knee. The long and short heads of the biceps femoris muscle provide dynamic stability, with the fabellofibular ligament being a thickening of the distal capsular edge of the short head of the biceps (1). The common peroneal nerve is located on the posterior border of the long head of the biceps (8). The mid third of the lateral capsular ligament is a thickening of the lateral capsule (1). Ultimately, the lateral meniscus increases the tibiofemoral conformity and thus the stability of the lateral compartment.

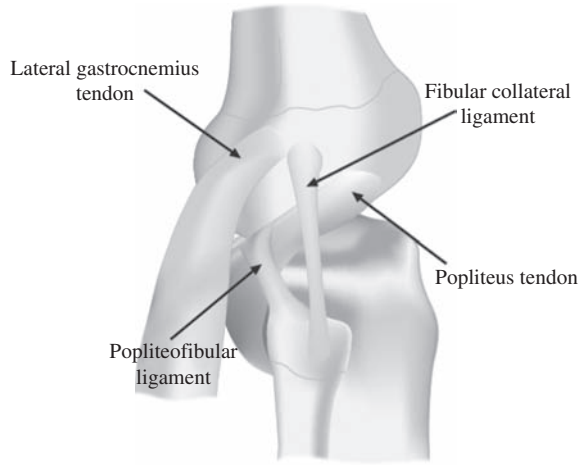

FIGURE 38.1

Illustration of the anatomy of the PLC demonstrating the three major components: lateral (fibular) collateral ligament, popliteus tendon, and PFL.

BIOMECHANICS

The primary function of the PLC is to resist varus rotation, external tibial rotation, and posterior tibial translation (4,6). Biomechanical studies involving selective sectioning and joint loading have helped to define the interrelationships between the PLC and the primary functions of the LCL, popliteus tendon, and the PFL (15). The LCL is the primary static restraint to varus opening of the knee (4–6). The response to direct force measurements of the LCL at 30 degrees of flexion is significantly higher than at 90 degrees of flexion (15). The individual maximum tensile strength of the LCL has been determined to be 295 N (16). The PCL has been found to play a role as a secondary restraint because, when sectioned in isolation, the PCL has no effect on varus rotation but, when the posterolateral structures are deficient, additional PCL sectioning results in a significant increase in varus rotation (4–6).

Selective ligament sectioning by Nielsen et al. (17–20) demonstrated the importance of the PLC as the primary stabilizer of external tibial rotation at all knee flexion angles. The LCL and the posterolateral part of the capsule resisted varus and external rotation of the tibia. The popliteus tendon resisted excessive external rotation of the tibia during knee flexion from 20 to 130 degrees, and it resisted excessive varus rotation of the tibia during flexion from 0 to 90 degrees (18). Isolated sectioning of the PCL did not affect varus or external rotation stability, whereas combined sectioning of the LCL and the posterolateral part of the capsule resulted in increased instability (17,19).

Gollehon et al. (4). and Grood et al. (6). found that combined injury to the PCL and posterolateral structures produced significantly greater increases in external tibial rotation, especially at 90 degrees of knee flexion. These studies provide the biomechanical rationale for performing the dial test at 30 and 90 degrees of flexion to determine the presence of an isolated PLC or combined PLC/PCL injury (21).

In a cadaveric study by LaPrade et al. (15), it was found that the mean load responses to external rotation in the LCL were significantly higher than those of the popliteus tendon and PFL at 0 and 30 degrees of flexion. The popliteus tendon and PFL, on the other hand, demonstrated higher loads at higher knee flexions, peaking at 60 degrees. It was concluded that the LCL, popliteus tendon, and PFL performed complementary roles as stabilizers to external rotation with the LCL assuming a primary role at lower knee flexion angles and the popliteus complex assuming a primary role with higher knee flexion.

Due to studies demonstrating that isolated sectioning of the PCL produces increased posterior tibial translation at all angles of knee flexion, with a maximum at 90 degrees, and isolated sectioning of the PLC structures produces increased posterior tibial translation at all angles of knee flexion, with a maximum at early knee flexion, it can be concluded that the PLC, not the PCL, is the primary restraint to posterior tibial translation near full knee extension (6,22). Furthermore, combined sectioning studies of both the PCL and the PLC have demonstrated significant increases in posterior translation at 90 degrees of flexion compared with the intact knee(s) with isolated PCL or posterolateral deficiency (4,6,23).

The interdependent relationship of the PLC structures and the cruciate ligaments is demonstrated through biomechanical analysis of posterolateral deficiency in the setting of ACL or PCL reconstruction (1). LaPrade et al. (24) sectioned the posterolateral structures and noted increased loads in the ACL graft with application of varus and coupled varus-internal rotation moments. Due to these findings, the authors recommend reconstruction or repair of a grade III PLC injury at the time of ACL reconstruction.

Failure to recognize and treat a PLC injury will result in increased stresses and possible failure in PCL reconstruction; therefore, a combined reconstruction is recommended (10). This is demonstrated by Harner et al. (10) as they sectioned the posterolateral structures and, compared to knees with intact posterolateral structures, found an increased posterior tibial translation in the reconstructed knees of 6 mm at 30 degrees and

4.6 mm at 90 degrees of flexion as well as increased external rotation of up to 14 degrees and increased varus rotation of up to 7 degrees. Furthermore, forces on the PCL graft increased significantly by 22% to 150% under all loading conditions.

Recently, there has been a trend toward reconstructing the three most critical biomechanical structures that control varus and external rotation: the LCL, popliteus tendon, and PFL (25,28). Two recent biomechanical studies reported by Nau et al. (28) and Markolf et al. (29), in which all three functional components were anatomically reconstructed, separately documented overconstraint of internal rotation and varus rotation, respectively.

CLINICAL EVALUATION

A complete and accurate history, with consideration toward the complexities of a complete knee evaluation, is necessary to accurately diagnose PLC injuries. Common mechanisms of injury include a posterolaterally directed blow to the anteromedial proximal tibia with resultant hyperextension; a noncontact hyperextension and external rotation twisting injury; direct blow to a flexed knee; or high-energy trauma (1). However, accurate determination of the exact mechanism of injury may be difficult to attain in the latter case of high-energy trauma.

PLC injuries rarely occur in isolation. They are often accompanied by other ligamentous injuries, especially PCL injury (1). Patients with chronic posterolateral injury may describe medial joint-line pain, lateral joint-line pain, and posterolateral pain (30–32). Patients may also frequently present with functional instability when the knee is extended, significantly limiting their level of activity. Instability is present with twisting and cutting actions and basic tasks, such as climbing up or down stairs, may cause the knee to give away or "buckle" into hyperextension. The term posterolateral rotatory instability is used to describe posterior subluxation of the lateral tibial plateau that can occur with an external rotation torque in knees with pathologic laxity of the PLC (3).

In the event of an associated injury, usually to the PCL, the possibility should be considered of a knee dislocation that spontaneously reduced before evaluation (1). Following such an injury, a complete neurovascular examination should be performed with attention given to the integrity of the popliteal vessels and the function of the peroneal nerve (1). Studies and reports by LaPrade and Terry (32) and Krukhaug et al. (33) showed an incidence of peroneal nerve injury of 13% in a series of 71 patients and in 16% of 25 patients, respectively. Calculation of an ankle-brachial index should be done to assess the vascular status of the limb (1).

Examination of the injury begins with a thorough evaluation of the overall limb alignment and gait. Patients may have a standing varus alignment and demonstrate a varus or a hyperextension varus thrust during the stance phase of gait (1). The knee should also be carefully examined for edema, ecchymosis, induration, and tenderness. Abrasion, laceration, or ecchymosis in the region of the tibial tubercle should raise the suspicion of concomitant injury of the PCL (34). Ligamentous examination is performed on both knees to provide a comparison between the injured and the normal state and to ascertain the functional integrity of specific structures.

To detect both varus and rotational deformities, varus stress testing is performed at 0 and 30 degrees of flexion. Clinically detectable varus opening at 0 degree is indicative of a severe posterolateral injury and an associated cruciate injury; however, isolated cruciate injuries do not affect varus stability (1). Isolated PLC injuries typically result in a maximum varus opening at 30 degree flexion but can still be present when there is minimal varus laxity with rotational instability.

The dial or posterolateral rotation test is the most commonly performed test to assess external rotation. The test is performed with the examiner placing one hand behind the posterior proximal tibia for support, ensuring the tibia is maintained in a reduced position. With the other hand, the examiner holds the patient's foot and externally rotates the foot at both 30 and 90 degrees of flexion. Injury to the PLC is isolated when examination at 90 degrees of flexion reveals a decrease in the amount of external rotation compared to 30 degrees (1). A combined PLC/PCL injury is present when there is further increased external rotation at 90 degrees of flexion.

Other common external rotational tests include the posterolateral drawer, the reverse-pivot shift, and the external rotation recurvatum tests. The posterolateral drawer test should be performed at 30 and 90 degrees of knee flexion to detect posterolateral injury. Furthermore, the status of the PCL is most commonly determined by the posterior drawer test performed at 90 degrees of flexion. A positive reverse-pivot shift test may indicate injury of the PLC complex but may also be positive in up to 35% of normal knees examined under anesthesia (1–3). The external rotation recurvatum test, described by Hughston et al. (1–3), is used to diagnose posterolateral rotatory instability in the extended knee. It is performed by lifting the patient's legs by the great toes and noting side-to-side differences in hyperextension, varus, and tibial external rotation.

Veltri and Warren (31) reported that the most useful tests for the diagnosis for posterolateral knee injury were the prone external rotation test at 30 and 90 degrees of flexion and the varus stress test at 0 and 30 degrees of flexion. They also used the reverse-pivot shift and the external rotation recurvatum tests to diagnose posterolateral instability.

CLASSIFICATION

The most commonly used classification system defines injury severity based primarily on varus instability. Grade I injuries are sprains with little or no varus instability (0–5 mm opening). Grade II injuries are partial injuries with moderate laxity (6–10 mm). Grade III injuries are complete injuries with significant laxity (>10 mm). Rotational instability is then defined by the dial test, with instability defined as an increase in external tibial rotation of 10 degrees compared with that of the contralateral knee. A problem with this grading system is that it minimizes the importance of rotational instability; many PLC injuries may have significant rotational instability with minimal varus instability. This has prompted some authors to use a grading system that combines both varus and rotational instability (1). Their grading system is defined as follows; grade I injuries have minimal instability (either varus or rotational instability of 0–5 mm or 0–5 degrees), grade II injuries have moderate instability (6–10 mm or 6–10 degrees), and grade III injuries have significant instability (>10 mm or >10 degrees). It is important note that as with all PLC classification systems, this system has not been validated. Generally speaking, grade III injuries are treated surgically, whereas grade I and grade II injuries are treated nonsurgically.

IMAGING

Imaging studies are a reliable modality to help accurately diagnose PLC injuries. Although standard posteroanterior and lateral radiographs of the knee are often normal, they may show either avulsion or tibial plateau fractures. Common avulsion injuries include the "arcuate" sign (i.e., fibular head fracture), Segond fracture, or Gerdy tubercle avulsions (1). It is crucial to identify bony avulsion injuries because they can be treated by primary repair in the acute phase. We recommend always obtaining a magnetic resonance imaging (MRI) whenever a PLC injury is suspected. MRI is helpful in elucidating the complex anatomy of the PLC. High field strength MRI with standard T1-weighted, T2-weighted, proton density, fat-saturated, and gradient echo sequences with coronal, axial, and sagittal views is the primary method to assess injuries (Fig. 38.2). Standard views should provide accurate visualization of the LCL, popliteus, biceps femoris, gastrocnemius, and IT band.

SURGICAL TECHNIQUE

Acute Injuries

PLC injuries appear to be best treated in the acute stage, before significant capsular scarring and stretching of secondary restraints occurs. This can be done by direct repair, with or without augmentation, or by primary reconstruction. Acute (immediate) repair generally gives more favorable results than does chronic (late) reconstruction because of the restoration of native anatomy and normal biomechanics (30,31). Repairs performed early (i.e., <3 weeks) usually provide superior results (30,31). However, more recent series report better results with reconstruction compared to direct repair, even in the acute setting (32).

A few basic principles exist for acute PLC primary repairs. First, one must diagnose and address all concomitant injuries. Second, avulsion injuries are generally best treated with either rigid internal fixation or sutures, depending on the nature of the avulsion (1). Third, although midsubstance repairs of the LCL can be performed,

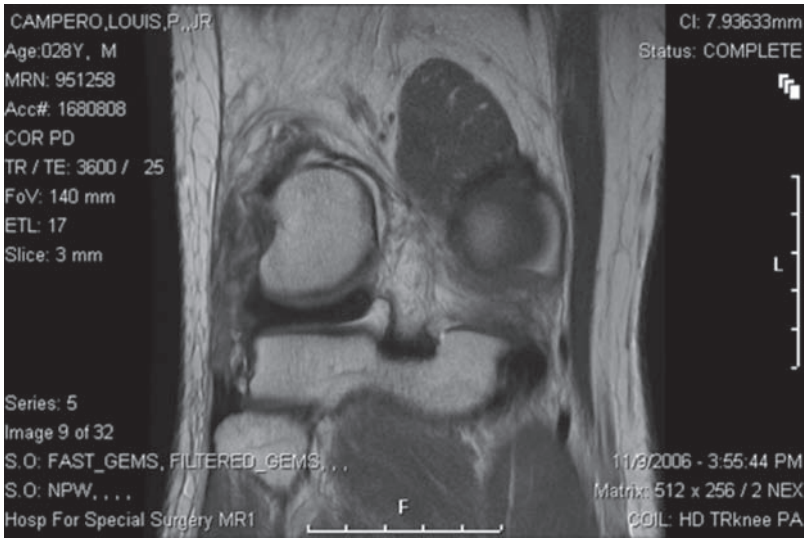

FIGURE 38.2

Coronal fast-spin echo MRI demonstrating a chronic LCL tear as well as popliteus tendon tear.

these are best treated acutely with a combined repair of the intrasubstance tear and a graft augmentation. This is because of the inconsistent healing of the LCL, higher published failure rates (37% for acute repair vs. 9% for acute reconstruction), and limited success in treating chronic LCL insufficiency (32,33). Fourth, the peroneal nerve may need to be released if there is any clinical evidence of compression, epineural hematoma, or if required for safe exposure. Another important point to consider is injury and possible instability at the tibiofibular joint. Although this is uncommon, it would affect any fibular-based PLC reconstruction technique. Lastly, for combined acute injuries, an attempt should be made to address all concomitant injuries at the same setting; however, this must be balanced against the increased risk of arthrofibrosis (34).

Some authors support reconstruction over repair in the acute setting. In a large series of 56 patients (57 PLC tears), Stannard et al. (32) reported that the failure rate was 37% (13/35) for the acute (immediate) repair cohort versus 9% (2/22) for the group reconstructed with a modified two-tailed anatomic technique. The reason for this discrepancy may have to do with the fact that most of the cruciate injuries of these knees were not treated primarily but were staged in treatment. Both groups were started on an early aggressive physical therapy protocol, and, because acute repairs require healing, the reconstruction group may have done better because of their more rigid graft fixation within the setting of early post operative range of motion. Although this controversy still exists, it is generally agreed that immediate surgical intervention, with or without local soft tissue augmentation, is superior to late reconstruction regarding the ability to restore dynamic function of the structures of the PLC.

Chronic Injuries

The treatment of chronic PLC injuries differs from that of acute disruptions.

Beyond 4 to 6 weeks from injury, significant pericapsular scarring makes it difficult to localize and repair discrete structures; thus, reconstruction is favored (1). PLC reconstructions can be broadly divided into two categories: nonanatomic and anatomic. Nonanatomic reconstructions do not directly address injured functional anatomic structures but provide primary varus support by advancement procedures in a nonisometric fashion. These reconstructions are primarily historical because most clinicians now favor anatomic reconstructions that can be broadly separated into fibular-based and combined tibial-fibular–based reconstructions (1). Tibial-fibular–based reconstructions have gained recent favor because these techniques reconstruct all three major components of the PLC—the LCL, the popliteus tendon, and the PFL (8,16,25,28). Some clinicians still favor fibular-based reconstructions because they are less technically demanding and have good clinical outcomes compared with more anatomically accurate reconstructions (30). Despite the numerous reconstructive techniques reported in the literature, data on long-term results of PLC reconstruction are limited (33,35). Many studies focus on combined PCL reconstructions with nonanatomic PLC techniques (36). In addition, effective comparison of clinical outcomes is difficult because of the high frequency of associated injuries, a mixed number of acute and chronic cases, and lack of consistent outcome measurements in the treatment of these injuries. Data have begun to emerge on more nearly anatomic PLC reconstructions. Latimer et al. (37) and Buzzi et al. (38) performed anatomic femoral LCL reconstructions with good results in combined cruciate injuries. Recently, Noyes and Barber-Westin (39) published their results with an anatomic PLC reconstruction in combined cruciate and PLC injuries. Yoon et al. (40) showed improved success comparing anatomic versus nonanatomic reconstruction. These studies show favorable short-term results for anatomic PLC reconstructions; however, it remains unclear, from both a clinical and a biomechanical perspective, which type of anatomic PLC reconstruction is superior. Potential problems with the anatomic reconstructions include increased technical difficulty and potential to overconstrain the knee (29). Nevertheless, short-term studies of these techniques demonstrate good clinical results. We generally use a fibular-based approach. The following is a description of the senior author's preferred technique.

SURGICAL TECHNIQUE

A basic goal of ligament reconstructions is to reproduce anatomy; thus, it is critical to understand the anatomic insertion sites of the LCL, popliteus tendon, and PFLs on both the femur and the fibula. LaPrade et al. (27) have defined these insertion points. They found that the fibular collateral ligament had an average femoral attachment slightly proximal (1.4 mm) and posterior (3.1 mm) to the lateral epicondyle. The fibular attachment of the LCL is 8.2 mm posterior to the anterior aspect of the fibular head. The popliteus tendon attachment on the femur is anterior to the fibular collateral ligament. These insertion sites of the LCL and popliteus tendon are separated by an average of 18.5 mm.

A critical point to consider is graft isometry. Attachment sites must be chosen that have minimum length change through the range of motion, a basic principle of any ligament reconstruction. The attachment sites for the popliteus tendon and PFL are highly nonisometric. This is due to the fact that the popliteus is a muscle-tendon unit, and thus has the ability to adjust length/tension with changes in muscle length. A graft reconstruction of these structures uses a static graft with a single fiber length. Sigward et al. reported that the mean relative length changes of popliteus tendon and PFL grafts with the attachment sites centered over the popliteus tendon

femoral footprint were 3.7 and 5.0 mm, respectively, in a cadaveric study (41). These data argue against simply reproducing anatomy with a static graft for the popliteus tendon and PFL. In contrast, this same study found that use of the native attachment sites for the LCL resulted in a satisfactory isometry profile.

An examination under anesthesia is performed on both extremities followed by an arthroscopic evaluation of the knee to assess for associated cartilage and ligamentous damage. In the cases of concomitant ligament injuries, most commonly a PCL, the PLC reconstruction is performed after the cruciate ligament reconstruction.

A lateral hockey stick incision is made, paralleling the posterior edge of the IT band. Exposure is carried out through three fascial incisions to provide adequate visualization of both the femoral and the fibular attachment points of the LCL, popliteus, and PFL: (a) along the posterior aspect of the biceps to expose the peroneal nerve, (b) between the IT and the biceps for access to fibular head, (c) a longitudinal incision in the midaspect of the IT over the lateral epicondyle. This incision originates distally from just proximal to Gerdy tubercle and extends proximally to the distal termination of the lateral intermuscular septum. A small horizontal incision (1.5–2.0 cm long) is made through the anterior arm of the long head of the biceps femoris, 1 cm proximal to the lateral aspect of the fibular head, which opens the fibular collateral ligament–biceps bursa. The attachment site of the fibular collateral ligament on the lateral aspect of the fibular head can be identified through this bursa. The common peroneal nerve is identified, and a neurolysis is performed from approximately 6 cm proximal to the fibula to just past the peroneus longus fascial sheath distally. The nerve is gently retracted during the reconstructive procedure.

A fibular-based reconstruction is recommended for acute PLC injury. A single, large graft placed into the fibula is the preferred technique, similar to that described by Noyes and Barber-Westin (26). The value of this technique is the ability to use a relatively large graft. The graft reproduces the LCL. It is placed into a drill tunnel at the LCL femoral insertion site and then into a tunnel in the top of the fibular head. Various fixation techniques in the fibula can be used, such as use of an interference screw or the "docking" technique. Femoral fixation can be performed with an interference screw or sutures pulled through to the medial side through a drill hole.

If there is excessive external rotation in addition to varus laxity, a different reconstruction technique may be considered. An Achilles allograft is used. The bone block is placed in the femoral popliteus tendon insertion site, and then the graft is brought through a drill tunnel in the fibular head. The graft is passed from posterior to anterior through this tunnel. A bioabsorbable screw is placed in the fibular tunnel to secure the graft in order to minimize graft motion. The graft is then brought into a drill hole in the femur at the LCL insertion. The posterior of these two limbs reproduces the PFL while the anterior limb approximates the LCL. However, as described above, this graft is nonisometric. For example, based on data from Sigward et al. if the graft were fixed at 30 degrees flexion, it would elongate approximately 4 mm as the knee comes into full extension.

The fibular drill tunnel is made by drilling a K-wire through the fibular head from the attachment site of the fibular collateral ligament on the lateral aspect of the fibular head to the attachment site of the PFL on the posteromedial fibular styloid process. A 7 to 8 mm tunnel is reamed over this guide pin. The guide placed for the femoral tunnels may be drilled across to the medial side in order to pull the graft sutures across the knee to aid in graft tensioning and fixation (Fig. 38.3). These guide pins will exit the distal femur proximomedial to the medial epicondyle and adductor tubercle. When the eyelet pins are aimed to this position, they do not encounter either an ACL or a PCL graft tunnel. We typically ream 9 to 10 mm femoral tunnels over each guide pin to a depth of 20 to 25 mm. The bone bridge between the femoral tunnels is approximately 8 to 9 mm. The graft is fixed with the knee in about 60 degrees of flexion and 5 degrees of internal rotation. Fixation may be carried out using bioabsorable or metal interference screws, sutures tied over a button, or the "docking" technique.

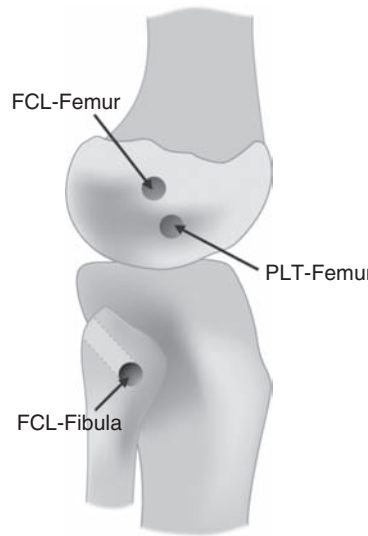

FIGURE 38.3

Lateral view of a reconstruction technique of the lateral (fibular) collateral ligament (LCL) and popliteus tendon (PLT). Note the positioning of the graft on the femur with respect to the insertion sites of the FCL and the PLT.

In the chronic setting, there may be increased laxity, with increases in both varus and external rotation. In this situation, an additional graft limb may be passed into the posterior tibia to replace the popliteotibial arm. One option to do this is to use an Achilles allograft tendon with a bone block placed into the lateral femoral condyle at the LCL insertion site. The soft tissue portion of the allograft is fashioned with two tails (a "split Y" graft), each 8 to 9 mm diameter. One limb is placed into a drill tunnel in the posterolateral tibia, entering posteriorly at the approximate site of attachment of the popliteus muscle/tendon unit to the posterior tibia. Sutures from this limb come out of the tibial tunnel anteriorly and are tied over a button. The second limb of the graft is placed into the top of the fibular head, as described above, to reproduce the LCL. An alternative technique that has been used in the chronic setting is to placed the two-limbed (split Y) graft at the femoral popliteus insertion point. One limb can be passed through a fibular drill tunnel as described above, to reproduce the PFL, and then brought back to the femur to reproduce the LCL. The second limb is placed into the tibial tunnel to reproduce the attachment of the popliteus to the posterior tibia. However, as described above, these attachment points for the popliteus tendon and PFL are nonisometric.

REHABILITATION

Postoperatively, the reconstructed knee is immobilized in a hinged knee brace locked in extension. The brace should be fashioned with a posterior support or bolster in order to prevent posterior sag that can occur from the effects of gravity and the posterior pull of the hamstrings. Patients usually maintain partial weight bearing, with the brace locked in extension, for the first 6 weeks. The brace is unlocked for range of motion exercises, including closed-chain minisquats and heel slides. Quadriceps exercises are the mainstay of rehabilitation, which includes quadriceps sets, minisquats, and straight leg raises. As range of motion and quadriceps strength improve, the brace is discontinued. Active knee flexion exercises (hamstrings) may be delayed for 4 to 6 weeks to minimize posterior pull on the fibula. Hip abduction exercises should also be avoided for the first 4 to 6 weeks since this places varus stress across the knee. Physical therapy continues with emphasis on restoration of normal gait, attainment of full range of motion, and gradual recovery of muscle strength, endurance, and proprioception. A safe and gradual return to work or athletic participation is achieved at approximately 10 to 12 months postoperatively

SUMMARY

Most PLC injuries are associated with other combined ligamentous injuries of the knee. Treatment emphasizes early, accurate diagnosis so that immediate surgical intervention can be performed. In acute injuries, an anatomic repair approach is preferred whereas chronic cases are best treated with graft reconstruction. There still is no benchmark reconstruction technique. There has been a recent trend, however, toward more nearly anatomic reconstruction, with attention paid to proper insertion site anatomy in order to restore native knee kinematics as well as possible. Reports of long-term outcomes of these techniques are limited, but short-term studies demonstrate good results.

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39 Knee Dislocation

Volker Musahl, Russell F. Warren, and Answorth A. Allen

INTRODUCTION

A knee dislocation is the most severe injury to the lower extremity. It can present as a pure soft tissue injury or as a fracture dislocation. A knee dislocation is defined as complete disruption of the femorotibial joint; whereas subluxation is defined as disruption of the joint with some remaining contact of the joint surfaces. A devastating and common complication of knee dislocation is injury to the neurovascular structures, which is reported to occur in 15% to 50% of all knee dislocations (11,27,29,35). A multiple-ligament injured knee is a knee that experienced subluxation or dislocation and has two or more ligaments disrupted (3,17,19,25). The most common clinical presentation is an occult knee dislocation; however, multiple-ligament injured knees should be treated as a "dislocated knee" even if dislocation was never witnessed (10,27).

Kennedy classifies knee dislocations according to the position of the tibia with respect to the femur. In order of decreasing incidence, knee dislocations are described as, anterior, posterior, lateral, medial, and rotatory (Figs. 39.1 and 39.2) (17). Rotatory knee dislocations are subdivided into four groups: (1) anteromedial, (2) anterolateral, (3) posteromedial, and (4) posterolateral. Up to 50% of knee dislocations are spontaneously reduced prior to evaluation and cannot be classified with the Kennedy system. Therefore, an anatomic system was developed that is based on ligament injury as well as additional designations of (C) arterial injury and (N) neural injury. Injuries are described from single cruciate tear (KD I) to involvement of all four ligaments (KD IV). Involvement of the medial collateral ligament (MCL) is designated with (M), involvement of the lateral collateral ligament (LCL) or posterolateral corner (PLC) is designated with (L). KD V involves a fracture dislocation (4).

Newer classification systems are based on surgical timing and staging. Fanelli et al. described a lateral side- and a medial side-classification system (5,8). In the lateral side classification system, a type A injury (isolated increase in external rotation) consists of injury to the popliteofibular ligament (PFL) and popliteus tendon. Type B injuries (increased external rotation and 5 mm varus laxity at 30 degrees of knee flexion) consist of injury to the PFL, popliteus tendon, and LCL. In type C injuries (increased external rotation and 10 mm varus laxity at 30 degrees of knee flexion), additional tearing of the lateral capsule occurs. In the medial side classification

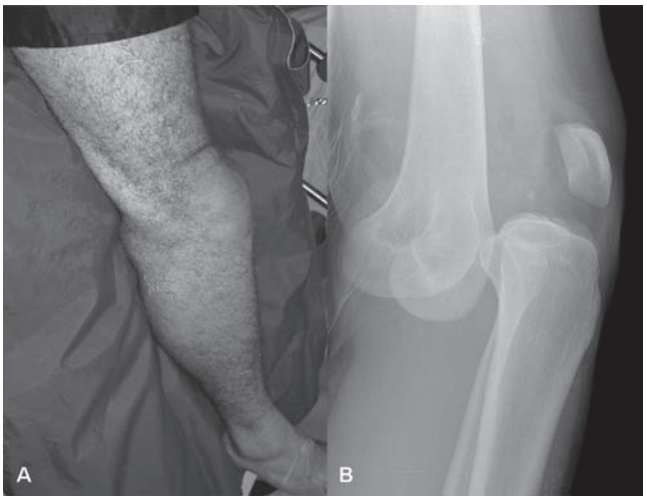

FIGURE 39.1
Clinical presentation of an anterior knee dislocation **(A)** and corresponding lateral radiograph **(B).**

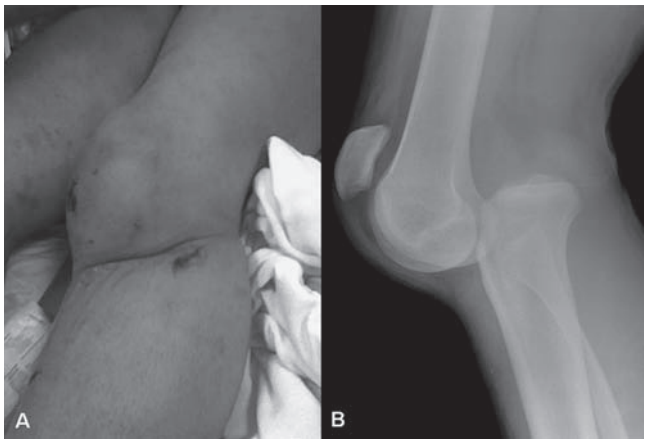

FIGURE 39.2

Clinical presentation of a posterior knee dislocation **(A)** and corresponding radiograph **(B).** Note patella alta, indicating disruption of the patella tendon.

system, type A injuries consist of isolated axial rotational laxity (anteromedial or posteromedial). Type B injuries consist of axial rotational laxity and additional valgus laxity at 30 degrees of knee flexion with a firm end point. In type C injuries, valgus laxity is gross with a soft end point. Surgical staging and timing according to this classification system is described later in this chapter (20).

HISTORY

Anterior knee dislocations usually result from a hyperextension mechanism (11,12,17). With increasing severity of hyperextension force, injury occurs to the posterior capsule at 30 degrees of knee flexion, followed by injury to the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL). The popliteal artery ruptures after 50 degrees of hyperextension (Fig. 39.3) (17).

Posterior dislocations are caused by direct posterior force to the anterior tibia (11). The anterior blow to the tibia can occur while foot is fixed on the ground during contact sport or by abrupt deceleration and dashboard strike to the anterior tibia with the knee in a flexed position during motor vehicle collisions (12,30). The PCL is the most important stabilizer to posterior tibial forces and is always disrupted in posterior dislocations. Because extreme posterior loads are required to rupture the PCL, concomitant disruption of the patella tendon is common (17). The ACL is also commonly injured during posterior knee dislocations (Fig. 39.4).

Occult dislocation is a common clinical presentation and especially occurs with lateral, medial, and rotatory dislocations. These injuries are usually the result of valgus, varus, or rotatory torques, respectively (12). The incidence of lateral and medial dislocations is far less common. However, there is a higher incidence of concomitant fractures, and peroneal nerve injuries with medial and lateral knee dislocations, respectively (3,30).

Lateral knee dislocations are associated with potential for irreducibility. The irreducibility is caused by interposition of the medial capsule into the knee joint. The medial femoral condyle buttonholes through the medial capsule. The classic presentation is a patient with a grossly deformed knee and a "dimple sign" of the medial soft tissue structures. Direct surgical approaches to the invaginated tissues are preferred to facilitate open reduction.

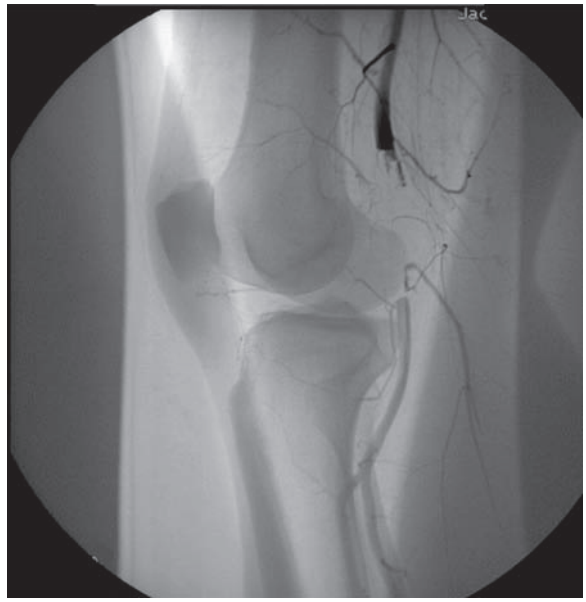

FIGURE 39.3

Arteriogram obtained intraoperatively demonstrates complete disruption of the popliteal artery.

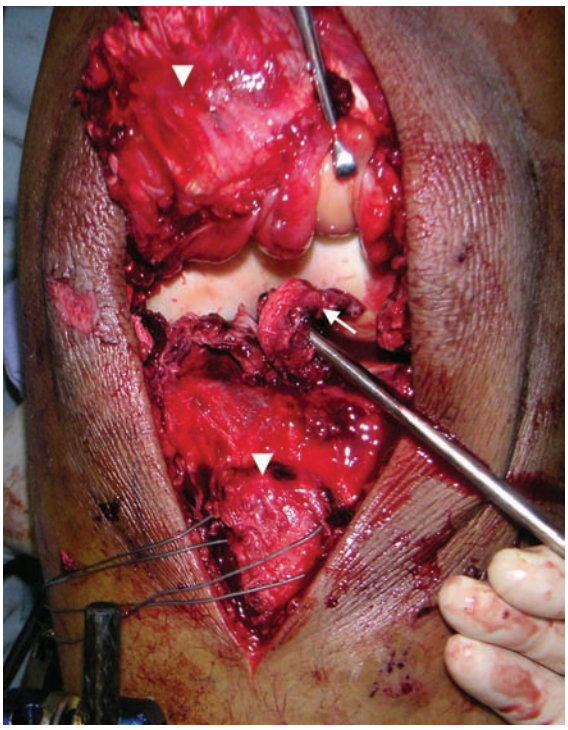

FIGURE 39.4

Intraoperative photograph of the same patient (Fig. 39.3) demonstrating complete disruption of the patella tendon from the tibial tubercle (*arrow heads*) and complete disruption of the ACL (*arrow*). The patella tendon was repaired with transosseous sutures in Krackow technique. The ACL was staged reconstructed.

MANAGEMENT

The initial management of knee dislocation is dependent on the clinical setting. Patients who present with a dislocated knee to the trauma center will be managed according to advanced trauma life support guidelines. The knee must be reduced in a timely fashion to prevent further injury to neurovascular structures and associated injuries to the soft tissue compartments. After stabilization of the patient in the trauma center or upon initial evaluation of a patient with occult knee dislocation in the office, it is recommended to follow a management algorithm.

1. The adequacy of reduction must be documented. Radiographs in two planes (anterior-posterior and lateral) should be obtained. In cases where closed reduction cannot be achieved, that is, lateral knee dislocation with interposition of soft tissues, open reduction should be performed emergently. If adequate reduction can be achieved but not maintained by noninvasive means, external fixation may be necessary to assist in maintaining the reduction of the knee. Surgical repair of damaged ligaments and tendons should be performed as soon as the patient's general condition will allow (ideally within 7–21 days).
2. Vascular examination. Perfusion of the distal extremity needs to be assessed carefully in every case of suspected knee dislocation. Physical examination includes hard signs of vascular injury, such as absent distal pulses, active bleeding, distal ischemia, expanding hematoma, and popliteal bruit or thrill. Presence of any of these findings denotes limb-threatening injury and mandate immediate exploration by a vascular surgeon (1,22). Arterial blood flow must be reestablished within 6 hours of the injury to prevent ischemic effects that would lead to amputation in the majority of cases. Patients with normal pedal pulses may be managed with observation and frequent monitoring by physical examination, ankle-brachial indices, or waveform assessment on Doppler evaluation. Arteriograms are obtained only when abnormal physical examination findings exist (20).

The incidence of popliteal artery injury is reported from 5% to 40% (11,16). Anterior dislocation usually results in a traction injury to the popliteal artery as the vessel stretches and is introduced into the intercondylar notch. This traction injury often results in intimal tears. In general, low-velocity injuries tend to be associated with fewer vascular injuries (27,29), whereas high-velocity injuries are reported to produce a greater incidence of vascular complications (35). Intimal flap tears are injuries to the endothelial lining of the arterial wall. They are often undetectable by physical examination and usually require an arteriogram for diagnosis. Potter et al. described popliteal fossa magnetic resonance angiography (MRA). In their series, a 100% correlation between MRA and arteriogram was found in six patients after knee dislocation (23).

3. Neurological examination. It is important to document any sign of peroneal nerve injury preoperatively. Peroneal nerve palsies have been noted to occur in 14% to 35% of knee dislocations (15). The most common occurrence is in posterolateral dislocations a result of traction injury as the nerve is stretched along the posterior aspect of the lateral femoral condyle (17,28). Recovery of function after peroneal palsy associated with knee dislocation has a guarded prognosis. The energy of this insult to the nerve usually results

in axonotmesis over a large segment of the nerve (35). Nerve grafting, rather than primary repair, is often required because of the long segment of injury.

4. Condition of the soft tissues. In open knee dislocations, surgical irrigation and debridement must be performed at the earliest opportunity. Healing of the soft tissue envelope is then monitored prior to attention to the ligament injuries. It is recommended to adhere to the same algorithm in cases of closed knee dislocation with severe blunt injury to the soft tissue envelope and skin. A high index of suspicion for compartment syndrome is important.
5. Physical examination. At this point, a thorough assessment of alignment, range of motion, extensor mechanism, and knee ligaments is performed. Because of pain, guarding, ipsilateral fractures, or altered mental status the physical examination may not be reliable. However, a knee that can only move from 10 to 45 degrees may still enable the surgeon to obtain useful information for preoperative planning. The integrity of the extensor mechanism can be assessed by a simple straight leg raise test. A minimal effusion in the face of a severe multiligamentous injury may give a clue to a capsule injury with extravasation. Compartments can be assessed. With a pillow under the knee, the Lachman test can be performed with reasonable sensitivity. The position of the anterior tibia with respect to the femur can be assessed at 45 to 60 degrees of flexion and reveal if there is normal (1 cm) anterior tibial step off or sag (Fig. 39.5). With the leg on the stretcher, a varus and valgus stress test can be performed to assess the integrity of the LCL and MCL, respectively. While

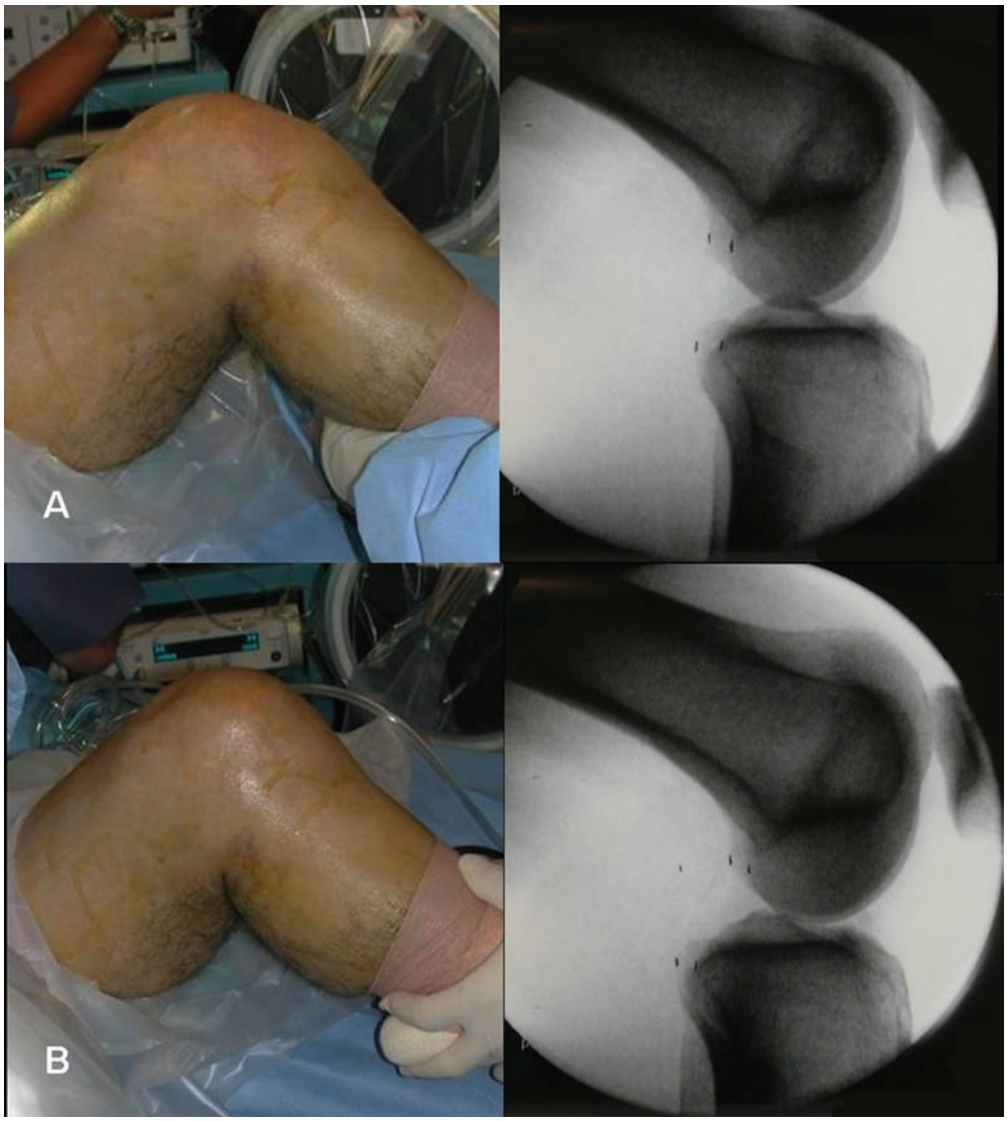

FIGURE 39.5

Assessment of posterior sag assisted by stress fluoroscopy. The tibia is held with an anteriorly directed force **(A).** The tibia falls posteriorly in a resting position, producing posterior sag that can be quantified on fluoroscopic images **(B).**

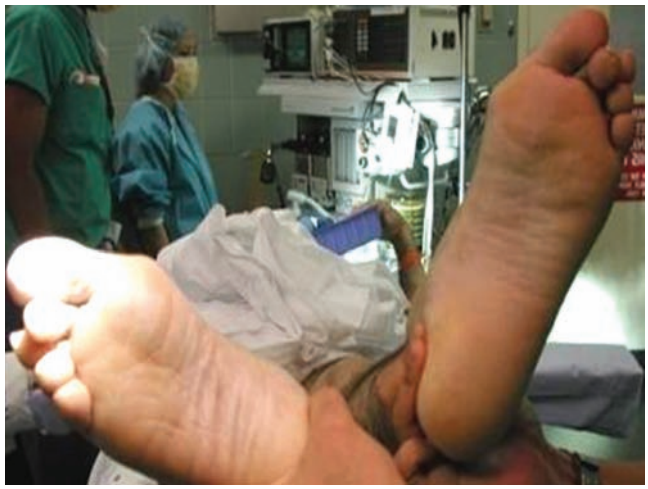

FIGURE 39.6

Assessment of posterolateral rotatory instability of the knee.

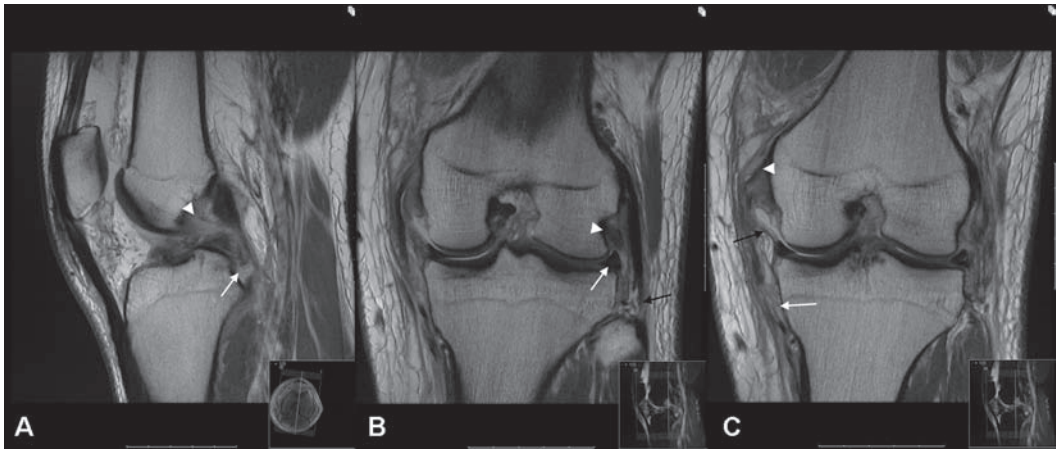

FIGURE 39.7

A: Sagittal fast spin echo MRI demonstrating complete tear of the ACL (*arrow head*) and partial tibial sided avulsion of the anterolateral bundle of the PCL (*arrow*). **B:** Coronal fast spin echo MRI demonstrating extrusion of the lateral meniscus (*arrow*), avulsion of the LCL off the fibula (*black arrow*), and intermediate signal in the popliteus tendon indicating interstitial injury (*arrow head*). **C:** Coronal fast spin echo MRI demonstrating complete tear of the tibial sided MCL (*arrow*), tear of the meniscofemoral ligament *(black arrow*), and partial tear of the MCL off the femoral insertion (*arrow head).*

the dial test at 90 degrees of flexion may not be possible, increased tibial external rotation at 30 degrees of flexion raises the suspicion for PLC injury (Fig. 39.6).

6. Magnetic resonance imaging (MRI). MRI is performed as the final step to classify the injury and formulate a preoperative plan. It enables complete soft tissue evaluation of ligaments, menisci, articular cartilage, occult fractures, capsule tears, and muscle tears (Fig. 39.7). Potter et al. showed that MRI is accurate in assessing soft tissue injuries and that there is excellent correlation of MRI with intraoperative findings (23). The findings from MRI are combined with findings from examination under anesthesia (EUA).

NONSURGICAL MANAGEMENT

In early series of uncomplicated knee dislocations "watchful neglect" was the preferred treatment (17,30). Nonsurgical management still has a role in the management of knee dislocations, particularly in patients after high-energy motor vehicle crashes with severe injuries to vital organ systems that require surgical attention with higher priority than extremity injuries. However, a recent meta-analysis of 132 retrospectively evaluated knee dislocations showed improved motion and Lysholm scores in the surgically treated patients. Early surgical management is currently recommended by the knee dislocation study group (20). Absolute indications for surgery include irreducible dislocations, dysvascular limbs, and open injuries. Relative indications include knee dislocations associated with fractures or avulsion injuries. Future efforts are directed toward collection of prospective data.

PREOPERATIVE CONSIDERATIONS

In approaching soft tissue reconstruction in a dislocated knee, the surgeon should consider options for repair and/or reconstruction of the main stabilizers of the knee, including the PCL, ACL, MCL, LCL, popliteus tendon, PFL, patella tendon, patella, and quadriceps tendon. Grafts choices include autografts from the injured side or contralateral leg and allografts. In particular for knee dislocation surgery, allografts have the advantage of no donor site morbidity, multiple graft size options, and less tourniquet time. Excellent clinical results have been demonstrated using allografts (6,14,20).

The use of a tourniquet is contraindicated in cases where vascular repair has been performed. Intraoperative fluoroscopy is helpful in the placement of tunnels for ligament reconstruction. Intraoperative radiographs should also be available to assess correction of posterior subluxation prior to final fixation of the grafts.

Arthroscopy

Arthroscopy is useful for the assessment of menisci, articular cartilage, and preparation of the intracondylar notch for ligament reconstruction. However, caution is advised in standard use of arthroscopy for multiligament cases, particularly in type C injuries. Capsular disruption may lead to extravasation of arthroscopy fluid into the surrounding soft tissue compartments and eventual compartment syndrome. The preferred approach is the use of a brief arthroscopic inspection with low-pressure flow and wrapping of the calf. A viable option is the use of dry or semiwet techniques, where intermittent fluid flushes aid in visualization. The surgeon should be prepared to perform the entire procedure in an open fashion.

External Fixation

External fixation is indicated preoperatively in open dislocations, dislocations with vascular repair, and reductions that cannot be adequately maintained in a splint. The advantage of external fixation in this setting is the ability to perform serial examination to assess the status of skin, wounds, compartments, and neurovascular structures. Khanna et al. reported on a staged protocol for 31 high-energy knee dislocations. Significantly improved motion was reported at 27 months when the initial stabilization was performed with a brace (129 degrees) versus external fixation (102 degrees). However, external fixation was the preferred treatment for more complex knee dislocations in their study (18).

Timing of surgery

There are no prospective randomized data available to support timing of surgery. However, three of the four retrospective comparative trials support better outcomes with early (<3 weeks) surgery (14,21,32). Harner et al. showed significantly better Knee Outcome Survey Sports Activity Scores in early surgery versus delayed surgery in 31 knee dislocations at 2 years (14). Fanelli et al. (7) showed no difference in 10 acute (<4 weeks) versus 11 delayed (>4 weeks) knee dislocations.

These studies are confounded by the fact that ligament reconstruction in patients with severe soft tissue injuries or concomitant injuries to vital organs may have been deferred for many weeks prior to definitive surgical treatment. It is generally accepted that early ligament reconstruction and repair, where appropriate, is the preferred algorithm for treatment of knee dislocations. Therefore, close collaboration with the trauma team is necessary to be able to proceed with ligament surgery in a timely fashion.

Surgical Technique

The position of the patient on the operating table is supine. The operating table should be adjustable for variable amounts of flexion at the hip and knee. The foot of the table should have the option of being dropped to allow for 90 degrees of knee flexion during the surgical procedure. The operating table should be radiolucent. The preferred anesthesia protocol consists of continuous lumbar epidural blockade. This will provide adjustable and long-lasting muscle relaxation and analgesia. Once appropriate anesthesia is established, a thorough EUA will be performed and correlated to the preoperative MRI as described above.

If not otherwise contraindicated, a high thigh tourniquet is placed. The operative extremity is prepped and draped in standard sterile fashion, and the foot is sealed off with adhesive plastic dressing. Arthroscopy is performed first with use of caution as described above. The use of tourniquet during arthroscopy can be avoided by adding 1 mg of epinephrine to each 3 L bag of arthroscopy fluid. After a standardized diagnostic arthroscopy, graft harvest is performed as indicated. The use of a sterile back table and a second assistant will allow for simultaneous graft preparation (Fig. 39.8). Arthroscopy is resumed after graft harvest to perform meniscal surgery if indicated and to prepare the intercondylar notch. All remnants of ruptured ligaments are removed if not adequate for repair. A notch plasty is performed to prevent future graft impingement. If not precluded by fluid extravasation, an accessory portal is established posteromedial for preparation of the tibial PCL tunnel (Fig. 39.9).

If there is marked fluid loss during arthroscopy, the medial repair may be performed prior to reconstruction of the cruciate ligaments to allow fluid containment during arthroscopy. For open ligament reconstruction, a

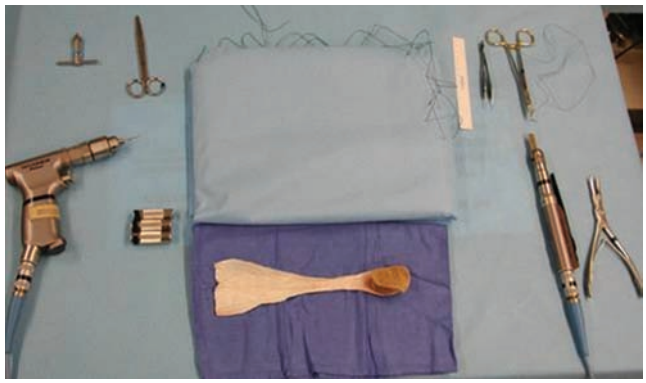

FIGURE 39.8
Sterile back table with instruments for preparation of an Achilles tendon allograft.

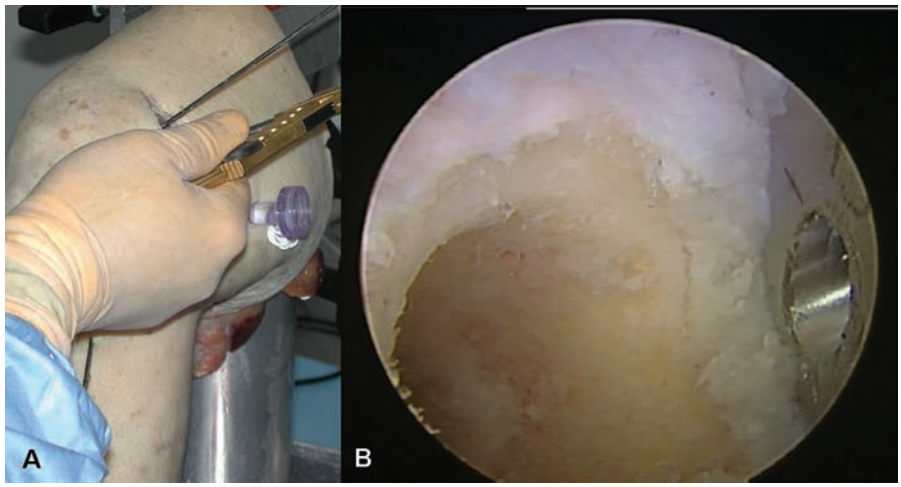

FIGURE 39.9
Plastic cannula in posteromedial (PM) portal in a right knee **(A).** View from PM portal with a 70-degree arthroscope showing the tibial tunnel and PCL tibial aimer **(B).**

long, oblique anterior skin incision is used in a proximal-lateral to distal-medial direction. With appropriate extension of the incision and elevation of skin flaps, this type of incision allows access to all aspects of the knee.

Ligament Reconstruction

The following principles should be followed for a systematic approach to multiple-ligament reconstruction:

1. The sequence of reconstruction should be PCL, ACL, PLC, LCL, MCL, and others (e.g., extensor mechanism, iliotibial band (ITB), biceps tendon)
2. Avulsion injuries to ligaments are treated with primary repair and augmentation as necessary
3. Cruciate ligament reconstruction is facilitated by the use of allografts. Achilles tendon allografts can be used for both PCL reconstruction and ACL reconstruction.
4. Midsubstance ruptures of PCL and ACL are treated with allograft or allograft reconstruction.
5. For bicruciate reconstructions, all required bone tunnels are established prior to passing of grafts to avoid injury.
6. Midsubstance ruptures of other ligaments are treated with primary repair and augmentation.
7. If allografts are unavailable in a bicruciate setting, the PCL is reconstructed with a BTB graft and the ACL is reconstructed with a hamstring graft.
8. Popliteus tendon and PFL injuries are treated acutely with primary repair and augmentation using a strip of ITB. Chronic injuries are treated with reconstruction using allograft (semitendinosus or tibialis anterior) for a fibula-based reconstruction.
9. LCL injury is treated by primary repair and/or augmentation with a strip of biceps tendon. Soft tissue allograft reconstruction can be used as well.
10. MCL injury is treated with primary repair, advancement of posterior tissues (if appropriate), and/or hamstring-augmentation (Bosworth).

Bicruciate Reconstruction

Fluoroscopy assistance is recommended for preparation of the tibial tunnels. This aids in safe and accurate placement of the guide wire into the posterior tibial footprint of the PCL without injury to the popliteal vessels (Fig. 39.10). The entry site for the tibial PCL tunnel on the anterior tibia is distal to the entry site of the tibial ACL tunnel. The tunnel exit of the tibial PCL tunnel should lie in the center of the posterior facet of the PCL insertion. The guide wire should exit 8 to 10 mm below the level of the joint line to insure proper tibial tunnel placement. A proper tibial tunnel will be parallel to the proximal tibiofibular joint and courses just proximal and parallel to the posterior curve of the proximal tibial cortex (Fig. 39.10, Table 39.1).

Arthroscopic tibial tunnel creation is best accomplished by using a posteromedial portal and a 70-degree lens. The posteromedial portal is located just posterior to the MCL, between zones A and B of the medial meniscus. The 30-degree arthroscope can be placed through the Gilchrist view or the posteromedial portal to view the posterior tibial ledge. Preparation of the tibial footprint is accomplished by working through the anterolateral portal or the posteromedial portal (Table 39.2).

The femoral PCL insertion is located anterior and proximal on the medial wall of the intercondylar notch. For a single-bundle reconstruction, the insertion of the anterolateral bundle is chosen at approximately the 11 o'clock position (Fig. 39.11). The femoral drill guide is positioned in an outside-in fashion. The entry site for the guide wire is on the anteromedial femoral cortex. The vastus medialis muscle is elevated and the guide wire is advanced to exit in the intercondylar notch. The tunnel is established by reaming over the guide wire with an appropriate-sized reamer.

At our institution, we prefer a transtibial double-bundle PCL reconstruction to better restore normal knee kinematics (13). The technique includes one tibial tunnel and two femoral tunnels to recreate both the anterolateral (taut in flexion) and the posteromedial (taut in extension) bundles. An Achilles tendon allograft is the preferred graft. It is split in its tendinous portion to create the two bundles for the femoral attachment sites (Table 39.3).

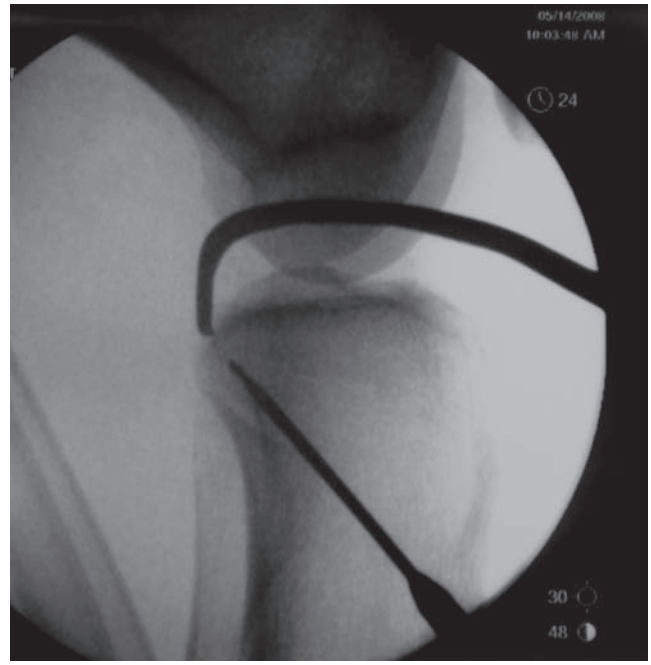

FIGURE 39.10
Fluoroscopic image of guide pin in tibial tunnel for PCL reconstruction.

TABLE 39.1 Pearls for Tibial PCL Tunnel Creation

1. Set length of guidewire, from tip to drill chuck, such that further advancement of the guidewire beyond the inner table of the posterior tibial cortex is prevented by the drill chuck hitting the PCL-drill guide
2. Advance the guidewire under fluoroscopic control. Use a mallet once the posterior cortex is reached
3. Penetrate the posterior cortex slowly under direct visualization from a posteromedial portal and fluoroscopic control
4. Prevent inadvertent advancement of the guidewire by use of an arthroscopic grasper or clamp
5. Set length of reamer as described in 1. Drill over guidewire under fluoroscopic control
6. Chamfer the edges of the tibial tunnel with a rasp

TABLE 39.2 Pearls for PCL Graft Preparation/Graft Passage

1. Graft of choice is BTB
2. Graft passage is transtibial
3. BTB: length of lead bone plug ≤20 mm to facilitate graft passage around posterior tibial corner
4. BTB: length of trailing bone plug ≥30–40 mm to facilitate interference screw fixation in tibial tunnel
5. BTB autograft: short bone plug is fashioned from patella
6. Transtibial graft passage is facilitated by use of an instrument, such as a probe or elevator, to manipulate the graft as it turns the posterior corner of the tibia. This will help prevent graft fracture
7. Achilles tendon allograft: can be used alternatively. The free tendon end is passed first and the bone plug is fixed in tibial tunnel. Graft fixation on femoral side with AO screw and washer

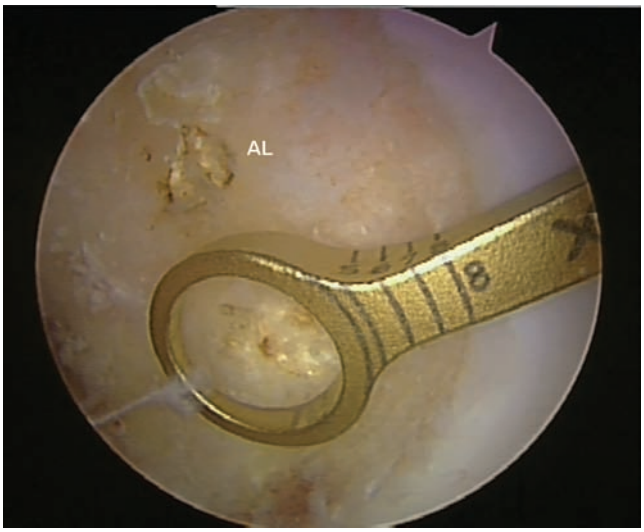

FIGURE 39.11
Arthroscopic view from anterolateral (AL) portal with a 30-degree arthroscope showing the femoral AL and PM (PCL femoral aimer) footprints on medial femoral condyle, marked with electrocautery.

TABLE 39.3 Pearls for Double Bundle PCL Reconstruction

1. Achilles tendon allograft bone plug thickness: 12 mm
2. Split tendinous portion into 10 mm (AL) and 6 mm (PM) limbs
3. Arthroscopic resection of PCL stump on femur
4. Posteromedial portal is used for notch plasty
5. Femoral drill guide is used in outside-in fashion
6. Placement of 2 guide pins a minimum of 12 mm apart at the exit in notch (creation of a minimum 4 mm bridge between the 10 and 6 mm tunnel)
7. Anterolateral pin is placed first; femoral drill guide is placed in the center of the anterolateral PCL attachment at the wall-roof junction
8. Placement of a pin guide for the second pin to allow a position 12 mm away
9. Direction of the second pin proximal and posterior to the first pin
10. Reaming of a 10 mm and a 6 mm tunnel over the guide pins
11. Débridement and smoothening of tunnel exits to facilitate graft passage
12. Required graft length is measured with a Mersilene tape passed through the tunnels outside-in; Burnell stitches are placed into the tendinous ends of the graft using 5 Ethibond (Ethicon, Inc., Somerville, New Jersey)

After the PCL tunnels have been established, attention is focused on creation of the tunnels required for ACL reconstruction. The tibial ACL tunnel is created using an ACL drill guide set at 45 degrees. The guide tip is placed slightly anterior to the center of the tibial ACL footprint, which is located in line with the anterior horn of the lateral meniscus and on a virtual line splitting the distance between the medial and the lateral tibial spines. The femoral ACL tunnel is created from the anteromedial portal. The center of the femoral ACL footprint is located approximately at the 8:30 o'clock position (or 2:30 o'clock for a left knee) and 5 mm anterior to the posterior wall of the notch (Fig. 39.12).

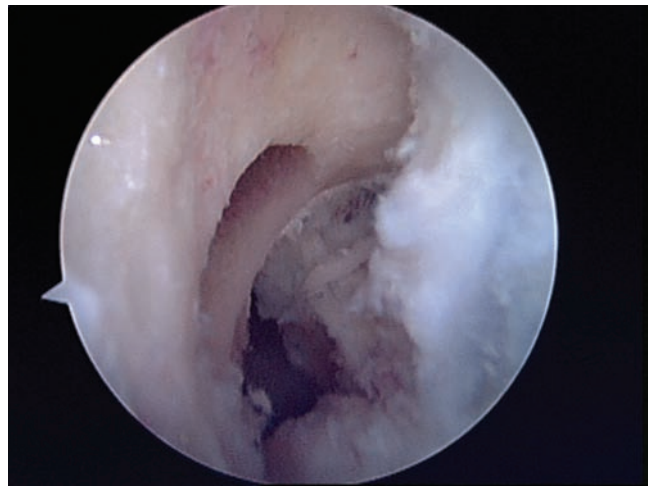

FIGURE 39.12

Arthroscopic view from anterolateral (AL) portal with a 30-degree arthroscope showing ACL femoral tunnel at 10:30 o'clock position. Note: The femoral tunnel can also be moved toward the 8:30 o'clock position (not shown).

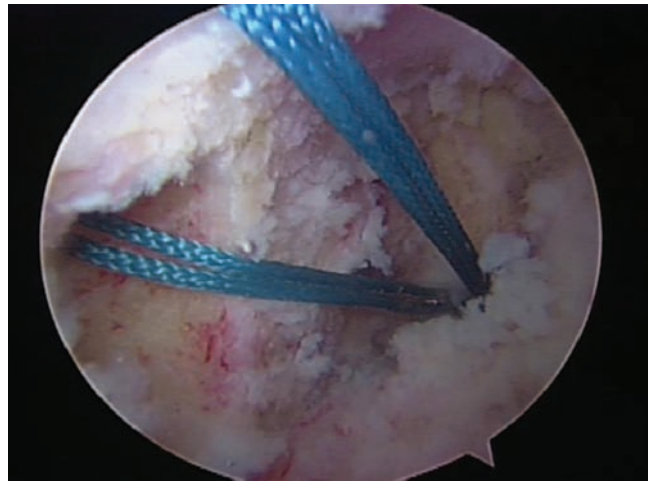

FIGURE 39.13

PCL draw sutures for double-bundle PCL reconstruction.

Once all tunnels are established, the PCL graft is passed first, followed by the ACL graft. The same order is followed for the tensioning protocol. A 22-gauge wire, fashioned with a loop, is inserted from outside-in into the tibial PCL tunnel. The leading edge is grasped through the anterolateral portal with a grasper and brought to the exit of the femoral PCL tunnel. A second grasper is passed from outside-in, through the femoral PCL tunnel, and into the notch. The leading edge is brought out the femoral tunnel. A second wire is looped through the leading edge of the first wire and brought back out the tibial PCL tunnel. The PCL draw sutures are then passed through the leading edge of the second wire and pulled up into the tibial tunnel, through the notch and out the femoral PCL tunnel (Fig. 39.13).

A beath pin is used to draw the ACL graft from the anteromedial portal into the femoral tunnel. A grasper is used in the tibial tunnel to pull the draw stitch from the femoral tunnel out the tibial tunnel. Pull on the draw sutures will allow for passage of the graft until the desired depth in the femoral tunnel is reached.

The PCL graft is tensioned first. If a single-bundle technique is used, the PCL is tensioned at 70 degrees of knee flexion. If a double-bundle technique is used, the anterolateral bundle is tensioned first at 90 degrees of knee flexion, followed by tensioning of the posteromedial bundle at full extension. Fixation on the femoral side is achieved with an interference screw. The knee must be reduced prior to tibial fixation. A manual anterior drawer is applied to recreate the anterior tibial step off of approximately 1 cm. An interference screw is used on the tibial side while applying axial tension on the draw sutures. Additional fixation can be provided with an AO screw and washer, staple, or soft tissue button, if indicated. The ACL graft is then tensioned in full extension with axial tension on the draw sutures and reduction of the knee. Fixation is achieved with interference screws.

Lateral Structures

The incision for PLC surgery is a hockey stick incision that starts 5 cm proximal and posterior to the lateral epicondyle and ends 5 cm distal to Gerdy tubercle just anterior to the fibular head (Fig. 39.14). Three fascial

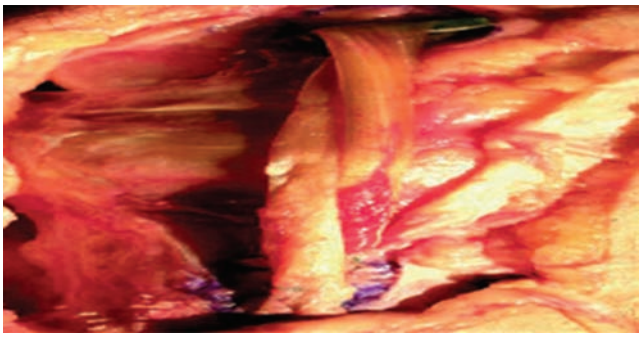

FIGURE 39.14
Exposure of the lateral sided knee for PLC surgery. Note: Forceps under LCL.

incisions are performed as described by Terry and LaPrade (31). The peroneal nerve is exposed and protected from inadvertent injury or traction during ligament surgery. In cases with compromise of the nerve, for example, intraneural hematoma, the epineurium is opened and hematoma is evacuated.

The LCL, popliteus tendon, and PFL are routinely injured in knee dislocations. The LCL is injured proximally in two thirds of the cases and distally in one third of the cases; the popliteus tendon is injured in two thirds of the cases from its proximal insertion and in one third of the cases at the muscle-tendon junction. Injury to the PFL occurs almost always (23). Primary repair can be performed in cases of bony avulsion and when there are adequate tissue remnants of the torn ligaments.

The popliteus tendon is reconstructed first. In some cases, the tendon substance is adequate for repair and can be reattached to its femoral insertion or advanced if attenuated. Another common injury complex is a tear of the popliteus at the muscle-tendon junction concomitantly with destruction of the PFL. In these cases, tenodesis of the popliteus tendon to the posterolateal corner of the tibia or posterior fibular head, at the insertion of the PFL, is performed. For the tenodesis to work, it is important that the proximal part of the popliteus tendon at the femoral insertion is free of injury. The insertion on the fibula head is on the posteriorly sloped surface 8 to 10 mm posterior and 3 to 5 mm medial to the insertion of the LCL and biceps tendon. The reconstruction is carried out by detaching the popliteus tendon from its muscular junction, controlling it with 2 Ethibond (Ethicon, Inc., Somerville, New Jersey), and attaching it through a K-wire tunnel over a suture button on the fibula. Tension is set at 70 degrees of knee flexion while the lateral tibia is drawn anteriorly to its neutral position. If the popliteus tendon is attenuated, it should be augmented with a thin strip of ITB left attached on Gerdy tubercle. This is placed in a drill hole from anterior to posterior on the tibia and routed along the popliteus tendon.

For fibula-based reconstructions, a soft tissue graft (hamstring autograft or tibialis anterior allograft) can be used for combined reconstruction of the popliteus and PFL. First, the fibula tunnel is established at the insertion of the PFL. A posterior retractor protects the common peroneal nerve. The fibula tunnel is reamed over a guide wire (6–7 mm) from anterior to posterior. The femoral insertion of the popliteus tendon is identified approximately 18 mm away from the LCL insertion, anterior and inferior. The femoral tunnel is reamed over a guide wire to 30 mm depth. The graft is passed through the fibula and both limbs are brought up toward the femoral tunnel. The graft is shortened, taking care not to exceed 25 mm of graft length in the tunnel. Both limbs are passed into the femoral tunnel by pulling on the draw sutures medially. Fixation is achieved at 30 degrees of knee flexion in internal rotation and valgus by a soft tissue interference screw in the femoral tunnel (Fig. 39.15) (34).

LCL surgery can be performed principally in three different ways: primary repair, partial reconstruction using biceps tendon, or combined fibula-based PLC reconstruction. The preferred treatment for acute (within 21 days) LCL avulsion from the femur is by primary repair. The LCL is reattached through a shallow bone

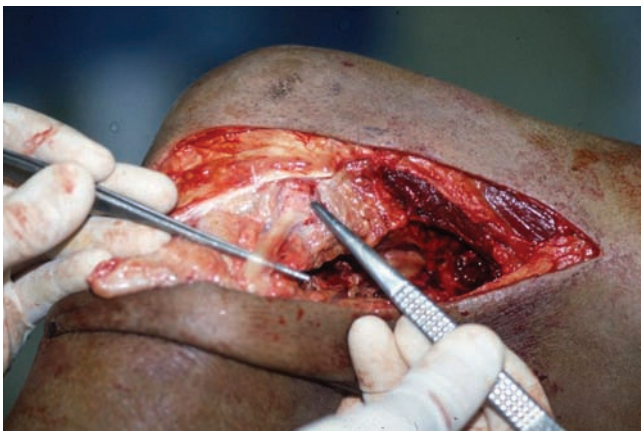

FIGURE 39.15
Fibula-based PLC reconstruction with semitendinosus allograft in docking technique as described by Verma et al. (34).

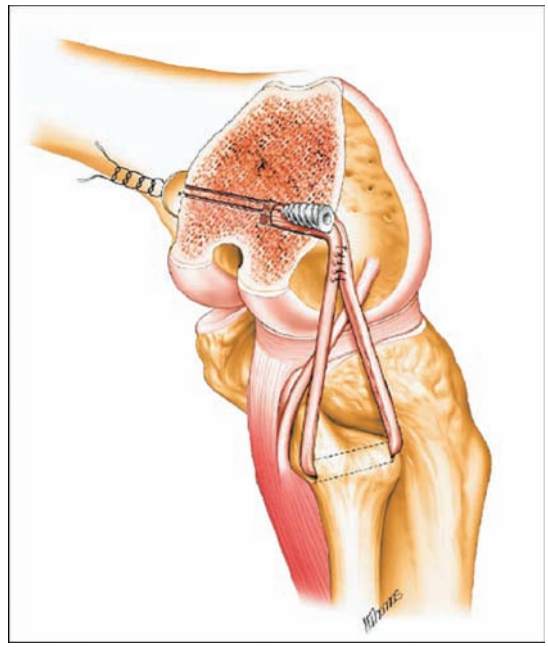

FIGURE 39.16

Technique for LCL reconstruction using biceps tendon as described by Veltri and Warren (33).

tunnel at the insertion site on the lateral epicondyle and secured over a suture button on the medial femoral condyle. The LCL insertion on the femur is chosen by principles of isometry. A guide wire is placed 25 mm proximal to the joint line in the lateral femur. With the knee at 30 degrees of flexion, ligament excursion is judged and the guide wire placement is adjusted to the point of lowest ligament excursion. A 5- to 10-mm shallow bone tunnel is established with a 6-mm reamer at the predetermined site. A beath pin driven through the tunnel and out the medial femoral condyle. Using draw sutures on the free end of the ligament, the LCL is drawn into the bone tunnel and secured medially over a suture button.

If direct LCL repair is impossible, the biceps tendon can be used as a graft. A 20 × 80 mm strip of biceps tendon is elevated from underlying muscle with a No. 15 blade and left intact at its insertion on the fibula head. The biceps strip is tubularized by rolling one half to the midline and rolling the other half around it. Several simple stitches are passed through the tubularized tendon strip. The tendon strip is fixed at the LCL insertion on the femur with a screw and washer (Fig. 39.16) (33).

At the completion of PLC reconstruction, it is recommended to release the anterior and lateral compartments to decrease the chances of compartment syndrome. Surgical dressings are applied loosely to avoid neurovascular compromise; the leg is placed in a hinged knee brace locked in extension and slightly elevated. Patients are observed during the first 48 hours for neurovascular checks, hematoma formation, drainage, and intravenous antibiotics.

MEDIAL STRUCTURES

In cases of combined cruciate and medial reconstruction, it is recommended to reconstruct the cruciate ligaments first to recreate a functional central pivot. The central pivot is necessary for accurate determination of isometry of planned reconstructions. A thorough assessment of the injuries to the medial side is completed. If the tibial MCL has been avulsed (rare) reattachment can be performed, after debridement of the distal insertion, with a screw and washer or staple. In approximately 80% of the cases, the MCL injury occurred at the femoral insertion (23). Repair is complicated by usually poor tissue quality of the proximal ligament stump. However, if the posterior MCL, posterior oblique ligament (POL), and posteromedial capsule appear to be of good quality, a repair can be performed. The posterior capsuloligamentous tissues are advanced anteriorly and reefed, and the MCL stump is secured to the femoral insertion with suture anchors.

In knee dislocations, the MCL, POL, and posterior capsule are usually complete severed and reconstruction with a ligament graft becomes necessary. Options include anatomic reconstruction with a tendon graft (hamstring or Achilles allograft) and augmentation with a semitendinosus tendon as described by Bosworth (2). The semitendinosus tendon is left attached at the pes anserinus on the tibia and dissected free proximally. Isometry is determined by placing a guide wire in the medial femoral epicondyle and assessing excursion of the semitendinosus tendon over the guide wire. Once minimal excursion is determined, the tendon is advanced to the predetermined center of rotation of the MCL on the femur. Fixation is provided by a screw and washer at 30 degrees of knee flexion and varus stress. MCL remnants on the tibia are secured to the semitendinosus tendon.

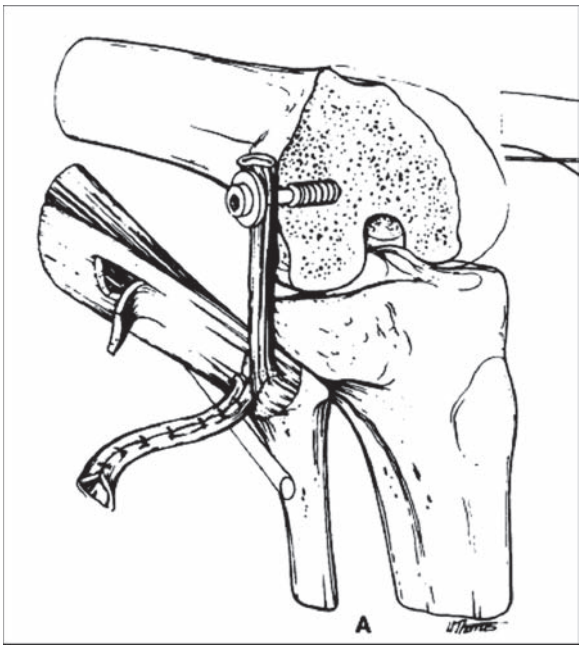

FIGURE 39.17

Double-bundle MCL reconstruction with staple in femoral origin of MCL (cadaveric left knee). (From Feeley BT, Muller MS, Allen AA, et al. Biomechanical comparison of medial collateral ligament reconstructions using computer-assisted navigation. *Am J Sports Med.* 2009.)

TABLE 39.4 Pearls for Double Bundle MCL Reconstruction

1. Graft: semitendinosus autograft, 7 mm, one fee end with Burnell stitches
2. Points of fixation: 3
3. Hardware: staple (1), interference screw (2)
4. Secure short limb at proximal insertion of MCL on tibia
5. Prepare femoral origin at medial femoral condyle for staple insertion
6. Secure graft at femoral origin with staple at 30 degrees of flexion
7. Create 7 mm tunnel at distal insertion of MCL on tibia
8. Pull free end of graft ≥ 20 mm into tibial tunnel and secure with interference screw at 30 degrees of flexion

We prefer an anatomic double-bundle MCL reconstruction over nonanatomic semitendinosus tenodesis to recreate the two separate anatomical insertions of the MCL on the tibia (Table 39.4) (9). A semitendinous graft is utilized and fixed with a staple or interference screw on the femur and two interference screws on the tibia (Fig. 39.17). The graft is tensioned at 30 degrees of knee flexion with axial load on the draw sutures with the knee held in varus and internal rotation. The remnant of the native MCL, if present, is reefed over the graft, thus repairing the posteromedial corner of the knee.

POSTOPERATIVE MANAGEMENT

Bracing and early motion are the hallmarks of the postoperative rehabilitation protocol. Patients who underwent multiple-ligament reconstruction should be treated slower than isolated ligament reconstructions and progressed on an individual basis.

The immediate postoperative management should be observed on an inpatient basis. Neurovascular checks, management of wound and soft tissues are prioritized. If possible, early continuous passive motion is begun at 0 to 30 degrees until a 0 to 70 degrees motion arc is comfortably maintained. Cold therapy is important.

Week 1 to 3: ambulation is allowed with crutches and nonweight bearing. No physical therapy.

Week 3 to 6: progression to partial weight bearing with the brace locked in extension.

Week 6 to 12: gradually discarding of crutches. Unlocking of brace from 0 to 30 degrees, gradual increasing motion arc, and supervised gait training. Range of motion therapy is begun more aggressively. Open kinetic chain active isolated quadriceps and hamstring exercises are avoided. Closed-kinetic chain exercises, such as leg press, half squats, and stair exercises are started. Stationary bicycle exercises are begun.

Week 12 to 16: full range of motion should be established. Closed-kinetic chain exercises are continued. Elliptical trainer exercises are begun.

Week 16 to 24: increasing resistance, proprioceptive, and agility training are added to the protocol. Return to full activity is not recommended before 9 to 12 months.

CLINICAL OUTCOME

Knee dislocations represent severe soft tissue injuries that make return of normal function challenging. The two most common etiologies for knee dislocation are motor vehicle collision, which usually present as a high-level trauma with associated injuries, and sports injuries, which can present as an occult knee dislocation. Clinical outcome is generally better for sports injuries, owing to the lower velocity of the injury (24). However, the initial management must not deviate, since both types of dislocations have been shown to have high association with neurovascular injury (36).

The most common complication following surgical treatment of knee dislocations is loss of motion. Early range of motion is important, as stated above, and manipulation under anesthesia is recommended if 90 degrees of motion are not achieved by 8 to 10 weeks postoperatively. Other common postsurgical complications include failure of the ligament reconstruction and posttraumatic osteoarthritis (26).

Activities of daily living can be more predictably achieved than high-demand sports activity or heavy manual labor, as shown by a recent study by Harner et al. (14). Patients who are treated acutely (<2–3 weeks) achieve better clinical outcomes than patients who were treated chronically (14,21).

CONCLUSION

The management of knee dislocations requires a team approach, including the trauma surgeon, the interventional radiologist, the musculoskeletal radiologist, the orthopaedic surgeon, and the physical therapist. It is the responsibility of the treating orthopaedic surgeon to have a systematic management approach in place that consists of emergent reduction and stabilization of the joint, neurovascular assessment (with arteriography if indicated), physical examination, MRI, and EUA. Careful formulation of a preoperative treatment plan and surgical technique of repair versus reconstruction is critical for optimal clinical outcome.

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40 Scope and Cartilage: Débridement and Microfracture

Andrew S. Greenberg, Nicholas A. Sgaglione, and Adam S. Levin

INTRODUCTION

Achieving a predictable and durable repair after an articular cartilage injury has remained a clinical challenge. Over the past decade, advancements in arthroscopy and magnetic resonance imaging (MRI) have led to an increase in the acute recognition of articular cartilage injuries. Several investigators have reported on the incidence of such lesions. Curl et al. (12) retrospectively reviewed 31,516 knee arthroscopies and reported lesions in 63% of patients. Similarly, Aroen et al. (2) published a survey of 993 consecutive knee arthroscopies, which revealed articular cartilage pathology in 66%, with a localized full-thickness lesion in 11%. Hjelle et al. (20) reported chondral or osteochondral lesions in 61% of 1,000 knee arthroscopies, 5% of which were full thickness.

Articular cartilage defects can result in pain, swelling, clicking, instability, and ultimately, progression to a more diffuse, degenerative process (10,37). Current surgical options include arthroscopic débridement and lavage using mechanical shavers or radiofrequency (RF) devices, arthroscopic marrow stimulation and microfracture techniques, osteochondral autograft transplantation (OAT) or allograft transplantation, and cell-based therapies, such as autologous chondrocyte implantation (ACI). More recently, second-generation methods to augment and improve upon the ACI procedure using three-dimensional scaffolds have been described.

The response of articular cartilage to injury, and thus healing, depends upon the type, location, and mechanism of the injury. Due to the avascular nature of cartilage, superficial injuries fail to stimulate a predictable healing response (10,35). However, full-thickness injuries that penetrate subchondral bone have vascular access and, consequently, have a greater capacity for healing. The repair tissue has the structure, histology, and biomechanical properties of a fibrocartilagenous mosaic. Despite the altered biomechanics and potentially inferior long-term durability, most patients report symptomatic and functional improvement (15,30,35,52).

Current articular cartilage biological resurfacing procedures can be characterized as either primary or secondary. Primary procedures can be carried out as a first-line treatment, usually arthroscopically, and include débridement, fixation techniques, marrow stimulation techniques, and OAT procedures. Secondary procedures are those that attempt to restore or replace hyaline cartilage in larger lesions or in those cases that fail primary treatment and must therefore be revised. These procedures include osteochondral allograft transplantation and ACI. This chapter focuses on the surgical techniques of two primary treatment methods: débridement and microfracture.

PREOPERATIVE PLANNING

A thorough history should be taken with any patient presenting with a possible articular cartilage injury and clinically correlative symptoms. Treatment indications optimally include those patients with defined symptoms and whose potential confounding pathology can be precisely characterized. Historically, clinical results for both débridement and microfracture vary depending on the type of chondral injury (degenerative vs. acute), as well as the age, body mass index (BMI), surgical history, and activity level of the patient. Thus, the timing, symptoms, mechanism of injury, occupation, and activity level of the patient should be appreciated. In an effort to distinguish traumatic or focal lesions from degenerative lesions associated with osteoarthritis, the type, timing, and location of symptoms as they relate to the injury must be defined, with distinction between focal mechanical symptoms from those that are more diffuse and general. Traumatic chondral and osteochondral lesions commonly present acutely with a hemarthrosis, pain, and often, mechanical symptoms suggestive of a loose body, while a subset of patients will describe a more chronic clinical scenario. The chronic patients will commonly present with progressive pain that is exacerbated with use and frequently demonstrate an effusion. A complete exam should follow, specific for the affected joint, and assessed relative to the unaffected limb. General appearance and focal tenderness to palpation should be noted, as well as an evaluation of ligamentous laxity. Range of motion should be measured in addition to the presence of crepitus. Furthermore, the mechanical and anatomical axis, as well as gait analysis should be assessed and measured.

Plain radiography should always be obtained including weight-bearing radiographs of the affected limb, as well as a standing hip to ankle radiographs. Additional views, such as a patellar skyline, notch or tunnel views, and 45-degree flexion weight-bearing posteroanterior views are helpful. MRI offers the ability to evaluate for coexistent meniscal or ligamentous injuries. Modern advancements in MRI technique have aided in both the early diagnosis and the subsequent treatment of osteochondral defects. With the use of cartilage-specific MRI and, more specifically, modified fast spin-echo sequence techniques, Potter et al. have demonstrated great precision in MRI detection of cartilage lesion size and depth. Newer, more specific cartilage-sensitive pulse sequences, in addition to fat suppression techniques, can better evaluate subchondral bone, thus distinguishing an osteochondral defect from an isolated shear injury, as well as better defining an acute, isolated osteochondral defect, from a more degenerative lesion. Furthermore, the use of three-dimensional pulse sequences and the addition of isotropic voxels allow a more precise measurement of lesion size, cartilage volume, and postoperative tissue fill (46,47).

Traditional grading systems for articular cartilage lesions are commonly based upon the surgeon's intraoperative visual assessment of the lesion. Classification systems include those described by Outerbridge (44), Insall (22), Bauer and Jackson (5), and Noyes Stabler (43). A more specific grading system was formulated in 2000 by the International Cartilage Repair Society (ICRS) in order to facilitate accurate mapping and description of cartilage lesions and osteochondral defects (8) (Table 40.1).

In those patients who remain symptomatic after a trial of nonoperative treatment, surgical intervention may be considered. The criteria used to indicate a patient for any chondral resurfacing procedure are multifactorial. Patient compliance is an important factor, as the success of many of these procedures is dependent upon the adherence to a strict physical therapy protocol. Patients who are unable to reliably follow postoperative weight

TABLE 40.1 Modified Outerbridge Classification versus ICRS[a] Classification System

	Modified Outerbridge (22)	ICRS[a] (8)
Grade 0	Normal	Normal
Grade I	Softening and swelling	Nearly normal: Soft indentation and/or superficial fissures and cracks
Grade II	Partial-thickness defect: Fissuring within softened areas	Abnormal: Lesion extending to < 50% of cartilage depth
Grade III	Full-thickness defect: Breakdown of the surface: Fibrillation	Severely abnormal: Lesion extending to A. > 50% of cartilage depth B. calcified layer C. to subchondral bone D. Includes blisters
Grade IV	Complete loss of cartilage Erosive changes and exposure of subchondral bone	Severely abnormal: Lesion extending through subchondral bone

[a] International Cartilage Repair Society

Source: Brittberg M. ICRS clinical cartilage injury evaluation system-2000. Third ICRS Meeting, 2000; April 28, 2000; Insall J. Patellar pain. *J Bone Joint Surg.* 1982;64A(1):147–152.

bearing and physical therapy orders are not candidates for chondral surgery. The age and preinjury activity level of the patient must also be considered, and patient expectations and goals should be addressed and discussed. Patients should be counseled as to the potential benefit and risks of the proposed procedure, as well as to the fact that, although often successful in providing pain relief and resumption of activities, no procedure can reliably reproduce the preinjury articular surface and uniform clinical success.

DÉBRIDEMENT

Indications/Contraindications

Surgical débridement for articular cartilage lesions dates back to the early 1940s. The technique of cartilage débridement was initially utilized to address the pain and mechanical symptoms secondary to osteoarthritis (34). With the advent of arthroscopy and evolution of minimally invasive surgery, arthroscopic débridement became popular as a technically easy and efficient method to treat articular cartilage lesions and arthritic knees. Using high-speed arthroscopic rotary shavers, handheld basket punches, arthroscopic curettes, and RF ablative devices, the procedure consists primarily of the removal of incongruent, unstable cartilaginous flaps, the shaving of fibrillated tissue, the removal of all loose bodies, and the resection of any unstable meniscal tears.

The use of RF devices has been described as an alternative to the mechanical shaving of chondral lesions. Studies have shown that mechanical débridement may result in perimeter irregularities and incomplete resection, which often lead to the damage or removal of healthy articular cartilage, while arthroscopic RF ablation produces smooth edges. However, clinical and basic science studies determining superiority of one débridement method versus the other have been inconclusive. Turner et al. conducted an in vivo study comparing the effects of a bipolar RF probe and a mechanical shaver on roughened articular cartilage in ovine knees. Those in the bipolar-treated group graded better with respect to histologic appearance and showed no evidence of subchondral necrosis (59). Similarly, in an explant study of human arthritic cartilage, the authors reported that RF devices create a smooth articular surface with no histologic alterations (27). Amiel et al. (3) further assessed the viability of chondrocytes ex vivo after treatment with RF and concluded that there was a relatively insignificant margin of chondrocyte death (100 to 200 μm), which did not approach the subchondral bone in any sample. However, in contrast, other studies have shown large margins of chondrocyte death. Lu et al. (33) reported up to 1mm of cell death in bovine cartilage treated with RF, using confocal laser microscopy, suggesting that previous histologic evaluations underestimated the depth of cell death. Similarly, an experiment on explanted human cartilage resulted in chondrocyte death extending to subchondral bone (13).

Several clinical studies have compared mechanical shaving to RF débridement. Owens et al. showed superior results with RF treatment of grades 2 and 3 chondral lesions compared with mechanical shaving (45). More recently, Barber et al. reported no subchondral bone damage or avascular necrosis, and significant clinical improvement in both groups when comparing the effects of monopolar RF and mechanical chondroplasty techniques on grade 3 femoral condyle lesions (4). While RF devices may have a role as an alternative method for chondroplasty, their superiority over mechanical shaving has yet to result in widespread acceptance, and clinical outcome comparisons have, thus far, been limited.

For appropriately indicated patients, arthroscopic débridement has been shown to produce early satisfactory outcomes in 50% to 90% of patients (1,21,24). Hubbard studied débridement versus lavage in 76 patients with a focal, degenerative grade 3 or 4 femoral condyle lesion, with no concomitant intra-articular pathology, joint deformity, or abnormal radiographs. He reported pain relief in 80% and 65% of patients in the débridement group at 1 and 5 years, respectively, compared with 20% and 11% for those patients who only received an arthroscopic lavage (21). Other satisfactory results have been seen in patients with symptoms <1 year, a specific history of trauma, and a low BMI (25).

In an effort to further establish and refine the indications for arthroscopic débridement and lavage for osteoarthritis, Aaron et al. noted that 90% of knees with mild arthritis experienced symptomatic relief, while only 25% with severe arthritis improved (1). Jackson and Dieterich (24) found, in a 4 to 6 year retrospective case series of 121 patients treated with arthroscopic débridement, more successful results in patients with earlier stages of arthritis. In a retrospective review of 204 knees with osteoarthritis, Harwin (19) reported on predictors of patient satisfaction following arthroscopic débridement and noted that those knees with minimal malalignment, no prior surgeries, and a low BMI had better results.

Despite the conclusions of these earlier nonrandomized, noncontrolled case series, recent investigators have found no benefit to arthroscopic joint débridement for arthritis without specific mechanical symptoms. In 2002, Moseley et al. performed a level 1 randomized controlled trial of 180 patients with osteoarthritis who failed medical management, comparing arthroscopic débridement, lavage alone, and placebo "sham" surgery. The results were similar in all three groups, with no surgical benefit proven (42). More recently, Kirkley et al. conducted a level 1 randomized controlled study of 188 patients treated with either arthroscopic débridement and lavage or physical therapy and medical management. Again, no significant improvement was realized in the surgical group (28).

In order to better define the indications for arthroscopic débridement of the symptomatic osteoarthritic knee, the American Academy of Orthopaedic Surgery convened a multidisciplinary expert panel to review the

body of literature and, as of December of 2008, established a set of guidelines for arthroscopic débridement for osteoarthritis. The guidelines recommend against performing an arthroscopic lavage, or débridement and lavage, for patients with a primary diagnosis of osteoarthritis but do state that arthroscopic débridement is indicated for those patients with a symptomatic torn meniscus and/or mechanical symptoms of a loose body and associated, underlying osteoarthritis (58). Furthermore, it should be noted that many focal lesions associated with traumatic etiologies or osteochondritis dissecans (OCD) may have associated perimeter nonviable pathologic chondral tissue that may require adjuvant débridement in association with a resurfacing procedure.

Arthroscopic débridement remains a potentially clinically useful, technically simple palliative treatment for focal, small chondral lesions, with minimal morbidity and few complications. The benefits, however, must be based upon the removal of mechanically unstable tissue, as well as the possible prevention of lesion propagation by débridement of flaps and blisters. The indications for the procedure include those symptomatic patients with well-aligned knees presenting with focal articular cartilage lesions (<1 cm) and lesions with associated flaps or loose bodies, including those associated with OCD or fractures, as well as unstable meniscal tears. Contraindications include diffusely arthritic knees, BMI > 25 to 30, underlying instability, rheumatologic and systemic disorders, sepsis, and joint malalignment.

Surgical Technique

Débridement and Lavage Standard anterolateral and anteromedial portals are used and a diagnostic arthroscopy is performed. All loose bodies, which typically settle in the medial and lateral gutters or the suprapatellar pouch, should be identified and removed using an arthroscopic grasper. Cartilage fibrillations and flaps should be shaved in order to eliminate any mechanical symptoms or pain caused by their entrapment, as well as to prevent propagation of any articular cartilage defect. Shavers, curettes, or electrocautery can be used to trim loose cartilage with care taken not to damage bordering healthy tissue, or to expose underlying bone (Fig. 40.1). One might consider using sharp curettes, either domed or ringed, to remove larger flaps, with care taken to avoid producing a loose chondral body.

When using an RF-based device, settings of <50 degree Centigrade should be used. The RF probe should be placed within 1 to 2 mm of the fibrillated cartilage, making controlled, steady, deliberate passes. This motion is different than the back and forth brushing of the cartilage performed with shavers. Care should be taken at all times to limit contact and application time of the RF probe. Once a stable rim of cartilage is established, careful measurements of lesion size are then taken and noted. Joint lavage can also then be performed.

Postoperative Care and Rehabilitation

Modified weight bearing to comfort, and immediate range of motion are encouraged. Inflammation reduction measures and the use of cryotherapy are advised throughout the rehabilitation process. The patient is instructed to perform a low-impact exercise regimen consisting of quadriceps setting, straight leg raising, active-assisted range of motion exercises, as well as cycling. The goal of rehabilitation is to achieve balanced muscle strength, flexibility, and full range of motion.

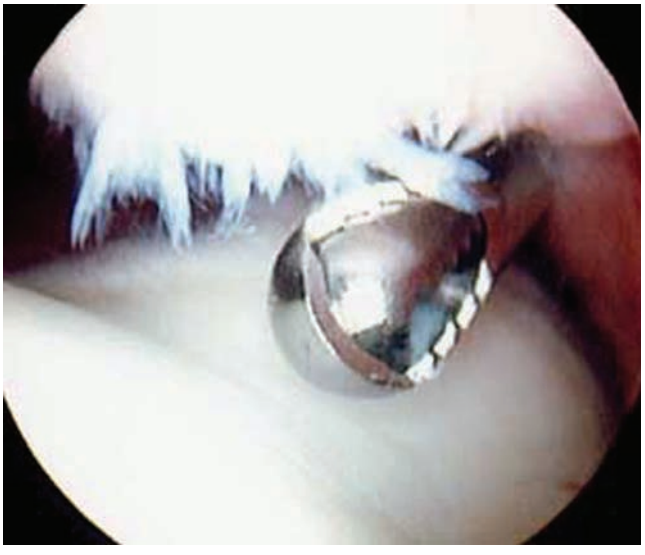

FIGURE 40.1

Shaver débridement. Shaver débridement of fibrillated cartilage, with the blade directed just off of the surface. Suction should be used to bring the fibrillations to the shaver.

Results

Outcomes after arthroscopic débridement have been inconsistent. For optimally indicated patients, arthroscopic débridement has been shown to produce pain relief, at least temporarily, in 50% to 90% of patients (1,21,24). The most favorable results have been shown in those patients with isolated chondral lesions and otherwise mild osteoarthritis. Aaron et al. reported a 90% symptomatic improvement in knees with mild arthritis (1,21). In 2007, Steadman et al. reported on 69 patients (average age of 57 years) with moderate to severe osteoarthritis, none of whom had focal traumatic lesions. The authors report on a distinct arthroscopic débridement treatment method (including preoperative joint insufflation, intraoperative removal of osteophytes, and lysis of specific adhesions in the suprapatellar pouch and anterior interval) in addition to a well-defined postoperative rehabilitation program geared toward maintaining the increased volume. Satisfactory results were reported, at an average follow-up of 31 months, in 71% of patients after the primary procedure (55).

Review of published literature concerning débridement reveals that there have been very few comparisons of débridement alone to other surgical methods of cartilage repair. While Hubbard (21) reported on focal arthritic lesions, there have been no studies, to our knowledge, focusing specifically on traumatic focal lesions and the benefits of débridement versus either lavage alone or medical management. Additionally, we are not aware of any published comparisons of débridement to microfracture. Bert and Maschka compared débridement and lavage to abrasion arthroplasty and showed little clinical difference between the two procedures (6). Similarly, Rand compared arthroscopic débridement with partial meniscectomy to arthroscopic débridement and abrasion arthroplasty in patients with osteoarthritis and found little benefit to the addition of abrasion arthroplasty (49). More recently, Fu et al. compared the effectiveness of débridement with that of ACI for the treatment of full-thickness, focal chondral defects of the knee. While functional improvement was noted in the débridement group, recipients of ACI achieved higher levels of knee function and increased pain relief (16).

MICROFRACTURE

Indications/Contraindications

The concept and surgical technique behind subchondral bone débridement and drilling was first popularized by Pridie in 1959. He noted that patients who had undergone penetration of eburnated subchondral bone with a drill, subsequently developed a layer of fibrocartilage overlying those drilled areas (22,48). In 1986, Johnson introduced arthroscopic abrasion arthroplasty. He reported on a series of 95 patients (average age of 60 years) and described the arthroscopic débridement of chondral defects with the use of a high-speed burr to superficially abrade the subchondral bone and create a bleeding surface. Initial clinical improvement was reported in 77% of patients and, at a 2-year follow-up, widened joint space on AP x-rays was noted in nearly 50% (26). Subsequent authors were unable to reproduce Johnson's outcomes and critics of the technique noted concerns for heat necrosis (6,49). An in vivo study in rabbits later reported increased fibrocartilagenous healing and longer lasting repairs with subchondral drilling compared with abrasion arthroplasty. However, the investigators found that both techniques produced suboptimal results (36).

In the 1980s, Steadman coined the term "microfracture," and later popularized the procedure when he described the surgical technique and favorable results in a series of patients in 1997. The technique employs the controlled and systematic use of arthroscopic awls (rather than high-speed drills, thus negating the risk of thermal necrosis), allowing superior control and offering improved arthroscopic access to greater articular surfaces of the knee (57). The careful débridement of chondral lesions to a stable peripheral rim prior to creating the perforations ("microfractures") allowed for the adherence of a "superclot," composed of marrow stromal cells, which ultimately filled the defect (56,57).

Early microfracture results have provided guidelines as to which patients would most benefit from the procedure. In their initial series of 1,200 patients treated with microfracture, Steadman et al. (57) noted worse results in patients presenting with chronic lesions and advanced age, and in those who failed to use a continuous passive motion (CPM) machine postoperatively. In a later 11-year follow-up of patients treated with microfracture, age <35 years was a predictor of better clinical outcome. Additional improved results were reported, although not statistically significant, with lesions smaller than 400 mm^2 compared with larger lesions (53). Mithoefer found, in a study of high-impact, pivoting athletes treated with microfracture, that a significantly higher rate of return to high-impact sports (64%) was noted in those patients with lesions <200 mm^2 as compared to those with larger lesions (22%). An increased time interval from injury was also found to be a negative prognostic factor, with return to sport increasing from 44% to 67% if microfracture was performed within 1 year of injury (39). This is further supported by Blevins and coauthors who found, on second-look arthroscopy, that prolonged preoperative interval from injury resulted in inferior macroscopic grading of microfracture-repaired cartilage (7). Less than optimal results have also been associated with an elevated BMI, as shown in a prior prospective cohort study by Mithoefer et al. (40), where worse clinical scores and lesion fill grades were reported in patients with a BMI > 30. In an effort to determine the effectiveness of microfracture in different areas of the knee, Kreuz et al. evaluated the knees of 85 patients at 6, 18, and 36 months postoperatively. The best clinical and defect filling results, as measured by MRI, were seen with lesions of the femoral condyles, with less favorable results with patellofemoral lesions (32).

TABLE 40.2 Indications/Contraindications for the Microfracture Procedure

Microfracture	
Optimal Indications	**Contraindications**
Full-thickness cartilage defects	BMI > 30
Small, contained defect (<200 mm^2)	Age > 55
Posttrauma	Inability to comply with postoperative rehab
Young, active patient (<35 y)	Ligamentous instability
Less than 1 y from time of injury	Malaligned knee
	Coagulopathy
	Advanced degenerative changes
	Underlying avascular necrosis
	Collagen vascular disease
	Sepsis

In summary, microfracture is indicated in knees with posttraumatic, full-thickness, symptomatic, articular cartilage lesions, and in some cases, mildly degenerative knees with focal, full-thickness cartilage lesions (56) (Table 40.2).

Surgical Technique

The surgical approach starts with preoperative counseling to assess patient expectations and to prepare patients for postoperative protocols and a potentially extensive recovery. The patient should be educated as to the tenuous nature of the repair tissue, in order to reinforce the importance of modified weight bearing and the need to strictly adhere to physical therapy protocols. A routine diagnostic arthroscopy is performed and all intra-articular procedures, other than ligament reconstruction, are initially carried out at this point. Microfracture should be left as the last step prior to wound closure in order to optimize the marrow clot. Once the lesion is identified, the periphery of loose, unstable cartilage is débrided back to a stable, perpendicular edge of viable cartilage using either an arthroscopic shaver or, preferably, a sharp domed or ringed curette (Fig. 40.2). This technique allows for the marrow clot to maximally adhere to the viable native cartilage and mature into reparative fibrous tissue.

Once the lesion perimeter is defined, the existing calcified cartilage layer is removed using a curette (Fig. 40.3). This has been shown to improve the adhesion of the superclot and subsequent bonding of the repair tissue to the defect site (14,15). Excessive removal of the calcified cartilage can lead to overpenetration of the subchondral bone and subsequent boney overgrowth, which can result in thin, biomechanically inferior repair tissue (9,40). The microfracture perforations should be made perpendicular to the surface of the lesion, avoiding skiving. The awls are typically available in 30, 45, and 90 degrees, and allow perpendicular placement to most areas of the knee joint, with the 90-degree awl generally reserved for patellar lesions (Fig. 40.4). The microfracture holes are made initially along the perimeter of the lesion to address peripheral integration of the repair tissue with the native hyaline cartilage. The perforations are made sequentially from the periphery to the center of the lesion. The holes are made as close together as possible without creating a fracture of the

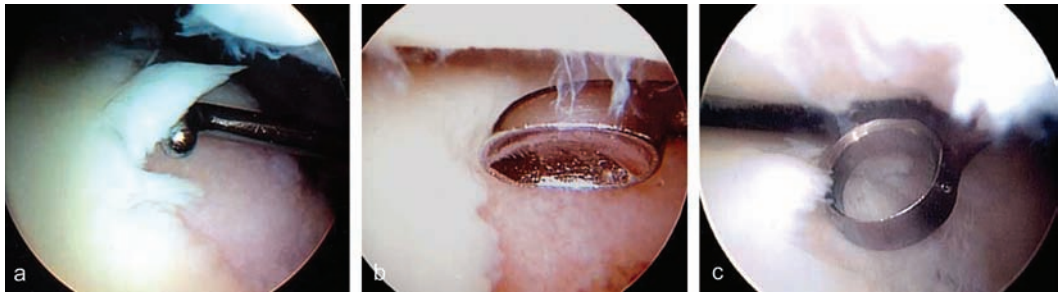

FIGURE 40.2

Microfracture lesion preparation. **A:** Unstable, nonviable cartilage should be debrided back to a stable, vertical rim to which the marrow clot can adhere. **B:** The use of a curette for débridement **C:** The use of a loop curette for débridement.

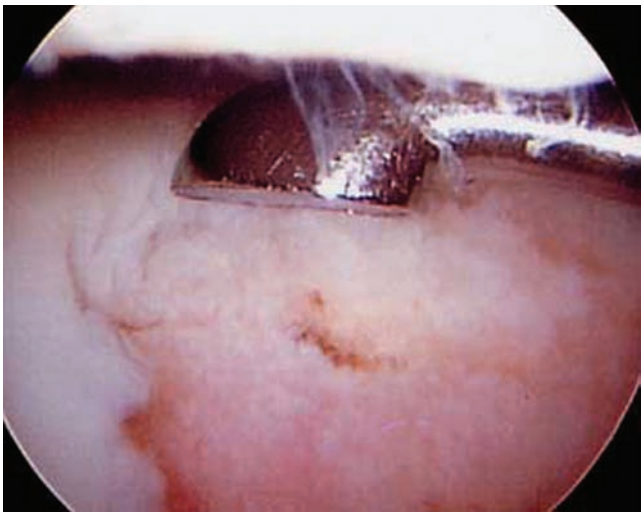

FIGURE 40.3
Curettage of calcified cartilage layer.

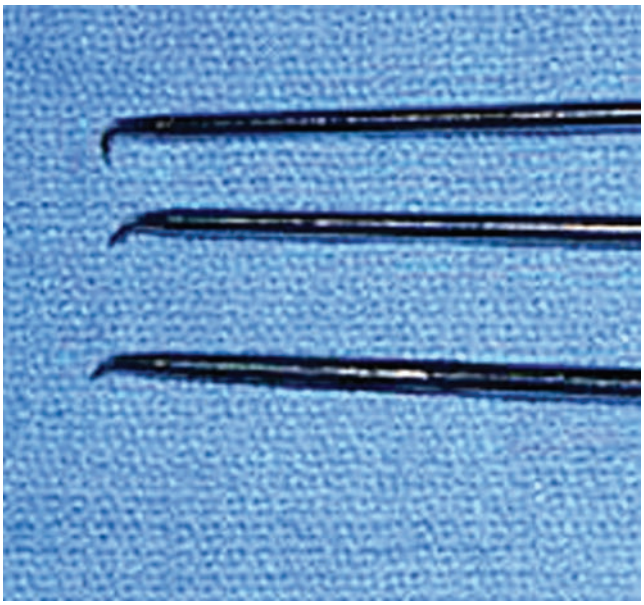

FIGURE 40.4
Microfracture awls.

subchondral bone bridge and subsequent confluence of holes (generally 3 to 4 mm apart) (Fig. 40.5A and B). Some microfracture awls have laser-lined depth markers on the tip, though appropriate depth can be assured by turning off the irrigation fluid (and letting down the tourniquet if used) and observing fat droplets and blood extruding from the microfracture holes (Fig. 40.5C). Adequately prepared lesion shoulders result in a stable bleeding bed to which the marrow clot can adhere (Fig. 40.6).

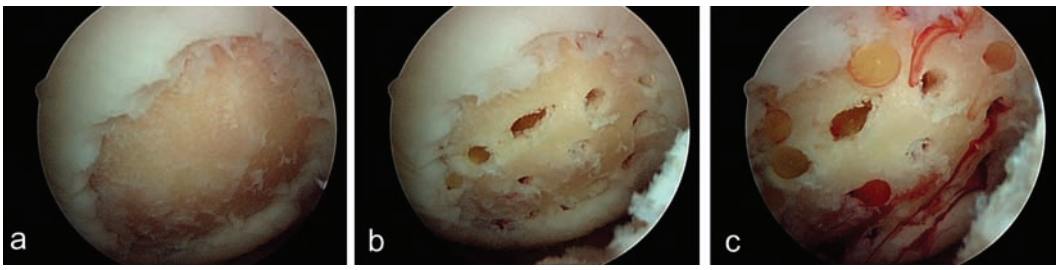

FIGURE 40.5
Microfracture sequence. **A:** Postdébridement of calcified cartilage layer. **B:** The microfracture should proceed in a periphery to central direction. **C:** Marrow elements including fat droplets and blood extruding from the microfracture holes assuring adequate penetration depth.

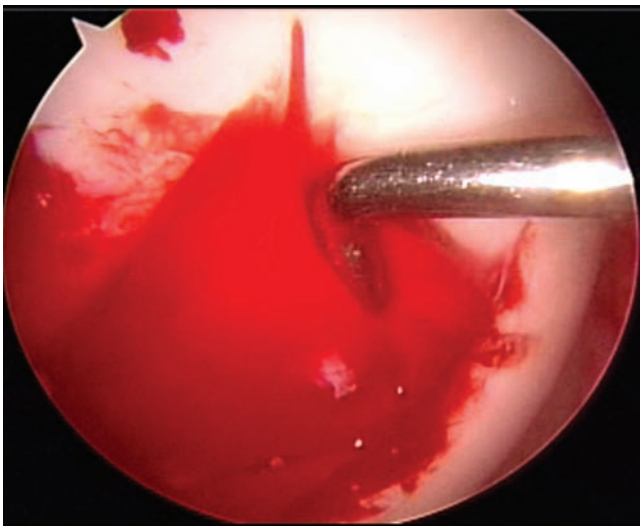

FIGURE 40.6
Adherent superclot to a stable rim of viable cartilage.

Postoperative Care and Rehabilitation

Immediately following surgery, CPM is begun with initial settings of 0 to 90 degrees and progression as tolerated for 6 weeks. Those patients for whom CPM machines are not available are instructed to perform 500 knee bends, three times daily, in order to build strength and range of motion. Bilateral leg presses and one-third squats are used, with range of motion and weight gradually increased. Stationary bikes with variable resistance, treadmills, and elliptical trainers are all used to achieve early strength and range of motion gains (11). The patient is also encouraged to perform active-assisted range of motion exercises several times daily. Achieving full passive extension is an important early goal. Active-assisted range of motion exercises are progressed as tolerated with an emphasis on closed-chain exercises.

The initial goals of physical therapy emphasize maximal protection of the treated lesion site and thus, initial weight bearing is toe-touch (<5 lb) with the use of crutches. Patellofemoral microfracture patients differ in that initial weight bearing is 50%, progression to weight bearing as tolerated is at week 2, and a brace is employed to initially permit only 0 to 20 degrees of motion and avoid flexion overload, thus not shearing the microfracture site. The hinged brace and knee range of motion are progressed over a period of 6 to 8 weeks. In cases in which condylar lesions are treated, crutches are weaned and a return to full weight bearing is begun at 6 weeks. Regarding return to sports or more stressful activities, sport-specific protocols and agility drills focusing on acceleration, deceleration, and cutting maneuvers are slowly added at around 4 to 6 months. It is generally recommended to wait 6 to 9 months before returning to high-impact sports requiring agile maneuvering.

RESULTS

Clinical outcomes of patients with full-thickness chondral lesions treated with microfracture have yielded good to excellent results in 60% to 80% of patients (40,53,57). Blevins in 1998 and Steadman in 2003 reported on microfracture outcomes in a cohort of elite athletes and reported that 76% to 77% of players returned to competition (7,54). Gobbi et al. later reported on competitive athletes (26 professional, 27 recreational) with an average age of 38 years and similarly found that 60% to 70% showed symptomatic improvement (pain, swelling, crepitus). However, at final follow-up, 80% showed a decline in sport activity level, suggesting that microfracture might not be as predictable and durable a treatment in the more elite athlete (17). More recently, Mithoefer et al. performed a prospective evaluation of microfracture in athletes who participate in high-impact, pivoting sports. Forty-four percent of the athletes were able to return to regular participation in high-impact, pivoting sports, 71% of which were at a competitive level. Fifty seven percent of returning athletes achieved their preoperative level of play, which is similar to the findings in soccer players treated with ACI (39,41).

Microfracture has been compared with osteochondral autologous transplantation (OAT) in the treatment of osteochondral defects of the knee. Gudas et al. randomized 57 young athletes to receive either OAT or microfracture. At 37 months, both groups had significant clinical improvement. However, 96% of OAT recipients had excellent or good results with respect to modified HSS and ICRS scores, compared with 52% for the microfracture procedure. Second-look arthroscopy showed good-to-excellent results in 84% of OAT patients compared with 57% after microfracture (18). However, it should be noted that the rehabilitation protocol in this study did not use CPM and encouraged weight bearing at 4 weeks, earlier than is recommended for microfracture patients.

In a level IA prospective randomized controlled comparison, Knutsen et al. compared clinical and histological outcomes (via arthroscopic biopsy at 2 years) of microfracture and ACI in 80 patients. Clinically,

TABLE 40.3 Microfracture versus Other Chondral Resurfacing Procedures

Microfracture Comparison	Study Design	Follow Up	Author	Comments
vs. ACI	Level I Prospective Randomized 80 pts[a]	2 y	Knutsen (2004)	Microfracture significantly better clinical improvement (SF-36 physical component) Histologically no significant difference No correlation between histological and clinical results Younger, more active patients with better clinical results
vs. OAT	Level I Prospective Randomized 57 pts	37 mo	Gudas (2005)	OAT significantly better clinical results (HSS, ICRS) OAT better macroscopic results at 12 mo OAT better histological results at 12 mo OAT better MRI results Younger athletes better clinical results in both groups OAT better return to preinjury level of sports activity
vs. ACI	Level I Prospective Randomized 80 pts[a]	5 y	Knutsen (2007)	No difference in radiographic or clinical results 23% failure rate in each group No correlation between histological and clinical results
vs. CCI	Level I Prospective Randomized 118 pts	12–18 mo	Saris (2008)	CCI better histologically Comparable clinical results (KOOS)
vs. Second-generation ACI (Hyalograft C)	Level II Prospective Cohort Study 80 pts	5 y	Kon (2009)	Second-generation ACI with better clinical results (IKDC) Second-generation ACI with more prolonged resumption of sports

[a]Studies with the same patients
ACI, autologous chondrocyte implantation; CCI, characterized chondrocyte implantation; HSS, Hospital For Special Surgery Knee Score; ICRS, International Cartilage Repair Society Score; IKDC, International Knee Documentation Committee—objective score; KOOS, Knee Injury and Osteoarthritis Outcome Score; OAT, osteochondral autograft transplantation ; Short Form-36.

both groups had similar improvement at 2-year follow-up, and histologically, the two groups produced similar tissue (more commonly fibrocartilage) (30). Longitudinal follow-up of the entire patient study group was completed at 5 years. Notably, there was no significant difference regarding clinical scores, radiographic changes, histology, or failure rates between the two groups (29). More recently, microfracture has been compared to characterized chondrocyte implantation (CCI), using cell marker–specific selected autologous chondrocytes, in a randomized controlled trial. Biopsy specimens taken at 1 year were analyzed, and revealed superior structural repair in the CCI group, but no significant difference in clinical evaluation (50). Second-generation ACI and implantable scaffolds have been developed to reduce the morbidity associated with the periosteal augmentation in ACI. Kon et al. compared the outcomes of second-generation ACI (Hyalograft C) with microfracture at a 5-year follow-up and showed that both groups improved but that IKDC subjective scores were higher in the second-generation ACI group. Additionally, equal numbers in both groups returned to preoperative levels of sports participation, but this was only maintained in the ACI group at 5 years (31). (Table 40.3)

COMPLICATIONS

Surgical complications from microfracture may be categorized into preoperative, intraoperative or procedure specific, and postoperative (51). Preoperative complications include poor patient selection, imprecise surgical indications, and incomplete preoperative counseling. Intraoperative complications include broken microfracture awls and fracturing of the subchondral bridge (Fig. 40.7A and B). Osseous overgrowth has been described by Mithoefer et al. in 6 of 24 patients at an average of 12 months postsurgery. Reported in 25% to 49% of microfracture patients, this is thought to result from metaplasia of the deep layer of repair cartilage, possibly due to excessive removal of the subchondral bone plate during débridement of the calcified cartilage layer. This overgrowth results in a relative thinning of the repair tissue with potential implications on long-term repair durability and possible revision with ACI (9,40,52). In a recent study, Minas et al. noted that previous marrow stimulation surgery negatively affected subsequent cartilage repair with ACI, producing a failure rate three times that of untreated knees (38).

CONCLUSION

In summary, both articular débridement and marrow stimulation, using the microfracture technique, offer the surgeon a cost-effective, practical, arthroscopic primary treatment for symptomatic chondral defects, associated with few complications and minimal morbidity. Precise patient assessment, as well as adherence to a

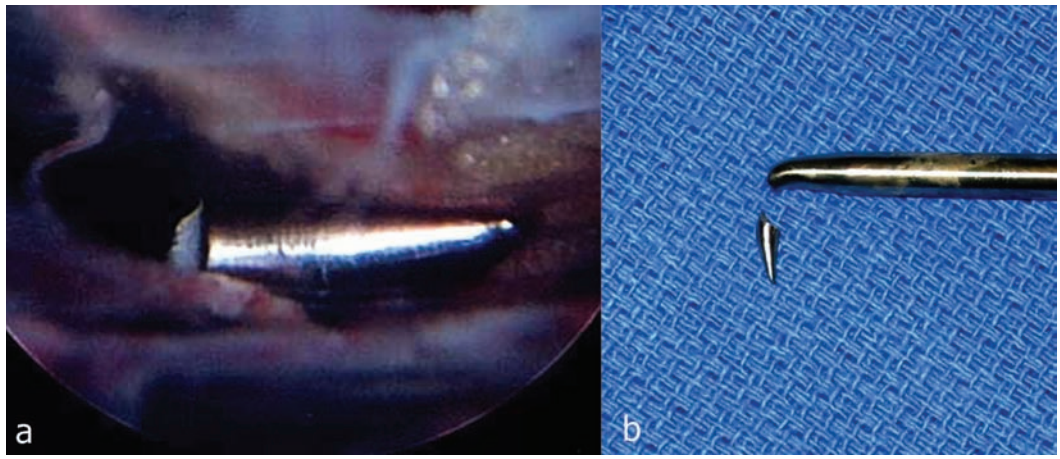

FIGURE 40.7

Broken awl **A:** Broken awl fragment within joint. **B:** Broken awl better appreciated, removed from body.

well-defined postoperative rehabilitation program, results in satisfactory subjective and functional outcomes in 50% to 90% of débridement patients and in 60% to 80% of patients treated with microfracture. Although neither microfracture nor débridement can reproduce the biomechanical characteristics of the preinjury joint surface, and are therefore by definition palliative, they are technically simple and result in satisfactory outcomes in a well-defined patient population.

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41 Mosaicplasty/ OATS

Emilio Lopez-Vidriero and Donald H. Johnson

INTRODUCTION

Osteochondral lesions have always been a challenge for orthopaedic surgeons. With the increasing use of arthroscopy, surgeons have been able to diagnose these lesions more often. However, the pathophysiology of osteochondral defects is unclear. Some defects are small and very painful, and others are not. These defects are probably due to the impaired ability of the joint surface to absorb energy and transmit load. Pain probably occurs because of the stimulation of nerve endings of the subchondral bone in these weight-loading surfaces.

The rationale for treatment of this pathology is that chondral lesions can lead to further injury to the joint and ligaments, as the irregular surfaces alter biomechanics. Further, partial-thickness tears (chondral fractures) (Fig. 41.1) tend to not heal and full-thickness tears (osteochondral fractures) heal variably (Fig. 41.2A and B). Usually, fibrocartilage fills the healing surface and it has a predominance of type I collagen with inferior biomechanical properties. This is in contrast to normal hyaline cartilage formed by collagen type II.

Treatment possibilities range from neglect, débridement to leave a stable defect, microfractures, and autologous condrocyte implantation, to osteochondral transplantation with auto or allografts. As yet, there is no gold standard technique in the armamentarium of the arthroscopist to treat osteochondral defects.

The guiding principle of osteochondral transplantation is that the loss of articular cartilage is replaced with identical hyaline cartilage tissue with similar biomechanical characteristics.

INDICATIONS

The best candidate for osteochondral autologous transplantation (OATS) is the young (20–30 years), thin (<25 BMI) patient who suffers a symptomatic, traumatic, unipolar, small (<2 cm^2), and type IV outerbridge chondral defect exposing subchondral bone (Fig. 41.2A and B), confirmed previously with an MRI.

However, most chondral defects are discovered during diagnostic or therapeutic arthroscopy for other purposes. The surgeon must consider this possibility in order to have the necessary tools ready. Chondral defects are more common in meniscectomized knees and ACL-deficient knees, both acute (33%) (1) and chronic (79%) (2). Other risk factors are PCL-deficient knees due to sheer force and malalignment of the lower extremity.

Originally, autologous osteochondral transplantation was limited to relatively small or medium-sized focal chondral and osteochondral defects of the weight-bearing surfaces of the femoral condyles and the patellofemoral joint. With time and experience, the indications have extended to other joints, including talar; tibial; humeral, both head and capitelar; and femoral head lesions.

The pathologies that are usually addressed with this technique are chondral defects, both traumatic (Fig. 41.2A) and degenerative (Fig. 41.2B); osteochondritis dissecans; and avascular necrosis. This is especially true if the knee is unstable.

The indications for osteochondral transplantation are limited mainly by donor-site availability and the biological healing response. Other technical circumstances also determine the indication for transplantation.

Practical considerations for successful transplantation suggest that the diameter of the defect should be between 1 and 4 cm^2. Usually, both patellofemoral peripheries allow graft harvest for defects of 3 to 4 cm^2 in size.

In certain cases where the deficiency of the loading site of the knee ranges from 6 to 9 cm^2, it may be possible to use the posterior medial femoral condyle as the donor. This technique is called Mega-OATS (3) and it is an option worth considering until such time as total knee replacement is indicated in young adults in whom hyperflexion of the knee is not needed.

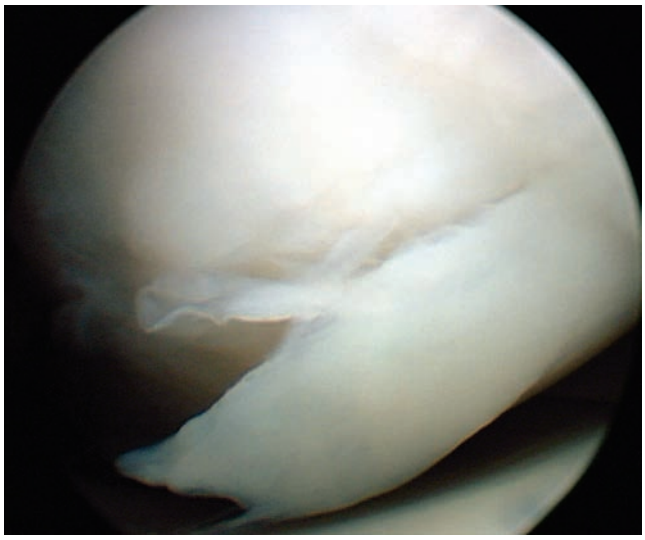
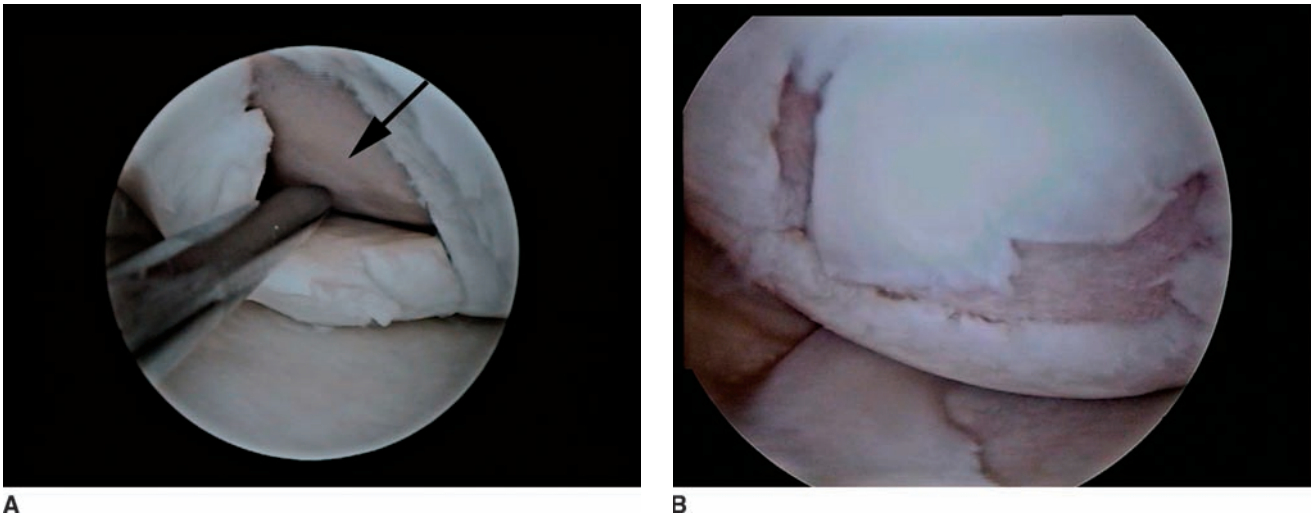


FIGURE 41.1

Partial-thickness chondral lesion with unstable flap.



A **B**

FIGURE 41.2

A: Traumatic chondral lesion. Note the full-thickness unstable flap with subchondral bone exposed. **B:** Degenerative complex chondral lesion with unstable flaps.

However, the potential use of osteochondral allografts has expanded the indications, removing donor site availability as a problem. Allografts will be discussed later in this chapter.

The biological healing response is mainly limited by age. Most surgeons consider that 50 years of age is the recommended upper limit for the procedure, and this reflects clinical outcomes of single-block osteochondral transfer (4).

It should be noted that the indications for this treatment depend on other possible pathologies that the recipient joint could suffer. Thus, the treatment of instability, malalignment, and meniscal and ligament tears must be incorporated in the operative and postoperative rehabilitation algorithms.

CONTRAINDICATIONS

Formal contraindications for this type of treatment are as follows:

- infections or tumor defects;
- generalized acute and chronic arthritis, rheumatoid and/or degenerative in type;
- delocalized uni/multicompartmental osteochondral lesions of the knee;
- tricompartmental knee arthrosis;
- chondrocalcinosis;
- not simultaneously corrected or noncorrectable malalignment or ligamentous instabilities.

Relative contraindications are the following:

- Age between 40 and 55
- Mild osteoarthritic changes
- Smokers

As stated before, patients over the age of 50 are usually not good candidates. Nor are those patients under the age of 50 with early unicompartment arthritis where the donor site cartilage is thin and the cartilage surrounding the defect is of poor quality. Smoking should be considered a possible contraindication due to its deleterious effects on the vascular tree, avoiding reparative tissue creation.

Technical difficulties make deep, large osteochondral defects unsuitable for osteochondral transplant, mainly because of the limited availability of autologous osteochondral grafts. Lesions deeper than 8 mm make it difficult to reconstruct the subchondral bone while achieving coverage and maintaining congruency of the transplanted cartilage surface. Also, it is difficult to reconstruct subchondral bone, restore the contour of the large defect area, and cover the entire defect area with hyaline articular cartilage.

TECHNIQUE

Cartilage transplantation can be performed either arthroscopically or open, including the miniopen technique. Some surgeons advise that those unfamiliar with the procedure should begin with the all open technique and after several cases, move to an arthroscopic procedure.

It is advisable to give intravenous antibiotics 30 minutes before the surgery. The type of anesthetic used, either general or regional, largely depends on patient preference. Both methods have been used with success. The application of a tourniquet is advised.

The patient's position on the operating table should allow the knee to flex over 120 degrees for recipient side management. The contralateral extremity is usually placed in a stirrup or in lithotomy.

As with the diagnostic procedure, arthroscopy is begun through the anterolateral portal. In addition to other pathologies, the cartilage lesion is evaluated thoroughly. If the cartilage repair is to be performed, then portals are introduced more centrally than usual. If concomitant pathology is going to be addressed, usually the mosaicplasty procedure is performed last to avoid any possible malposition or movement of the plugs during the other procedures.

Defect Preparation

The edges of the lesion must be débrided until all unstable flaps are gone (Fig. 41.3A and B). The use of curettes is useful in obtaining clean edges, and the shaver is used to abrade the lesion to viable subchondral bone. The defect should be left surrounded by well-defined walls of stable normal hyaline cartilage to receive the plugs and stop progression of the lesion (Fig. 41.4).

The size of the lesion determines the number of plugs of different sizes that are needed to fill the gap. Generally, a gap filled to more than 70% is considered optimal, but rates can be increased up to 90% and 100% with variable-sized grafts (4,5).

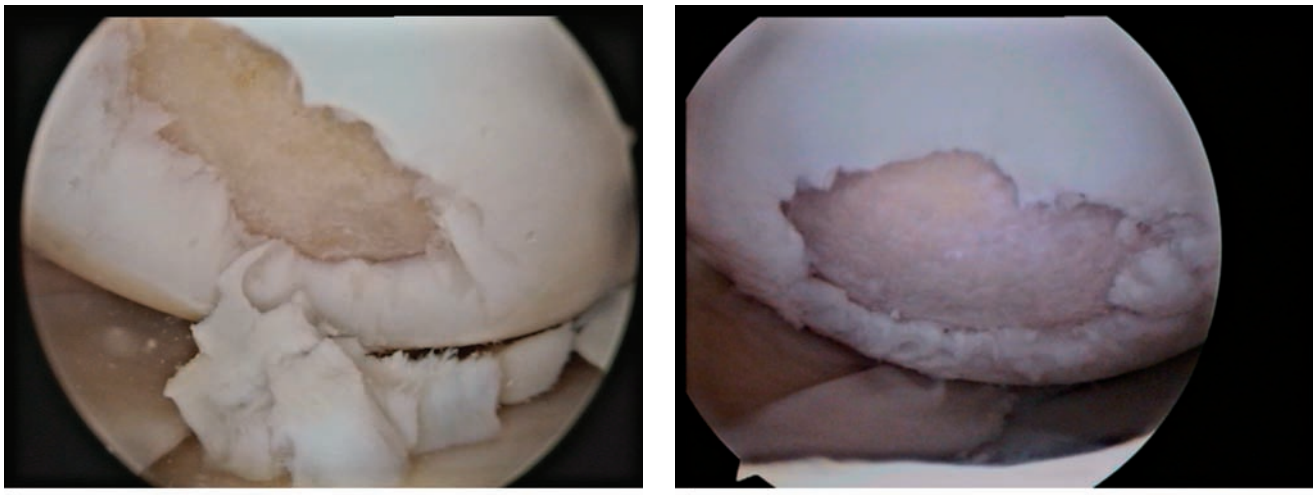


FIGURE 41.3

A: Débridement of the unstable flap and borders of traumatic tear seen in Figure 41.2A. **B:** Débridement of unstable flap of degenerative tear seen in Figure 41.2B.

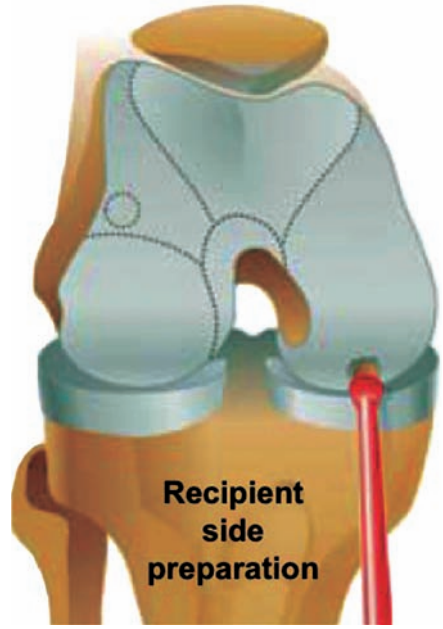


FIGURE 41.4

Preparation of the recipient side of the osteochondral transplant. The defect should be left surrounded by well-defined walls of stable normal hyaline cartilage to receive the plugs and stop progression of the lesion.

The size of the recipient side can be estimated by using a drill guide or sizers to measure the lesion on prepared subchondral bone. The various commercially available systems include different diameter tube harvesters, ranging from 2.7 to 14 mm, which are helpful in choosing the appropriate graft size. Subchondral bone can be marked with the harvesting chisels to give an approximate vision of the desired final result.

The aim is to achieve the best congruent filling and avoid gaps between the graft plugs that will be filled with fibrocartilage. There is a delicate balance to limiting the fill tissue between grafts, while optimally re-creating a flush, congruent articular surface.

Donor Side Selection and Harvesting

There are several cartilage donor regions that may be chosen depending on their shape and congruency with the recipient side (Fig. 41.5).

Harvesting may be performed either arthroscopically or in an open fashion. Due to the importance of obtaining a perfectly perpendicular graft, the surgeon should decide whether to use one approach or the other. If arthroscopic harvesting is chosen, portal selection is crucial. The use of spinal needle before opening the portal is helpful in visualizing the possible orientation of the tube harvester that will be used next.

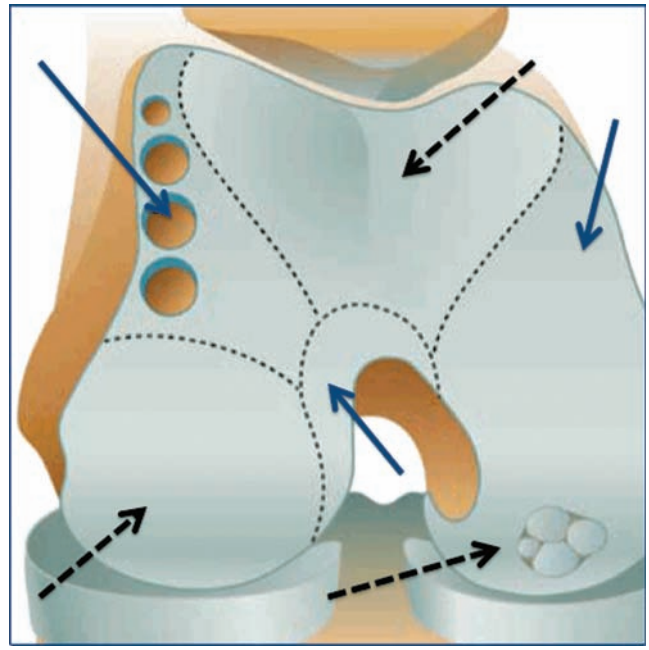


FIGURE 41.5

Donor regions are marked with blue arrows. Recipient regions are marked with *dashed arrows*. Donor regions that may be chosen depending on their shape and congruency with the recipient side.

As long as care is taken not to damage healthy underlying articular cartilage or meniscus, portals may be made safely over much of the knee region.

A contralateral portal is advisable for viewing the portal site and ensuring a perpendicular alignment.

The knee may be extended to access more superior donor sites and then flexed progressively to reach the more inferior areas.

The sulcus terminalis of the femur is usually considered the inferior limit for graft harvest on both lateral and medial femoral condyles.

The originators of the technique suggested that the donor sites be at the periphery of the articular surface of the femur above the sulcus terminalis, including the lateral, medial, and superior edges (6). They studied ten different sites for harvesting and found that those exerting the least contact pressure were the superior lateral aspect of the lateral femoral condyle, followed by the superior medial aspect of the intercondylar notch.

All possible donor regions are important because each has a role in articular movement (7). Thus, harvesting is not free of consequences, but the least contact has been shown at the femoral condyles around the edge of the patella.

Because the patella is already displaced laterally with knee distension, making it easier to place the portal and do the harvest, some surgeons (4,5) prefer to use the medial border of the medial femoral condyle in the arthroscopic approach.

The shape of the donor site should also be taken into account depending on the recipient site. Normally, the periphery of the femur gives convex cores and the notch area produces grafts with concave articular surfaces.

Once the desired tubular graft harvester is chosen, it is introduced through the correct portal and placed perpendicularly over the selected donor cartilage (Fig. 41.6). If the superior condylar site is chosen for harvesting, the best way to control perpendicularity is to use the ipsilateral inferior portal for vision. When the harvester is in position, it is seated with the help of a mallet to a depth of 15 mm for chondral defects and 25 mm for osteochondral defects. This 10-mm difference provides additional cancellous bone in those defects that potentially need it. As the depth is important, visualization of the markings on the barrel must be clear to provide accurately sized grafts (Fig. 41.7). As a general rule, the graft should be two times longer than the diameter.

Once at the desired depth, the plug is released from subchondral bone. The different systems available have different release methods. The harvester may need to be toggled 5 degrees with no rotation (Smith and Nephew Mosaicplasty), or rotated 90 degrees clockwise and counterclockwise (Athrex OATS) (Fig. 41.7), or rotated 720 degrees (De Puy-Mitek COR), in order to fragment the cancellous bone at the base of the graft. The S&N system requires that the osteochondral graft be removed from the harvester. The graft is then pushed out from the osseous end to avoid cartilage injury and it is placed in a saline-filled basin. The Arthrex and De Puy-Mitek sets do not require free handling of the graft, as they remain in the harvester tube for transplantation.

Up to three grafts may be obtained from the standard portals. If more grafts are needed or if the surgeon prefers to go superiorly, superomedial or superolateral portals may be necessary. Additional grafts can be harvested by flexing or extending the knee.

Spacing the grafts' harvesting to avoid confluence at depth (~3 mm) will avoid any weakening of the condyle. The donor site holes will eventually fill with cancellous bone and fibrocartilage (2,4,8–10). Care should be taken when harvesting 6.5- and 8.5-mm grafts to avoid creating patellar tracking problems or weakening the condyle.

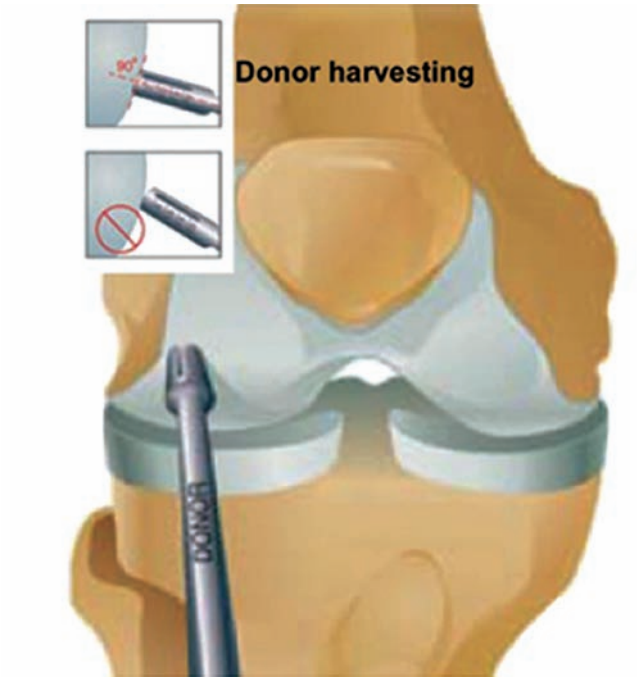


FIGURE 41.6

Donor site harvesting. Note that perpendicularity is critical for the success of the procedure.

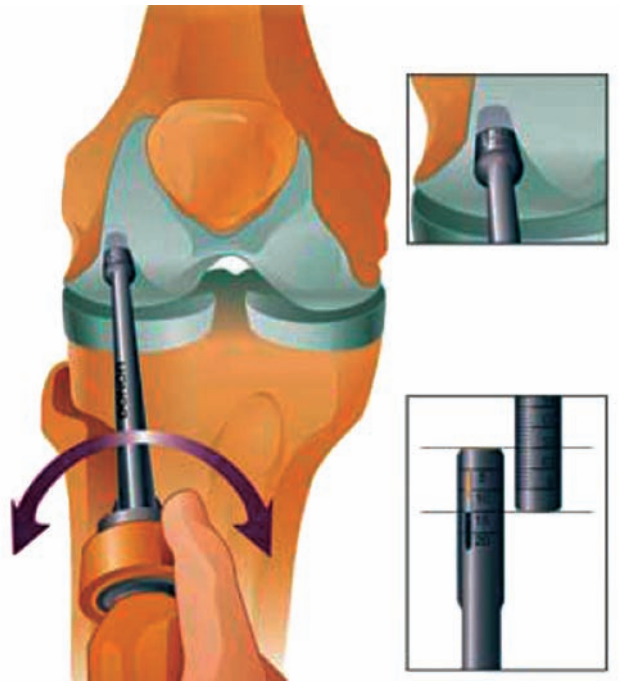


FIGURE 41.7

Donor harvesting. Direct control of depth is important for correct press fit implantation at the recipient side. Different systems have different ways of separating the osteochondral plug from the donor site. In this case, 90 degrees turns clockwise and counter clockwise are used (OATS system, Arthrex, Naples, Florida).

Usually, the harvest site is left open, but some surgeons prefer to use the subchondral bone taken when preparing the receiver socket to fill the remaining gap (11). On the other hand, this could lead to loose bodies forming if the cancellous bone becomes unstable and arthroscopy would be needed to remove them (11). Thus, leaving the donor site open is advisable in order to save time and avoid technical difficulties and complications.

Receiver Socket Preparation and Graft Insertion

Due to the press-fit fixation of the osteochondral grafts, preparation of the bed is critical to enable a secure fixation (Figs. 41.3A,B and 41.4).

There are two different ways of preparing the recipient site. The first one is the drill, dilate, and deliver technique (S&N mosaicplasty). With this technique, a universal drilling guide is tapped in the subchondral bone, perpendicular to the prepared defect. Then, the appropriate size drill bit is inserted and drilled to the desired depth. Usually, the length of the recipient hole is a few millimeters deeper than the length of the graft. This is desirable to minimize high intraosseal pressure. At this point, inflow should be reduced in order to minimize leakage. Once the drill is removed, a dilator is inserted into the drill guide to the desired depth and then removed. Then, the graft is seated slightly higher than the depth of the defect with the aid of the delivery tamp. At this point, inflow should be stopped, due to the possibility of pushing the graft out of the tube. Then, final delivery of the graft is performed through the drill guide with the tamp. It must be emphasized that the graft should be flush with the original articular surface.

The second possibility is the manual punch technique (Arthrex OATS), where the recipient harvester tube is 1 mm shorter in diameter than the donor tube to allow for press-fit fixation (Fig. 41.8). Both harvesters are used manually with the aid of a mallet when needed. In contrast to the other technique, the length of the recipient hole is 2 mm less than the autograft, usually 13 mm depth for a 15-mm autograft. With this system, the harvester is rotated instead of levered to pull out and remove the cancellous bone from the base of the tunnel. Additionally, creating recipient sockets slightly shallower than donor grafts allows better accuracy when seating grafts flush with surrounding cartilage. The OATS system has alignment rods that may be used to measure the depth of the socket and confirm alignment for graft insertion. The donor harvester with the core graft is reinserted into the driver assembly (Fig. 41.9). The impaction cap is unscrewed and a collared pin exposed, advancing the graft into the socket. The harvester has a beveled leading edge that is easily inserted into the socket. This seats the harvester and serves to stabilize it for final graft seating. A mallet is used to gently tap the pin for seating of the graft (Fig. 41.9). It is recommended that the graft be left 1 mm exposed and final seating be performed with an oversized tamp (Figs. 41.10 and 41.11).

Unlike the other systems, the COR system (DePuy-Mitek) drills the recipient side to the same depth as the ostechondral graft.

When multiple grafts are to be transplanted, it is very important that each one is completed before the creation of additional recipient sockets to avoid fracture of the recipient tunnel walls. The osteochondral graft is

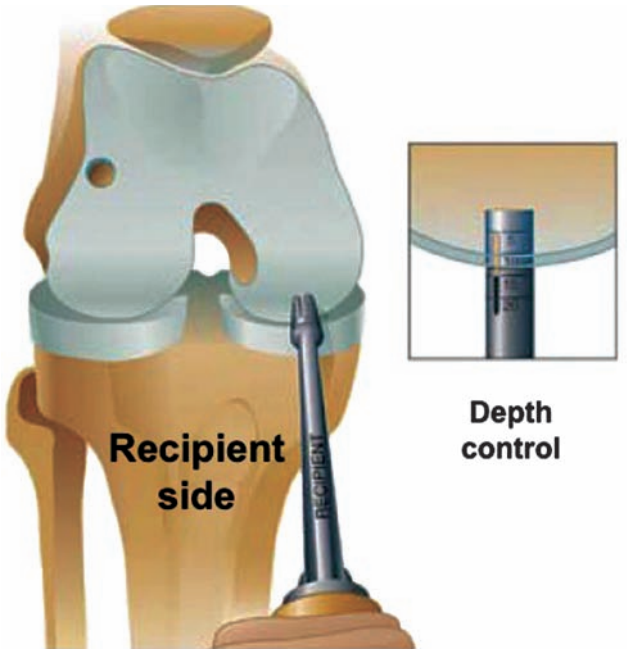


FIGURE 41.8

Recipient site preparation. Different depths are chosen depending on the system used. The recipient harvester tube is 1 mm shorter in diameter than the donor tube to allow for press-fit fixation in the OATS system (OATS system, Arthrex, Naples, Florida).

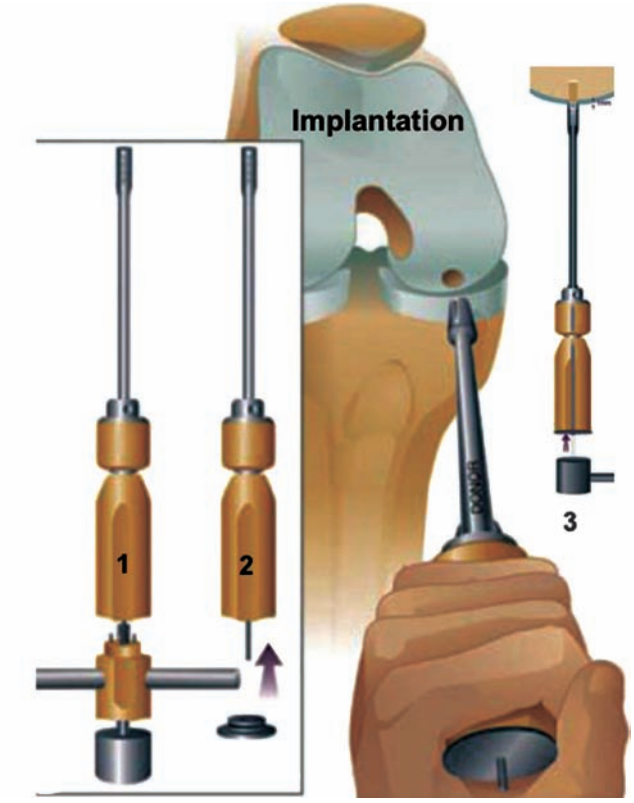


FIGURE 41.9

Recipient site implantation. The impaction cap is unscrewed (*1*) and a collared pin exposed (*2*), advancing the graft into the socket. The harvester has a beveled leading edge that is easily inserted into the socket. This seats the harvester and serves to stabilize it for final graft seating. A mallet is used to gently tap the pin for seating of the graft (*3*) (OATS system, Arthrex, Naples, Florida).

considered in position when flush and when congruency is achieved. Where the plug is seated too deeply, it is possible to prepare the next recipient hole and by using this hole, place a probe and pull the former plug until it is in the perfect position. Conversely, raised grafts should be pushed down with the available instruments, depending on the technique used, due to possible remodeling and alteration of the biomechanics of the knee.

Stability of the OATS technique has been evaluated in a porcine model (12). The main result was that 15- and 20-mm grafts were significantly more stable than those 10 mm in length. Moreover, when the diameter was taken into account, larger diameter grafts were more stable than smaller ones and that reinsertion after pullout significantly reduced primary fixation strength. Interestingly, stability was compromised when the harvest was performed and levering was used, as opposed to the recommended rotation with this system.

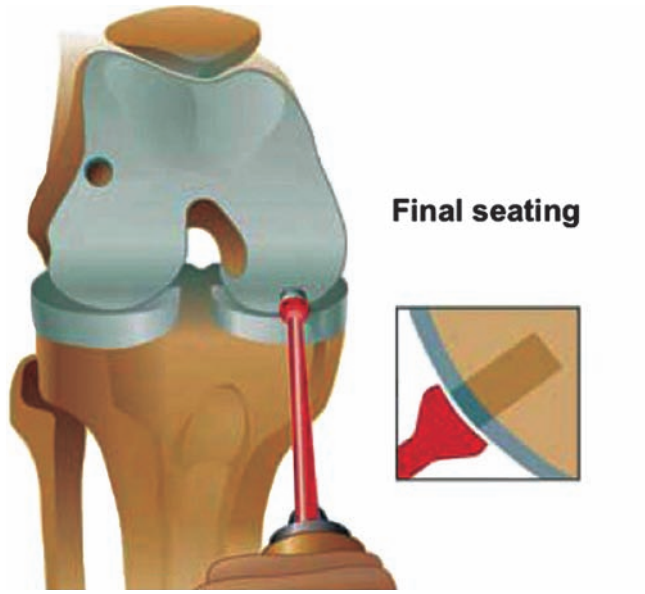


FIGURE 41.10

Final seating of the osteochondral plug. It is recommended that the graft be left 1 mm exposed and final seating be performed with an oversized tamp in the OATS system (OATS system, Arthrex, Naples, Florida).

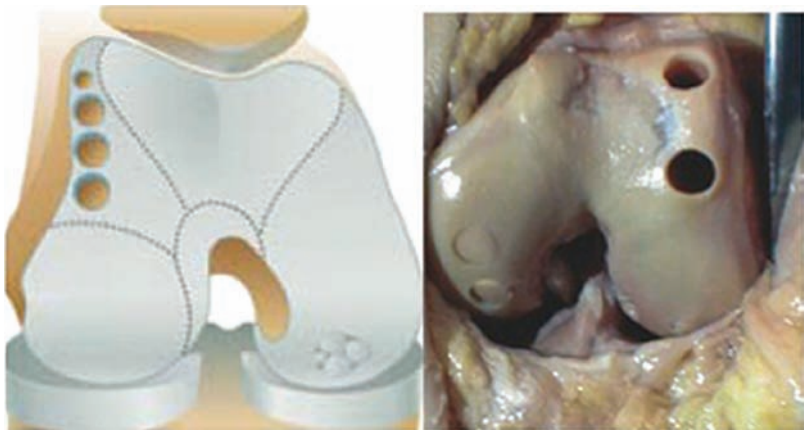


FIGURE 41.11

Final appearance of the osteochondral transplant. Cadaveric view with open exposure.

Drilling increases the temperature and could lead to thermal damage to the surrounding cartilage. Manual punch techniques of graft harvest and socket creation have shown to improve chondrocyte survival over power techniques (13).

CLOSURE AND POSTOPERATIVE TREATMENT

Once the osteochondral deficiency is filled and the grafts are in place, the knee should be put through a full range of motion and varus-valgus stress. This confirms the stability of the plugs and helps them to be finally seated. After draining the knee through any portal, the usual closure can be done. Surgeons who prefer to use drainage can remove it when it is not productive after 24 to 48 hours.

Generally, the patient is left non–weight bearing for the first 2 weeks and progresses to partial weight bearing for 4 more weeks. In the case of osteochondritis dissecans, 6 weeks of non–weight bearing is advisable. Range of motion and isometric quadriceps exercises and swimming are encouraged during this period. If no complications arise, return to full activities can be made in 2 to 4 months.

COMPLICATIONS

General complications due to any surgical procedure may occur. In the largest series published of 1,097 mosaicplasties, Hangody et al. (14) reported four deep infections and four deep venous thromboses. They also reported 56 painful hemarthroses (8%). All deep infections and 12 hemarthroses (1.7%) were treated by means of arthroscopic or open débridement. The rest of the articular hemorrhages were only treated by aspiration and cryotherapy.

Technical complications may arise during surgery or be the cause of postoperative problems. At the donor site, the possibility of filling the gap with different types of grafts is considered, although mobilization of the graft and loosening could happen (11). At the recipient side, breakage of the autograft and free loose body could occur. Moreover, positioning the plug imperfectly, either protruding or too deep, could cause excessive cartilage wear, pain, or impair the healing rate.

USE OF ALLOGRAFTS

The main restriction for the use of autografts is their limited availability and the possibility of iatrogenic damage to the cartilage contact surface of the donor site.

The use of the allograft is becoming more popular, not only because it avoids donor site morbidity and is not limited by the size of the defect but also because it decreases the surgical time and reduces the risk of clinically significant immunologic reactions (15). Moreover, it allows for precise preparation of graft material in any number of sizes.

The fact that the cartilage matrix is avascular and alymphatic reduces the possibility of immune response dramatically as compared to other allografts. This is especially important when considering chondral allografts for transplantation. There is no immune response from host cells against the allograft chondrocytes because the cartilage matrix shields their MHC class I antigens (16).

The main indication for osteochondral allografts instead of autografts are large lesions, over 2 cm^2 and deeper than 10 mm, that are more difficult to address with other reparative or restorative procedures (17).

Osteochondral allografts can also be used in revision surgery when other procedures to preserve cartilage have failed. They have been used as a salvage procedure after microfracture, autologous chondrocyte implantation (ACI), and mosaicplasty (18).

Other indications could be considered in the case of posttraumatic and degenerative lesions associated with intra-articular fractures where extensive osteochondral defects are present.

There are two main techniques for osteochondral allograft transplantation: the shell technique and the press-fit technique, also named dowel.

The shell technique consists of manually contouring the allograft to exactly fit the defect. It is mainly indicated for large asymmetric defects. Because of the asymmetric contour of the graft, usually press-fit fixation is not possible. Thus, bioabsorbable pins or low-profile, countersunk interfragmentary screws are used for final fixation.

The main advantage of this technique is that it avoids gaps between grafts that might be filled with fibrocartilage, decreasing the sacrifice of normal host cartilage. On the other hand, it needs "sculpting" skills not amenable to all surgeons and there exists the possibility of complications due to hardware protrusion.

The dowel technique is similar to the autograft technique where the surgeon is able to insert single or multiple osteochondral allograft plugs into the defect, matching the curvature of the lesion (Fig. 41.12).

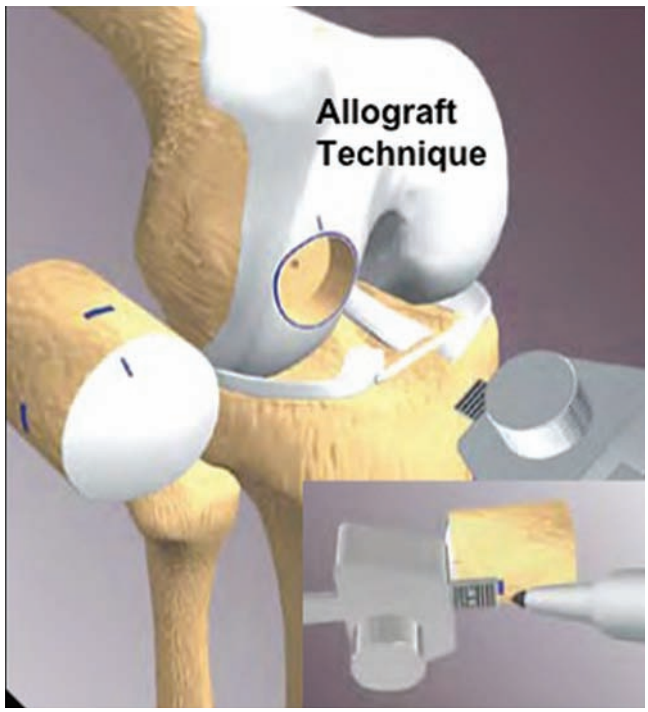


FIGURE 41.12

Osteochondral allograft dowel technique. This technique is similar to the autograft technique where the surgeon is able to insert single or multiple osteochondral allograft plugs into the defect, matching the curvature of the lesion. Note the importance of marking the allograft in order to match the original curvature of the recipient site as accurately as possible.

The indications are large defects between 15 and 35 mm in diameter. The allografts can be up to 15 mm thick. The fixation is similar to the autograft technique, being precontoured for a press-fit insertion into the gap.

The main sources of osteochondral allografts are the femoral head of a live donor after total hip replacement, multiorgan donors, and postmortem donors. Probably, the best option is the live donor due to the possibility of double test, to the patient and to the graft before and after the surgery.

One of the major concerns regarding allografts is the method of conservation. There are three main methods: the allograft is considered fresh when stored in a Lactated Ringers solution at 4 to 37 degrees. It is considered fresh-frozen when stored at −80 degrees, and finally, if the graft is stored frozen, but with an added DMSO solution that avoids ice formation, it is considered cryopreserved (19).

Generally, fresh allografts have been considered the best option due to the highest rates of chondrocyte viability (20). It is also important to take into account the time that fresh allografts have been stored because it has been shown that their biomechanical properties and chondrocyte viability decrease with time. Although the time from storage to implantation has been considered to be ideal before the 14th day, fresh allografts implanted before the 28th day are still considered viable for implantation (21,22). There is no doubt that the sooner, the better.

The main disadvantage of the allograft is not their price or their availability but the possibility of disease transmission. For that reason, several sterilization techniques have been developed trying to balance chondrocyte viability and collagen preservation with infectious agents' elimination. Presently, the use of low-dose (2.5 Mrad) gamma irradiation to kill surface pathogens is the most accepted procedure (19).

RESULTS

References to the results of autologous osteochondral transplantation can be found as early as 1952 when Wilson and Jacobs (23) published their results for fractures with successful outcomes from 6 months to over 10 years. Moreover, they demonstrated that hyaline cartilage could survive after transplantation over this period of time.

Short-term results on osteochondral transplantation were promising. Bobic published good clinical results (2) on 10 over 12 patients undergoing simultaneous first-generation OATS and ACL reconstruction. They also showed, in a histological sample, the survivorship of hyaline cartilage.

At 2 to 4 years, good and excellent results (80%) were found in a retrospective study, reviewing 16 knees (24). No progression of the lesion was found on x-ray after treatment at the medium and final follow-up. These short-term results are in agreement with other authors that have published their series (25,26).

At medium-term follow-up, the results continued to improve. In a consecutive series of 52 patients treated with osteochondral autografts of the knee, the level of knee function improved from 86% at 2 years to 92% at 5 years (27). In another study at 40 months, all 15 patients were able to return to their preinjury levels of IKDC score. Also their quality of life related to the knee measured with the KOOS score was 93,4 for activities of daily living, and the knee function increased in 86% (28).

A longer follow-up, with the highest number of enrollment series, has been published by Hangody et al. (4,5). They described their experience in 831 patients with mosaicplasty in different locations at 10 years. They obtained good to excellent results in 92% of patients treated with femoral condylar implantations, 87% of those treated with tibial resurfacing, 79% of those treated with patellar and/or trochlear mosaicplasty, and 94% of those treated with talar procedures.

The overall success rates for fresh frozen allografts in the literature range from 10% to 95%, depending on different etiologies and indications (19,29–35). The least favorable results have been found when performing bipolar reconstruction of the femur and tibia (29,36,37), as well as the patellofemoral joint (36,38).

Chondrocyte stability after allograft has been found as late as 29 and 25 years (20,39). However, long-term allograft survival has been shown to depend on the stability of host-graft bone interface (30).

Although results in the review series are good, to our knowledge there does not exist any study comparing the autochondral transplantation with placebo.

As well, there are no studies comparing fresh osteochondral autografts with allografts in humans. However, when they have been compared in a dog model, both showed excellent bony incorporation. There were no significant differences in any of them at 3 or 6 months, versus control in the biomechanical testing. Lastly, articular cartilage composition did not show any difference after 6 months of implantation (40).

Microfracture has been considered the gold standard in the treatment of chondral defects due to its good results (41–43) and uncomplicated technique. However, when compared to osteochondral autografts in young competitive players in a randomized clinical trial at 3 years (44), OATS was found to have better clinical results at 12, 24, and 36 months. Patients in the OATS group had 96% of good and excellent results versus 52% in the microfracture group, using the HSS and ICRS outcome scores. The number of patients able to return to their preinjury level of sports activity at 6.5 months was higher in the OATS group (93% vs. 52%). When taking into account the level of integration shown in MRI studies, the OATS group had excellent or good repairs in 94% of the patients compared to 49% in the microfracture group. OATS also did better in the histological analysis.

The other option that surgeons have when treating osteochondral defects is the ACI. There are two studies, comparing the results of OATS and ACI (45,46) in a prospective randomized manner. Results are quite controversial in this aspect. In the Bentley (46) study at 1 year follow-up, ACI had better clinical and arthroscopic results using the Cincinnati and Stanmore scoring system (88% vs. 69%) and the ICRS score (82% vs. 35%). These results should be viewed with caution due to the different rehabilitation protocols used, and also due to the fact that the mean size of the defects treated were greater than the ideal indication (47). In contrast, Horas et al. (45) reported their results at 2 years in 40 patients with lesions in the femoral condyle. They used the Lysholm and Tegner scores finding no clinical differences between the techniques, although the ACI group showed a slower recovery. Histologically, there was more viable hyaline cartilage in the OATS group, although there was lack of complete integration of the core grafts and that surrounding the articular surface.

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42 Autologous Chondrocyte Implantation

Brian T. Feeley, Christina R. Allen, and Hubert T. Kim

INTRODUCTION

Autologous chondrocyte implantation (ACI) was first described in the New England Journal of Medicine in 1994 (1). At that time, ACI was a truly pioneering application of tissue engineering to treat full-thickness cartilage defects. In this technique, chondrocytes are isolated from the patients' own articular cartilage, expanded ex vivo, and reimplanted into the defect under a periosteal patch. The primary advantages of ACI are the ability to address relatively large defects and the development of more hyaline-like cartilage within the repair site (2). Theoretically, the presence of more hyaline-like cartilage will enhance the long-term durability and performance of the repair tissue.

Indications

The indications for ACI are similar to those of other cartilage procedures. The appropriate patient has a symptomatic grade III to IV lesion on the weight-bearing portion of the femoral condyle(s) or trochlea, between the ages of 15 and 55 years (Fig. 42.1). The typical size of the lesion is between 2 and 12 cm^2. Larger lesions and/or multiple lesions are also amenable to ACI treatment. Many patients would have had one or more prior cartilage procedure (i.e., debridement or microfracture). It is generally our preference to avoid performing microfracture in patients who are likely to undergo ACI. Although bony involvement is not a strict contraindication, bone loss of more than 6 mm in depth generally precludes the use of traditional ACI. However, significant bone involvement can be addressed by combining ACI with staged or concurrent bone grafting. Patients with grade III or grade IV reciprocal "kissing" lesions on the femur or tibia are not good candidates for ACI. Patients who are unable to be compliant with the postoperative restrictions and rehabilitation program should not undergo this procedure. Malalignment or instability of the affected limb that would overload the repair tissue should be corrected either before or at the time of ACI. It is our usual practice to perform any necessary corrective surgeries first and allow for recovery prior to any ACI procedures; however, other surgeons regularly perform ACI in conjunction with concurrent osteotomy and/or ligament reconstruction with good results.

Surgical Technique

The technique for standard ACI has remained essentially unchanged since its original description (Figs. 42.2–42.5). The initial phase of ACI, harvesting of the patient's articular cartilage, typically is performed as part of a standard knee arthroscopy. During the arthroscopy, areas of grade III to IV cartilage change are identified, and the size of the lesion is determined. Care is taken to identify any reciprocal grade III or IV "kissing" lesions, as this would be a contraindication to proceeding with ACI. Cartilage biopsies are usually obtained from the superomedial or superolateral aspect of the femoral condyles along the peripheral margin of articular cartilage. Alternatively, cartilage biopsies can be taken from the intercondylar notch. There are no data to suggest that any of these sites is clearly superior to the others. The cartilage biopsy is obtained using a gouge or ringed curette to remove approximately 200 to 300 mg (two "Tic Tacs") of tissue. A sharp gouge is frequently easier and more efficient to use than a curette. Inclusion of a small amount of bone with the cartilage specimen is common and not a problem, as subsequent processing prior to in vitro expansion will remove the contaminating

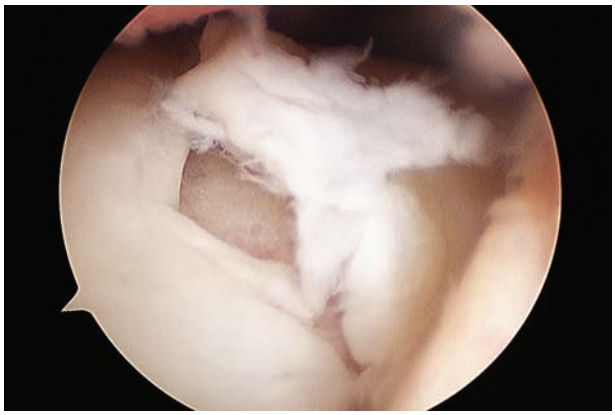

FIGURE 42.1

The patient is an active 37-year-old man with a 1-year history of activity-related knee pain and swelling after a direct blow to his knee. He has been unable to return to his usual sports activities in spite of standard conservative management. This intraoperative photograph taken at the time of the index procedure shows a large cartilage lesion involving the anterior aspect of the lateral femoral condyle. The articular cartilage had delaminated from the underlying bone, and the area of involvement was estimated to be at least 5 cm^2. The loose cartilage flaps were debrided. A cartilage biopsy specimen was performed in preparation for possible ACI. To be safe, sufficient cartilage (four Tic-Tac size pieces) was harvested for the preparation of two vials of expanded chondrocytes. No microfracture was performed.

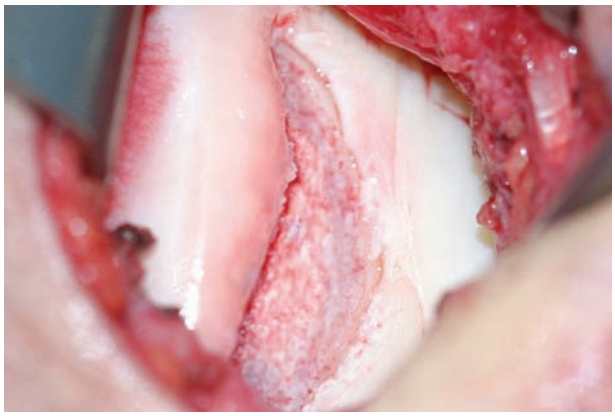

FIGURE 42.2

Eight weeks after the index procedure, the patient underwent the second stage of ACI. Based upon the location of the lesion, a limited lateral parapatellar arthrotomy was made. For the most part, there was a clear demarcation between the damaged area and surrounding normal cartilage. The margins of the lesion were cleanly outlined with a scalpel. Attention to tactile feedback is important during this step as the cut cartilage should feel relatively firm; otherwise, it is unlikely to hold a suture, and the margin should be extended in that area. The damaged cartilage was removed with a ringed curette down to subchondral bone. Punctate bone bleeding was controlled using small thrombin soaked sponges.

bone component. While it may be tempting in some cases to harvest mildly degenerative cartilage, we believe this is should be avoided. The harvested tissue is placed into a sterile transport container that is shipped to the cell processing facility. In the United States, almost all cartilage tissue processing for ACI is performed by Genzyme Corporation (Cambridge, Massachusetts). Chondrocytes are released from the cartilage matrix by enzymatic digestion and are then expanded under standard tissue culture conditions. The details of this process are considered proprietary and may vary slightly from one facility to another. The end product is a cell suspension of partially dedifferentiated chondrocytes. Typically, one vial of cells containing approximately 12 million cells is sufficient to treat a defect up to 7 cm^2 in size. Larger lesions may require more than one vial of cells, and this must be taken into account when sizing the defect(s), harvesting cartilage, and ordering cells for implantation.

The second procedure for implantation of the expanded chondrocyte cells is performed a minimum of 4 weeks following the index procedure to allow for in vitro expansion of the harvested chondrocytes. The procedure can be performed under either general or regional anesthesia. The patient is positioned supine on a standard operating table. It is helpful to tape a sand bag or 3-L saline bag to the table at the midcalf level so that

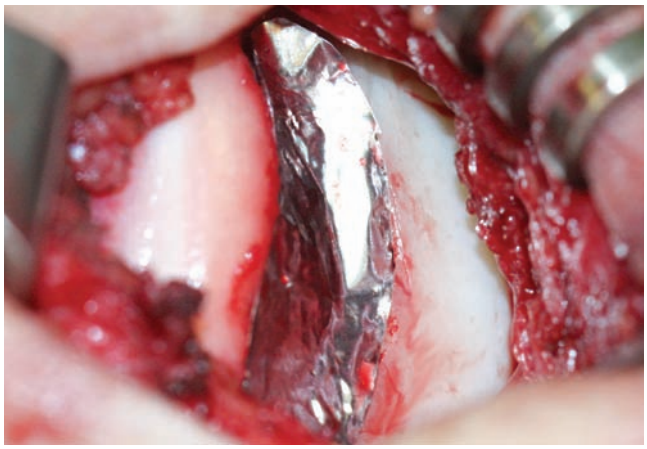

FIGURE 42.3

Sterile foil from a scalpel blade wrapper was cut to match the size and shape of the defect. This step requires some trial and error but must be performed precisely as a poorly sized or shaped template will make the rest of the procedure much more difficult.

FIGURE 42.4

For this case, a synthetic collagen I/III collagen membrane (Bio-Gide) was used in lieu of an autologous periosteal patch. Prior to surgery, this modification to the standard ACI procedure was discussed with the patient in depth as this treatment is "off label." This membrane has smooth and rough sides. The rough side is treated like the cambium side of a periosteal patch. A standard skin marking pen is used to mark the smooth side to maintain orientation. The collagen membrane is easier to manipulate and cut to shape when dry. Suture passes through this material more smoothly than through periosteum, so the use mineral oil is not necessary.

the knee can be held flexed to approximately 90 degrees. An Alvarado positioner can be used instead, and it has the added benefit of being able to fine-tune the knee position for optimal exposure. A lateral post is also useful to keep the leg vertically positioned. The leg is prepped distal to a nonsterile tourniquet, which is not typically inflated. For most cases, we prefer a midline skin incision, which can most easily be incorporated into any future surgical procedures on the knee. Alternatively, a parapatellar skin incision can be used and is equally effective. The arthrotomy is performed based on the location of the lesion. For trochlear lesions, we favor a medial parapatellar arthrotomy with a "midvastus" extension as necessary. Any dissection distally along the tibial plateau should be performed carefully in order not to damage the anterior horn of the medial or lateral meniscus.

For defects involving the medial or lateral femoral condyles, bent Homan retractors are placed on either side of the affected condyle. Knee flexion is adjusted to an appropriate angle to best expose the lesion in the operative field. For trochlear lesions, typically less flexion or even full extension provides optimal exposure. Once the defect is well visualized, the perimeter of the lesion is demarcated with a fresh No. 15 blade cutting perpendicular to the articular surface down to the subchondral bone. Although some surgeons use a sharp curette for this step, we believe a scalpel minimizes iatrogenic damage and cell death in the surrounding cartilage that may affect repair tissue integration. Straight, angled, and ring curettes are used to remove all remaining cartilage

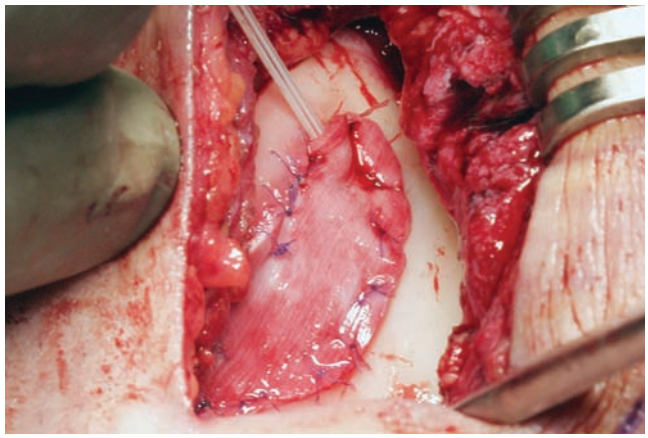

FIGURE 42.5

The membrane is secured to the margins of the cartilage defect using 6-0 Vicryl sutures spaced approximately 4 mm apart. Saline is injected under to patch to check for watertightness, and additional sutures as placed as necessary. We strive for water-tightness with sutures alone, but a small amount of leakage can be managed with fibrin glue. The cultured chondrocytes are gently resuspended in the transport vial and then injected under the patch. The opening is closed with an additional suture and sealed with fibrin glue.

within the outlined lesion. The goal is to create a sharp line of demarcation with vertical walls of surrounding articular cartilage. Care should be taken to avoid penetration of the subchondral bone so as to prevent bleeding that may have an adverse effect on the implanted cells. If some bleeding in the prepared bed is identified, hemostasis can usually be obtained by placing a thrombin-soaked sponge in the defect during the harvesting of the periosteal graft and/or with the use of fibrin glue. Ideally, the repair site is prepared such that the entire perimeter of surrounding cartilage is completely normal. However, "real world" lesions not infrequently are bordered by some areas of slightly softened articular cartilage. Our experience is that ACI can be performed successfully in these situations as long as the cartilage is firmly fixed to the underlying bone and that sutures can be placed securely into the surrounding cartilage. If not, the area to be repaired must be enlarged.

The defect is then measured to determine the proper size of the periosteal patch. Either sterile paper or a small piece of aluminum is placed over the lesion site and marked with a surgical marker as a template for periosteal graft harvest. We typically use the aluminum foil from the sterile scalpel blades as this is easy to manipulate as a template for the graft. The template should be sized 1 to 2 mm larger than the defect around the entire circumference.

The periosteal graft can be obtained from multiple sites. The most common location is the proximal medial tibia, just distal to the pes insertion. The periosteum at this site is particularly well suited for implantation. The incision can be extended or a separate incision can be made. The dissection is carried down to the periosteum sharply, and all fat and subcutaneous tissue is removed from the harvest site. The periosteum to be harvested is marked from the template, and a fresh No. 15 blade or sharp and thin periosteal elevator is used to elevate the periosteum from the underlying bone. Prior to harvesting, it is useful to mark the exposed surface of the graft with a standard marking pen so that there will be no confusion as to which side is the cambium surface. Electrocautery should not be used to harvest the periosteal graft as this will kill cells that potentially contribute to the repair. It is important to handle the periosteal graft gently and not allow it to dry out. Although every attempt should be made to harvest the periosteum as an intact sheet, perforations do occur and can be repaired using interrupted or running 6-0 Vicryl suture.

The graft is fixed over the lesion to the surrounding cartilage using a 6-0 Vicryl suture with a cutting needle, cambium layer down. Sutures are placed at 3 to 4 mm intervals around periphery of the lesion. Using a dyed suture, though not necessary, makes visualization of the suture material considerably easier during graft fixation. The use of magnifying loupes during this portion of the procedure may also be helpful. Sterile mineral oil can be used to coat the suture prior to passage through the periosteum in order to prevent binding of the suture to the periosteum. The needle is first passed through the periosteum, 2 mm from the edge, and then into the cartilage edge, exiting approximately 4 mm from the edge. It is sometimes helpful to decrease the needle's radius of curvature by carefully bending it with needle drivers, maintaining a smooth curve. Simple instrument tying techniques are used to secure the sutures. The knot should be placed over the periosteum, not the adjacent native cartilage. It is often easiest to place the first four sutures at the 12, 6, 3, and 9 o'clock positions for round or oval defects. For more rectangular-shaped defects, the first four sutures are best placed in the "corners." It is also possible to address lesions that are not completely bordered by articular cartilage by securing the periosteal patch using small suture anchors. In these cases, anchors should be placed not more than 5 mm apart. Alternatively, sutures can be placed through transosseous tunnels made with a small K-wire. A potential downside to

the use of either anchors or transosseous tunnels is the risk of increased bleeding at the repair site. However, bleeding from the bone holes usually can be controlled using fibrin glue. Regardless of fixation method, secure graft fixation is paramount.

A small area at the most superior aspect of the repair site is left open to accommodate an 18-gauge angiocatheter through which the cells will be injected. Otherwise, the repair must be essentially watertight prior to cell implantation, which should be verified by injecting saline under the patch. Additional sutures are placed as necessary. Any fluid beneath the patch is aspirated. The chondrocyte cell suspension is then drawn into a syringe and injected under the periosteal patch. The angiocatheter is removed, and additional sutures are placed to complete the watertight seal. We routinely seal the edges of the repair site with fibrin glue, which may decrease the chances of subsequent leakage. The use of fibrin glue may be especially prudent if the quality of the surrounding cartilage is less than ideal or if suture anchors were used to secure part of the patch. If the tourniquet was inflated, it should be released and meticulous hemostasis obtained prior to wound closure. We prefer not to use intra-articular anesthetics based on recent reports of toxicity to chondrocytes, particularly when they lack the protective barrier of their native extracellular matrix.

Recent modifications to the original ACI procedure have made the procedure substantially simpler. Most notably, the use of a type I/III collagen membrane as a substitute for the periosteal graft has become increasingly popular (3). The membrane is derived from porcine peritoneum and skin (Bio-Gide, Geistlich Pharma) and currently is approved in the United States for dental procedures. The use of this membrane for ACI is "off-label" and, as such, must be discussed with patients prior to surgery. The primary benefits of the so-called collagen membrane covered ACI (c-ACI) include decreased morbidity associated with graft harvest, decreased operative time, and decreased reoperation rates to address graft hypertrophy. In spite of the loss of potential regenerative cells from the periosteal graft, short- and intermediate-term clinical results have been at least equal to those of traditional ACI.

POSTOPERATIVE CARE

Postoperative rehabilitation following ACI is felt to be critical to achieving optimal results. Immediately after surgery, patients are immobilized for 6 to 12 hours to allow the cells to adhere to the subchondral bone. The first phase of the rehabilitation process, lasting approximately 6 weeks, focuses on protection of the repair site to allow for initial filling of the defect with repair tissue. Typically, patients are instructed to remain non–weight bearing during this phase, particularly for lesions involving the central weight-bearing areas of the femoral condyles. Patients with trochlear lesions or femoral lesions outside of the central weight-bearing areas may be advanced more rapidly, with range of motion limits set to prevent engaging the defect during weight bearing. A CPM is initiated from postoperative day 1 and used 6 to 12 h/d for 4 to 6 weeks if possible. The second phase, lasting through week 12, focuses on a gradual increase in functional activities while protecting the repair tissue, which remains soft and highly susceptible to damage. Low impact exercises such as stationary bicycling and treadmill walking are initiated, and transition to full weight bearing is allowed as tolerated. The third phase, lasting through the 6th postoperative month, focuses on achieving full functional capacity other than sports. The goal should be normal knee motion, leg strength, balance, and stability. By this point, the repair tissue is more durable and tolerant to impact activities. Full activities, particularly high impact sports, are limited for the first 12 to 18 months postprocedure to allow for further repair tissue maturation.

RESULTS

The initial outcomes of ACI were reported in 1994 by Brittberg et al. (1). The 23 patients ranged from 14 to 48 years of age, and the lesions ranged from 1.6 to 6.5 cm^2. The average follow-up was 39 months. A majority of the patients underwent multiple "second-look" arthroscopies. At 3 months, the grafts were level with the surrounding tissue and spongy when probed. At a second arthroscopy, the grafts looked similar but had significantly more firmness. Biopsies showed that 11 of the 15 femoral transplants and 1 of the 7 patellar transplants had the appearance of hyaline cartilage. Fourteen of the sixteen patients with femoral condylar lesions had good or excellent results. The other two patients required a second operation due to severe central wear and persistent locking and pain. Recently, these authors reported long-term 10- to 20-year results demonstrating maintained clinical and functional benefits based on patient-completed questionnaires (4). There have been very few well-controlled studies that have evaluated the outcomes of ACI. Zaslav et al. (5) recently performed a prospective clinical study to determine the effectiveness of ACI in patients who failed prior treatments for articular cartilage defects in the knee. There were 154 patients with a mean follow-up of 4 years in this multicenter trial. At the time of follow-up, 76% of the patients were deemed a clinical success based on knee pain, quality of life, and overall health. The results did not differ if the patients had a marrow stimulation procedure prior or a debridement alone. Seventy-six (49%) of the patients had a subsequent surgical procedure. The authors concluded that ACI was effective in providing pain relief as well as improved quality of life in patients who had undergone a previous knee cartilage procedure.

Several studies have compared ACI to other cartilage restoration techniques. Anderson et al. (6) compared ACI to microfracture in a prospective study. There were 23 patients in each group, and all lesions were >2 cm^2. There were mean improvements in overall condition scores in both groups (microfracture: 1.3; ACI 3.1, $p < 0.05$). Two patients in the ACI group and six in the microfracture group were categorized as treatment failures.

Bentley et al. (7) performed a prospective, randomized study comparing ACI to mosaicplasty, with 50 patients in each treatment group. The patients were young (average age: 31 years) and the lesions were an average of 4.7 cm^2. The patients typically had a long duration of symptoms (mean: 7.2 years), and many had had a previous surgery. At 19 months average follow-up 88% of the ACI patients and 69% of the mosaicplasty patients had a good to excellent result with clinical outcome scores. Arthroscopy at 1 year demonstrated excellent or good repairs in 82% after ACI and in 34% after mosaicplasty. The authors concluded that there was a significant advantage of using ACI compared to mosaicplasty, as it appeared to offer better clinical outcomes with better repairs as visualized by arthroscopy.

There are several limitations to ACI. Many patients are unwilling to undergo two procedures and the long recovery time necessary in order to allow the cartilage to mature. The additional cost of a second surgery, along with the cost of ex vivo chondrocyte expansion, is substantial and may negate any clinical benefit from a cost-utility standpoint. In the United States, insurance authorization can be problematic, but is greatly facilitated with good clinical documentation. Wood et al. (8) reviewed the adverse outcomes of ACI reported to the FDA from 1996 to 2003. During this time, there were 7,500 lots of Carticel (Genzyme Tissue Repair, Cambridge, Masschusetts) distributed to physicians and 294 adverse event reports. More than one adverse event was reported for 135 of the 294 (46%) patients. The median interval from implantation to the diagnosis of an adverse event was 240 days (range: 1–2,105). The most common adverse event was graft failure, accounting for 24.8% of all adverse events. Delamination represented 22.1% of adverse events, and tissue hypertrophy accounted for 17.7% of adverse events. Of the 294 patients who had an adverse event, 273 (93%) had 389 surgical revisions subsequent to implantation. Most of the revisions (48%) involved subsequent cartilage procedures and included debridement, chondroplasty, and microfracture. Almost 25% of the reoperations were periarticular procedures such as a lysis of adhesions, lateral release, or synovectomy. Eight patients required a total knee replacement. The data from this study reflect the outcomes of previous studies examining the outcomes of ACI. Peterson et al. reported 52 adverse events in 101 patients, including 26 instances of periosteal hypertrophy and seven graft failures. Similarly, Minas describes 5 of 70 patients requiring additional surgical intervention following ACI (9). While the overall complication rate and need for reoperation for ACI have been relatively high, addressing these problems typically involves simple debridement and yields excellent results. Furthermore, procedure modifications including the substitution of a collagen matrix patch for the traditional periosteal patch markedly decreased the need for reoperation. Nevertheless, it is prudent to specifically discuss with each patient the possible need for an additional, but straightforward, arthroscopic surgery after ACI.

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43 Osteochondritis Dissecans

Cecilia Pascual-Garrido, Mark A. Slabaugh, Nicole A. Friel, and Brian J. Cole

INTRODUCTION

Osteochondritis dissecans (OCD) is a pathological condition that results in destruction of subchondral bone with secondary damage to overlying articular cartilage (6,13). OCD is classically divided into juvenile and adult forms on the basis of the patient skeletal maturity (6). Juvenile OCD occurs in children and young adolescents who have open growth plates. Although adult OCD may arise *de novo*, it is more commonly the result of an incompletely healed previously asymptomatic juvenile OCD lesion (21). Juvenile OCD has a much better prognosis than does adult OCD, with higher rates of spontaneous healing with conservative treatment (5). Adult OCD lesions have a greater propensity for instability and once symptomatic, typically follow a clinical course that is progressive and unremitting (31). The highest incidence rates in juvenile OCD appear among patients between 10 and 15 years old, ranking among the most common causes of knee pain and dysfunction in young adults (5,31,36). The prevalence of OCD is estimated at 15 to 21 per 100,000 (28). Lesions most frequently occur on the femoral condyles but are also found in the elbow, wrist, ankle, and femoral head (3,7,18,44,48). Nonoperative treatment (activity modification) drilling and fragment fixation are strategies to preserve the native articular cartilage. Restorative biological therapies such as marrow stimulation, autologous chondrocyte implantation (ACI), osteochondral autograft, and fresh osteochondral allograft (OA) are indicated to replace the damaged cartilage with hyaline or hyaline like tissue when preservation fails (40) (Fig. 43.1).

PRESENTATION AND IMAGING

The typical presentation of OCD in the knee includes pain and swelling related to activity. Instability is not usually reported, though mechanical symptoms (catching or locking) do usually occur in the presence of a loose body and are frequently the initial presenting symptoms. On physical exam, patients typically have tenderness localized over the OCD lesion. More than 70% of OCD lesions are found in the "classic" area of the lateral aspect of the medial femoral condyle (MFC) intersecting the intercondylar notch near the PCL. Central lateral condylar lesions account for 15% to 20% and femoral trochlear lesions for <1%. Patellar involvement is uncommon (5%–10%) and is typically located in the inferior medial area (31).

The patient may walk with an antalgic gait or with the leg externally rotated (Wilson sign) to decrease pressure over the lesion (39). Effusion, decreased range of motion, and quadriceps atrophy are variably present depending upon the severity and duration of the lesion (17).

Standard anteroposterior and lateral radiographs of the knee permit localization of the lesion and assessment of the physeal status of the patient. Additional images such as tunnel or sunrise views are useful for suspected distal MFC or patellar lesions, respectively. By convention, lesions may be anatomically localized using the Cahill classification (6) (Fig. 43.2). Magnetic resonance imaging (MRI) is the mainstay in diagnosis of OCD lesions. Lesion qualities including bone edema, subchondral separation, and cartilage condition may be evaluated prior to determining a treatment course (Fig. 43.3). Intraoperatively, OCD lesions may be classified using the criteria suggested by Guhl (25) (Table 43.1).

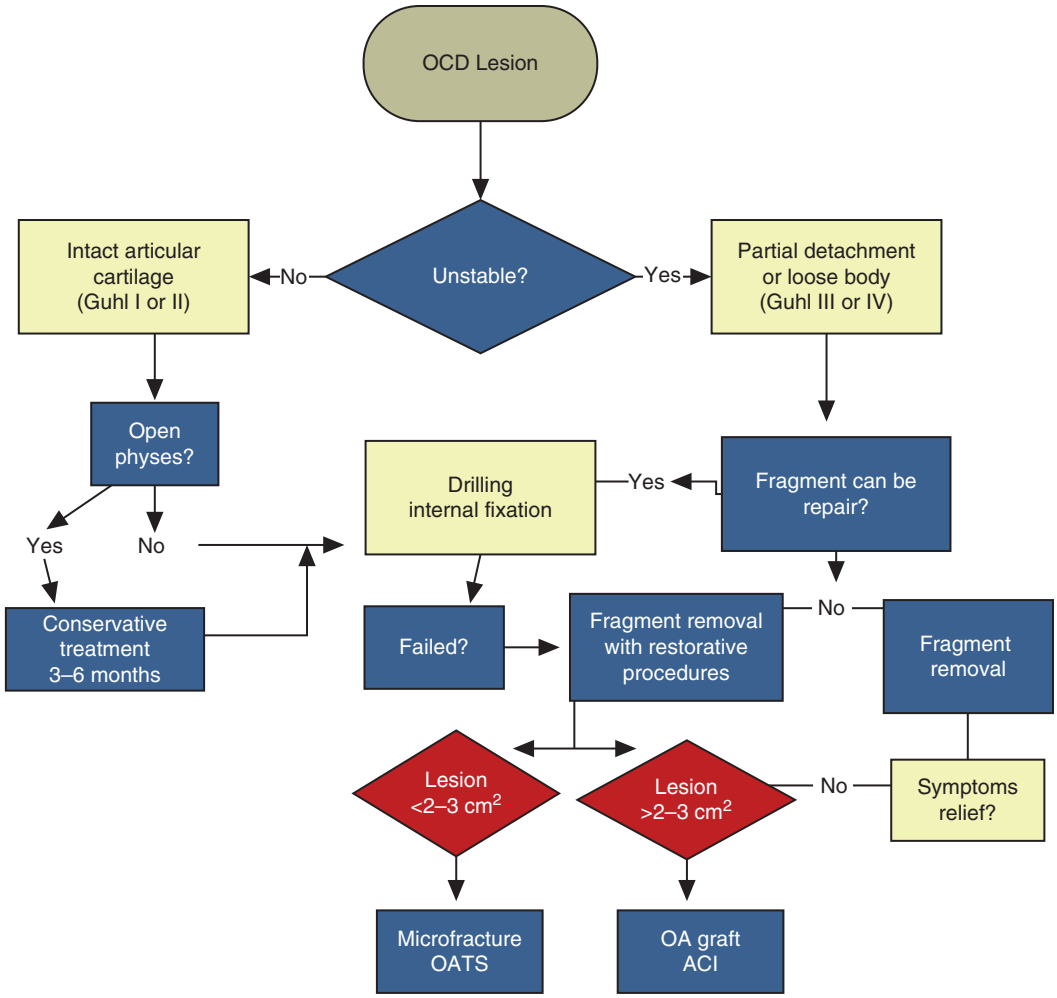

FIGURE 43.1
Algorithm for surgical treatment of JOCD/OCD. Surgical goals should always try to reestablish the joint surface and conserve the osteochondral fragment. If not, restorative treatment should be implemented.

TABLE 43.1 Description of the Guhl's Classification

Grade	Intraoperative Finding
I	Normal articular cartilage
II	Fragmentation in situ
III	Partial detachment
IV	Complete detachment, loose body present

Source: Guhl JF. Arthroscopic treatment of osteochondritis dissecans. *Clin Orthop Relat Res.* 1982;167:65–74.

NATURAL HISTORY AND PROGNOSIS

The natural history of untreated OCD lesions is poorly defined. Most adult OCD cases arise from established untreated or unrecognized juvenile OCD. Many younger adult OCD patients have a history of knee symptoms dating back to a time when their physes were open. These cases probably represent juvenile OCD that did not heal and evolved to adult OCD. Spontaneous healing of juvenile OCD lesions has been reported when the lesion is not in the classical location of the lateral aspect of the MFC (11).

Neither the literature nor our experience allows us to definitively determine whether untreated OCD, either with the fragment in situ or following fragment excision, categorically has a more significant likelihood of developing symptomatic DJD in the future. Linden performed a long-term retrospective follow-up study of patients with OCD of the femoral condyles with an average follow-up of 33 years after initial diagnosis (36). It was concluded that individuals who are older when the osteochondritis manifests (adult OCD) have an increasing incidence of gonarthrosis with age. In contrast, OCD diagnosed in childhood have no increase risk of osteoarthritis later in life when compared to the normal population. In contrast, Twyman et al. (53) completed

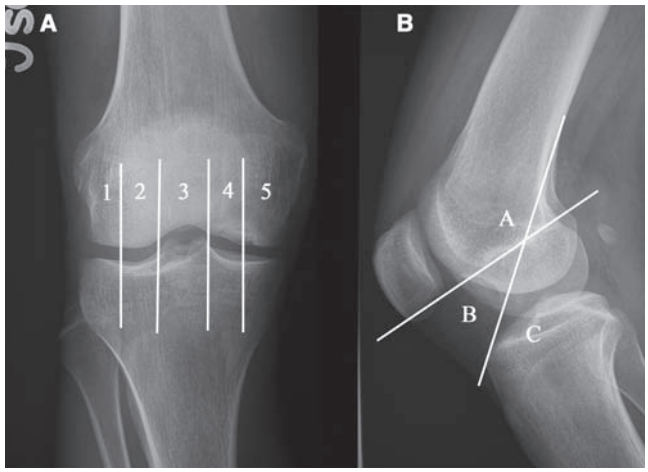

FIGURE 43.2

A: Anteroposterior radiograph of a 35-year-old male with an OCD lesion occupying the weight-bearing area of the femoral condyle. As per Cahill's classification, numbering of the five anatomic areas begins in the middle side. The condyles are bisected and area 3 is bounded by the walls of the intercondylar notch. **B:** Lateral radiograph of the same OCD lesion. The line separating A and B represents the roof of the intercondylar notch. The line separating B and C is a continuation of the posterior femoral cortex.

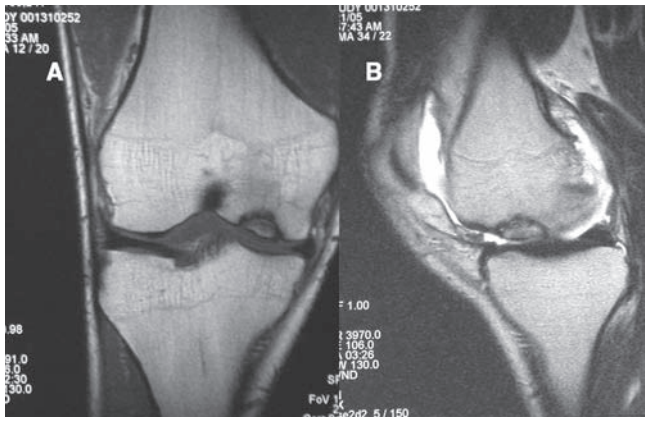

FIGURE 43.3

A: Coronal MRI of the knee of an OCD lesion of the MFC of the left knee. Note the low-intensity signal between the osteochondral fragment and the subchondral bone, suggesting an unstable fragment. **B:** Sagittal MRI through the MFC.

a prospective follow-up of 22 knees with juvenile OCD into middle age and found 50% had some radiographic signs of osteoarthritis. The likelihood of osteoarthritis development was also found to be proportional to the size of the area involved.

Early studies evaluating the results of treatment of these lesions focused on fragment excision. Denoncourt et al. (12) treated 37 patients with arthroscopic removal of the fragment and curettage of the lesion. They reported complete "healing" in ten cases by second-look arthroscopy. They recommended this treatment in adults and children who have failed initial attempts at nonoperative treatment. Similarly, Ewing and Voto (16) excised the fragments and drilled the defect in 29 patients. They reported a satisfactory result in 72% of their patients with short-term (<1 year) follow-up. Recent reports suggest that fragment excision may provide short-term pain relief but not provide long-term success with further follow-up. Anderson et al. (1) evaluated 19 patients with 20 OCD lesions who were treated with fragment excision. Follow-up between 2 and 20 years showed that only five patients could participate in strenuous activity without significant symptoms. Eleven patients had pain with activities of daily living, and the remaining three patients had pain with light activities. It was concluded that fragment excision may show improvement of the symptoms in the short term, but the remaining defect and involved compartment may worsen with time.

Contemporary surgical decision making is based upon patient age, skeletal maturity, lesion appearance, and clinical symptoms. Stable OCD lesions in young patients have a favorable prognosis when treated initially with nonoperative treatment. The ideal goal of conservative treatment is to obtain lesion healing before physeal closure. Authors who focus on the biology of the fragment-subchondral bone interface argue that the knee should be protected in a knee immobilizer and treated similar to an intra-articular fracture (6). Alternatively, some authors place a premium on the health of the articular cartilage and note the value of continuous motion (6). Hughston et al. (28) demonstrated the detrimental effects of prolonged immobilization, including stiffness, atrophy, osteopenia, and, potentially, chondropenia. Traditional nonoperative treatment for juvenile OCD consists of an initial phase of knee immobilization with partial weight bearing (4–6 weeks) in those patients in whom no detachment is noted on MRI. Once the patient is pain free, weight bearing as tolerated is permitted and a rehabilitation program emphasizing knee range of motion and low-impact strengthening exercises ensues. If there are radiographic and clinical signs of healing at 3 or 4 months after the initial diagnosis, patients

may participate in a gradual return to sports with increasing intensity allowed in the absence of knee symptoms. The likelihood that the lesion will heal with this management is approximately 50% at 10 to 18 months (7).

Operative treatment is indicated for young patients with detached or unstable lesions or those approaching physeal closure whose lesions have been unresponsive to nonoperative management (6,16). Operative treatment may also be considered in patients who are unable participate in or intolerant of a prolonged nonoperative course. In contrast, adult OCD typically follows a clinical course requiring early surgical intervention (21). A large multicenter review of the European Pediatric Orthopedic Society study (509 knees, 318 juvenile, and 191 adult in 452 patients) suggests an improved prognosis with conservative treatment in young patients with a small lesion (<2 cm^2) in the classic location with no signs of dissection or effusion. In cases of chondral separation, surgical results are better than those with nonsurgical treatments (27,50).

SURGICAL OPTIONS

Reparative Treatments

The goal of reparative procedures is to restore the integrity of the native subchondral interface and preserve the overlying articular cartilage (39). Interventions such as drilling or internal fixation are indicated for the symptomatic juvenile patient who has failed a course (generally 3–6 months) of nonoperative treatment. Depending on the severity of symptoms, when the presence of significant mechanical symptoms dominates the clinical presentation, a decision to operate might occur earlier, especially when the MRI shows a detached articular fragment. These procedures provide clinical relief in a majority of patients and leave many viable options for revision in case of inadequate symptomatic relief.

Drilling

The disruption of subchondral blood supply is thought to be an important factor in the development of OCD (2). Treatment to enhance fragment healing incorporates the creation of vascular channels to the devitalized region. Drilling is generally limited to low-grade lesions (Guhl grades I and II, respectively) in young patients with open physes. Typically, these lesions are not grossly unstable with palpation. Drilling may be an adjuvant to improve the blood supply to the lesion; transchondral and retrograde approaches have been described. Antegrade drilling—through the articular surface and into the femoral epiphysis—is done arthroscopically under direct visualization (8,32,37). If the lesion is not accessible via standard portals, accessory portals are created to obtain an orthogonal drilling angle. A K-wire 2 cm longer than a small cannula facilitates the direction and depth of the channels (2). Return of blood and fat droplets through the articular surface confirms penetration of cancellous bone. More commonly, drilling can be performed by entering at a nonarticular location. For example, the classic OCD lesion along the lateral aspect of the MFC can be entered at the anterior aspect of the PCL origin along the inner margin of the MFC with a K-wire introduced percutaneously or through the inferolateral portal. Retrograde drilling is inherently more difficult when targeting the lesion base. C-arm visualization is needed and will help avoid joint penetration or dislodgement of the OCD fragment. Alternative methods including sonography (4) and the use of an ACL guide (33) have been proposed. Large-diameter drilling with iliac crest bone graft supplementation has also been described (34).

Outcomes of OCD drilling are generally favorable, with patient age being the best prognostic factor. Individuals with OCD diagnosed and treated with drilling as an adult have decreased radiographic healing and less favorable symptom outcomes (2). Louisia et al. (37) noted 71% (12/17) radiographic healing and two poor results in juvenile OCD compared with 25% (2/8) healing and four poor results in adult OCD patients. Overall, good to excellent results are observed in >80% of adolescent patients, with 70 percent or more being able to return to sports (3,31,33,37). It is our opinion that the ideal patient with symptomatic OCD to treat with drilling is when the defect is grossly stable to palpation despite some MRI evidence of fluid behind the fragment indicating biologic instability. Occasionally, we will augment the treatment of these lesions with the placement of a bioabsorbable differentially pitched threaded compression screw (Arthrex, Inc., Naples, Florida).

Internal Fixation

Higher grade OCD lesions with articular cartilage flaps or loose bodies (Guhl grades III and IV, respectively) are generally not amenable to conservative treatment. Reattachment of partially detached lesions or loose bodies is appropriate for large fragments containing sufficient subchondral bone to provide union and support of the fixation system. Lower grade lesions (Guhl grades I or II) may be fixed if conservative treatment has failed or there is clinical suspicion of instability. Fixation can be accomplished with bone pegs, osteochondral grafts, metal or bioabsorbable devices (1,22,43). In vitro studies suggest that compression, resulting in friction between the fragment and the base, improves stability and resistance to shear loading. Unstable "trap door" lesions that are partially elevated from the subchondral bed require fixation (45,55). If accessible, the base of the lesion and bony surface of the flap are debrided. Microfracture awls can be used to penetrate the base and allow improved access to the subchondral blood supply. The fragment is reduced and temporarily fixed with

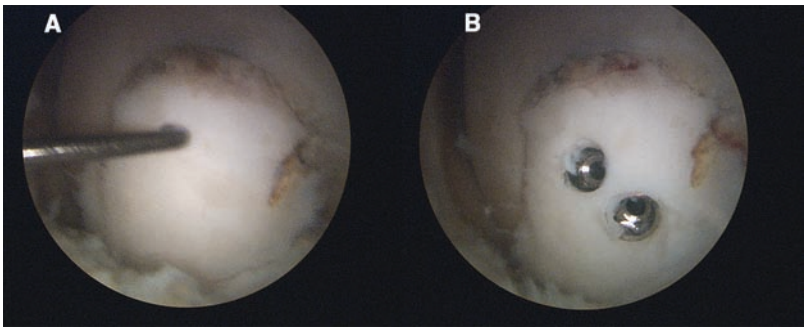

FIGURE 43.4

A: Intraoperative, arthroscopic view of OCD lesion of the MFC in a 20-year-old male. **B:** Anatomic reduction and fixation of the osteochondral fragment was performed with compression screws fixation.

K-wires to facilitate the final placement of the fixation device. In most cases, fixation is accomplished at two or more locations to impart compression and rotational stability to the fragment. All devices should be recessed beneath the cartilage surface, with metal screws being removed postoperatively when evidence of union is seen (Fig. 43.4), typically 6 to 8 weeks later. Bioabsorbable fixation is an option, especially when patients desire to avoid a second surgery. However, second-look arthroscopy and hardware removal provide the dual benefit of verifying defect healing and removing hardware, which might become prominent should the fragment settle around the fixation device. Postoperatively, patients may heel-touch weight bear and, when available, utilize continuous passive motion (CPM) machines for 4 to 6 h/d.

Favorable outcomes after internal fixation of OCD fragments have been reported for both metallic and bioabsorbable devices. Kivistö et al. (29) noted good to excellent results in 86%of young patients treated with staple fixation (53% radiographic healing). A study of Herbert compression screw fixation yielded 13/15 (87%) normal knees by IKDC grading and radiographic healing in 93% (38). Gomoll et al. (22) evaluated 12 adolescent patients with unstable Cahill Type 2C lesions treated with compression screw fixation with average 6 year follow-up. All lesions healed without clinical or radiographic evidence of degenerative disease. Fixation with self-reinforced poly-L-lactic acid nails and pins permits radiographic healing in 60% to 100% of cases (14,46). A cohort study by Weckström et al. (54) suggests that implant geometry (i.e., presence of barbs or a flared head) is a factor in successful outcomes. Complications associated with OCD fixation included damage to opposing cartilage surfaces from proud hardware, broken hardware, loose bodies, and synovitis (19,29,50).

Restorative Treatments

In the event that the fragment cannot be initially stabilized and requires excision or fails to heal after initial fixation, some decision making is inevitably required to determine the clinical relevance of the remaining defect. Many patients have coexisted with OCD only to become symptomatic when the osteochondral fragment becomes unstable. Fragment removal can lead to symptom relief. Arguably, because the natural history of OCD is poorly understood, performing a restorative procedure immediately is debatable. Careful questioning of the patient prior to fragment fixation or following fragment removal can help determine if the defect bed is clinically relevant. Complaints of achy discomfort, effusions unrelated to mechanical symptoms, weight-bearing pain over the lesion may be indicative that symptoms are due to the defect itself rather than the unstable or displaced fragment. The easiest decisions are when the defects are relatively small or from areas with less contact pressure (51) (i.e., classic OCD located near the PCL origin on the "upslope" of the MFC) and associated with the acute onset of mechanical symptoms in a skeletally mature adult. Fragment removal and observation may be all that is required. Appropriately educating patients about defect-related symptoms is critical to successful follow-up to detect if further intervention and cartilage restoration are indicated. Cases of OCD where the lesion is large and weight bearing (i.e., OCD of the lateral femoral condyle) require far more difficult decision making. Arguably, these lesions are likely to be associated with the worst natural history and therefore, depending on the depth of subchondral bone loss, may require more complex restorative intervention.

Restorative procedures attempt to replace damaged cartilage with hyaline or hyaline-like tissue (8,35). It is critical that the surgeon consider the "next step" option if initial surgical management fails and the patient has classic symptoms related to the defect itself. The treatment algorithm proceeds from the least destructive and invasive methodologies to avoid "burning bridges" for future options (11). Most importantly, identifying and treating each patient with relevant comorbidities such as malalignment, meniscal and ligament deficiency is imperative to render successful treatment.

Marrow Stimulation Techniques

Abrasion chondroplasty, subchondral drilling, and microfracture involve breaching the subchondral bone to allow the influx of pluripotent stem cells from the marrow into the osteochondral defect resulting in fibrocartilage formation (52). Microfracture is indicated in patients with a localized cartilage defect (<2 cm to 4 cm^2). Patients with low demand and bigger lesions can also improve with this technique. The calcified cartilage layer

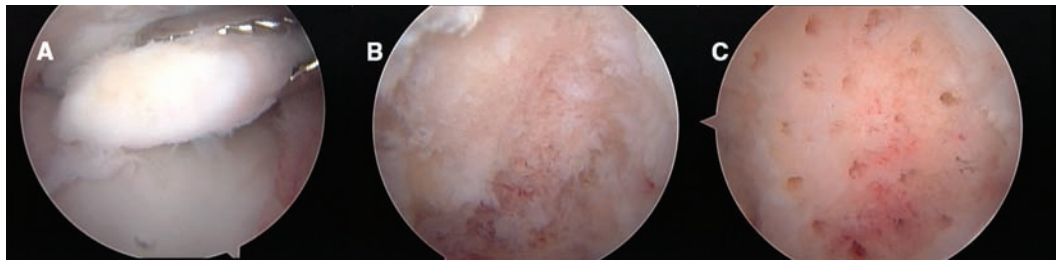

FIGURE 43.5

A: Intraoperative, arthroscopic view of an unstable osteochondral fragment. **B:** Removal of the unstable lesion, revealing the underlying subchondral bone. **C:** Microfracture holes throughout the entire area of the OCD lesion.

is carefully debrided and surgical awls are used to penetrate the subchondral bone to enhance defect fill (20) (Fig. 43.5). Postoperative rehabilitation requires up to 6 weeks of non–weight bearing with the use of CPM machines for 6 h/d. Gudas et al. (24) suggested that OCD lesions treated with microfracture have a significantly worse clinical outcome than traumatic cartilage lesions. Normally, large lesions (more than 2 cm^2) treated with microfracture demonstrate deterioration with time due to decreased fibrocartilage resilience and stiffness (41). Knutsen et al. compared results at 2- and 5-year follow-up in 80 patients who had a single chronic symptomatic cartilage defect on the femoral condyle of the knee, treated randomly with microfracture or ACI (30). Twenty eight percent of these lesions were due to OCD. Both treated groups showed satisfactory results in 77 percent of the patients at 5 years. No significant difference between the two treatments groups was evident. They proposed that microfracture should be preferred as first-line treatment option for defects located on the medial or lateral femoral condyle of the knee. Microfracture should therefore be considered as the first-line treatment in lesions <2 cm^2 with subchondral bone integrity and in patients with lower physical demand levels and slightly larger lesions (2–4 cm^2).

Osteochondral Autograft Transplantation

The technique of transplanting osteochondral tissue from a non–weight-bearing region of the knee to restore a damaged articular surface has been well described (25). The indications and optimal patient population for this technique remain narrow. A single plug autograft is preferred for defects smaller than 1 cm^2. However, some authors perform mosaicplasty with multiple smaller plugs on defects as large as 4 cm^2 with encouraging results (26). Protected weight bearing is encouraged for up to 6 weeks after surgery. The advantages of the osteochondral allograft transplantation (OATS) technique include absence of disease transmission risk and the lower cost of a single-stage procedure. Disadvantages include donor site morbidity and limited available graft volume. In addition, it is technically difficult to position the plugs to re-create the exact contour of the condylar surfaces. Despite these limitations, results from isolated small- to medium-sized lesions of the femoral condyle have been good: 91% good to excellent results at >3 years (26). Interestingly, Miniaci et al. (43) have suggested using the OATS technique for the fixation of unstable OCD lesions of the knee. Twenty patients with OCD lesions were fixed in situ by using multiple 4.5-mm osteochondral dowel grafts harvested from the edges of the trochlea. At 18 months postoperative, all knees were scored as normal and radiographically healed at 6 months postoperatively. Advantages of this technique include the fact that a considerable volume of the original lesion is replaced by autologous bone graft. This technique was used to provide stable biological fixation using autogenous bone graft. Outerbridge et al. (47) reported favorable short-term results using autografts harvested from the lateral facet of the patella in ten patients with large femoral OCD lesions. When treating the empty defect with osteochondral autografts as a reconstruction technique, specific attention to re-creating the natural contour of the condyle with accurate depth and plug placement and avoiding graft instability due to relative uncontainment are critical to avoid early failure.

Osteochondral Allografting

Larger OCD lesions (>2 cm^2) may be treated with OATS (23). OA transplantation provides the ability to resurface larger and deeper defects with mature hyaline cartilage, while addressing the underlying bone deficiency. Potential disadvantages include limited graft availability, decreased cell viability, immunogenicity, and disease transmission. Commercially available instrumentation systems permit sizing and matching of a cylindrical allograft plug to the defect. Usually, it is possible to press fit the graft; however, if necessary fixation of the allograft with bioabsorbable compression screws or headless differentially pitched titanium screws is performed. Postoperatively, restricted weight bearing is recommended for at least 8 weeks. In a cohort of 64 patients treated with fresh OATS, 72% had good to excellent clinical outcomes at 7.7 years after

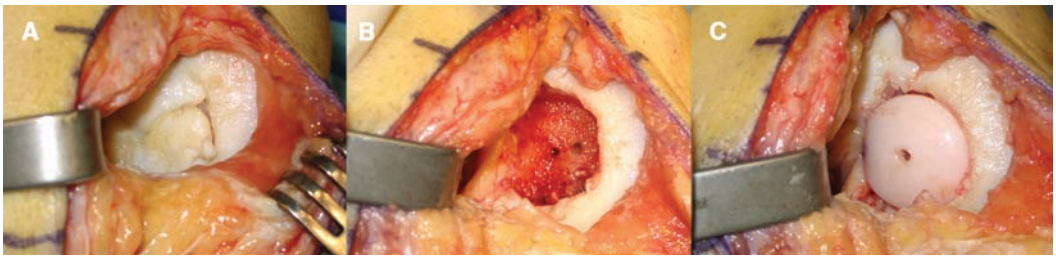

FIGURE 43.6

A: Intraoperative photo demonstrating a large OCD lesion located on the MFC. **B:** The OCD fragment was removed and the recipient site was cored. **C:** The lesion was treated with a fresh OA.

surgery (15). Garret et al. (21) reported on a series of 17 patients treated with a OAs with 94 percent clinical success at a mean follow-up of 3 years. McCulloch et al. (41) studied the clinical outcomes on 25 patients who underwent prolonged fresh OA (these grafts are harvested and are typically maintained refrigerated at 4°C for up to 28 days). Six of these patients were diagnosed with OCD. They reported 84 percent patient satisfaction and 88% radiographic incorporation of prolonged fresh allografts to the femoral condyle. Convery et al. reviewed retrospectively 12 patients treated with OA grafts with a mean follow-up of 5 years. Four of these patients had OCD. Overall, outcomes were rated as excellent in all but one patient, who had a gross technical deficiency. The need for technical proficiency in performing fresh osteochondral allografting was assessed (10). In summary, treatment of OCD with osteochondral allografting provides subjective improvement in 75% to 85% of patients and has the longest-term follow-up in the literature (22) (Fig. 43.6).

Autologous Chondrocyte Implantation

ACI is ideal for symptomatic, unipolar, well-contained chondral and osteochondral defects measuring between 2 and 10 cm^2 with bone loss <6 to 8 mm. Healthy chondrocytes are biopsied from a non–weight-bearing region and expanded in vitro over 4 to 6 weeks. Alternatively, the cells may be cryopreserved for up to 5 years and utilized when necessary. At implantation, defect preparation involves debriding to the calcified cartilage base and creating vertical walls of healthy cartilage to shoulder the lesion. A periosteal patch from the proximal tibia or synthetic collagen membrane is attached to the perimeter using interrupted 5-0 or 6-0 Vicryl sutures. The edges of the patch are sealed with fibrin glue and the cells injected beneath the patch into the virtual chamber. Postoperatively, non–weight bearing and continue passive motion is indicated. Defects deeper than 8 to 10 mm can be approached by concomitant or staged bone grafting. Bone grafting should be performed up to the level of the subchondral bone (42). Prior to bone grafting, drilling through the bed following debridement allows appropriate blood flow into the defect, ensuring subsequent bone graft incorporation. When bone grafting is performed as a primary procedure in an effort to stage for definitive treatment with ACI, most surgeons will wait for a minimum of 6 months to allow for bone graft incorporation. Limited experience exists with anecdotal results of a "sandwich" technique where bone grafting is performed in combination with ACI using a "periosteal sandwich" with both cambium layers facing one another and the cells injected in between.

Peterson et al. (49) evaluated 58 patients (mean age: 26.4) with OCD who underwent ACI after a mean follow-up of 2 to 10 years. Thirty-five patients had juvenile OCD and 23 adult OCD. Integrated nonarticular cartilage repair tissue had formed (29), and successful clinical results were noted in more than 90% of patients. Only 30% of the 27 patients with preoperative and postoperative radiographs showed joint space narrowing. ACI appears to be a reasonable alternative in OCD lesions. Results evaluated at a minimum 2-year follow-up essentially mirror that reported in the literature: 76% successful outcomes at 4-year follow-up (9) (Fig. 43.7).

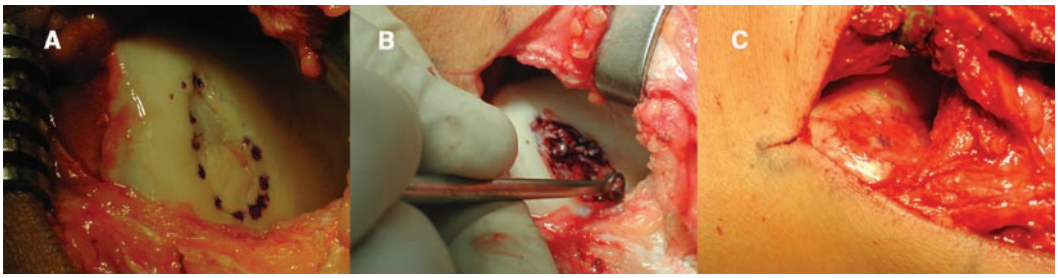

FIGURE 43.7

A: Lesion of the lateral femoral condyle, circled to define the borders for ACI. **B:** Preparation of the defect. **C:** Lesion following injection of cultured chondrocytes and suturing of periosteal graft in place.

SUMMARY

OCD of the knee requires a timely diagnosis in order to prevent compromise to the articular cartilage and maximize opportunity to perform a restorative procedure. Indications for surgical treatment are based on lesion stability, skeletal maturity, and clinical symptoms. Reestablishing the joint surface, improving the blood supply of the fragment, rigid fixation, and early motion are primary goals for osteochondral fragment preservation. When the fragment is not suitable for preservation, careful consideration of defect location and the patient's clinical presentation will determine when cartilage restoration procedures should be utilized. Successful restorative options should relieve pain, restore function, and prevent the development of secondary osteoarthritis.

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PART FOUR

HIP

44 Cartilage Transplantation: Fresh Osteochondral Allograft

David M. Bear and Constance R. Chu

Articular cartilage has unique compressive and viscoelastic properties, which help to maintain normal joint motion and provide cartilage with a coefficient of friction that is fifteen times less than that of ice on ice (32). Despite its impressive qualities, cartilage is avascular and has limited regenerative capacity (31). Cartilage defects can result in an irregular articular surface, altering the normal joint mechanics, and may lead to pain, meniscal tears, and early osteoarthritis (11,24). Full-thickness lesions, which are more common among young active patients (2), have reduced structural integrity and exposed bone, leading to more rapid progression and disability (10,31,35).

Numerous surgical options are available for the treatment of cartilage defects; however, each surgery has its drawbacks. Microfracture is commonly used, but the fibrocartilage that forms in the repair tissue lacks the unique properties of healthy cartilage. Mosaicplasty and autologous chondrocyte transplant can also be performed; however, these options lead to donor site morbidity and may not be adequate in the treatment of larger defects. While partial or total joint replacement is an option for large, bipolar lesions, this treatment is not recommended in young or high-demand patients due to limited longevity and risk of loosening. Tissue-engineered cartilage constructs have great potential (9,16,18,46) but require further investigation prior to being instituted as a standard treatment for cartilage defects.

Osteochondral allograft transplantation is an excellent surgical option for the treatment of large, full-thickness cartilage and osteochondral defects. Allograft transplant allows for the precise restoration of the articular surface, helping to recreate normal joint mechanics. There is no donor site morbidity. The structurally normal articular cartilage used for transplantation is already fully formed and provides viable donor chondrocytes that aid in long-term maintenance of the matrix. Osteochondral transplant has shown good to excellent results in numerous long-term studies (8,22,40). The drawbacks of cartilage transplant include tissue availability, immunogenicity, and the potential for disease transmission. While these issues are still present, the commercial availability of cartilage allograft beginning in 1998 has led to improved tissue availability. To minimize disease transmission potential, rigorous screening has been instituted (39), and grafts are not released until final culture results are obtained 2 to 3 weeks following donor death. Some studies show reduced chondrocyte viability after prolonged cold storage (39,49), which may impact long-term clinical results.

INDICATIONS/CONTRAINDICATIONS

The main indications for osteochondral allograft transplantation include a focal full-thickness cartilage or osteochondral lesion that is symptomatic (6,8,20,21). The defects should be large, with diameters approaching 2 cm. Although there is no defined limit as to how large a defect can be, osteochondral allografting is typically limited to large defects up to 10 cm^2. Improved results are seen with unipolar defects where the opposite surface is still healthy (8). Osteochondral transplant is generally indicated for posttraumatic and osteochondritis dessicans (OCD) lesions; however, this procedure has also been used to treat lesions caused by osteonecrosis (17), as well as tibial plateau fractures (20,42). Allografting is typically indicated for younger patients, who represent the vast majority of patients presenting with these lesions in the clinical setting. Successful clinical results have been noted in the treatment of patellofemoral and unicompartmental chondrosis (26).

Contraindications to osteochondral allograft transplantation include osteoarthritis, particularly when both the tibial and the femoral surfaces are affected. Rheumatoid arthritis (RA) and steroid induced osteonecrosis are considered relative contraindications. Age is also a relative contraindication as patients older than 60 years treated with osteochondral transplantation were found to have worse outcomes than patients younger than 60 (5).

PREOPERATIVE PLANNING AND GRAFT SELECTION

Preoperatively, patients should undergo a thorough history and physical examination. Weight-bearing radiographs to include a full-length standing radiograph to assess alignment are needed (Fig. 44.1). Malalignment may indicate the need to perform an osteotomy in addition to the planned allograft transplant. Magnetic

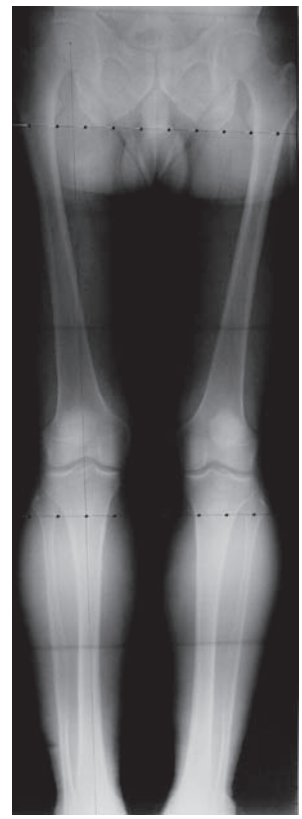

FIGURE 44.1

A full-length standing radiograph was obtained preoperatively in order to evaluate limb alignment. A white line has been traced along the mechanical axis of the right lower extremity, starting at the center of the femoral head and continuing through the center of the ankle. The line passes through the center of the knee indicating normal alignment, so a corrective osteotomy will not be needed in this case.

resonance imaging (MRI) may also be used to evaluate the articular cartilage and soft tissues. Diagnostic arthroscopy is often performed prior to the allograft procedure and allows better characterization of chondral defects and can address associated meniscal or ligamentous injury.

Graft selection is a critical aspect of the preoperative planning process. While freezing of osteochondral allografts decreases the immunogenicity of the tissue, this process destroys both the cell viability and the cartilage matrix (15,38). Cryopreservation of allografts allows preservation of the matrix, but chondrocyte viability is not maintained (41,44). Fresh allografts are recommended for transplant as they have an intact matrix and good chondrocyte viability, compared to frozen or cryopreserved allografts. Based on the drawbacks of freezing and cryopreservation, fresh allograft transplantation is recommended.

Allografts should be obtained within 24 hours of donor death, and stored at 4°C in Lactated Ringer (LR) or culture medium with added cefazolin and bacitracin. Transplant occurring 3 to 7 days after harvest permits retention of cartilage cell viability and matrix constitution (12,28). The avascular bone, which is attached to the allograft, serves as a nonviable scaffold and requires replacement by host bone through creeping substitution (12). With the advent of commercially available osteochondral allografts, complete tissue testing is performed according to the American Association of Tissue Banks guidelines. While this strict screening process aids in the prevention of disease transmission, it may take up to 2 to 4 weeks after donor death for the tissue to become available for transplant. This increased screening time may have a negative effect on graft health as prolonged storage has been shown to decrease chondrocyte viability, although the matrix is likely maintained (1,39,49). Improved graft storage will likely decrease these negative effects. One study demonstrated improved chondrocyte viability and metabolic activity for allografts stored for 14 days in proprietary culture medium, compared to grafts stored in traditional LR solution (4).

In order to obtain an appropriate allograft, the donor must be size matched to the recipient. This is accomplished by measuring the anteroposterior and lateral dimensions of the tibial plateau from standard radiographs or MRI. The donor and host tibial diameters are determined with measurements taken 1 cm below the articular surface. If the patellofemoral joint is to be treated, the widest diameter of the patella should be measured. The donor allograft is determined to be an acceptable size match if both of the measured planes in the host fall within 2 mm of the corresponding regions in the donor.

SURGERY

Patient Positioning

The patient is positioned supine on a radiolucent table. The hip and knee of the operative leg is flexed to 90 degrees, and a bump is placed under the hip and a sandbag under the ankle (Fig. 44.2). A tourniquet is placed around the thigh.

Graft Preparation

The graft is visually inspected for damaged cartilage and measured to ensure it is size matched to the recipient immediately prior to surgery. The graft is then placed in a solution containing LR and bacitracin on a back table where graft preparation will take place. A commercially available allograft instrumentation system can be used for the procedure.

Surgical Technique

Arthroscopic examination of the knee may be performed prior to the procedure. If this has not been done or if questions remain, arthroscopic examination prior to opening the knee is recommended. The use of a tourniquet

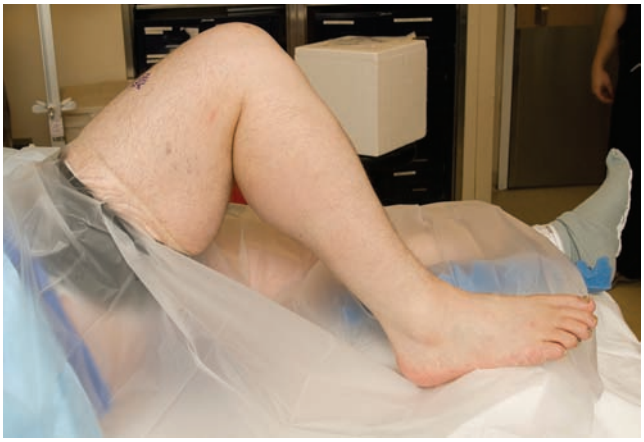

FIGURE 44.2

The patient was positioned with 90 degrees of hip and knee flexed. A tourniquet was applied around the thigh. A bump was placed under the hip and a sandbag placed under the ankle.

is recommended in order to allow proper visualization of the joint surface during the procedure. An Esmark is used to exsanguinate the limb, after which the tourniquet is inflated.

A standard midline incision can be made centered over the patella and extending to the tibial tubercle. Additionally, a miniopen medial or lateral incision centered over the condylar defect can be used. Depending on the location of the defect, either a medial or a lateral peripatellar arthrotomy is performed and the defect is exposed using a retractor (Fig. 44.3).

A sizing cylinder that is able to completely cover the lesion is used to determine the correct size of the defect. Using a marking pen, a circle is traced around the perimeter of the cylinder and a mark is made at the 3, 6, 9, and 12 o'clock positions. With the sizing cylinder in place, a guide pin is placed through the center of the cylinder and is drilled to a depth of approximately 2 cm. The cylinder is then replaced by a reamer of the same size, which is placed over the guide pin and drilled to a depth of 8 to 10 mm while irrigation is applied. This depth requires only a small amount of subchondral bone to be removed, allowing for a good press fit of the graft, while at the same time decreasing potential immunogenicity by limiting the amount of donor bone needed (Fig. 44.4). In order to obtain a precise volumetric assessment of the depth of the reamed area, a depth gauge is inserted once the reamer has been removed and the depth of the reamed area is measured at the 3, 6, 9, and 12 o'clock positions.

The allograft is then placed next to the exposed defect and the orthotopic location is matched between the graft and the defect area in order to replicate the same surface contour after grafting has taken place (Fig. 44.5). The allograft should now be placed into the graft station on the back table and using the alignment guide, the selected orthotopic location should be positioned into the area where the donor graft will be taken.

Once the exact dimensions of the reamed defect have been determined, attention should be turned back to the allograft that has been placed into the graft station. The sizing cylinder that was previously used over the defect area is now placed into an alignment guide, and a bushing is rotated around the allograft until a location is selected that best approximates the size and contours of the host defect area. Using a marking pen, the

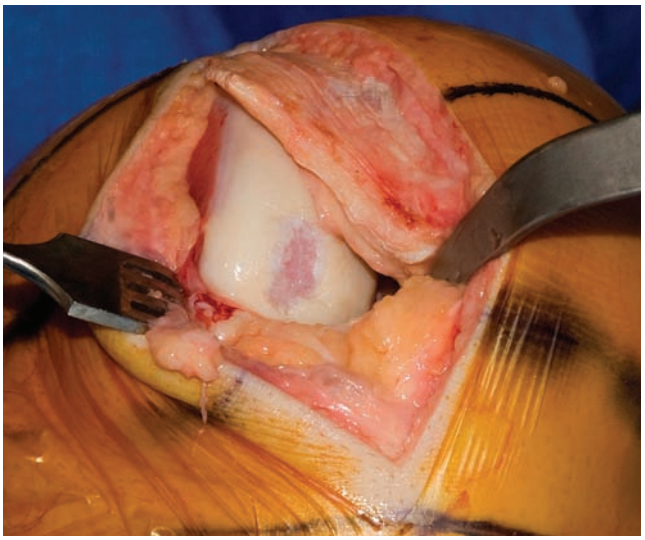

FIGURE 44.3

Following a midline skin incision, the lateral condyle defect was exposed using a lateral peripatellar arthrotomy.

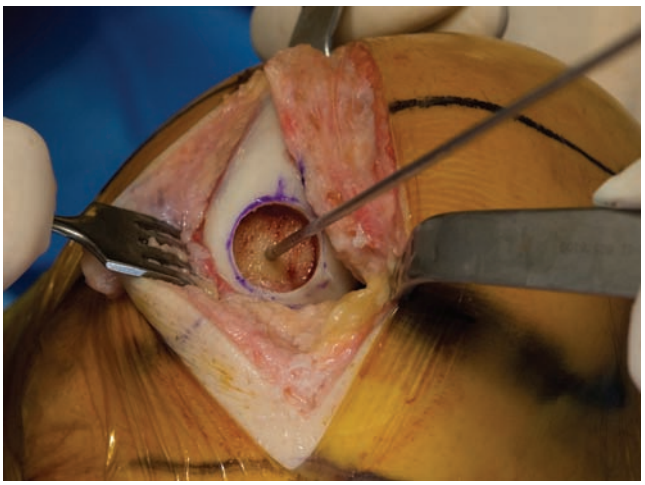

FIGURE 44.4

The cartilage defect was removed, along with only a small amount of subchondral bone. This will allow for a good press fit of the graft, while at the same time decreasing potential immunogenicity by limiting the amount of donor bone needed.

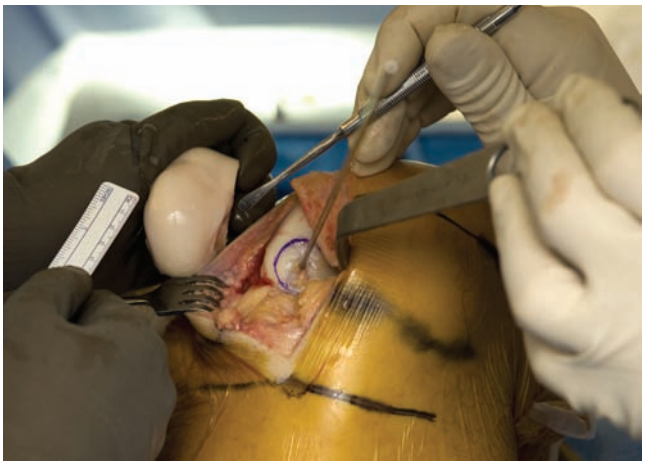

FIGURE 44.5

The allograft was placed next to the exposed defect and the orthotopic location was matched in order to replicate the same surface contour after grafting has taken place.

12 o'clock position of the selected region is marked in order to ensure proper orientation after removal. A core reamer, which has been size matched to the lesion size, is advanced over the region of interest to a depth greater than that needed for transplant. In order to remove the allograft core, a sagittal saw is used to make a cross cut below the graft surface at a level greater than that needed to fill the host defect. The allograft core is then removed and a mark is made at the 3, 6, 9, and 12 o'clock positions at depths corresponding to the previously measured depths from the host defect. Using graft forceps, the allograft core is positioned so that the depth marks are aligned with the underside of the forceps. A sagittal saw is then used to remove the subchondral bone to the level of the measured depths (Fig. 44.6). At this point, the allograft core should possess the ideal contour and dimensions necessary to fill the host defect. The allograft is placed into the host defect and care is taken to ensure the correct alignment (Fig. 44.7). A dilator may be used to dilate the host defect area an additional 0.5 mm in order to facilitate insertion of the allograft. The graft should be gently inserted using a press-fit technique with the pressure of a finger. If further pressure is needed, a bone tamp can be used, although care should be taken to avoid damaging the allograft cartilage in order to minimize chondrocyte death and disruption of the matrix. The graft should be placed nearly flush with the surrounding host articular surface and up to 1 mm proud. Avoid reaming the bone to where the graft is depressed relative to the host cartilage.

While many defects can be treated with the allograft plug technique described above, larger defects will require the use of a customized bulk of shell allograft. During this procedure, the damaged articular surface is removed using an osteotome in a rectangular pattern. Using a high-speed burr, abnormal tissue should be resected in order to expose a layer of bleeding subchondral bone. Great care is taken to remove only the amount of bone needed to facilitate graft incorporation through a fracture healing mechanism. After obtaining careful measurements of the defect size, a bulk area of osteochondral allograft, which closely matches the size and location of the host defect, should be removed from the donor tissue. The subchondral bone should be burred down to a thickness of 5 to 10 mm, leaving enough bone for healing by creeping substitution, while decreasing

FIGURE 44.6

Using graft forceps, the allograft core was positioned so that the depth marks were aligned with the underside of the forceps. A sagittal saw was then used to remove the subchondral bone to the level of the measured depths.

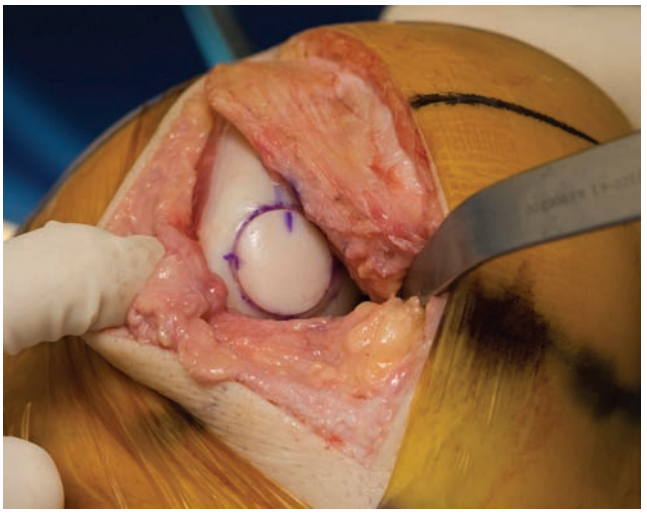

FIGURE 44.7

The allograft was placed into the host defect and care was taken to align the marks made at the 3, 6, 9, and 12 o'clock in order to ensure the correct alignment.

the potential for immunologic reaction. Immunogenicity may be further reduced by using pulsatile lavage to remove antigenic marrow cellular elements in the tissue. If possible, the allograft should be press fit into the host bed. If a secure press fit cannot be obtained, fixation can be augmented using cancellous screws or bioabsorbable pins.

It is important that the normal load across both the medial and the lateral compartments is restored before the surgery is complete. Preoperative standing radiographs and examination will dictate whether restoration of alignment is necessary. Alignment should be restored by performing a corrective osteotomy, and not by altering the size of the allograft.

POSTOPERATIVE MANAGEMENT

The postoperative management of patients who have undergone osteochondral allografting is critical in order to obtain a successful surgical outcome. Patients require non–weight bearing or touchdown weight bearing for 6 to 12 weeks, with length of time dependent on degree of graft containment, graft size and location, and clinical signs of healing. The decision to use postoperative bracing is surgeon dependent, with some surgeons advocating the use of a hinged knee brace for the first 8 weeks, followed by a unicompartmental unloader brace for another 4 months. If a tibial osteotomy has been performed, a long leg hinged brace with knee lock can be used.

The use of a continuous passive motion (CPM) machine is recommended for 4 to 6 weeks postoperatively. CPM use should occur three times daily, with each use lasting 1 to 2 hours. The CPM should initially be set for 0 to 45 degrees of flexion and this can be gradually increased. Although range of motion (ROM) is an important aspect of postoperative management, restrictions may be instituted if an osteotomy has been performed. In addition to the use of a CPM, a supervised rehabilitation regimen with physical therapy should be initiated 2 weeks postoperatively and should continue for 4 to 8 months. Emphasis should be placed on restoring normal gait, ROM, and increasing quadriceps strength. Postoperative activity is restricted to closed-chain kinetic exercises until 4 weeks, after which low-impact activities can be performed. All activity restrictions may be removed at 6 months if the patient continues to be clinically stable. In order to avoid graft collapse, however, large osteochondral allografts may require permanent cessation of high-impact sports (36).

Postoperative clinical follow-up should occur at 1, 3, 6, and 12 months after surgery. Assuming the patient is doing well at 1 year, future follow-up visits can occur on a yearly basis. Standard radiographs are typically obtained at follow-up visits to assess graft incorporation. MRI can be a useful tool to evaluate the transplanted allograft and can assess the bone-cartilage interface (Fig. 44.8). Trabecular integration of the graft as visualized on MRI has been shown to be an important prognostic indicator of allograft health and viability (48). MRI can also assess cartilage health, surface smoothness, and thickness of the allograft cartilage compared to the native cartilage (7). Furthermore, MRI evaluation of cartilage after autologous chondrocyte implantation was found to correlate with both histology and second-look arthroscopy at 12 months (23). In addition to standard clinical MRI, emerging quantitative MRI techniques, including T1rho and T2 mapping, have significant potential clinical utility and provide valuable information about articular cartilage structure and biochemical integrity (13,34,37).

COMPLICATIONS

Allograft nonunion or delayed union has been observed. This is due to failed bony incorporation of the graft bone to the host bone, which may be improved intraoperatively by adequate resection of damaged host tissue to bleeding bone, as well as removing enough subchondral bone on the allograft to allow for creeping substitution.

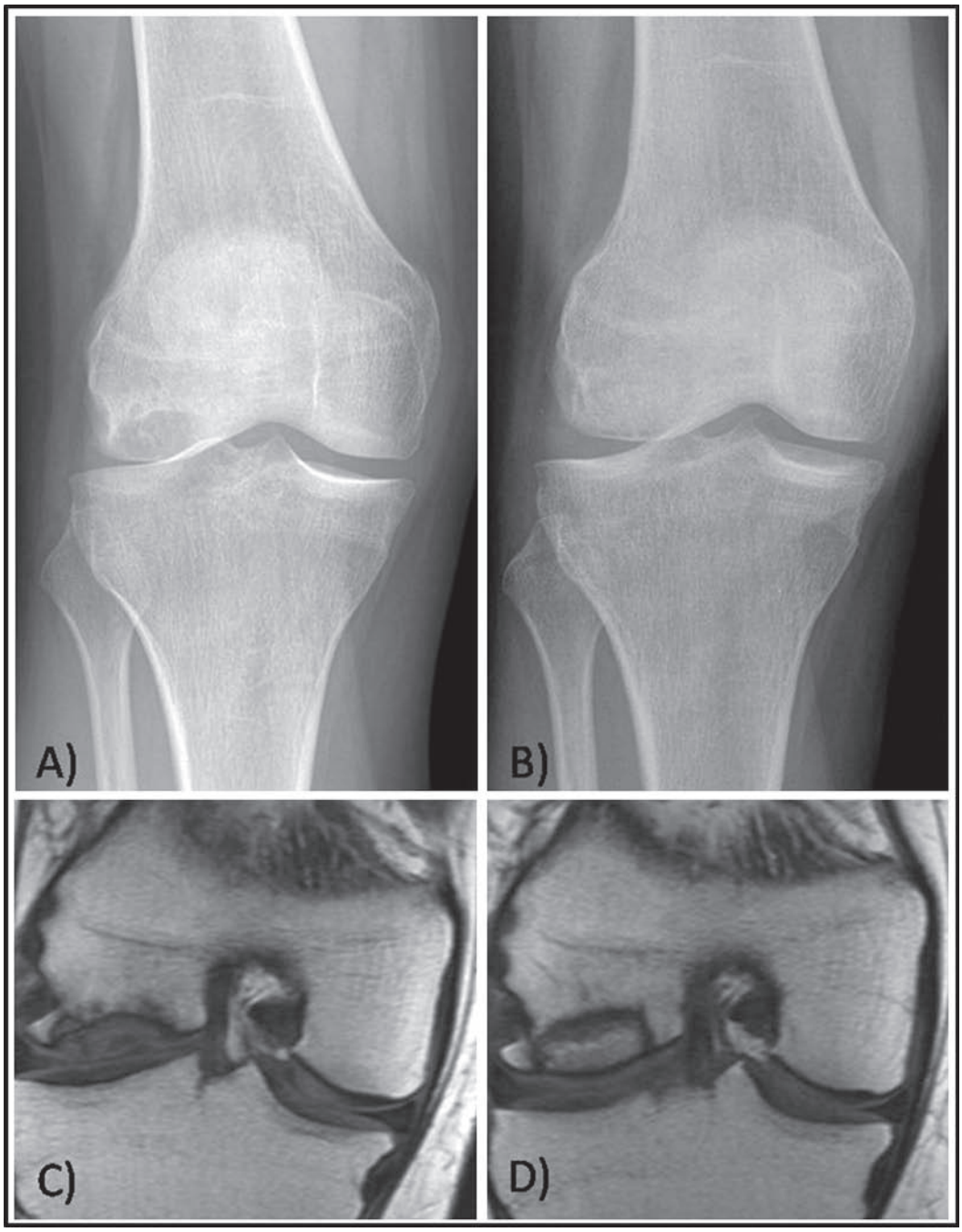

FIGURE 44.8

Preoperative radiograph **(A)** and T1-weighted MRI **(B)** of the knee demonstrating a lucency in the area of the defect on the x-ray and a damaged articular surface on the LFC on MRI. Postoperative radiograph **(C)** and MRI **(D)** reveal a normal appearing LFC on x-ray and a restoration of the LFC articular surface after allograft implantation.

Allograft failure or collapse is another common cause of postoperative complications, although the exact cause of failure is not completely clear (48). A study by Ghazavie et al. determined that allograft failure was related to age over 50, bipolar defects, worker compensation cases, and malalignment of knees causing overstressing of grafts (20). Failure may also occur as a result of insufficient allograft preservation prior to transplantation, resulting in decreased chondrocyte viability and disruption of the cartilage matrix. Both allograft failure and host-graft nonunion have also been found to be a result of mechanical instability (22). One study, however, determined that allograft failure is likely a result of a weakened osseous portion in the allograft, and that cartilage collapse occurred as a result of osseous collapse (43). Other postoperative complications that occur include infection and immune rejection, although the potential for infection transmission has been decreased by the rigorous screening instituted by tissue banks.

RESULTS

Long-term results for osteochondral transplant have consistently demonstrated good to excellent outcomes, and viable chondrocytes have been harvested from grafts even at 25 and 29 years after surgery (27,33). A study by Chu et al. (8) evaluated pain, ROM, and function in 55 knees transplanted with fresh shell allografts. Seventy-six percent of patients with an average 6-year follow-up had good to excellent results, while 73% of patients transplanted 10 or more years prior had similar results. Another study using fresh osteochondral allografts to treat femoral condyle defects noted an 85% graft survival at 10 years and a 74% survival at 15 years using Kaplan-Meier survivorship analysis (3). Of twelve patients with failed grafts, three required graft removal and nine required conversion to total knee arthroplasty. Patients with intact grafts had good function and treatment of medial and lateral condyles had equal outcomes. Also, patients who underwent a realignment procedure or who required a meniscal transplant had equally good outcomes, compared to patients treated with allograft alone. In a study by Ghazavi et al. (20), graft survival in posttraumatic defects treated with fresh allografts was 95% at 5 years, 71% at 10 years, and 66% at 20 years (20). A similar study by Beaver et al. (5) demonstrated 75% success at 5 years, decreasing to 63% at 14 years (5). In both studies, graft failure was based on the need for further surgery or a decrease in knee score.

When specifically evaluating treatment of OCD lesions in the femoral condyle, Emmerson et al. (14) found allograft treatment resulted in good to excellent results in 72% of patients with an average 7.5-year follow-up. Another study also found excellent results with success in 94% of patients treated with fresh allograft for OCD lesions of the lateral femoral condyle (LFC) (19). For allograft treatment of osteonecrosis of the distal femur, a study by Flynn et al. (17) noted a 70% success rate with a mean follow-up of 4.2 years. Osteochondral transplant has also demonstrated success when evaluating treatment of defects from tibial plateau fractures, with a 95% survival rate at 5 years, which decreased to 65% at 15 years (20,42).

Studies comparing the results between treatment of a defect on one articular surface in the tibiofemoral joint (unipolar), compared to both the tibial and femoral articulating surfaces (bipolar) have found worse outcomes after bipolar transplant (5,8,20). In one study, 84% of patients receiving unipolar transplant achieved good to excellent results, compared to only 50% of patients treated with bipolar transplant (8). Increased failure in the bipolar group was thought to be due, in part, to increased immunogenic reaction caused by the larger amount of tissue being transplanted. Interestingly, good to excellent results were found in all four patients who received a patellar transplant and in three of four patients undergoing bipolar transplant of the patellar and trochlear surfaces. A study by Jamali et al. (26) also demonstrated favorable results in the patellofemoral joint after both unipolar and bipolar transplants.

The clinical effect of increased allograft storage times due to the advent of commercially available osteochondral allografts is not yet well understood as most studies evaluating the effects of graft storage were performed with <1 week of storage. One study by Williams et al. evaluated the structural and functional outcomes of fresh allografts, which were stored for a mean of 30 days. Function was assessed with the Activities of Daily Living Scale and the Short Form-36 with a mean follow-up of 48 months, while structure was assessed using MRI with a mean follow-up of 25 months. Prolonged allograft storage was found to be successful in achieving good structural and functional results in this short-term follow-up; however, long-term outcome is unknown (47).

FUTURE DIRECTIONS

While current methods of allograft transplant have favorable outcomes, improved methods of tissue preservation are necessary. Optimization of preservation techniques, including cryopreservation, has the potential to improve allograft chondrocyte viability and matrix integrity for longer periods of time, in order to improve surgical outcomes.

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45 Hip Arthroscopy

Vonda Wright and Antonia Chen

The arthroscopic approach to hip pathology is rapidly becoming an accepted and common tool in the orthopedic surgeons' armamentarium. Improvements in instrumentation, technique, and surgeons' experience have made the minimally invasive treatment of multiple hip derangements possible. This chapter provides the novice hip arthroscopist with a detailed description of the indications, operative setup, and technique for performing hip arthroscopy.

BACKGROUND, PRESENTATION, AND INDICATIONS FOR HIP ARTHROSCOPY

Although rapidly gaining in popularity, hip arthroscopy is not a new procedure. For decades, few surgeons approached the hip arthroscopically as the procedure itself requires significant technical acumen and definitive diagnosis of hip pathology is sometimes difficult. The clinical symptoms and physical finding associated with hip pain may be varied and subtle. Diagnosis is often delayed by an average of 21 months as patients are referred to an average of 3.3 health care providers before reaching a hip arthroscopist. During that period, they have often undergone a variety of treatments including physical therapy, nonsteroidal anti-inflammatory or narcotic medications, or other surgery including spine, ovary, or hernia exploration.

Not all pain believed to be emanating from the hip is actually intra-articular hip pain. The numerous anatomic structures in the vicinity of the hip joint may confuse the clinical presentation. Presentation of intra-articular hip pain is most commonly groin pain with or without radiation to the knee, pain localized by the patient with his or her hand encircling the lateral hip above the greater trochanter with the thumb posterior and fingers in a C-shape (C-sign), mechanical clicking or pinching in the groin, or pain with sitting and getting in and out of the car. The presence of mechanical symptoms in addition to groin pain is a favorable prognostic factor with more than 85% improvement postoperatively (34) Intra-articular hip pain is not lateral pain over the greater trochanter, buttock/posterior leg pain or palpable hip girdle tenderness (Table 45.1).

Proper patient selection is paramount in achieving a successful outcome from arthroscopic hip surgery. In addition to the history and physical, a focused exam, as summarized in Table 45.2, provides valuable clues for localizing pathology.

Perhaps the most important tools in evaluating the hip are plain radiographs. Table 45.3 summarizes important radiographs and the measurements they provide.

In addition, the Dunn or elongated-neck lateral (performed with the hip in 90 degrees of flexion and 20 degrees of abduction) may be used to further identify femoral neck offset. The False profile radiograph, with the patient rotated 65 degrees and the beam perpendicular to the hip, demonstrates anterior osseous coverage of the hip.

When history, physical and plain radiographs indicate intra-articular pathology, the final two steps in preoperative diagnosis are MR Arthrogram (MRA) and diagnostic injection with analgesics (Figs. 45.1–45.3). Soft tissues of the hip should be visualized using MRA in most clinical settings. Figures 45.4 to 45.6 demonstrate common MRA views. While some institutions report the ability to visualize these structures adequately without the addition of contrast, in most settings, the addition of contract is vital. MRA has 90%/91% sensitivity and accurate for detecting hip pathology, while plain MRI has only 30%/36% sensitivity and accuracy (1). Finally, confirmation of intra-articular pathology as the source for hip pain is obtained via intra-articular injection. At the time of MRA, a mixture of lidocaine (6 mL 1%), marcaine (6 mL 0.25%), and kenalog (80 mg) is injected into the joint. The patient is then asked to perform the activities that normally cause pain to the hip and report the degree of relief from these symptoms within the first 3 hours following injection. The amount of relief from

TABLE 45.1 Summary of Hip Symptoms Associated with Labral Tears

Onset of symptoms	Insidious	61%
	Acute	30%
	Trauma	9%
Intensity	Moderate/severe	86%
Location	Groin	92%
	Ant. thigh/lateral hip/buttock	
Quality of pain	Sharp	86%
	Dull	80%
	Combination sharp/dull	70%
	Activity related	91%
	Night pain	71%
	Mechanical symptoms	53%–77%
	Pain during walking	70%
	Pain during pivot	70%

Source: Adapted from *J Bone Joint Surg.* 2005;88-A:1450.

TABLE 45.2 Focused Physical Exam of the Hip

Exam Name	Exam Indication
Gait	Antalgic—pain/trendelenberg—gluteal weakness
Trendelenberg sign	Gluteal weakness
Palpation (groin, lateral hip, buttocks)	Intra-articular pathology generally not palpable
Strength (hip flexors/abd/add)	
Thomas sign	Tight hip flexors
Range of motion	Flex—FAI, ER—tight hip capsule, IR—OA
Log roll/heel strike	Intra-articular pathology/fracture
Scour test	Labral tear
FADIR	Impingement ± popping/clicking
FABER (location important)	SI joint/iliopsoas/FAI

TABLE 45.3 Radiographic Evaluation of the Hip

Radiograph	Measurement
AP WB pelvis	CEA—dysplasia <20 under coverage 20–40 normal >40 pincer lesion
	Tonnis angle <10 degrees normal >10 degrees increased lateral contact pressures
	Cross over sign—anterior rim crosses in front of posterior rim indicating retroversion of the acetabulum
AP hip Cross table lateral	CAM—decreased femoral neck offset

this diagnostic injection within the first 3 hours following injection is 90% predictive of the relief the patient can expect postoperatively.

Hip arthroscopy is indicated when patients present with persistent pain that is unrelieved by thorough physical therapy and reproducible by physical exam, are nonresponsive to conservative measures, and have documentation of intra-articular pathology by MRA and positive relief from intra-articular injection within the first 3 hours after injection.

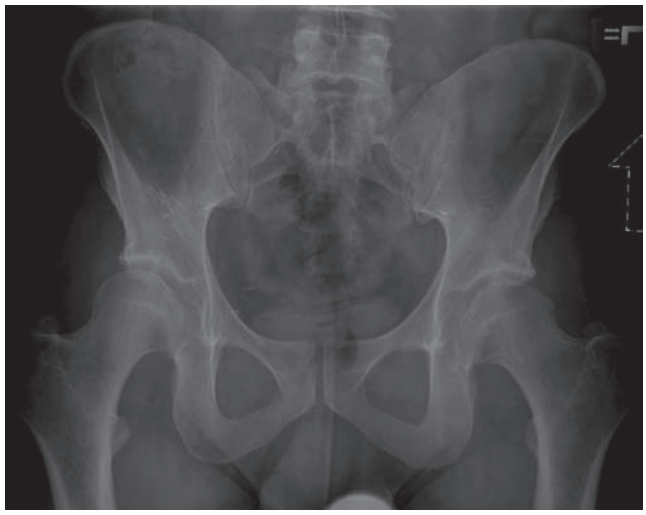
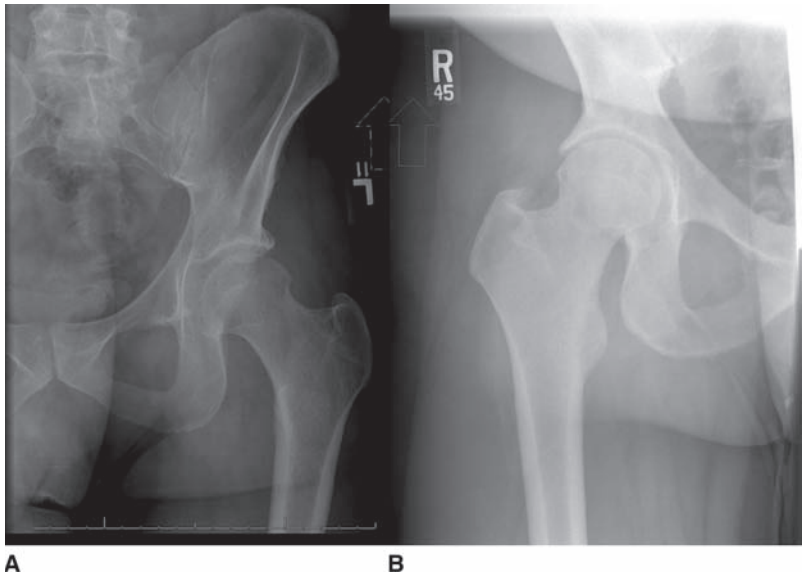


FIGURE 45.1
AP pelvis without crossover sign.



A B

FIGURE 45.2
A: AP hip with normal CEA
B: AP hip with Pincer lesion.

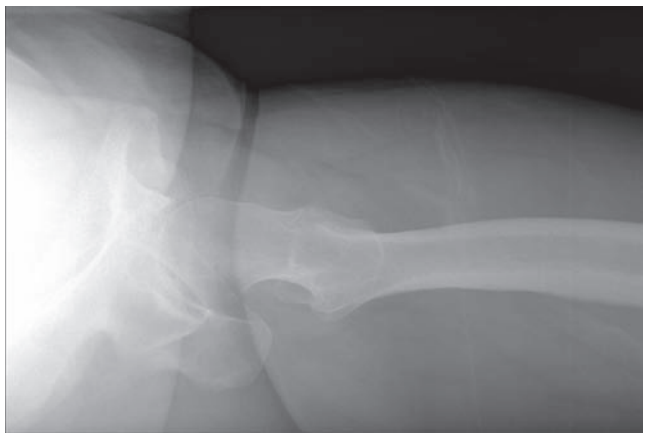


FIGURE 45.3
Cross table lateral with CAM lesion.

In recent years, much focus has illuminated the pathology behind labral tears. Though the pain associated with a torn labrum is often the inciting reason patients seek medical care, labral pathology itself is the consequence of the primary underlying hip derangement. These pathology include femoral acetabular impingement (FAI), major or athletic hip trauma, capsular laxity/hip hyper mobility, hip dysplasia with a shallow center edge angle (CEA) of <20 degrees and subsequent hypertrophic labrum, iliopsoas impingement and snapping over the anterior pelvic rim and DJD with degeneration of the labrum as well as the cartilage. Detailed coverage of several of these topics appears in subsequent chapters and will be described in brief here.

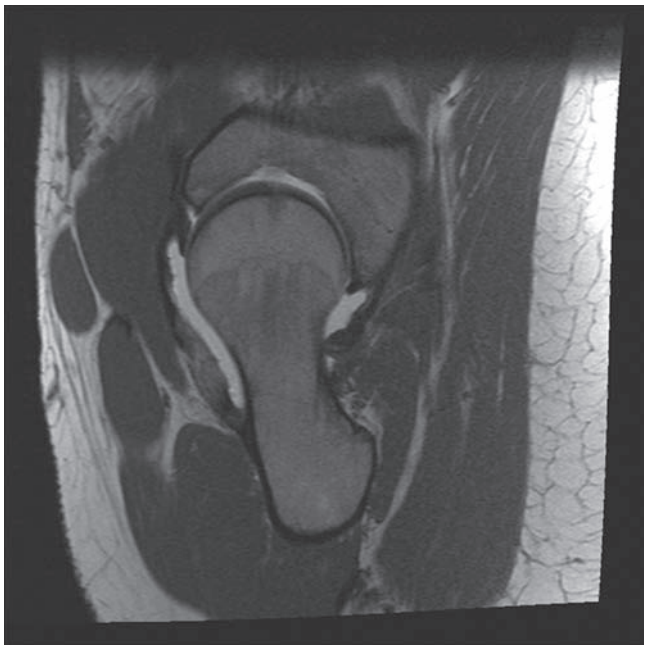


FIGURE 45.4
MRA axial oblique with labral tear.

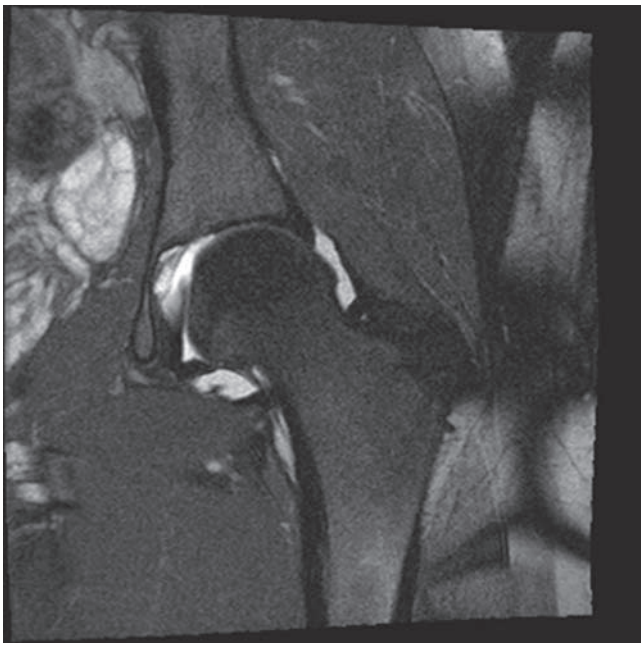


FIGURE 45.5
MRA coronal.

Femoral acetabular impingement

First described in 1965 (25), FAI describes the repetitive abutment and subsequent microtrauma between the femoral neck and acetabular rim (Table 45.4). The impingement occurs as the femoral neck CAM lesion flexes against a normal or overhanging (high CEA) acetabulum and pushes the labrum up and away from the acetabular edge. This leads to labral tearing or fraying and is thought to eventually peel back the acetabular cartilage at the area of impact leading to early arthritis. The concept of optimal femoral neck offset is well known from the arthroplasy literature with too little offset leading to hip instability, with the head levering out of the cup, impingement, and wear. Historically, surgical management of FAI included periactabular osteotomy (30) and surgical dislocation (28). Now, FAI, including osteoplasty of the acetabular rim and femoral CAM lesion, is performed arthroscopically as described in following chapters.

Acetabular Dysplasia

Acetabular dysplasia is a part of a continuum of developmental disorders that includes FAI. While severe dysplasia cannot be treated by arthroscopy alone and requires open osteotomy, mild and moderate dysplasia may be.

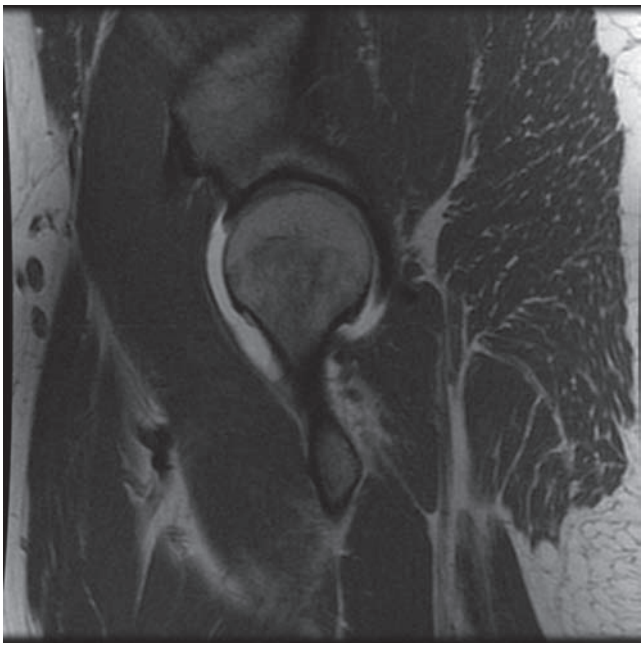


FIGURE 45.6
MRA sagittal.

TABLE 45.4 Functional of the Acetabular Labrum

The labrum runs circumferentially around the acetabular perimeter to the base of the fovea and then attaches anterior and posterior to the transverse acetabular ligament. Blood supply is provided peripherally.
Decreased cartilage surface pressure
Participates in load bearing in flexion
Stability in capsular laxity and dysplasia
Performs a sealing function
Structural resistance to altered motion of the femoral head
Provides proprioception

Source: Adapted from Kelly, *Arthroscopy*. 2005.

Acetabulum with CEA of 16 to 28 degrees is amenable to arthroscopic labral surgery (20). With the dysplasia, the labrum becomes hypertrophic in the anterior and superior regions and is more susceptible to tearing (14). In these cases, the labrum is repaired back down to acetabular rim. Developmental dysplasia is also associated hypertrophy of the ligamentum teres and increased wear with time causing impingement and pain. Débridement of the ligamentum and repair of the labrum in dysplasia demonstrate improved clinical outcomes (6,9).

Avascular Necrosis of Femoral Head

Osteonecrosis of the femoral head can present in the pediatric and adult populations. In children, avascular necrosis (AVN) may present as Perthes disease or as a sequelae of slipped capital femoral epiphysis disorder. Treatment of these conditions by routine arthroscopic procedures for débridement of loose bodies and chondroplasty demonstrated positive outcomes in children and adolescents (19). For adults, hip arthroscopy can be can be used for treatment of AVN in its early stages. Patients who fail conservative therapy and have chondral flaps, loose bodies and/or labral tears may benefit from arthroscopic débridement and repair (21). Additionally, hip arthroscopy can be performed simultaneously with other surgical treatments of AVN, such as core decompression, to evaluate the joint surface and accurately stage the severity of AVN.

SEPTIC HIP

The standard treatment for septic arthritis of the hip is a formal arthrotomy. However, open arthrotomies that may require dislocation of the femoral head can result in higher morbidity, with an increased risk for AVN, increased pain, and a longer hospital stay. An alternative to an arthrotomy is to perform hip arthroscopy with ample irrigation and débridement of infected tissue. A study by Nusem demonstrated that the 3-portal technique with the patient in the supine position (5) can adequately treat infections and provides rapid postoperative recovery with minimal complications (27).

DEGENERATIVE DISEASE

Osteoarthritis (OA) in the hip often occurs in association with labral tears, as anterior tears are associated with cartilaginous lesions in the femoral head or acetabulum (22). With time and wear, these cartilage lesions erode and result in OA. In general, it is not recommended to perform hip arthroscopies in patients with severe degenerative disease, where the articular cartilage is fully denuded and is unable to be restored. However, in cases of early and mild OA, studies have shown that arthroscopic intervention may decrease pain after performing capsular release, débridement, synovectomy and/or microfracture (16). In patients who have anatomic deformities that lead to OA, such as FAI and pistol grip deformities of the femoral neck, treatments by osteoplasty and chondroplasty through arthroscopy can be beneficial (17,12,11).

TRAUMA

Using hip arthroscopy to remove loose bodies is a well-established indication. This has traditionally been employed in removing chondral fragments (10). Two additional uses of hip arthroscopy in the use after trauma include removal of bony fragments after traumatic hip dislocations and acetabular wall fractures, as well as the removal of foreign bodies as a result of trauma. Bullet fragments within the hip joint may be removed arthroscopically (16). For traumatic hip dislocations, the femoral head impinges against the acetabular lip and the trauma may result in bony and cartilaginous fracture fragments. In a study by Mullis and Dahners, 36 patients underwent hip arthroscopy after hip dislocation and 92% of patients were found to have loose bodies. Of note, these fragments were not all seen on radiographs or computed tomography scans (18). This finding highlights the importance of direct visualization of fracture fragments with hip arthroscopy.

ADHESIVE CAPSULITIS

Adhesive capsulitis is a condition defined by capsular fibrosis that is diagnosed on physical exam under anesthesia by decreased range of internal and external rotation with the hip in 90 degrees of flexion. To release the adhesions, the affected hip is placed in the figure-of-four position and a downward force is placed on the medial aspect of the knee. Arthroscopic débridement is performed to remove debris within the joint. Surgical intervention is indicated for patients who have unremitting hip pain and patients who not have severe degenerative changes (18).

PERITROCHANTERIC

Disorders Peritrochanteric disorders encompass a variety of conditions that are associated with greater trochanteric pain, which is often found in young athletic female patients. Historically, surgical interventions were performed through open incisions, but with arthroscopy, these procedures may be performed with decreased morbidity. These conditions include trochanteric bursitis, external snapping of the iliotibial band, and gluteus medius and minimus tears. Trochanteric bursas may be derided arthroscopically, and recalcitrant trochanteric bursitis may require a concomitant release of the iliotibial band (32). Snapping of the posterior one third of the iliotibial band, or coxa saltans externus, may also be relieved by release of the iliotibial band (24). Additionally, gluteus medius and minimus tears may either be repaired or derided arthroscopically.

SYNOVIAL ABNORMALITIES

The synovial lining of the hip degenerates over time as a result of inflammatory arthopathies, trauma, and/or repetitive stresses to the joint. Early treatment of conditions by arthroscopic débridement may slow the deterioration of articular cartilage. Primary synovial chondromatosis is a benign condition of cartilaginous metaplasia that produces intracapsular and extracapsular loose bodies. Studies have shown that treating primary synovial chondromatosis arthroscopically produces good to excellent results, as measured by patient satisfaction questionnaires, visual analogue scale for pain and mobility scales (26). Arthroscopy can also be used to treat pigmented villonodular synovitis as a diagnostic tool to obtain tissue for pathology analysis, a prognostic tool to assess the cartilage and a therapeutic tool to perform partial synovectomies. Similarly, arthroscopy can have a role in treating the early stages of rheumatoid arthritis by debulking inflamed synovium to provide pain relief and improve mobility (7).

TOTAL HIP ARTHROPLASTY

Hip arthroscopy also plays a role in total hip arthroplasty (THA) revisions, as well as complications from THAs. Infected THAs can be irrigated and derided arthroscopically, especially in patients who are unable to tolerate an arthrotomy. Debris from polyethylene wear and pelvic osteolysis can be derided arthroscopically

with less morbidity than open procedures (13). Arthroscopy can also be used for diagnostic purposes when assessing the need for revision surgery. Acetabular cup loosening can be evaluated arthroscopically before proceeding to a revision THA. In cemented THAs, the femoral cement mantle can be assessed, removal of the distal cement centralizer can be examined, and preparation of the cement mantle for recementing can be performed (34).

Procedure The importance of setup is to facilitate the procedure being performed in order to correct the diagnosed pathology. Careful consideration must be used when positioning patients and placing portals. Erroneous portal placement may cause chondral scuffing or may not allow adequate access to certain compartments of the hip. Incorrect patient positioning may require prolonged distraction time and may result in transient pudendal or peroneal nerve injury. The following sections describe various patient positioning and portal placement in depth.

Setup

The patient is identified and the operative site verified by the surgeon, patient, and operating room staff. The patient is then brought back to the operating room and carefully placed on the operating room table. Anesthesia is induced at this time with general anesthesia most commonly employed. If a sufficient motor block is established, a spinal anesthesia may be used. Preoperative antibiotics are administered.

Supine

Supine positioning is the most common approach to the hip joint for arthroscopy and allows the use of a fracture table without special attachments. The patient is positioned with his or her perineum against a well-padded perineal post and the feet are placed in well-padded boots or padded with webril prior to being secured to the fracture table. Initially, the traction cranks are fully unloaded. Many fracture tables allow lateralization of the bed, and the bed should be lateralized toward the operative leg. The patient's arms are draped out of the field. The author's preference is to place the arms between two pillows, held with a draw sheet pulled up from each side of the table and secured with arcs of tape (Fig. 45.7).

Both legs are extended straight, in the fracture boots by the surgeon without engaging the traction mechanism. An x-ray C-arm is placed across the table, opposite the operative leg, and traction is pulled through the pelvis under direct fluoroscopic guidance. Traction is gently pulled manually through the nonoperative leg first to level the pelvis and then through the operative leg to ensure proper distraction can be achieved. When maximum manual distraction is obtained, the traction mechanism of the table is used to further distract the operative hip when needed. The foot may be internally rotated to eliminate the effect of femoral antiversion during the approach and the entire operative leg adducted against the perineal post to further open the hip joint (3). When the surgeon is satisfied that the hip can be adequately distracted to perform arthroscopy, the traction is released and the operative leg prepped and draped. The goal is to minimize traction pressure against the perineum and thereby minimize pudendal nerve neuropraxia. This author prefers to drape out the operative field with four 1,000 drapes placed proximal to the umbilicus, as midline as possible, just proximal to the knee and one posterior. This area is then cleansed and draped with a shower curtain–type drape. The C-arm is draped sterilely and brought in over the field. Traction is then reestablished.

Anatomic landmarks are made marked at this time and include the anterior superior iliac spine (ASIS) with a line drawn sagitally from this point to distal in the field and the superior and anterior edges of the greater trochanter. The vertical ASIS line is a visual reminder of the most medial extent of the safe field as the femoral neurovascular structure lie within 3 to 4 cm of this line (4) (Fig. 45.8).

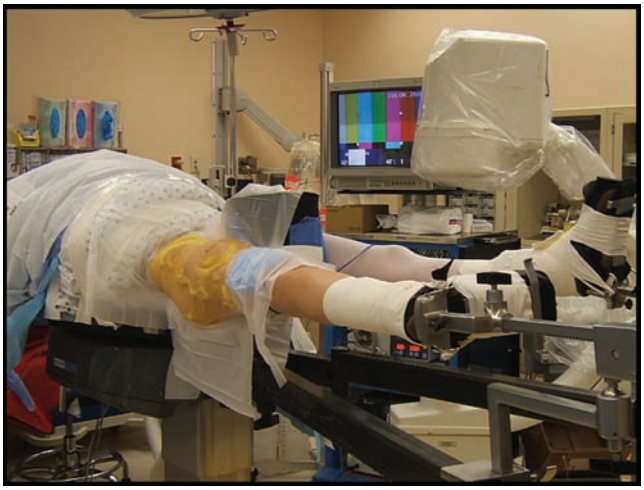


FIGURE 45.7
Patient positioning for supine hip arthroscopy.

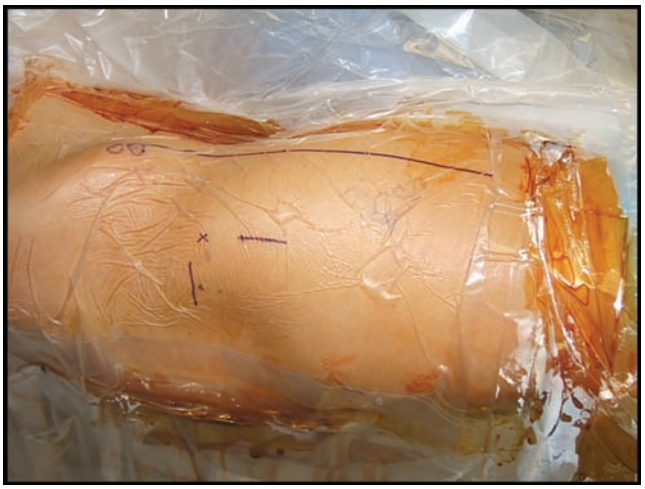


FIGURE 45.8
Hip arthroscopy anatomic landmarks.

The supine approach is more difficult with obese patients with a large pannus and in patients with large anterolateral osteophytes. For these patients, the lateral approach allows gravity to pull the pannus and buttocks away from the field. The lateral position is also thought to allow more easy access to the posterior portion of the hip. The lateral approach, however, may be more time consuming to set up as it requires multiple adjustments to the perineal traction posts. A perineal post is placed against the medial thigh of the surgical leg, and the hip is slightly flexed and abducted to relax the hip capsule. Special traction devices may be used to distract the leg and allow visualization of the hip joint. However, if traction devices are not available, a traction post may also be used. The contralateral leg is padded and may be secured to the table (31).

PORTALS

Portal Placement

Correct portal placement is crucial to adequate visualization of the hip. Three main portals, the anterolateral, anterior, and posterolateral, are the basic portals needed to evaluate the central compartment arthroscopically. The anterolateral and anterior portals are the workhorse portals of hip arthroscopy. The anterolateral portal is often created first and is placed approximately 1 cm anterior and 1 cm superior from the tip of the greater trochanter. The anterolateral portal enters the lateral capsule at the anterior margin through the gluteus medius muscle (8).

The posterolateral and anterior portals are then placed under direct visualization once the anterolateral portal is established. The anterior portal is normally placed second and is placed at the intersection of a vertical line drawn from the ASIS and a horizontal line drawn at the level of the greater trochanter. The anterior portal enters the anterior capsule by piercing the sartorius and rectus femoris muscles approximately 6.3 cm distal from the ASIS (4). Caution must be taken when placing this portal, as the lateral femoral cutaneous nerve and a terminal branch of the lateral circumflex femoral artery may be affected (29).

The posterolateral portal is placed posterior and superior to the greater trochanter. It is approximately 4 cm from the gluteal nerve and 2.9 cm from the lateral edge of the sciatic nerve (4). This portal enters the posterior margin of the lateral capsule by going anterior and superior to the piriformis tendon and piercing though the gluteus medius and minimus.

After the patient is prepped and draped, traction is reestablished, to distract the joint approximally 1 cm, and the anterolateral portal is established first under direct fluoroscopic visualization using a spinal needle. The needle is directed slightly posterior and cephalad into the joint with the goal of establishing a portal that does not violate the femoral head cartilage or the labrum. The need for fluoroscopic visualization of this entry is minimized by experience. At this point, some surgeons opt to distend the joint with 30 to 60 mL of saline although this is not mandatory (Fig. 45.9).

Once in the joint, the needle is exchanged for a nitinol wire, a small vertical skin incision is made with a No. 11-blade and a 4.5 cannula/obturator is slowly advanced along the wire, through the thick capsule and into the joint. Gently pronating and supinating the wrist increases ease of passage through the soft tissue. The obturator and the wire are removed together to prevent breakage of the wire. Many surgeons place a 5 cannula directly over the wire into the joint instead of the 4.5 and scope using this portal. This author prefers to use a cannula with both an inflow port and an outflow port (as in shoulder arthroscopy) and therefore exchanges the 4.5 cannula over a switching stick with a dual port cannula prior to placing the 70-degree camera into the joint. The joint is then irrigated as needed (Fig. 45.10).

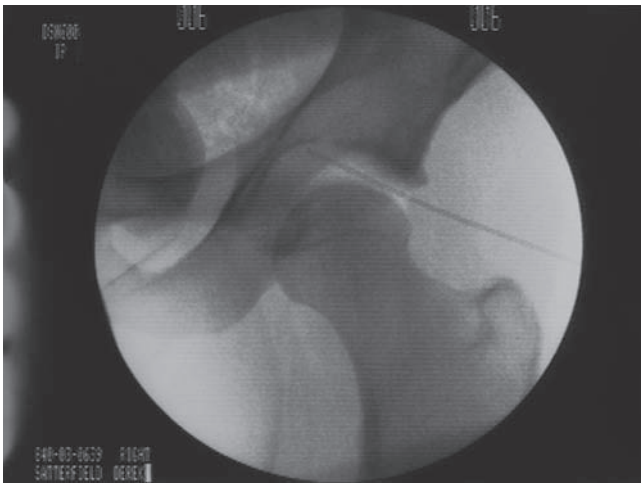


FIGURE 45.9
Anterolateral portal placement.

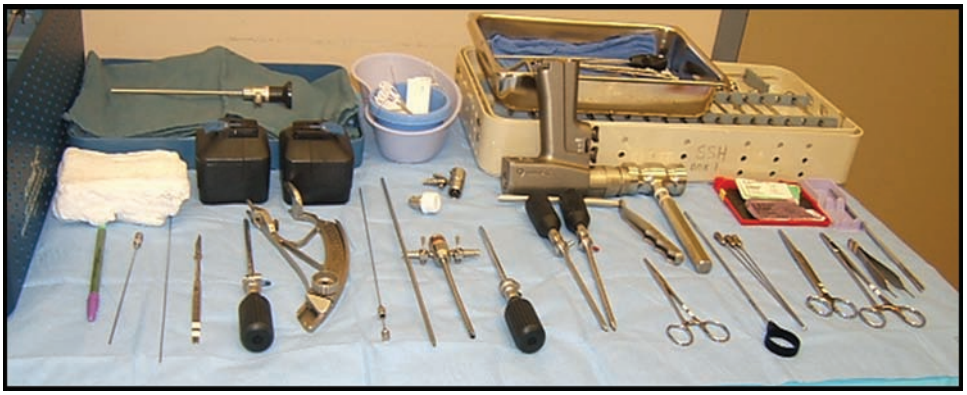


FIGURE 45.10
Standard hip arthroscopy equipment.

With the 70-degree scope in place, it is possible to visualize the anterior triangle made by the femoral head distally, the labrum and actabulum superiorly, and the hip capsule superiorly. The medial wall of this triangle is the anterior capsule that overlays the iliopsoas tendon (Fig. 45.11). This capsule is often red and inflamed when the iliopsoas tendon is tight or popping over the anterior actetabulum.

With the anterior triangle in view, the anterior portal is established under direct visualization. The C-arm is of minimal value in the establishment of this portal. The anterior portal is begun at the intersection of the ASIS sagittal line and the superior edge of the greater trochanter. The spinal needle is directed approximately 45 degree cephalad and 30 degree medial. The needle should be visualized entering the joint adjacent to but not through the anterior superior labrum. The hip joint is sometimes filled with serosanguanous joint fluid, and this portal must be established without visualization. When this is the case, placing the spinal needle anteriorly into the joint and placing the suction directly onto this needle will assist in joint irrigation. After the anterior portal is established, a 5 cannula is placed into the joint as previously described. The anterior portal then becomes the working portal and a probe is placed intra-articularly.

In addition to the three main portals, other accessory portals have been described to provide visualization and treatment of other hip pathology in the central, peripheral, and peritrochanteric compartments. The central compartment can be accessed by the anterolateral, posterolateral, anterior, and midanterior portals. The midanterior portal is placed distally and equidistance from the anterior and anterolateral portals. Recent studies have highlighted the usefulness of ultrasound for guiding the placement of portals in real time, without the need for radiation from fluoroscopy (15).

Once the portals are established, either the 30- or 70-degree scopes may be used. Literature supports the use of the 70-degree scope in all portals and the 30-degree scope in posterolateral and superior trochanteric portals where wider visualization may be obtained (23).

Diagnostic Scope

Evaluation of the hip begins with placement of the 70-degree camera through the anterolateral portal. This allows the greatest visualization of the more peripheral portions of the joint and the best view of the anterior/superior hip. The 70-degree camera also allows for direct visualization of the anterior and posterior joint for accessory portal placement. The anterior portal is placed under direct visualization and a probe is introduced.

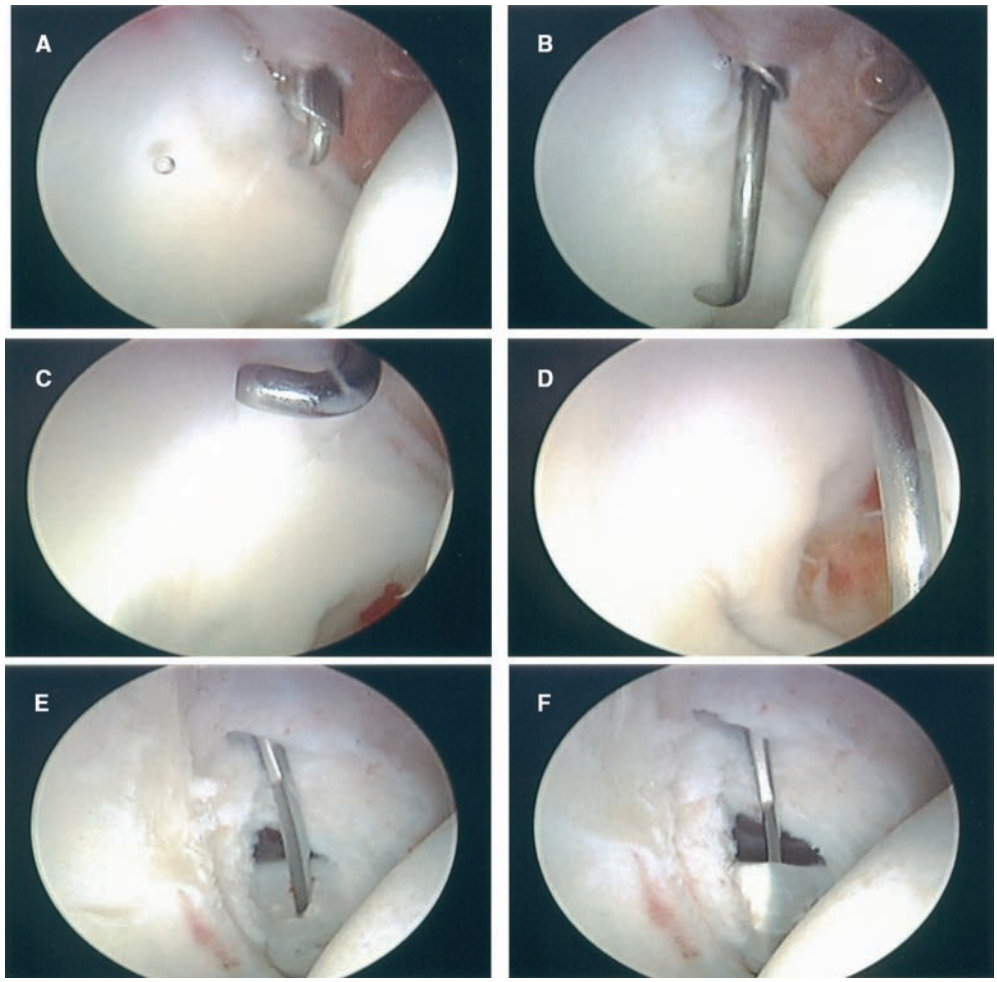


FIGURE 45.11
Intra-articular hip anatomy. **A:** femoral head; **B:** acetabulum; **C:** labrum; **D:** anterior capsule; **E:** acetabular cartilage; **F:** fovea.

The intra-articular structures including the anterior and superior labrum, acetabular cartilage, femoral head cartilage, anterior capsule overlying the iliopsoas tendon, transverse acetabular ligament, and the fovea and its contents are easily evaluated. Introduction of the 30-degree scope through the anterolateral portal allows a more direct view of the fovea and its contents (Fig. 45.11)

The camera can then be placed in the anterior portal to evaluate the position of the anterolateral portal and the most inferior margin of the anterior labrum (2). Finally, if a posterior lateral portal was established, the camera is placed there for viewing the posterior labrum. For extra-articular pathology that is still intracapsular, patients should be placed in 30° to 45° of hip flexion to relax the anterior capsule. This allows for access to the peripheral compartment of the hip and allows treatment of synovial disease, loose bodies in the peripheral recess and adhesive capsulitis (7). Problems with excessive flexion include potential sciatic nerve palsy and may obstruct anterior portal entry.

Following thorough evaluation of the hip joint, the intended surgery is initiated. The following chapters will address the arthroscopic management of labral tears of the hip and osteoplasty for femoral-acetabular impingement.

Complications

Complication rates associated with hip arthroscopy are low but not zero and range between 0.5% and 6.4% in the literature (31). The most common complications are neuropraxias of the pudendal nerve secondary to traction and lateral femoral cutaneous nerve secondary to anterior portal placement. Other complications include infection, damage to the femoral neurovascular structures, DVT, fluid extravasations, iatrogenic chondral or labral damage, and intra-articular instrument breakage.

CONCLUSION

Hip arthroscopy has expanded as a field over the last decade. The indications for performing hip arthroscopy have grown, as well as surgical techniques to treat these conditions. Newer indications are being developed in

other areas of orthopedics, such as arthroplasty and trauma. Further studies will need to be conducted to evaluate the long-term effectiveness and sequelae of these newer uses. Overall, the field of hip arthroscopy continues to grow and will continue to provide promising treatments to disease processes.

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46 Labrum: Débridement or Repair?

Karl F. Bowman Jr. and Jon K. Sekiya

INTRODUCTION

The acetabular labrum has been widely recognized as a source of hip pathology. The clinical manifestations of injury to this structure are being reported with increasing frequency. Injury to the labrum has been documented as a result of femoroacetabular impingement (FAI) or hip dysplasia, hip dislocation, athletic injuries, or it may have an idiopathic origin (1–4). Labral tearing can result in hip pain and mechanical symptoms and has been implicated in the accelerated development of degenerative osteoarthritis (5). Surgical techniques to manage labral pathology have also developed rapidly. Initial techniques included surgical hip dislocation with labral débridement and management of associated pathology. Current arthroscopic techniques appear to lead to similar or improved initial outcomes, while allowing a shorter recovery period and more rapid return to activity (6).

The acetabular labrum itself is a complex structure consisting of a fibrocartilaginous rim composed of circumferential collagen fibers spanning the entirety of the acetabulum, becoming contiguous with the transverse acetabular ligament (TAL) and anchored through a well-defined 1 to 2 mm transitional zone of calcified cartilage at the acetabular rim. The labral surface immediately adjacent to the articular cartilage of the femoral head becomes continuous with the hyaline articular cartilage of the acetabular surface through a similar transitional zone (1). Histologically, the labrum is composed of dense connective tissue divided into bundles at the peripheral rim and transitions to fibrocartilage at the inner surface. The vascular supply is derived primarily from the joint capsule, originating from the medial and lateral circumflex, inferior and deep branch of the superior gluteal arteries (1,7,8). There is a relatively hypovascular zone within the internal substance of the labrum and extending to the distal margin that may predispose this area to injury from acute or repetitive trauma and lead to degenerative change. The peripheral attachment of the labrum near its bony attachment has been shown to have a robust vascular supply, and in conjunction with the highly vascularized synovium, there may exist the potential of labral neovascularization and healing in the setting of labral injury (1,7).

The complete physiological function of the labrum is not completely defined, but it appears to serve multiple purposes, including a limitation of extreme range of motion and deepening the acetabulum to enhance the stability of the hip joint. Studies have shown that the labrum contributes approximately 22% of the articulating surface of the hip and increases the volume of the acetabulum by 33% (1). This serves to dissipate the large forces across the hip with stride and athletic activities as these joint reactive forces can be as high as four times the body weight (9). The labrum also provides a sealing rim around the femoral-acetabular joint, enabling increased hydrostatic fluid pressure, which facilitates synovial lubrication and resistance to joint distraction (10).

The highly organized composition of the labral fibers provides exceptional radial tensile stiffness, while its low permeability assists in maintaining the articular fluid homeostasis. In conjunction with the TAL, it contains an inherent elasticity that allows excellent conformity with the articular surfaces during range of motion while providing for minor joint incongruities. This allows the labrum to function in its most important role of dissipating the high potential contact forces encountered by the hip joint during activity and weight bearing at any flexion angle.

Pathologic alterations of the acetabular labrum have classically been associated with developmental disorders of the hip including Legg-Calve-Perthes disease, developmental dislocation, and acetabular dysplasia. Injury to

the labrum from acute trauma, repetitive injury, and impingement syndromes have more recently been identified as a source of pain (2,3,11). Once injured or torn, the role of the labrum is compromised and can lead to further damage to surrounding structures in the hip, including the articular cartilage loading, delamination, and subchondral cyst formation. It has been shown that the loads across the femoral and acetabular articular cartilage in a labrum-deficient hip are up to 92% greater than those encountered with an intact labrum. Labral deficiency also imparts a decreased constraint of the femoral head, allowing the center of joint contact to displace laterally toward the acetabular rim, creating this focal area of increased articular forces. The mechanical stability of the hip may further be compromised due to the reduced resistance to hip distraction and disruption of the intra-articular hydrostatic environment. Such alterations in the kinematics of the native hip anatomy may contribute to the progression of hip osteoarthritis following labral injury (12–15). This was initially evidenced by the increased incidence of osteoarthritis in patients with developmental dysplasia of the hip, chronic labral tears, and full-thickness chondral lesions (16). Attempting to improve the symptoms of hip pain while potentially reducing the progression of osteoarthritic degeneration of the femoro-acetabular joint have spurred significant interest in the operative management of labral tears and associated pathology.

CLINICAL PRESENTATION

The anatomic relationship of labral tears to underlying bony and musculotendinous hip pathology has been well defined in the literature. These include trauma, FAI, capsular laxity, and hip dysplasia. There is less evidence regarding the clinical usefulness of signs, symptoms, and examination in accurately detecting labral tears without further diagnostic testing. However, the most important initial step in the evaluation of hip pain is the history and clinical examination (17).

A labral tear can be the result of a traumatic event, usually involving an external rotation force with the hip in a hyperextended position (18). There may also be a chronic component without acute injury, with labral tearing occurring from microtrauma associated with repetitive activities during routine hip motion, such as with FAI. A careful history including any inciting trauma; onset, duration, and progression of symptoms; aggravating and mitigating factors; previous interventions; and activity-related consequences should routinely be obtained during the initial visit. It is frequently helpful to ask the patient to demonstrate the activities or extremity position that reproduces the symptoms, as this may assist in identifying the etiology of the complaint.

Reported symptoms of a labral tear may include pain, clicking, mechanical locking, instability, a feeling of giving way, or joint stiffness. Anterior groin pain is frequently associated with intra-articular complaints, and a high number of patients diagnosed with labral tears will report this findings. The pain associated with an intra-articular source may less commonly radiate to the posterior hip, buttock, greater trochanter, medial thigh, or knee. One must use caution as these symptoms are relatively nonspecific and do not confirm the diagnosis of a labral tear (19).

Other etiologies of the presenting symptoms must also be carefully considered to identify possible contributing sources. These include the urogenital system problems, sacroiliac (SI) joint pain, spinal pain, abdominal symptoms, soft tissue contusions, and abdominal wall pain. If there is a suspicion of an extra-articular component to the patient complaint, the history and physical examination must be adjusted appropriately (20).

PHYSICAL EXAMINATION

The clinical evaluation of a patient with hip pain can be challenging and requires a systematic approach to the physical examination to aid the clinician in correctly identifying the source of the complaint. These symptoms may arise from both an intra-articular and an extra-articular source, and care must be taken to appropriately direct the diagnostic algorithm to successfully locate the source of the complaint and guide therapeutic interventions. After an appropriate history has been obtained, the physical examination can assist the physician in further narrowing the diagnosis (20).

A focused physical examination should include evaluation of the lumbar spine, SI joints, and the femoroacetabular joint. The examination of the hip can be complicated by the relatively common incidence of referred pain from genitourinary, visceral, and gynecologic etiologies to the area in question (21). These external sources of pain may masquerade as hip pathology and must be ruled out (4).

In patients with unilateral complaints, all objective examinations should be compared to the contralateral side. A gait examination, if able to be performed, is frequently the initial step in the evaluation. Particular attention should be placed on stride length, core balance, posture, and the duration of the stance phase of gait. One should also take care to notice evidence of scoliosis, limb-length discrepancy, muscular deficit, or joint contractures (22). The focused examination of the hip should include localizing areas of maximal pain or tenderness and any atrophic muscular changes identified with palpation. Intra-articular pathology will rarely be associated with external discomfort. Hip range of motion is assessed with comparison to the contralateral extremity in the supine position with all deficiencies documented. This should include measurement of flexion, extension, internal and external rotation, and any associated deficit or discomfort. Increased passive external rotation of the leg with the hip in neutral extension may indicate the presence of capsular laxity. Provocative testing is used to functionally

evaluate patient symptoms in various limb positions. Placing the hip into flexion/adduction/internal rotation places the anterolateral femoral head and neck into proximity with the anterior and lateral acetabular margin. This may cause compression of the labrum and associated pain in the presence of a labral tear. The FABER test consists of flexion/abduction/external rotation of the hip and places the iliopsoas tendon on stretch while stressing the SI joints. The Ober test assesses iliotibial (IT) band tightness with the patient in the lateral position with the symptomatic extremity in placed superiorly. A positive result is when the leg remains abducted while the hip and the knee are passively extended. A flexion contracture of the hip can be assessed with the Thomas test as it minimizes the ability to compensate for decreased hip extension with excessive lumbar lordosis. The contralateral hip is flexed, reducing lumbar lordosis and assessing full hip extension in the supine position. Assessment of a "snapping" sensation should also be performed as this may be due to the IT band gliding across the greater trochanter or the iliopsoas tendon riding over the anterior margin of the superior pubic ramus.

While the physical examination is a critical component to diagnosis, it should be noted that multiple studies have found that the diagnostic accuracy of clinical findings may be variable. One additional function of the examination is to guide the physician in ordering appropriate diagnostic tests to identify and confirm the source of symptoms (23,24). There is also a limited correlation between physical examination findings and those patients with true intra-articular hip pathology.

IMAGING

Imaging of the hip is a routine part of the diagnostic algorithm for management of intra-articular pathology and includes plain radiographs, computed tomography (CT), magnetic resonance imaging (MRI), and magnetic resonance arthrography (MRA). Plain radiographs of the pelvis are the mainstay in the initial evaluation of hip pathology and are excellent in the identification of fracture, dislocation, arthritic change, bony abnormalities including FAI and dysplasia, and identification of radio-opaque loose bodies. A standard radiographic series should include anteroposterior pelvis and lateral views (25). Certain radiographic findings may immediately lead the orthopaedic surgeon to suspect labral pathology, or identify another etiology responsible for the patient's symptoms. These may include stress fractures, cam or pincer-type femoral acetabular impingement, excessive acetabular retroversion, joint space narrowing, subchondral sclerosis, osteophyte formation, or femoral head collapse associated with avascular necrosis.

CT imaging allows excellent spatial resolution of the bony architecture of the hip joint and assists in the identification of fracture, neoplasm, arthritic changes, congenital dysplasias, and as an alternative to the patient who cannot obtain an MRI for various reasons. The addition of intra-articular contrast material allows improved identification of labral pathology and resolution of the articular surface (26). It should be noted, however, that CT scans do deliver a relatively high dose of radiation compared with plain radiographs.

Standard MRI of the hip joint is useful for evaluation of extra-articular bony and soft tissue anatomy, but without the addition of contrast agent it is insufficient to evaluate the labrum and intra-articular contents of the hip joint (27,28). MRA allows improved visualization of the labrum, articular surface, and capsule via the injection of gadolinium contrast directly into the joint. A labral tear is identified by a linear defect through the substance of the labrum (Fig. 46.1). This is most easily visualized on T1-weighted coronal images with fat

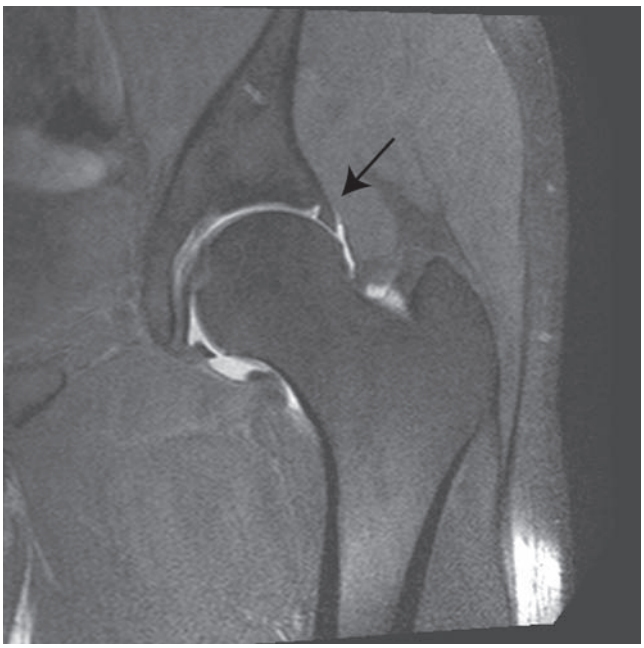


FIGURE 46.1

MR arthrogram revealing a large labral tear of the left hip (*arrow*) (T1-weighted coronal image with fat suppression).

suppression as a majority of intra-articular pathology occurs in the anterior and superior portions of the joint (27,29,30). MRA has been shown to have a sensitivity as high as 90% and a specificity of 44% when compared with direct arthroscopic visualization, correlating to a >90% positive predictive value. Intra-articular contrast also allows improved visualization of articular cartilage defects, although a high false-negative rate has been reported for identification of chondral defects when compared to arthroscopic visualization (31–33). Despite the often excellent identification of pathology utilizing MRA, a negative study does not necessarily exclude significant intra-articular pathology that may be encountered at the time of surgery.

One diagnostic strategy is to use a mixture of local anesthetic, corticosteroid, and gadolinium contrast medium for intra-articular injection prior to MRA. In our clinical practice, we will combine 6 mL of 0.25% marcaine, 6 mL of 1% lidocaine, and 80 mg of kenalog (instead of saline) with Gadolinium to combine diagnostic and therapeutic goals while minimizing the number of invasive procedures. A specific set of postinjection instructions is then provided to the patient to rate symptomatic relief on a scale of 0% (no relief) to 100% (complete relief) within the 2 hours immediately following injection during the time of maximum local anesthetic effect. This information is then combined with the response to initial nonoperative treatment to formulate an appropriate therapeutic strategy (23). If an MRI has previously been performed, we do an isolated fluoroscopic injection without the Gadolinium using the same percent relief determination protocol.

CLASSIFICATION

A classification of labral pathology identified during hip arthroscopy was described by Villar in 1996. This classification of labral tears was divided into an etiologic classification and a morphological classification, each with four distinct subgroups. The etiologic classification includes traumatic, degenerative, idiopathic, and congenital groups. Traumatic tears were associated with an identifiable hip injury, degenerative tears are identified by the presence of degeneration of surrounding tissues, including the articular cartilage or the labrum itself, idiopathic tears have no identifiable cause and are not associated with degenerative changes, and congenital tears are associated with structurally normal but functionally abnormal labral tissue. The morphological classification describes the pattern of labral tearing and includes radial flap tears, radial fibrillated tears, longitudinal peripheral tears (i.e., bucket-handle tears), and unstable tears associated with congenital changes (34).

The American Academy of Orthopaedic Surgeons classification of labral tears is based on their appearance at arthroscopy. Stage 0 identifies a labral contusion with synovitis. Stage 1 signifies the presence of a discreet labral tear with normal articular cartilage. A stage 2 lesion contains focal articular damage of the femoral head without acetabular change. Stage 3 describes a labral tear with an adjacent focal acetabular lesion, with or without femoral head changes. These are further subclassified into a 3A lesion, involving <1 cm of the acetabular cartilage, and stage 3B lesions, involving >1 cm of articular cartilage. Stage 4 signifies extensive labral tearing with diffuse osteoarthritic changes throughout the joint (30,31).

CONSERVATIVE MANAGEMENT

Most patients who are evaluated for hip pathology are given an initial trial of nonoperative management. Depending on the etiology of the hip pain, we recommend activity modification and a 6- to 12-week course of stretching and physical therapy. Traumatic injury is managed with a 2- to 4-week period of protected weight bearing and activity modification followed by enrollment into a physical therapy program (29). The rehabilitation program focuses on patient flexibility and range of motion of the affected and surrounding joints. We also focus on stretching-associated musculotendinious structures, such as the iliopsoas, IT band, and trochanteric bursa that may be contributing to symptoms of hip pain (20). Therapeutic modalities, such as icing, heat, aquatherapy, ultrasound, and iontophoresis, are frequently used as adjuvant treatment. Athletic activities are gradually reintroduced, beginning with cycling and running followed by a return to cutting and jumping maneuvers.

If activity modification and physical therapy fail to achieve an adequate amount of improvement, or if the initial clinical and radiographic examination is concerning for a primary intra-articular pathology, an intra-articular injection of local anesthetic and corticosteroid is used. The immediate postinjection relief afforded by the local anesthetic can be a helpful marker in predicting the amount of the patient's symptoms originating from an intra-articular source, while the steroid affords a certain degree of longer-lasting pain control. This can often be combined with a contrast medium as previously discussed to achieve both a diagnostic and a therapeutic effect while minimizing invasive procedures. The amount of relief provided by intra-articular injections may assist to some degree in estimating the potential symptomatic improvement that can be expected with operative management (23,29).

OPERATIVE MANAGEMENT

Operative management of labral pathology due to trauma was first described by Altenberg, who reported on two patients successfully treated with open labral excision (35). This is one of the earliest reports implicating the traumatic injury to the acetabular labrum as a source of hip pain. Since that time, several studies have been

published describing multiple techniques for the evaluation and management of labral pathology (36). As hip arthroscopy has developed over the last several decades, most lesions of the acetabular labrum can be managed with this technique.

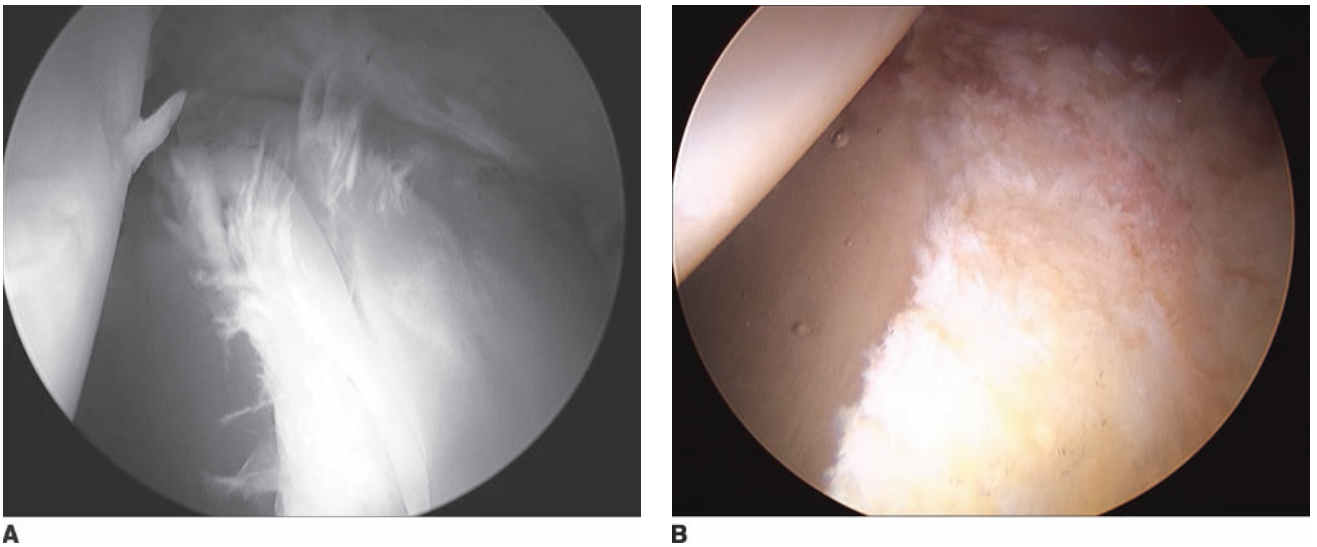
Hip arthroscopy is preferably performed under general anesthesia with appropriate muscular relaxation to allow adequate distraction of the hip joint. The patient is positioned supine with both extremities secured in a traction apparatus with placement of a well-padded perineal post. The operative hip is then placed into extension with approximately 25 degrees of abduction and maximal internal rotation. Traction is then applied to the operative extremity to obtain 7 to 15 mm of joint distraction to allow intra-articular instrument placement. Commercially available traction devices permit multiple degrees of freedom, allowing both a static and a dynamic evaluation of the femoroacetabular articulation during the procedure. Fluoroscopic image intensification is used to confirm joint distraction and procedural assistance (37,38).

We initially establish a standard anterolateral portal for placement of the arthroscope, followed by placement of an anterior portal and accessory portals as necessary. Once established, these portals allow excellent visualization and access for manipulation of the entire anterior, posterior, and lateral aspects of the labrum utilizing a combination of 30- and 70-degree arthroscopes. Evaluation of the femoroacetabular articular surfaces and management of concurrent pathology is also facilitated (37–39).

Initial arthroscopic evaluation of the labrum includes a thorough visual inspection followed by mechanical probing of the integrity of the structure. Careful attention should be paid to areas of tearing or fraying, and associated degenerative changes. The location of the pathology within the substance of the labrum should also be considered as this can have implications for the likelihood of labral healing. Histological studies show that the distal third of the labral cartilage is relatively avascular and is likely to have poor healing potential. In contrast, the peripheral two thirds have been demonstrated histologically to contain a much more robust vascular supply with the added possibility of neovascularization from the neighboring synovium. This likely contributes to the ability of certain labral tears to be repaired primarily and preserve its protective function within the hip (7).

While significant debate exists regarding the optimal management of labral pathology, the current options include débridement and repair. Labral débridement involves removing small, unstable radial and flap tears in the peripheral margin of the labrum that contribute to pain and mechanical symptoms. The goal is removal of abnormal tissue and any area potentially contributing to the patients symptoms while preserving as much of the overall integrity as possible to minimize the deleterious effects of labral deficiency. This may be accomplished with a motorized shaver, a flexible ligament chisel, or a monopolar radiofrequency ablation probe (40,41). The tissue should be gently débrided to a stable base (Fig. 46.2A and B). Attention must be paid to possible intra-articular sources of the labral tear including FAI, loose bodies, or other associated abnormalities. Direct arthroscopic observation of the labrum through a full range of motion will help to identify contributing pathology that can subsequently be managed appropriately.

The results of labral débridement have been well documented in many large case series with uniformly positive results (26,29,40–42). As can be expected, the patients who seem to benefit the most are those with isolated labral tears without additional intra-articular abnormalities and minimal arthritic degeneration. As the function of the labrum is more clearly defined and the potential benefits of labral preservation are realized, the indications for labral débridement may change.



A **B**

FIGURE 46.2

Degenerative tearing of the acetabular labrum before **(A)** and after **(B)** débridement. Note the intrasubstance tearing of the labral tissue.

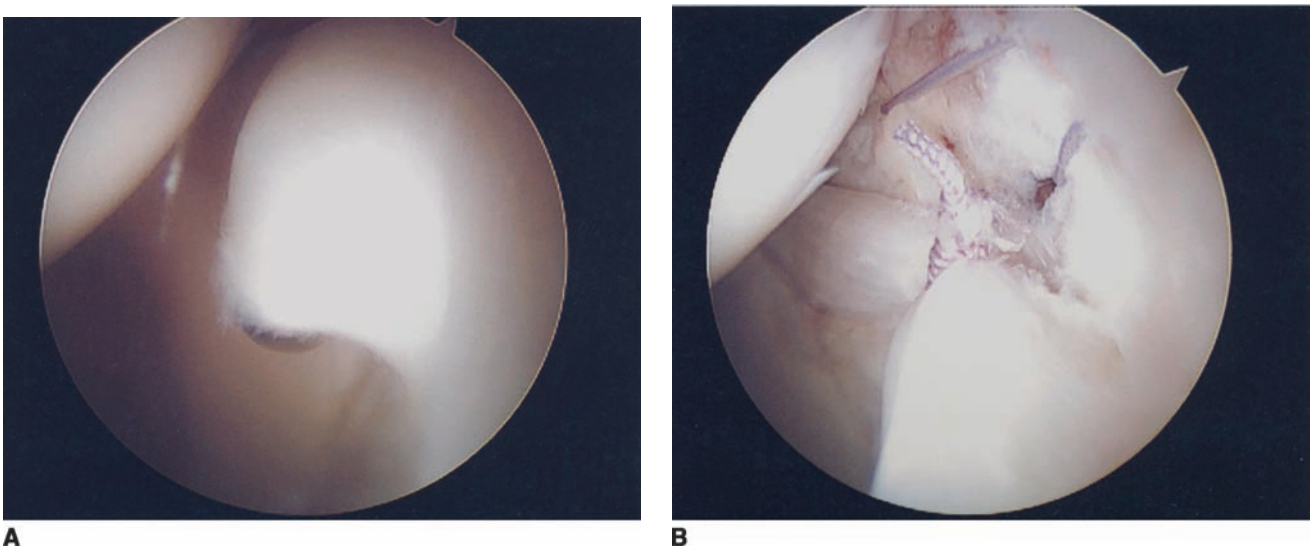
Labral tears that involve the base of the tissue or detachment from the acetabular rim may be amenable to primary repair as opposed to débridement. As previously discussed, the vascular supply in this region is robust and can facilitate tissue healing. Reapproximation and preservation of the labral integrity manages to restore the native anatomy, provide relief of pain, and possibly slow the progression of degenerative osteoarthritis. This is accomplished through the maintenance of joint stability, fluid dynamics within the hip, and stress shielding of the femoro-acetabular articular cartilage (10).

Following characterization of a labral tear through arthroscopic examination and probing, the extent of the labral tear must be determined through the mechanical débridement of surrounding nonviable tissue. This will often reveal the tear to be larger than initially appreciated on MRA or preliminary examination. Labral tears amenable to repair generally fall into one of two characteristic patterns. The first pattern is a longitudinal detachment from the acetabular rim, analgous to a bucket-handle tear commonly encountered during management of meniscal tears. This longitudinal tearing generally occurs at the transition zone between the hyaline articular cartilage and the fibrocartilaginous labrum. On visual inspection, the labrum appears to have separated from the bony acetabular rim. The second characteristic tearing pattern is a midsubstance tear of the labrum oriented along the longitudinal fibers of the structure (1).

If the labrum is detached from the bone, suture anchors are utilized to provide initial stabilization of the fibrocartilaginous rim to the acetabular margin (Fig. 46.3A and B). A bed for attachment of the detached labrum should be prepared utilized on the acetabular rim using a combination of a high-speed burr and osteotomes. Suture anchors are then sequentially spaced every 10 to 12 mm along the length of the tear. The anchors are placed parallel to the lateral source on the extra-articular margin of the acetabular rim. This avoids penetration into the joint surface and allows the arthroscopic knot to be located away from the articular cartilage. Depending on anchor type, pretapping the anchor site may assist in preventing iatrogenic chondral injury due to subchondral fracture. One limb of the suture is then passed into the substance of the labrum and reapproximated to the bony acetabular rim. There are multiple knot-tying techniques described in the literature including simple and mattress-type configurations. In our clinical practice, we utilize a simple suture in an interrupted pattern. A standard arthroscopic knot is then tied with the final knot placed in an extra-articular location (2). The knot should ideally be tied in a nonsliding fashion to avoid cutting through the labral tissue during the sliding of the abrasive braided suture material (Fig. 46.4A–E).

Operative management of pincer-type FAI and acetabular retroversion frequently involves elevating the labrum from its bony attachment prior to performing an osteoplasty. Following adequate resection of bony pathology, the labrum is then reattached via a technique similar to the one previously described for longitudinal labral tears occurring along the fibrocartilaginous rim (Fig. 46.5A–E).

Intrasubstance tears of the labrum oriented longitudinally are also amenable to arthroscopic repair. An interrupted suture technique involves utilizing arthroscopic instrumentation to place a suture through the peripheral margin of the tear between the articular surface and the proximal edge of the lesion. The suture is then passed distal to the tear and retrieved. The lesion is reapproximated as the suture is tied in an arthroscopic fashion with the knot placed extra-articular (2). Repair enhancement techniques, such as those used to augment red-white and white-white meniscal repair, may be of benefit in management of these intrasubstance longitudinal labral tears due to the decreased tissue vascularity in the more distal regions of the labrum. These include labral rasping, placement of a fibrin clot, growth factors, serum augmentation, and synovial abrasion. Such modalities



A B

FIGURE 46.3

Longitudinal (bucket-handle) tear of the labrum with minimal degenerative changes before **(A)** and after **(B)** repair.

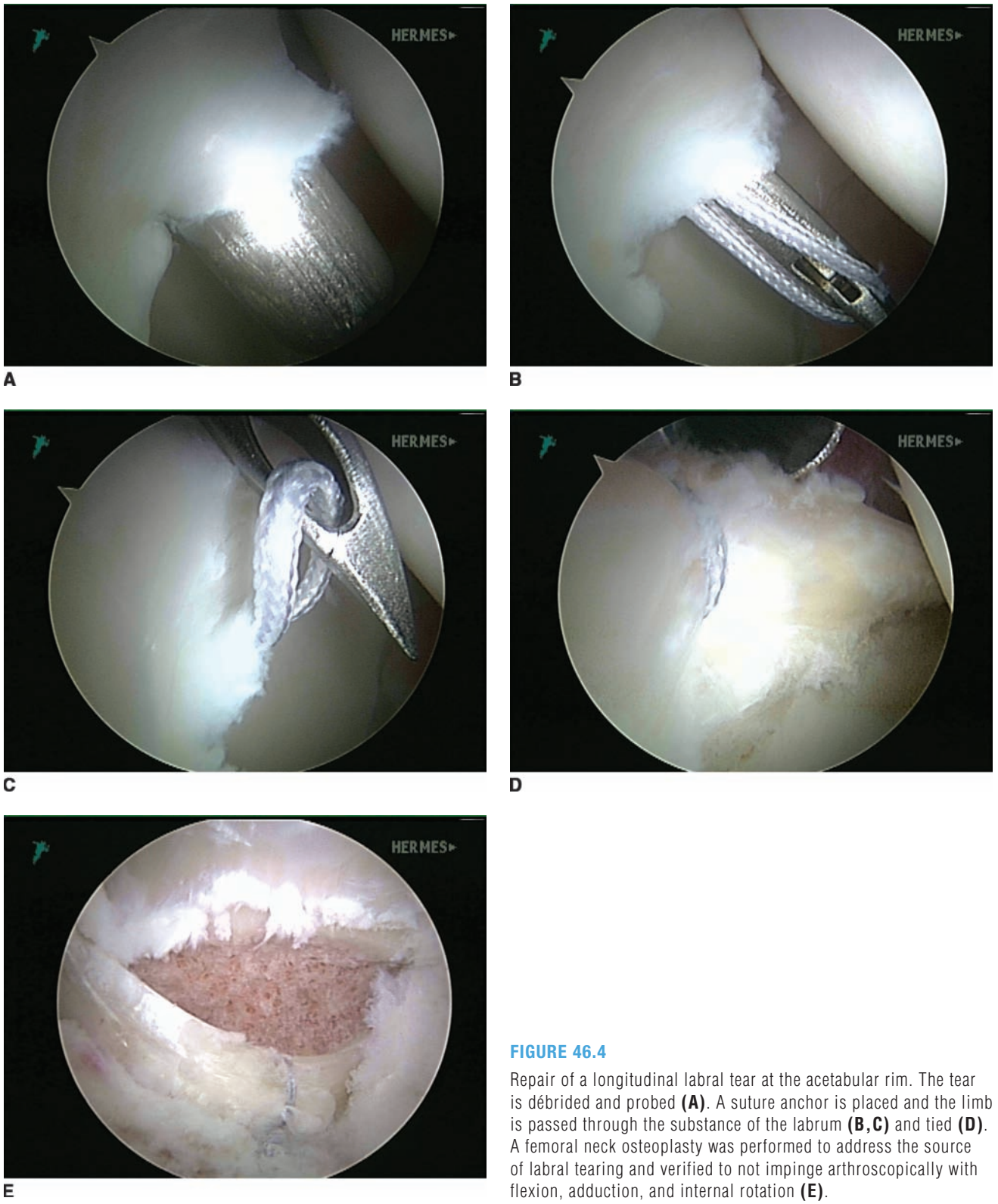
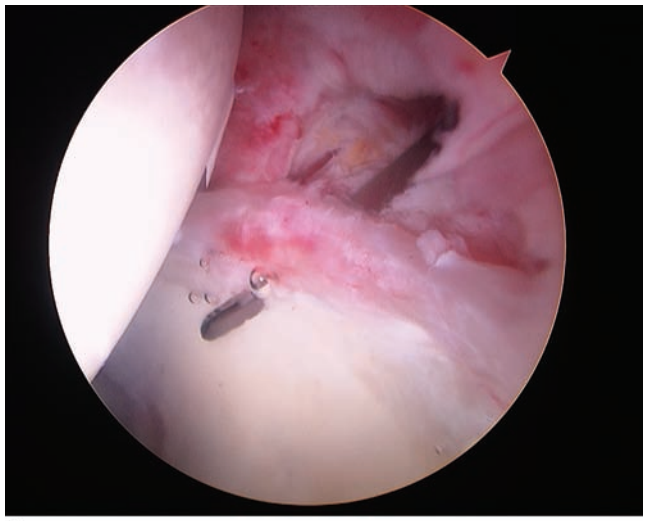


FIGURE 46.4

Repair of a longitudinal labral tear at the acetabular rim. The tear is débrided and probed **(A)**. A suture anchor is placed and the limb is passed through the substance of the labrum **(B,C)** and tied **(D)**. A femoral neck osteoplasty was performed to address the source of labral tearing and verified to not impinge arthroscopically with flexion, adduction, and internal rotation **(E)**.

may further assist with tissue regeneration as histological models have demonstrated a persistent superficial cleft located on the articular side of the labrum following repair and subsequent healing of an intrasubstance tear. This has been attributed to incomplete healing of intralabral portions of the tear (43).

Repair of radial tears with disruption of the longitudinal fibers is not well described, but this may provide some benefit due to the unique mechanical properties of the labrum. The continuous attachment of the labrum to the bony acetabular rim may provide partial continued stability in the presence of radial clefting. While the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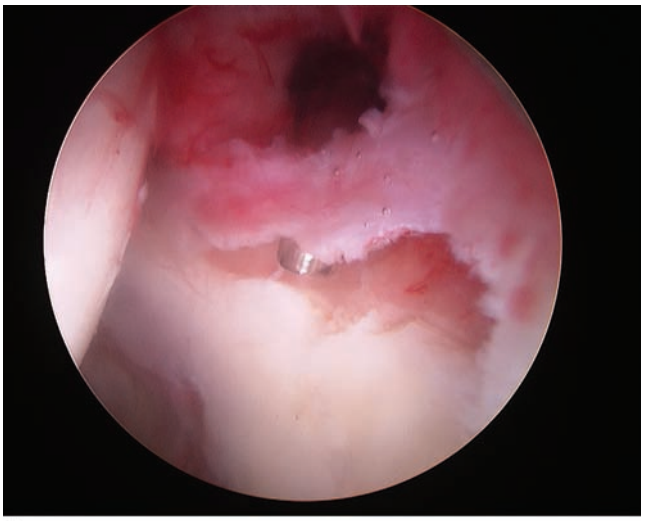
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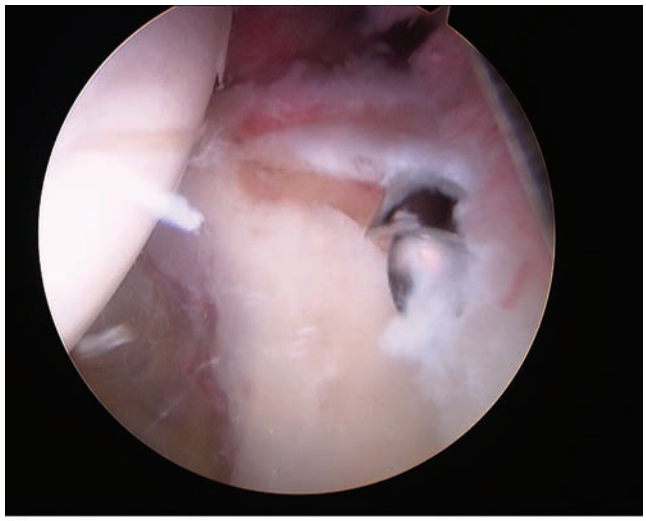
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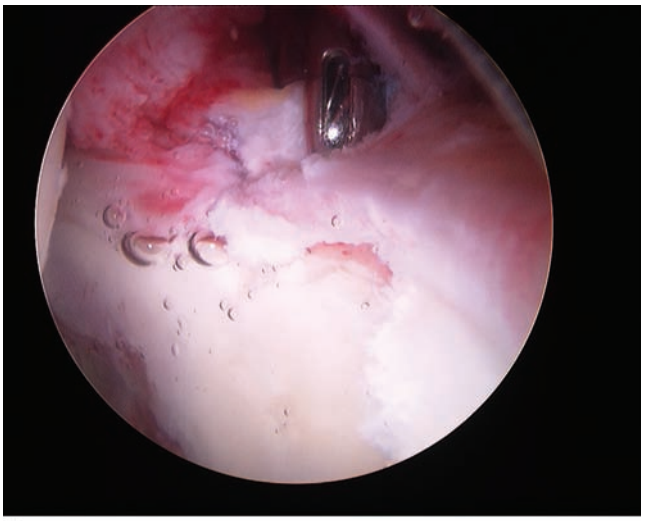
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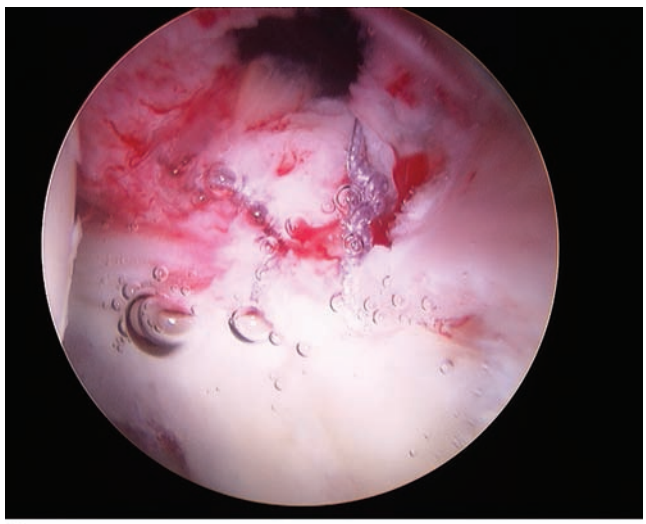
E

FIGURE 46.5

Arthroscopic management of pincer type FAI in a patient that had previously undergone labral débridement from an outside institution without symptomatic relief. Note the extensive bruising and inflammation in the labral tissue consistent with chronic impingement. The labrum is elevated from the acetabular rim and any degenerative tears are gently débrided **(A,B)**. An acetabuloplasty/rim trim is performed **(C)** followed by placement of multiple suture anchors **(D)** and labral reattachment **(E)**.

intra-articular seal is disrupted, the "bumper effect" of the labrum and contribution to the acetabular depth remain and may provide continued benefit. Further investigation is required to explore this possibility.

Clinical outcomes for labral repair are encouraging and include reported improvements in both hip pain and the ability to delay the need for total hip arthroplasty. Recent studies have found that labral repair appears to be equivalent or superior to labral débridement in reported postoperative pain, patient satisfaction, and with validated scoring systems such as the Harris Hip Score, nonarthritic hip score, and hip outcome scores. While no long-term case series are available due to the relatively short existence of modern hip arthroscopy, these results are encouraging and appear to support labral preservation techniques as a viable option for the management of certain of hip pathologies (44,45).

Labral reconstruction for the management of advanced labral degeneration or deficiency is a newly described technique that seeks to recreate the anatomical benefits of the labrum and potentially delay or avoid the onset or progression of osteoarthritis. Multiple graft choices have been proposed for the reconstruction including a section of the IT band, the ligamentum teres, or allograft tendon. This technique is in its infancy and no convincing data on long-term outcomes, pain relief, or progression of osteoarthritis have been published to date (46).

The importance of diagnosing and treating pathology associated with the initial development of the labral tear at the time of débridement or repair cannot be stressed enough. This may include capsular plication for laxity, rim trim/acetabuloplasty for pincher FAI, or osteoplasty for cam FAI. Failure to manage these concomitant pathologies may lead to recurrence and poor postoperative results (6).

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47 Femoroacetabular Impingement

Zackary D. Vaughn and Marc R. Safran

INDICATIONS/CONTRAINDICATIONS

Background

The pathology of femoroacetabular impingement (FAI) was initially described (1992) and published (1995) by Ganz, but first presented in the English literature in 1999 (1). Although FAI is a three-dimensional disorder with varying degrees and anatomic locations of pathologies, two main forms of impingement have been described. The first description was of an abnormality in acetabular overcoverage, known as pincer impingement. This results in a crushing of the labrum and acetabular rim against the femoral head-neck junction, which can lead to complex degenerative labral tearing from the crushing mechanism, edge loading of acetabular rim, calcific changes to the labrum with possible labral ossification and a type of "contrecoup" lesion of chondromalacia in the posterior aspect of the acetabulum and femoral head from subtle subluxation of the femoral head as it levers anteriorly (2–7).

The second form of FAI described is that of cam impingement, resulting from a bony abnormality of femoral head-neck junction with the loss of normal femoral head sphericity and femoral head-neck offset. This abnormal area of bone impacts the acetabulum and labrum leading to labral-chondral separation and a delamination of articular cartilage at the acetabular periphery. Although characterized as separate entities, it is most common to have both types of FAI present, although one form may predominate (2–7). The goal in the treatment of FAI is to restore the normal anatomy of both the acetabulum and the femoral head-neck junction, while also treating any associated pathology of the labrum or articular cartilage. Controversy has existed as to the best means to accomplish this, as both open and arthroscopic techniques have been described. The recent advances in hip arthroscopy have made the arthroscopic treatment of both the intra-articular and extra-articular components of FAI a safe and reliable procedure in experienced hands.

We believe that the labrum has several significant functions (8,9). Thus, if a labral tear is reparable, then we will repair the labrum in connection with FAI surgery. If the labrum is damaged within its substance, then we will perform a partial labrectomy.

Indications

Hip arthroscopy has seen a recent increase in interest since the 1980s. Subsequently, arthroscopy of the hip has been in a constant state of evolution with the advent of new instrumentation, improved knowledge of safety and techniques, and increasing surgeon experience, allowing for an expanding list of indications. Arthroscopic treatment for FAI is indicated in patients with a diagnosis of symptomatic FAI with or without associated labral or chondral injury. Some authors believe that surgery for FAI should be performed to prevent arthritis, even if it is asymptomatic. However, currently, no evidence exists that surgical correction of the FAI anatomy will prevent the development of arthritis, even though FAI may be a major cause of premature degenerative arthritis. Though not everyone with the anatomy of FAI will develop arthritis, there is no evidence that surgery for FAI will prevent arthritis (9). It is likely that the combination of this underlying anatomic abnormality and various activities that require an extended range of motion, such as cycling, running, soccer, and martial arts, will result in the breakdown of soft tissues, resulting in symptomatic impingement. Therefore, we recommend that only the hip with symptoms that can be attributed to FAI should be treated, whether open or arthroscopic.

Contraindications

The arthroscopic treatment of FAI is contraindicated in any patient who has contraindications to general anesthesia or elective surgical interventions of any kind based on medical comorbid conditions or infections. Patients with evidence of significant degenerative changes on plain radiographs with joint space narrowing or a predominance of aching pain at rest due to arthritis are not likely to have significant benefit from arthroscopy. Surgical treatment of FAI should also be avoided in patients who do not obtain symptom relief with an intra-articular injection of local anesthetic and further evaluation should be directed at other diagnoses.

PREOPERATIVE PLANNING

History

Patients with symptomatic FAI generally present with an insidious onset of aching pain in the hip and groin. Common aggravating activities include putting on or taking off shoes and socks, motions that generate deep flexion of the hip joint, sitting for prolonged periods of time, arising from a seated position, ascending or descending stairs or steep hills, sudden starts and stops, or any cutting and pivoting motion (10). The pain is typically made worse with impact activity and is described as originating from the groin, inguinal region, or deep within the joint (10). Patients may also note a gradual decrease in range of motion, particularly in flexion, adduction, and internal rotation (11). More abrupt onset of symptoms may be associated with a labral tear, labral-chondral separation, or a chondral flap, any of which can present with mechanical symptoms of painful locking, clicking, or catching.

Physical Examination

A complete review of the evaluation of the hip is beyond the scope of this chapter, but the reader is referred to references (12–14). A complete examination of the hip will include evaluating core and abdominal strength and ruling out pathology from the spine and knee. An evaluation of both stance and gait and inspection of the skin about the hip is the initial part of the exam. Trendelenberg and Ober tests are utilized to evaluate weakness and tightness of the hip abductors, respectively. Hip range of motion must be carefully documented in the supine position and related to the unaffected side. In patients with impingement, there is typically a limitation of internal rotation, particularly when the hip is flexed to 90 degrees. A positive impingement test is elicited with pain generated when the hip is brought to 90 degrees of flexion, adducted across the midline, and internally rotated (Fig. 47.1). Additionally, patients may have pain with a labral stress test (passive circumduction of the hip from abduction and external rotation with flexion, to a flexed, adducted, and internally rotated position) or with a resisted straight leg raise generating groin pain. These tests are often positive in FAI, both cam and pincer types, and also with other intra-articular pathology (12.14).

FIGURE 47.1

Impingement test. With the patient supine, the examiner brings the patient's hip to 90 degrees of flexion, adducts the hip, and then internally rotates the hip. Reproduction of groin pain is consistent with a positive impingement test, often associated with intra-articular hip pain. (Figure used by permission of Marc R. Safran, MD.)

Imaging Studies

Plain radiographs including an appropriate AP pelvis with the coccyx centered 1–3 cm above the pubic symphysis (Fig. 47.2A) and a true cross-table lateral (Fig. 47.2C) of the affected hip are essential to evaluating patients with hip pain consistent with the impingement process. The cross-table lateral/Dunn view and modified Dunn view are true lateral views of the hip and are more useful to provide both information about the proximal femur and the acetabulum compared to the frog-lateral projection (Fig. 47.2B), which provides limited evaluation of the acetabulum while demonstrating the lateral proximal femur. On these images, the femoral head is generally symmetric and has a distinct femoral head-neck offset. The loss of this sphericity in the femoral head and neck region may be consistent with cam impingement (15–17) (Fig. 47.2A–C). This can be demonstrated

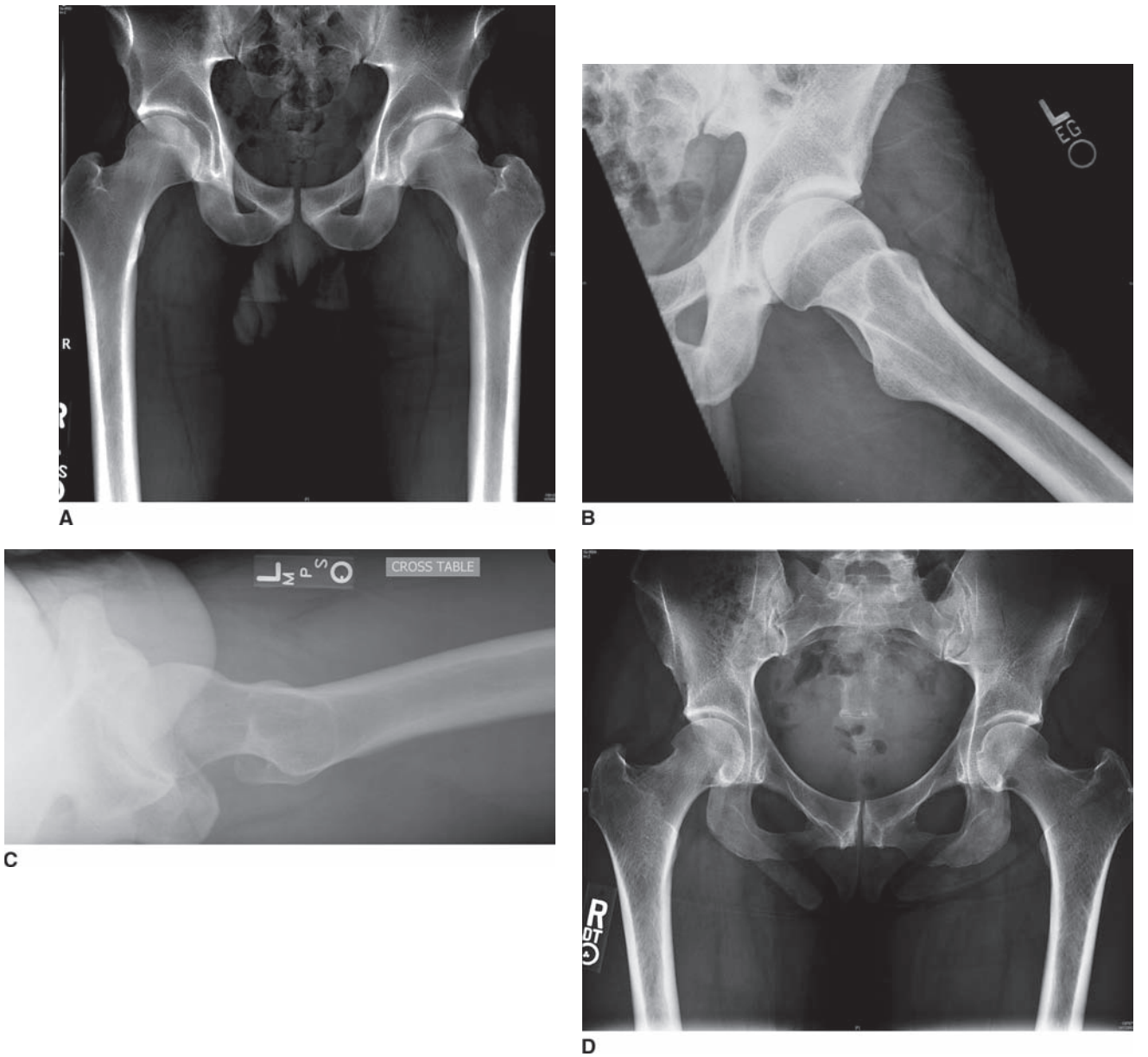


FIGURE 47.2

Combined-type femoral acetabular impingement. **A:** AP Pelvis radiograph of a 22-year-old collegiate basketball player that demonstrates the loss of femoral head-neck offset consistent with cam-type FAI. Note how the anterior wall of the acetabulum crosses the posterior wall, resulting in a figure–of-eight sign, indicative of cranial retroversion, seen with pincer impingement in both hips. Also, note the ossification of both hips, more clearly seen on the right hip. Thus, this patient has combined-type FAI. **B,C:** Are lateral radiographs—a frog-lateral and a cross-table lateral radiograph demonstrating the loss of femoral head neck offset with an anterior bump. **D:** Is an AP pelvis of a 37-year-old elite female triathlete with bilateral coxa profunda, where the floor of the acetabulum extends beyond the ilioischial line. (Figures used by permission of Marc R. Safran, MD.)

by a lack of concavity to the femoral head-neck junction on the AP view, appearing that the femoral head is not centered over the femoral neck. In some cases, a bony bump can be seen on the lateral view at the anterolateral femoral head-neck junction that may project beyond the femoral head or have a sharp transition or even a hook appearance to this area. Pincer impingement can also be well evaluated on these routine radiographs, demonstrating coxa profunda, protrusio, acetabular retroversion, and evidence of developmental dysplasia and arthritic changes. Coxa profunda is demonstrated on the AP pelvis when the floor of medial acetabulum is at or beyond the ilioischial line (Figs. 47.2D and 47.3). Protrusio is present when the most medial aspect of the femoral head is found to extend to or beyond the ilioischial line. The crossover sign is indicative of acetabular retroversion as the lines of the anterior wall and posterior wall are found to cross over one another on the properly positioned AP pelvis view (Fig. 47.2A). Dysplasia is evaluated with the lateral center edge angle of Wiberg measured on the AP view, or the anterior center edge angle of Lequesne measured on the false profile view of the pelvis. With either measurement, a value of <25 degrees is considered abnormal and a sign of dysplasia (Fig. 47.3).

Additional imaging modalities include CT scans, particularly a 3D reconstruction series, and MRI sequences. The CT scan is helpful for demonstrating the bony anatomy involved in the impingement process, while the MRI, particularly an MR arthrogram with a small field of view for the hip, is beneficial in alpha angle measurement, demonstrating the cam lesion, labral tears, chondral lesions, and edema or cysts within the femoral neck. The alpha angle (Fig. 47.4) as described by Notzli to quantify the femoral head-neck junction offset is based upon measurements on a radially generated axial MRI sequence (18). Most surgeons use 55 degrees as a cutoff value for defining cam impingement; however, the accuracy of measurement, reproducibility of measurement, and the positive correlation between correction of this measurement and surgical outcomes have not been shown.

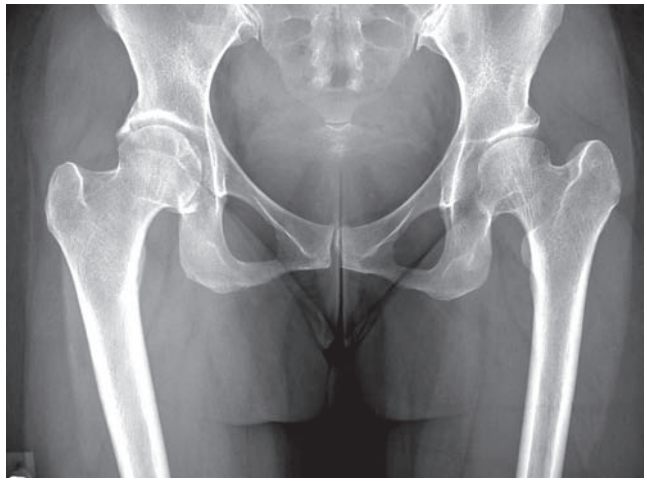


FIGURE 47.3

Is an AP radiograph of a 27-year-old woman with FAI on her right hip (coxa profunda and calcification of her labrum, functionally making her center edge angle 63 degrees) and dysplasia of her left hip, with a center edge angle of 24 degrees. (Figure used by permission of Marc R. Safran, MD.)

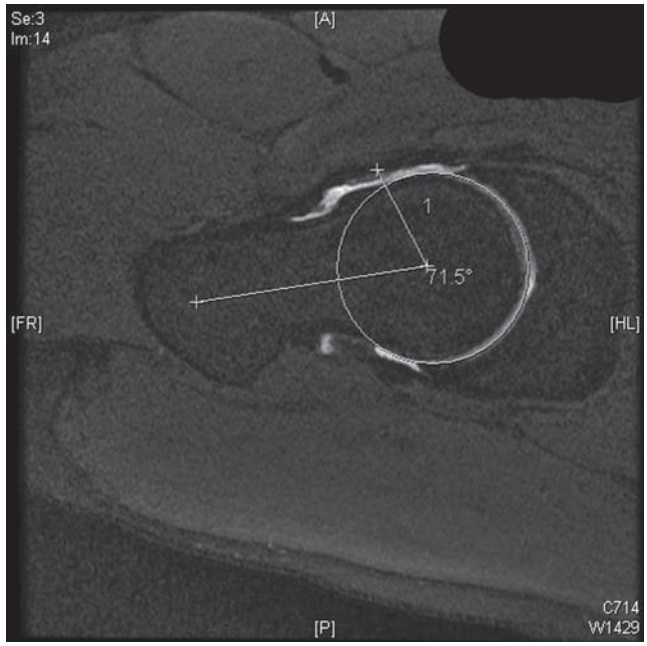


FIGURE 47.4

Is an example of an MRI from the basketball player in Figure 47.2, with the measurement of the alpha angle of 71 degrees. The alpha angle is measured as a line draw perpendicular to the narrow part of the femoral neck. A circle is drawn that most closely approximates the head size. A line is drawn from the center of the head to the point where the anterolateral femoral head exceeds the radius of the circle. The angle made by these two lines is the alpha angle. An angle <50 or 55 degrees is considered normal. (Figure used by permission of Marc R. Safran, MD.)

Our imaging protocol for the evaluation of FAI is to obtain a proper AP pelvis, cross-table lateral view, and a dedicated hip MR arthrogram utilizing a small field of view, with the use of intra-articular gadolinium and local anesthetic. This injection helps confirm the intra-articular source of pain with the temporary relief of symptoms from the local anesthetic component (19).

SURGERY

The goals of surgery for FAI are to relieve the abutment between the femoral head-neck junction and acetabular rim, in addition to treating the associated pathology of labral tears and chondral lesions. While this may be done in the supine or lateral position, our preference is the supine position. The following will describe our preferred arthroscopic technique for acetabuloplasty for pincer impingement and cheilectomy (or femoral osteoplasty) for cam impingement.

Patient Positioning and Draping

The patient is anesthetized with a general anesthetic in the supine position on a traction or fracture table with the feet well padded in mobile spars for the legs. The patient is brought into position against the padded perineal post and slightly lateralized away from the operative hip to allow for relief of pressure on the perineum and pudendal nerves and to allow for the appropriate direction of force for the traction (20). This places the perineal post against the proximal medial thigh of the operative hip. Gentle traction is applied to the contralateral leg in 45 to 60 degrees of abduction. The operative leg is placed in 10 degrees of abduction, with neutral rotation and neutral flexion-extension. The operative leg is then distracted until adequate distraction (8–10 mm) is verified with fluoroscopy. The general room setup is depicted in Figure 47.5.

Operative Technique

The superior aspect of the greater trochanter is identified and the proposed anterolateral portal site is marked (20). This portal is created just anterior to the anterolateral margin of the superior aspect of the greater

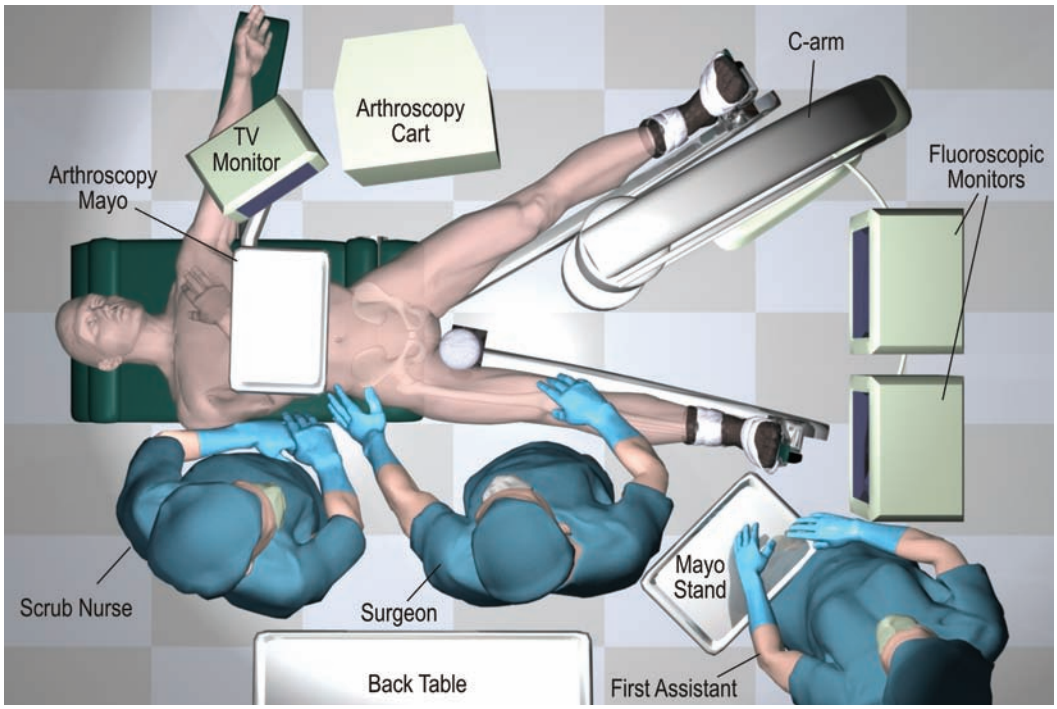


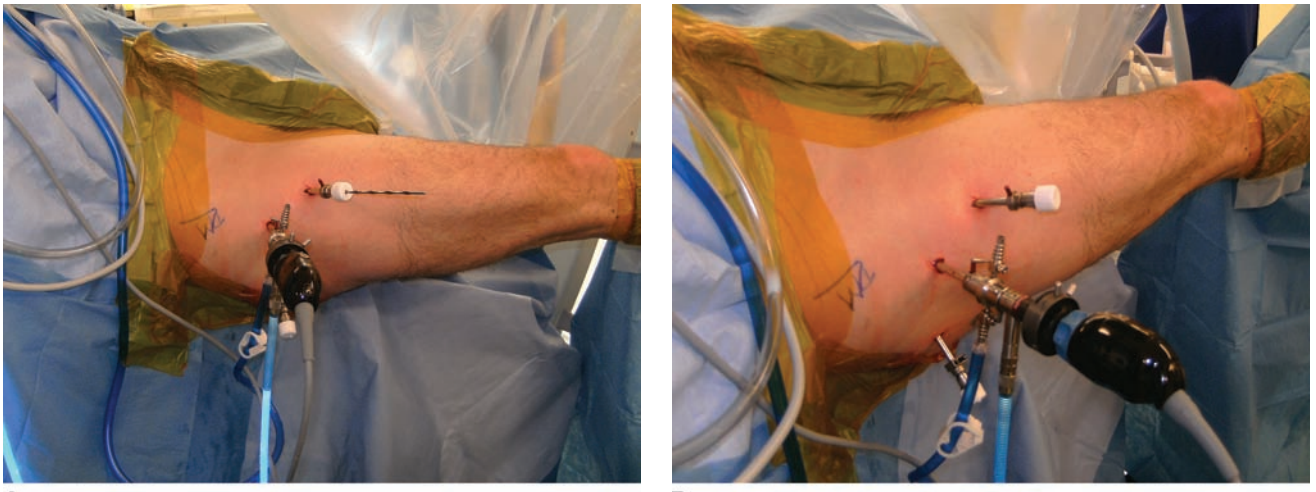
FIGURE 47.5

Typical operating room setup for supine hip arthroscopy utilized by the senior author. The patient is supine on a fracture table, with the perineal post lateralized toward the operative hip. The nonoperative leg is abducted 45 to 60 degrees and slight traction applied. The operative leg is abducted 10 degrees with neutral rotation and neutral flexion-extension. The surgeon, assistant, and scrub nurse are on the same side as the operative hip. The fluoroscopy machine is brought in between the patient's legs. The fluoroscopic monitor is at the foot of the table, while the arthroscopic monitor is across the patient from the surgeon. (Figure used by permission of Marc R. Safran, MD.)

trochanter. Identification of this portal can be assisted with the use of a spinal needle placed superficially over the hip joint under fluoroscopy to identify the safe path of entry. The area is then prepped with Betadine swabs and an 18-gauge spinal needle is then introduced at this site and placed into the hip joint under fluoroscopic guidance. Careful placement of the spinal needle will allow safe entry without damage to the chondral surfaces or labrum (20). Correct placement can be verified with removal of the stylet from the spinal needle, allowing air to enter the hip joint, creating an air-arthrogram and relieving the intra-articular negative pressure seal. This verifies positioning and reduces the force necessary to achieve adequate distraction. The needle is then removed and the traction released until after full prepping and draping is completed to minimize total traction time.

Complete circumferential prepping of the leg to include the knee distally and the abdominal midline and iliac crest proximally is required. The sterile-drape covered fluoroscopy unit can be brought into position between the patients legs and kept in position throughout the procedure (20). The anterolateral portal site is once again identified with use of a spinal needle. Once within the hip joint, the stylet is removed and a guide wire placed through the spinal needle. The needle is then removed and a superficial skin incision is made with a No. 11-blade scalpel over the guide wire. A blunt tipped, cannulated trocar is then introduced carefully over the guide wire and can be felt to penetrate the hip capsule and enter the joint (Fig. 47.6). The 70-degree arthroscope is then introduced and the remaining portals are created under arthroscopic visualization. The other described standard portals include an anterior portal and a posterolateral portal. The modified anterior portal that we have used for the last few years is 7 cm distal and anterior-medial to the anterolateral portal at a 45-degree angle (Fig. 47.6). This portal has been used because it reduces the risk of injury to the lateral femoral cutaneous nerve, reduces the risk of postoperative rectus femoris tendinitis, and allows a better approach to the joint should a labral repair be warranted. The modified anterior portal is created in the same technique, but augmented by arthroscopic guidance to placement of the spinal needle to avoid the labrum and chondral surfaces. Care should be taken to make the incision only skin deep, to reduce the risk to the lateral femoral cutaneous nerve. Once the portal and cannula are appropriately placed, the arthroscope can be placed into this cannula to visualize the initial cannula to verify and determine if the initial (anterolateral) portal injured the labrum. The posterior portal is created off the posterolateral edge of the superior greater trochanter in identical fashion, typically in a parallel and converging direction with the arthroscope in the anterolateral portal (Fig. 47.6B).

The evaluation of the central compartment of the hip will allow for treatment of labral and chondral lesions, the ligamentum teres, removal of loose bodies, and the treatment of pincer-type impingement. Seventy- and thirty-degree lens are used for full evaluation of the hip joint. The 70-degree lens is useful to evaluate the periphery of the central compartment, allowing for effective treatment of labral, acetabular, and chondral lesions. The 30-degree arthroscope lens demonstrates the central area of the central compartment and is most useful in evaluating the ligamentum teres as well as for peripheral compartment treatment of cam-type impingement.



A B

FIGURE 47.6

Intraoperative photograph of a man undergoing central compartment arthroscopy of the right hip. **A:** Shows the hip draped. The head is to the left and the feet (and knee as seen) to the right. The arthroscope is in the anterolateral portal, just anterior to the most proximal aspect of the greater trochanter. A probe is in a cannula in the modified anterior portal, approximately 7 cm anterior and medial to the anterolateral portal at a 45-degree angle. There is a cannula in the posterolateral cannula, seen better in **(B).** (Figures used by permission of Marc R. Safran, MD.)

Surgical Treatment of Pincer FAI

After a complete evaluation of the central compartment of the hip, the offending area of the acetabular overcoverage can be addressed. As noted, with pincer type of pathology, the labrum may be ecchymotic, degenerative, and have cystic or calcific change, which may necessitate extensive debridement or even resection. However, if we find that the overlaying labrum is healthy and intact, it can be carefully separated from the abnormal acetabular rim using an arthroscopic knife (banana blade). The knife is introduced typically through the cannula in the anterior portal and is introduced from between the labrum and capsular reflection on the outer edge and carefully between the labrum and articular cartilage, using the curvature of the blade to gently separate the labrum from the acetabular rim (Fig. 47.7). This must be delicately performed to avoid transection or damage to the labrum itself and avoiding undermining any healthy adjacent cartilage. After elevating the labrum, a nonabsorbable monofilament traction suture may be passed arthroscopically with a curved suture passer around the entire labrum to use as a traction device on the healthy labrum (Fig. 47.8). With the labrum distracted, the underlying acetabular rim can be safely accessed for performing an acetabuloplasty. We utilize a hooded, round, high-speed burr to remove abnormal areas of bony overcoverage, removing the bone where the overcoverage exists, based on preoperative planning. We usually begin anteroinferiorly and progress laterally

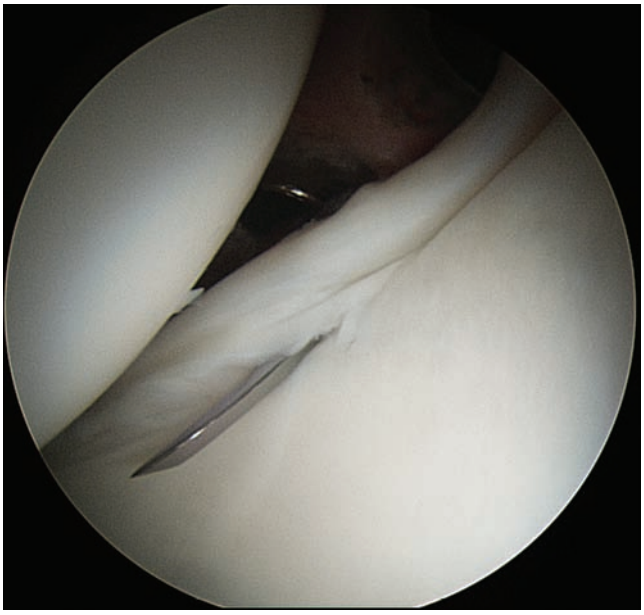


FIGURE 47.7

Arthroscopic view of a left hip of a 19-year-old female collegiate soccer player and sprinter, showing an arthroscopic knife between the labrum and acetabular cartilage. This knife is brought from behind the labrum to detach the labrum from the acetabular rim to allow for an acetabuloplasty. (Figure used by permission of Marc R. Safran, MD.)

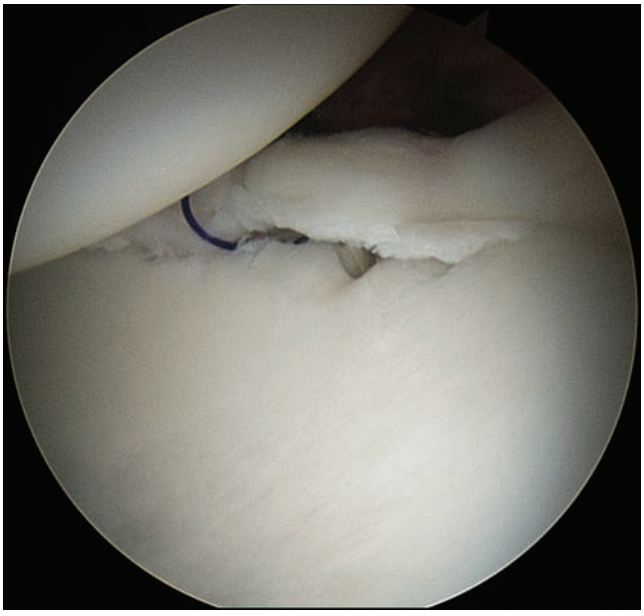


FIGURE 47.8

A nonabsorbable, monofilament suture is used to retract the detached labrum to enhance visualization of the acetabular rim to allow for acetabuloplasty and placement of the suture anchors. This is the same athlete as in Figure 47.7, without traction on suture. (Figure used by permission of Marc R. Safran, MD.)

and posteriorly, when needed (Fig. 47.9). Typically, the anterior aspects of the acetabulum are addressed with the burr entering from the more anterior portal, while the superior (lateral) acetabulum is accessed via the anterolateral portal.

The amount of acetabular resection is typically 3 to 5 mm; however, this amount varies based on pathology and can be estimated from preoperative imaging, verified with an intraoperative measurement with a laser etched graduated probe, and examined with intraoperative fluoroscopy. Care should be taken not to overresect bone, causing iatrogenic dysplasia, which may result in hip instability and/or pain and early degenerative change. With the fluoroscopy as guidance, one can visualize the initial crossover sign and an initial anterior-inferior starting point for the burr, just inferior to the start of the crossover sign and ultimately confirming the appropriate amount of resection. The is done by confirming that the line of the anterior wall is visible medial to the line of the posterior wall with a smooth gradual convergence of both lines as they meet superiorly. When this is confirmed, the appropriate version has been re-created. At the conclusion of the resection on the acetabular side, the labrum is then repaired on the new acetabular rim with suture anchors (Fig. 47.10). After repair, the traction may be released and visualization from the peripheral compartment will verify restoration of the labral seal (Fig. 47.10C) and a dynamic assessment can be performed to evaluate for residual areas of impingement.

It should be stressed that careful preoperative planning and intraoperative examination with fluoroscopy are vital to ensure that the level of resection is appropriate. An adequate AP projection of the pelvis should be obtained during patient positioning and may be augmented by slight alteration to the plane of the traction table as needed as well as rotation of the leg, and this position is maintained throughout.

Surgical Treatment of Cam FAI

Entering the peripheral compartment of the hip is required for treatment of cam type of impingement. This is performed by removing traction from the patient's leg with the preferred technique of keeping the foot in the traction boot with simple release of traction. This will allow for relaxation of the capsuloligamentous structures about the hip to improve maneuverability and still have control over the foot for dynamic evaluation. The space of the peripheral compartment can be further augmented by flexing the hip 20 to 45 degrees to further relax the capsule; however, this comes at the expense of altering the fluoroscopic image and may change the perception of the level of bone resection. Currently, we do not routinely place the hip in flexion and have found adequate space peripherally after performing our partial anterolateral capsulectomy.

To enter the peripheral compartment, the standard anterolateral portal, and an accessory proximal anterolateral portal made 3 to 4 cm proximal to and in line with the standard anterolateral portal, are utilized (Fig. 47.11). The blunt trocar and sheath for the 30-degree arthroscope are placed through the anterolateral portal, onto the anterolateral aspect of the femoral head-neck junction, at the apex of the deformity as visualized with fluoroscopy. The trocar is then exchanged for the arthroscope, keeping this position on the capsule

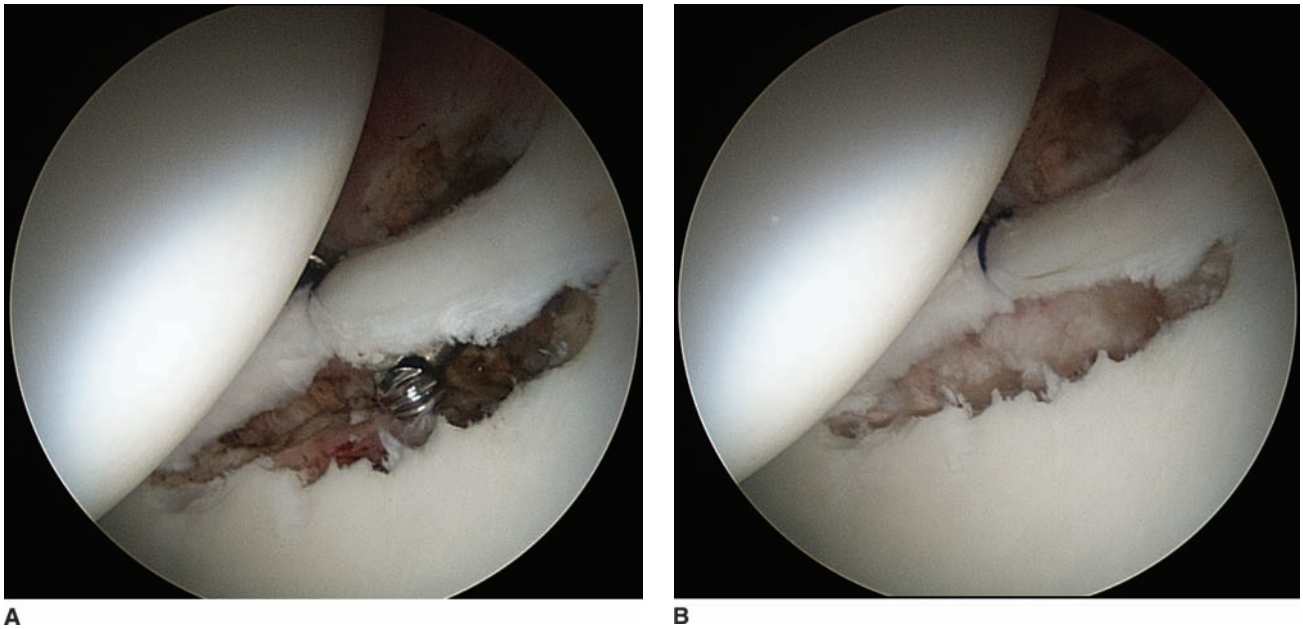
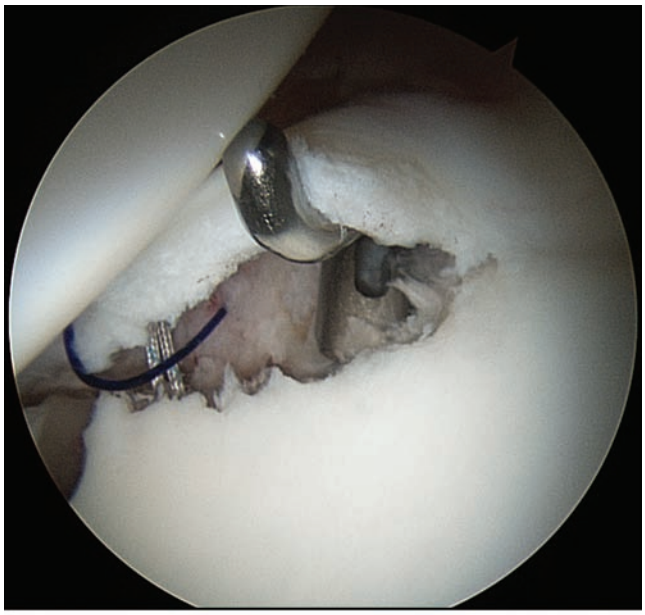
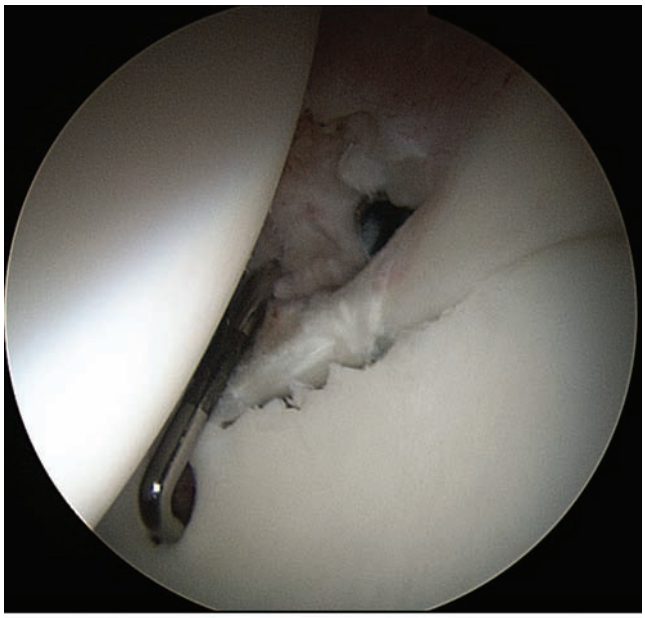


FIGURE 47.9

Arthroscopic view of an arthroscopic motorized burr being used to perform an acetabuloplasty. This is the same athlete as in Figures 47.7 and 47.8. **A:** Demonstrates retraction of the labrum using the traction stitch. A chondroplasty has been performed and the burr is in place to perform the acetabuloplasty. **B:** Demonstrates the appearance after the acetabuloplasty has been completed. (Figures used by permission of Marc R. Safran, MD.)



A



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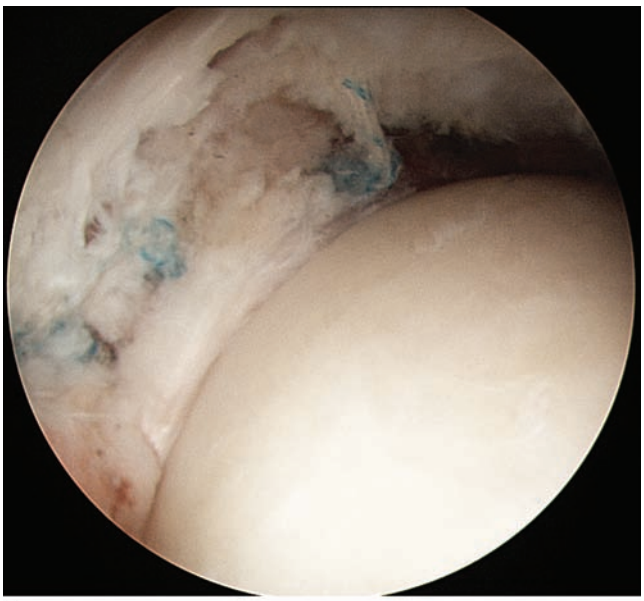


C

FIGURE 47.10

Arthroscopic labral repair. Same athlete as in Figure 7-9 undergoing the labral repair. **A:** Shows sutures placed in the labrum and the drill guide in place to drill and place another anchor. **B:** Shows the labrum after the sutures have been tied. Note that the knots are behind the labrum, out of view and out of potential contact with the femoral head. **C:** Is a 21-year-old collegiate rugby player demonstrating a cam lesion following acetabuloplasty and labral repair seen from the peripheral compartment. Again, note the suture knots away from the femoral head and the suction seal restored. (Figures used by permission of Marc R. Safran, MD.)

and bone. An arthroscopic motorized 5.0 mm aggressive shaver is introduced through the accessory proximal anterolateral portal and by using triangulation and fluoroscopy and brought into position at the tip of the camera (Fig. 47.12). This places the shaver directly onto the overlying capsule. This can then be utilized to clear away some of the soft tissue over the capsule, and as the shaver tip becomes visible, it is used to create a capsulotomy of the anterolateral capsule. This can then be enlarged to approximately 1.5 cm diameter as a partial capsulectomy and allow access to the peripheral compartment (Fig. 47.13). A radiofrequency wand may also safely be used to help augment the partial capsulectomy as needed.

Once within the peripheral compartment, a partial synovectomy is performed to allow for adequate visualization of the femoral head-neck junction and the cam deformity (Figs. 47.13–47.15). Also, a previously performed acetabuloplasty may be visualized, as well as labral repairs as mentioned above, to verify re-creation of the labral seal (Fig. 47.10C) and evaluate for any residual areas of impingement with a dynamic assessment. Additionally, the lateral synovial fold can be visualized, which is a marker for the retinacular vessels, as well as the zona orbicularis and medial synovial fold as a marker for the iliopsoas tendon on the other side of the capsule.

The femoral head-neck junction in the presence of a cam lesion will often appear grossly abnormal simply from the surface, but can be verified for location with fluoroscopy and dynamic evaluations (Fig. 47.14A and B). Using the motorized burr, the femoral head-neck offset is restored by removing the area of excess bone (Fig. 47.14C–E). The area of bone removed may be variable, and thus every patient must be evaluated individually with the ultimate goal of restoring the offset to normal. Depending on the specific location and size of the

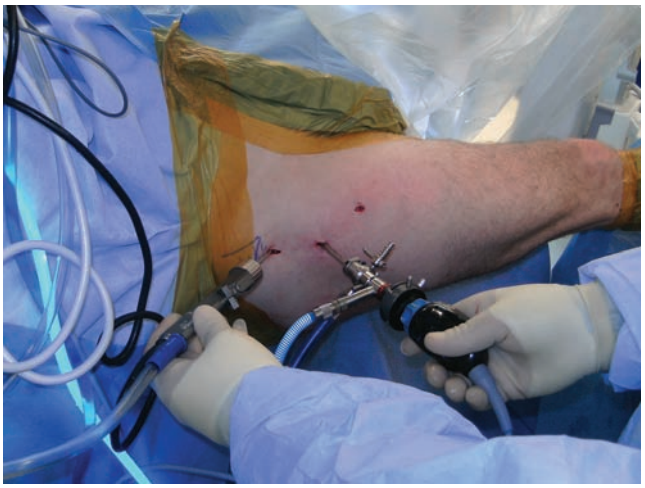
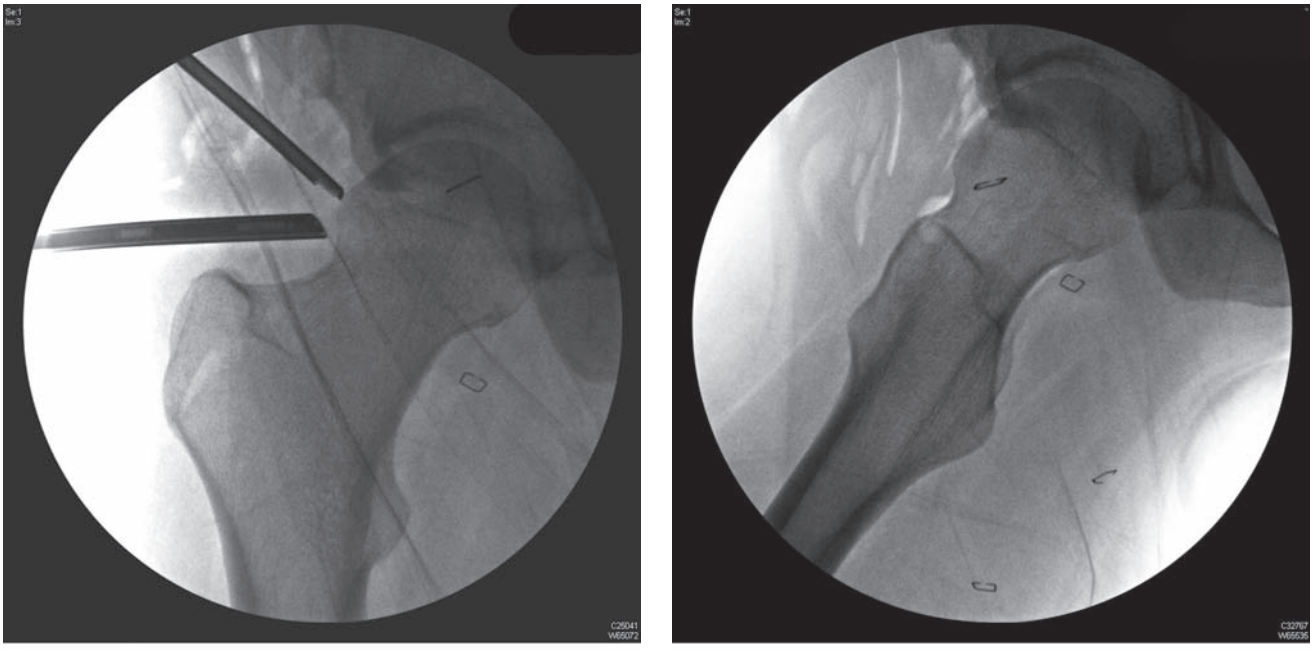


FIGURE 47.11

Portals utilized for peripheral compartment arthroscopy and decompression of the cam lesion. The right hip of this patient is exposed, with the feet to the right and the head to the left. The arthroscopic is in the standard anterolateral portal, just anterior to the most proximal aspect of the greater trochanter. The proximal anterolateral portal is 4 to 5 cm proximal to the standard anterolateral portal. (Figures used by permission of Marc R. Safran, MD.)



A B

FIGURE 47.12

Intraoperative fluoroscopic images of a 26-year-old male cricket player prior to cheilectomy. **A:** Is an intraoperative fluoroscopic AP view of the placement of the arthroscope and shaver to perform a partial capsulectomy to allow for visualization to perform a cheilectomy (femoral osteoplasty) for cam impingement. **B:** Is a frog leg lateral intraoperative fluoroscopic image of this same patient. (Figures used by permission of Marc R. Safran, MD.)

cam lesion, the hip may be rotated, flexed, abducted, or adducted to help reach different areas for bony resection. Also, the arthroscope and burr may be interchanged between these two portals as needed.

The ideal amount of bone to resect has not been determined. Some clinicians start their resection 7 to 10 mm from the labral edge and work distally. However, to restore the alpha angle, one has to remove bone up to the labral edge. Yet, removal of bone to the labral edge can result in loss of the sealing function of the labrum. Further, the clinical outcomes of decompression of the cam lesion have not been shown to correlate to restoration of the alpha angle to below 50 degrees.

The amount of bone removed should be individualized based on the pathology. General guidelines suggest the resection should be <1 cm deep, 8 mm from proximal to distal, and 15 mm medial to lateral, though again, this is a generalized starting point and the amount of resection needs to be customized to the degree of deformity. Mardones and associates have determined that resection of over 30% of the femoral neck width increases the risk to fracture the femoral neck (21). Thus, resection is kept to <30% of the femoral neck width, and usually much less than that is necessary to eliminate the impingement. Sometimes, the cam lesion is well circumscribed and demarcated, while other times it is not. Thus, fluoroscopy can help identify the lesion as well

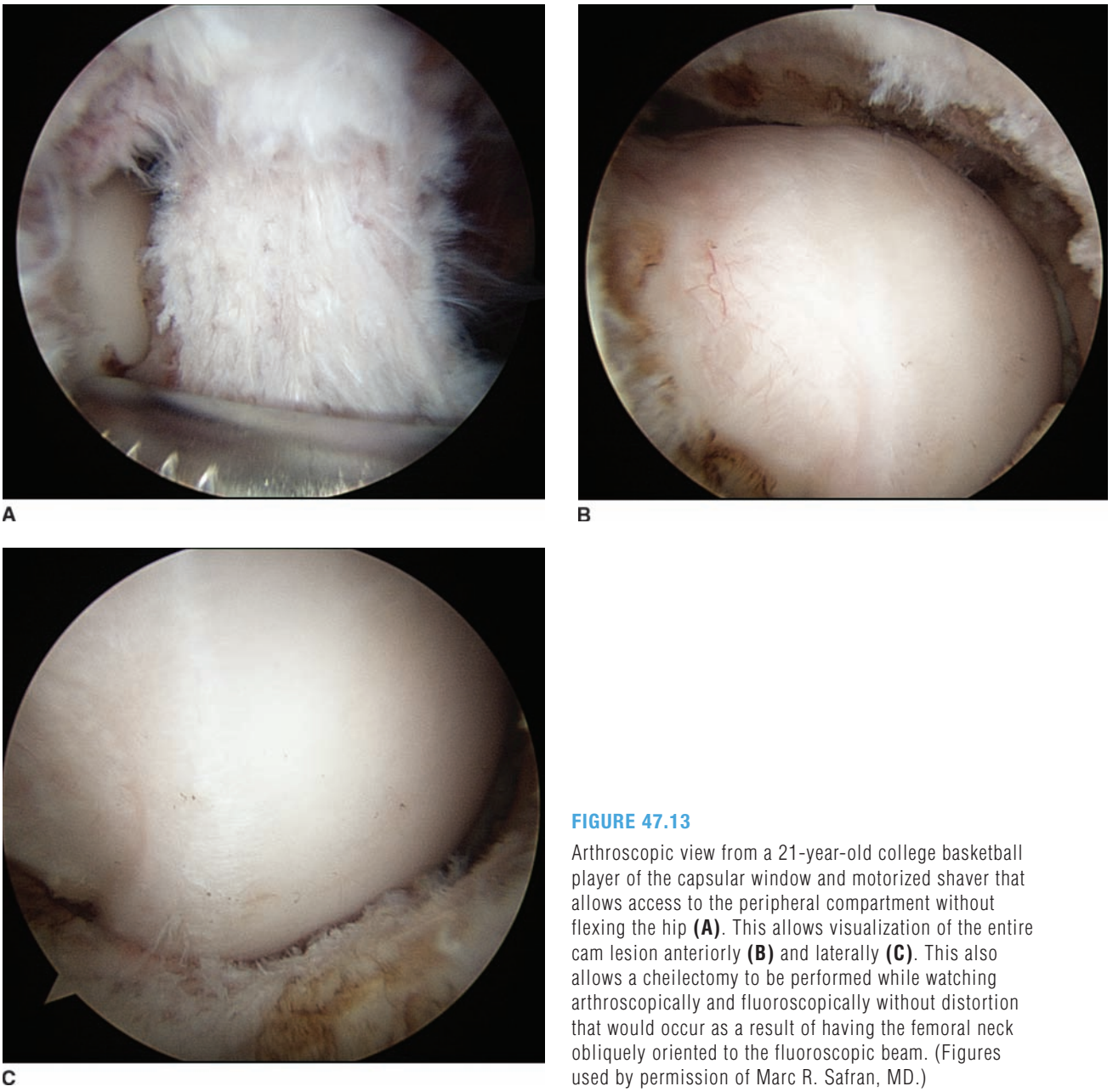


FIGURE 47.13

Arthroscopic view from a 21-year-old college basketball player of the capsular window and motorized shaver that allows access to the peripheral compartment without flexing the hip **(A)**. This allows visualization of the entire cam lesion anteriorly **(B)** and laterally **(C)**. This also allows a cheilectomy to be performed while watching arthroscopically and fluoroscopically without distortion that would occur as a result of having the femoral neck obliquely oriented to the fluoroscopic beam. (Figures used by permission of Marc R. Safran, MD.)

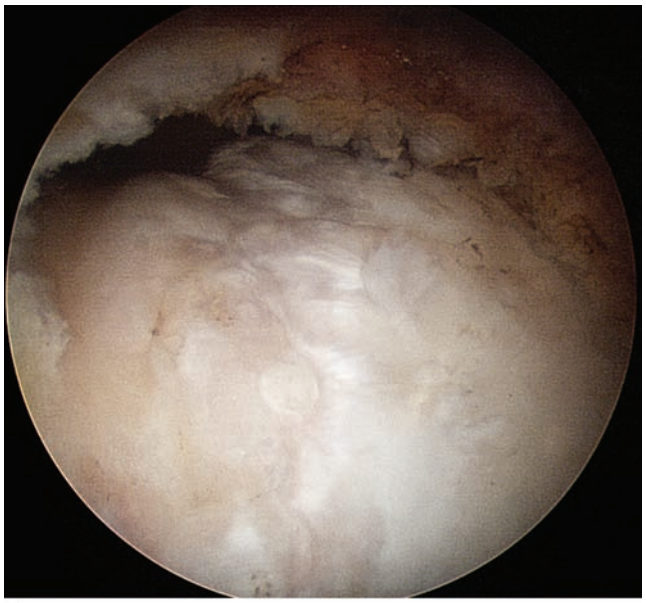
as help assess how much bone is removed to avoid overresection and increased risk of fracture, while helping to ensure adequacy of resection (Fig. 47.16). Further still, the hip may be dynamically assessed under arthroscopic visualization during the bony resection to ensure adequacy of bony resection.

After resection is complete, excess bone debris is removed with suction through an oscillating shaver to help minimize synovitis and heterotopic bone formation. Instruments are removed and portals closed. This allows for safe injection of local anesthetic into the operative site. Sterile bandages are applied. If a labral repair or capsulorrhaphy is performed, a hip abduction brace is applied with slight abduction and limited flexion, based on the location of the labral repair. A bunny boot is also placed on the patient's foot to limit external rotation.

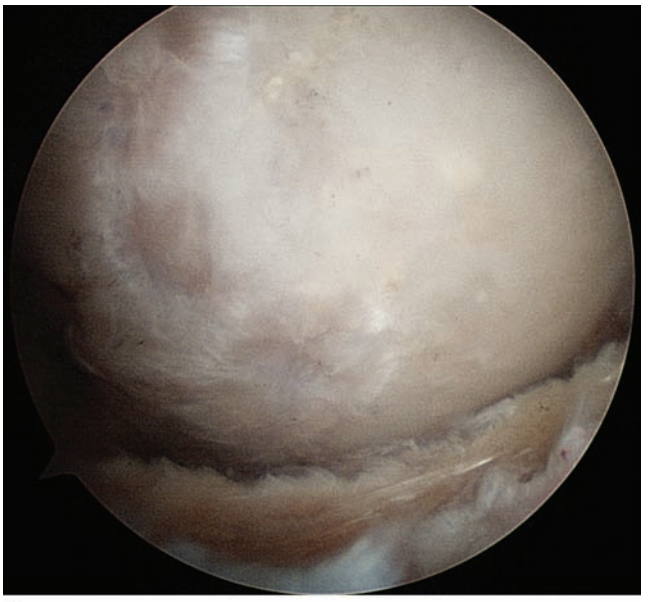
POSTOPERATIVE MANAGEMENT

There is very little evidence or scientific investigation to guide postoperative rehabilitation for hip arthroscopy. It also will vary based on the procedure performed and from surgeon experience of preference. Our postoperative protocol has been developed in conjunction with physical therapists and has been modified over the years based on clinical experience and feedback from those physical therapists who have been working with our patients over the years.

Our protocol for postoperative rehabilitation after hip arthroscopy for the treatment of FAI includes flat-foot weight bearing to 20 lb of pressure for 2 weeks assuming adequate bone quality. The duration of limited



A



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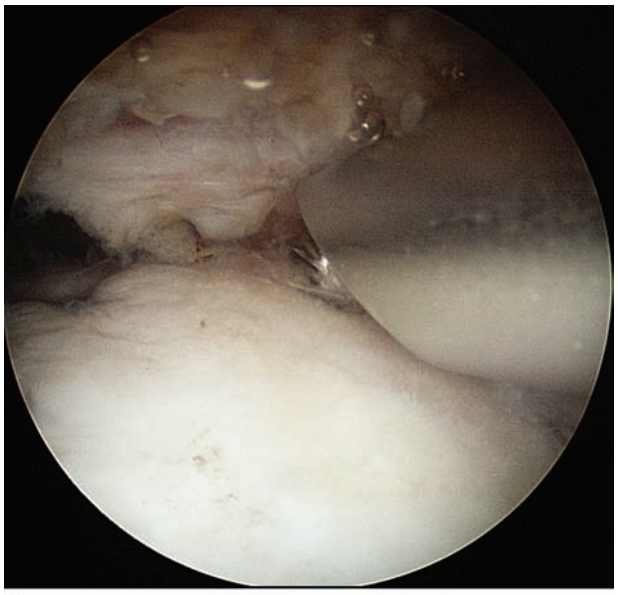

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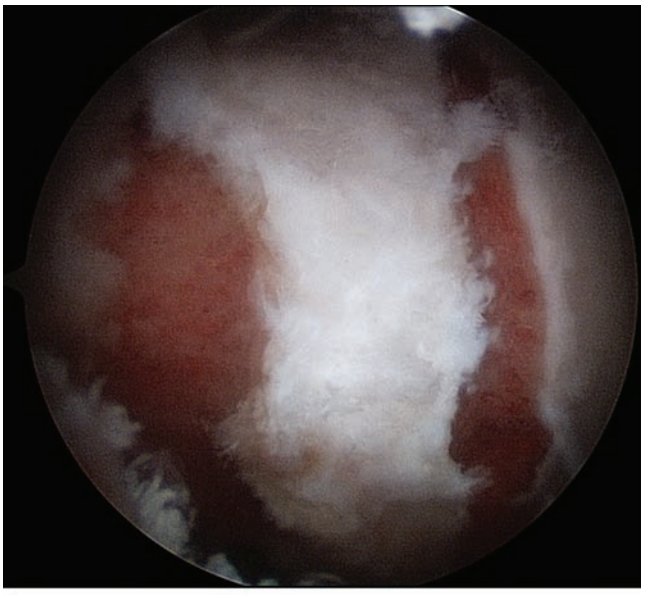

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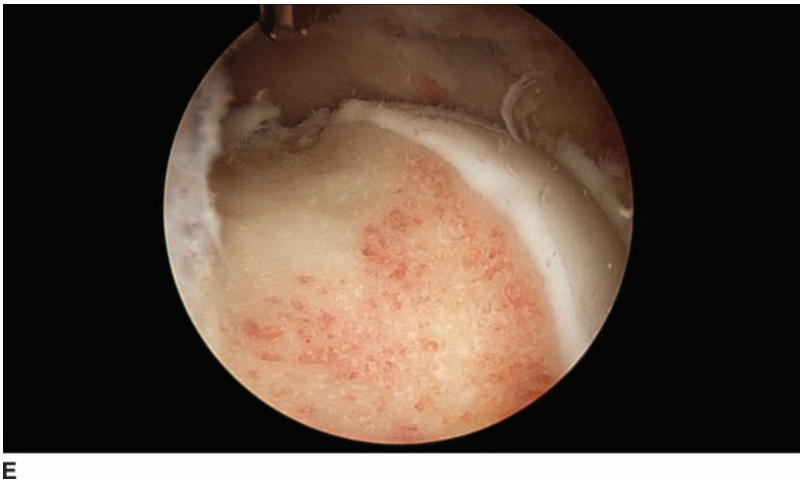

E

FIGURE 47.14

Arthroscopic view from the peripheral compartment for cam impingement of the left hip of a 21-year-old college football player. Note the cam lesion with irregularity and notching anteriorly **(A)** from the acetabulum and lateral wear from the impingement as well **(B)**. **C,D:** demonstrate the area to be resected as demarcated by the motorized burr. **E:** shows the femoral neck after the cam lesion has been resected (cheilectomy, femoral osteoplasty). (Figures used by permission of Marc R. Safran, MD.)

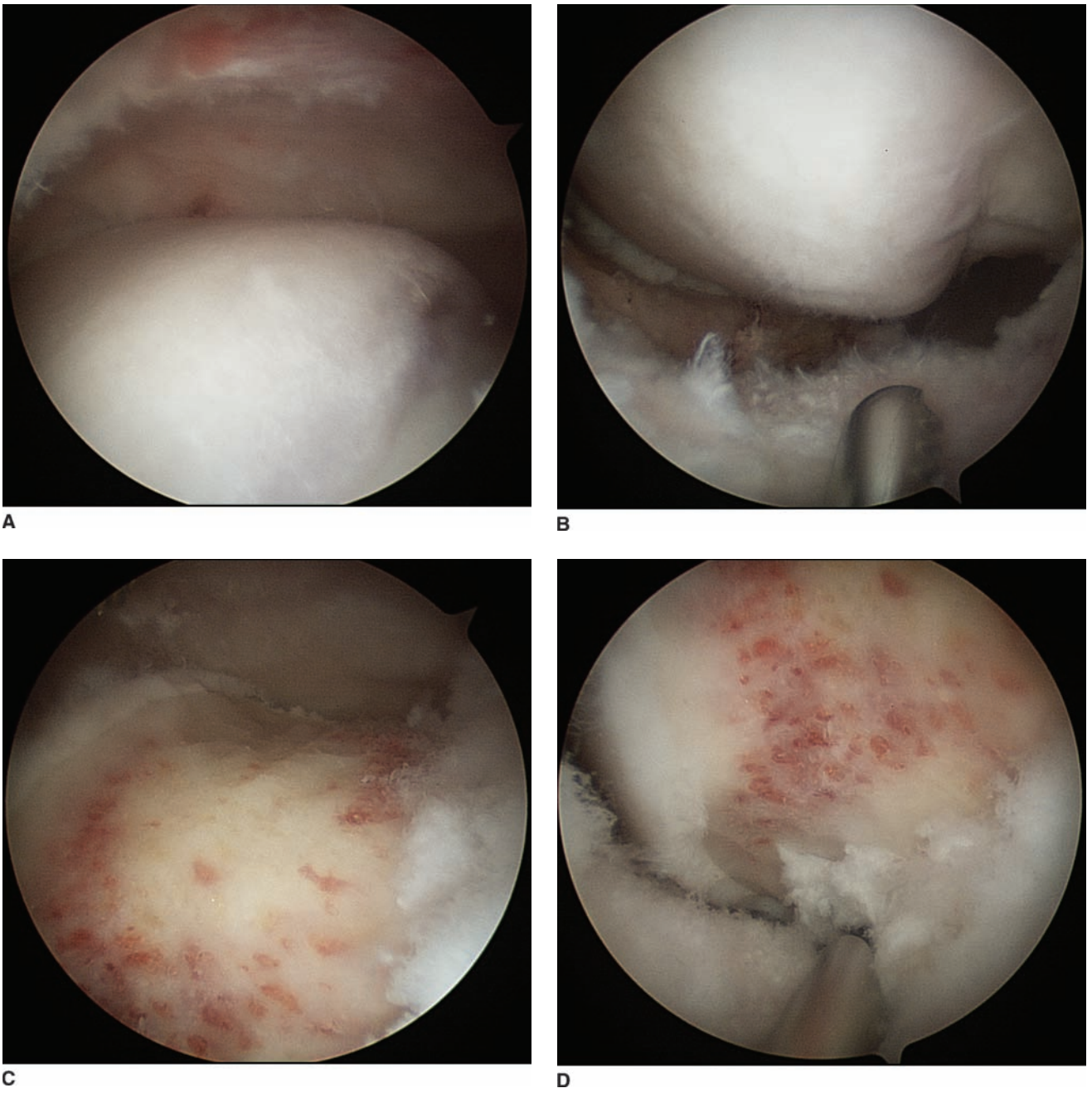

FIGURE 47.15

Arthroscopic view before and after a right hip cheilectomy of a 22-year-old professional basketball player. Note the elongated femoral head with loss of anterior **(A)** and lateral **(B)** offset. **(C)** demonstrates the anterior head neck junction, while **(D)** shows the restoration of lateral offset following cheilectomy/femoral osteoplasty. (Figures used by permission of Marc R. Safran, MD.)

weight bearing is increased to 8 weeks if a microfracture has been performed. Also, we add an extra week of limited weight bearing for every decade of age over age 39 for women and over age 49 for men. This is to prevent femoral neck fractures and stress fractures, as anecdotal reports have been noted with immediate full weight bearing. We reserve the use of a temporary abduction orthosis and a rotation limiting bunny boot for labral repairs and capsular plications to protect the repair. We encourage early motion, including the use of a continuous passive motion machine, passive circumduction exercises, and early physical therapy. Rehabilitation should ideally be performed with a physical therapist experienced in hip arthroscopy postoperative patients and includes stretching exercises as well as hip and core musculature strengthening. Proprioception exercises are also included in the early phases. Later phases of therapy (usually the second and third months) include balance progression, stationary cycling with resistance, strength training, side stepping, and elliptical training. By the fourth month, plyometrics and agility drills are progressed with the addition of running and side-to-side movements, anticipating a return to sports between 4 and 6 months after surgery.

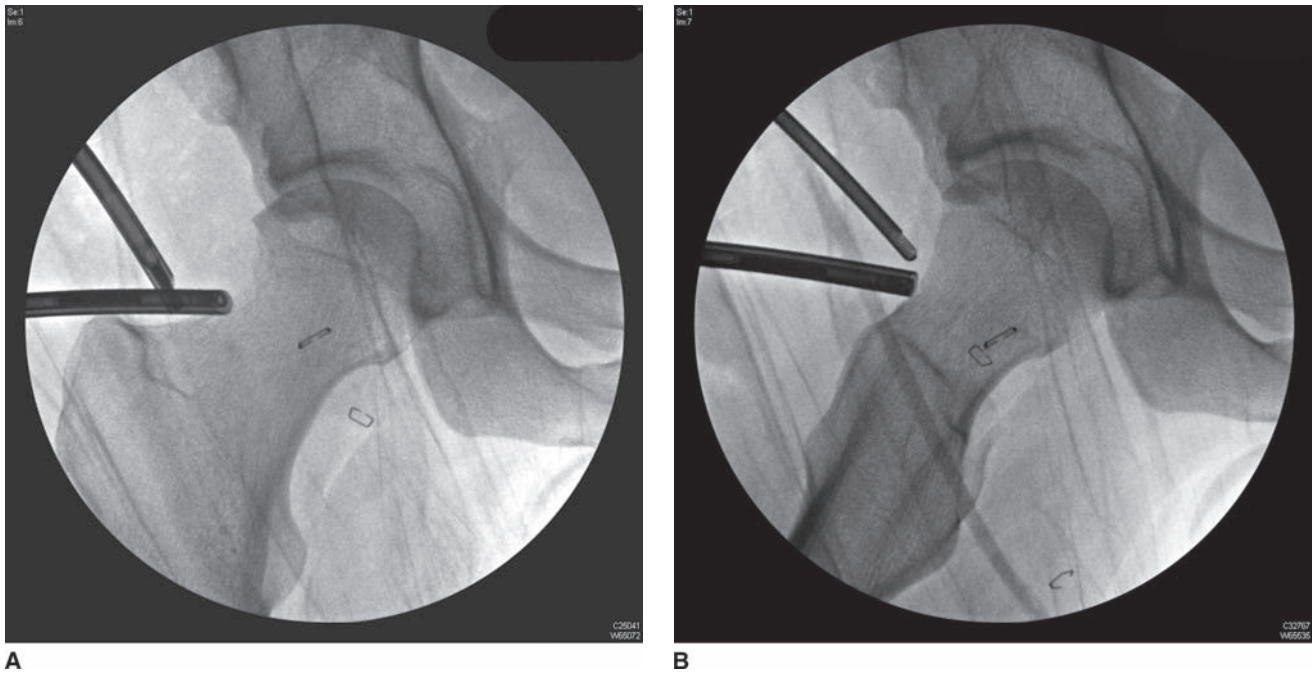

FIGURE 47.16

Intraoperative fluoroscopic images of the patient in Figure 47.9, following arthroscopic cheilectomy. **A,B:** are AP and frog leg lateral postresection fluoroscopic images, confirming the adequacy of decompression. (Figures used by permission of Marc R. Safran, MD.)

RESULTS

The outcomes after arthroscopic treatment of FAI are increasingly reported in the literature, although very few include follow-up beyond 2 to 5 years. However, the results have demonstrated, despite various techniques used and pathologies encountered, that the combined treatment of FAI and labral tears in the nonarthritic hip has good to excellent results in 75% to 95% of cases, with worse results in the presence of chondral damage, arthritic change, and with incomplete treatment all of associated pathologies (22–31). A recent review of the literature demonstrated that there have been over 800 cases of arthroscopically treated FAI with <3% progressing to hip arthroplasty, as compared with 179 cases of open hip dislocation (with trochanteric osteotomy) with an 18% conversion to hip arthroplasty (32). The open dislocation requires an extensive approach, trochanteric osteotomy and refixation, limited weight bearing of up to 3 months, longer hospitalization, and the risk of significant blood loss and trochanteric nonunion, making the arthroscopic approach more desirable.

Review of the literature confirms that the results are less predictably good when chondral damage is present and that the results of FAI surgery do not correlate with restoration of the alpha angle to <50 or 55 degrees (32). Results are significantly worse if the labral injury is addressed without also addressing any associated impingement pathology (33–36). One problem with assessing nonarthritic hip problems in the athletic patient is the lack of a methodologically sound, validated outcome measure (37). Recently, a research collaborative of clinically active hip arthroscopists (MAHORN group) completed a 3-year task of developing a methodologically sound, validated hip outcomes score, the MAHORN Hip Outcomes Tool (37).

COMPLICATIONS

Complications related to hip arthroscopy, in general, are usually related to traction (too much or too little), patient positioning, and fluid management. Complication rates are between 1.5 and 5.5% and include inability to perform arthroscopy due to access issues and neuropraxias of the sciatic, femoral, perineal, pudendal, or lateral femoral cutaneous nerves that often resolve spontaneously (38). Also reported are vaginal tear and scrotal necrosis related to excessive lateral traction force, portal bleeding, hematomas, intraarticular instrument breakage, and infection. Heterotopic ossification has also been noted, including after FAI surgery. Labral repairs may not heal, and in some cases, labral repairs have been associated with capsular adhesions postoperatively, which may limit motion and cause pain. The most commonly underreported complications are iatrogenic, including articular cartilage damage and labral injury. Though not reported in the literature, there are reports of deep venous thrombosis and pulmonary embolism in relation to hip arthroscopy that have been discussed at meetings.

Complications related to the arthroscopic treatment of FAI include femoral neck fracture related to overresection of the femoral neck when treating cam impingement and overresection of the acetabular rim leading to instability (39,40). Another risk is underresection of the femoral neck resulting in incomplete reshaping of the FAI deformity, although the exact amount and location to remove have yet to be defined. This is also likely underreported and may be the source of continued pain and dysfunction after surgery that results in revision procedures. The risk of avascular necrosis (AVN) after FAI surgery is a potential concern, although the area of resection is typically far away from the posterolateral femoral neck where the vessels are located. No cases of AVN have been reported after FAI surgery.

ACKNOWLEDGMENT

All intraoperative images and perioperative radiologic images are provided by Marc R. Safran, MD.

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PART FIVE
ANKLE

48 Anterior Ankle Arthroscopy: Indications and Surgical Techniques

Gregory C. Berlet

INTRODUCTION

Arthroscopy of ankle allows the direct visualization of intra-articular structures without an arthrotomy or osteotomy. Advances in technology with improved video, small joint instrumentation, and noninvasive distraction, combined with the demand for minimally invasive treatment have expanded indications for arthroscopic-mediated care of the ankle. Over the past decade, these advances have forwarded anterior ankle arthroscopy as a necessary skill for the orthopaedic surgeon.

ANKLE ARTHROSCOPY—OVERVIEW

Anterior ankle arthroscopy is a well-established procedure used for both accurate diagnosis and operative management of many ankle disorders. Arthroscopic surgery of the anterior ankle allows the direct visualization and manipulation of intra-articular structures including bone, cartilage, and ligamentous structures.

Diagnostic indications for the use of ankle arthroscopy include unexplained pain, swelling, stiffness, instability, hemarthrosis, and locking or popping, as well as a negative workup in a patient with symptoms unresponsive to a thorough conservative treatment program.

Therapeutic indications include injuries of the articular cartilage and soft tissue, bony impingement, débridement of soft tissue lesions, synovectomy and loose body removal, arthrofibrosis, ankle fractures, and osteochondral defects. Ankle arthroscopy can also be used in ankle stabilization procedures and arthrodesis, as well as for irrigation and débridement of septic arthritis.

ANATOMY RELEVANT TO ANTERIOR ARTHROSCOPY

The congruency of the distal tibia and talar dome makes arthroscopic visualization difficult through a single portal. The distal tibia is concave in the sagittal plane and convex in the coronal plane. The anterior tibial plafond is slightly convex with a medial notch (notch of Harty), which recedes approximately 4 mm, near the junction of the plafond with the medial malleolus. This is an ideal location for introduction of the arthroscopic instruments. The medial malleolus is about 2 cm anterior to the lateral malleolus. Anatomic studies have shown that in any position, the tibial plafond covers only two thirds of the talar dome.

Portal placement is strongly influenced by the neurologic patterns of the lower extremity. Anteromedially, the saphenous nerve is on average 7 mm away for portal placement next to the tibialis anterior. The medial portal is always created first as it allows the easiest access and the least risk to neurologic structures (Fig. 48.1).

The anterolateral portal is established second and under direct visualization. The superficial peroneal nerve and its branches are at risk with this portal. The superficial peroneal nerve divides proximal to the ankle into the intermediate and medial dorsal cutaneous branches. The intermediate cutaneous branch passes superficial to the inferior extensor retinculum, crosses anterior to the extensors to the fourth and fifth toes, and then runs toward the third interspace between toes 3 and 4. This is the nerve at greatest risk with anterior ankle arthroscopy (Fig. 48.1)

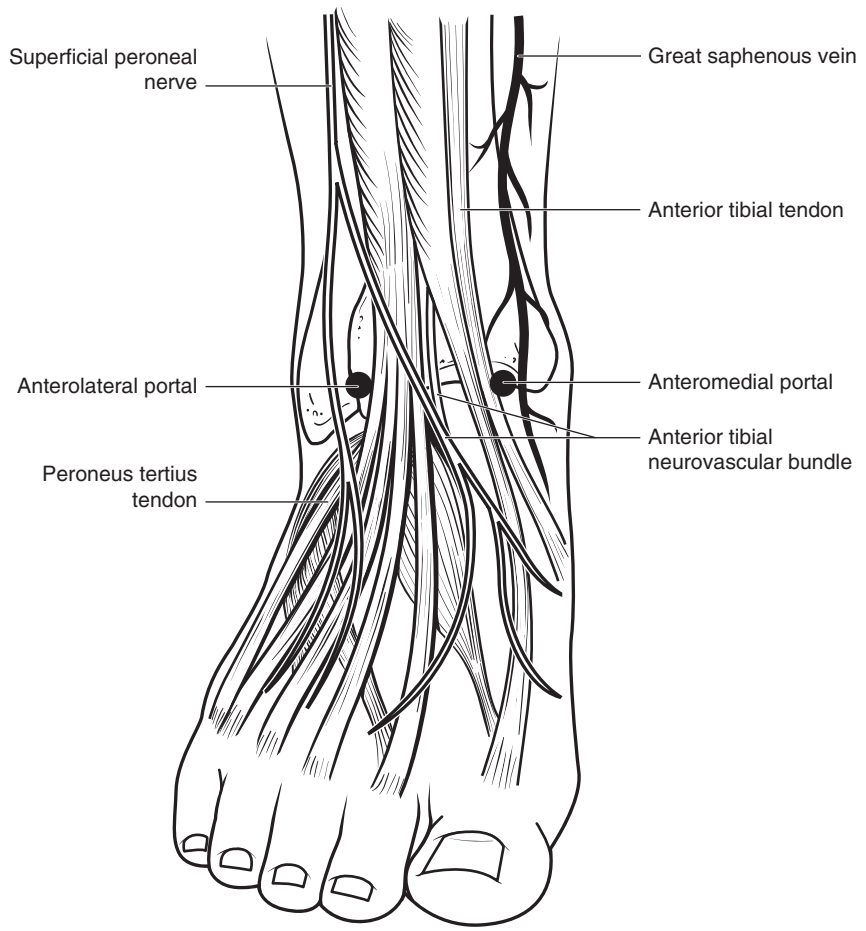

FIGURE 48.1

Portal Anatomy for ankle arthroscopy.

FIGURE 48.2
Noninvasive distraction strap.

EQUIPMENT NEEDS AND PATIENT POSITIONING

Equipment needs specific for ankle arthroscopy include noninvasive distraction system, 3.5- or 2.0-mm 30-degree arthroscope, pressure inflow system or gravity flow system, arthroscopic shaver, and small joint arthroscopy instruments including graspers, currets, and awls.

The patient is placed supine on the operative table. A well-padded tourniquet is applied to the upper thigh and the operative extremity is placed in a thigh/knee holder with the knee flexed at approximately 45 to 60 degrees, with the foot and ankle resting approximately 3 to 4 in above the operating table. The holder is padded sufficiently to ensure there is no pressure on the peroneal nerve.

Distraction techniques facilitate the placement of the arthroscope and instruments into the tightly configured ankle joint. Noninvasive techniques involving straps, harnesses, and outriggers are the most commonly used distraction methods. These techniques minimize the risk of neurovascular injury and other complications (1) (Fig. 48.2).

After sterile preparation and drape of the ankle, a noninvasive ankle distractor strap is applied (Arthrex Inc, Naples, Florida). This may be safely distracted until the straps have significant tension. EMG studies have confirmed that neurologic change of the tibial nerve does not occur until there is 30 lb of tension (2). The manual strap does not allow this threshold to be reached.

PORTAL PLACEMENT

Anterior ankle arthroscopy is performed traditionally through two anterior portals. Neurologic structures are subcutaneous and portal placement is made in all cases by blunt dissection after the skin has been incised with the knife.

The anteromedial portal is located at the level of the joint line just medial to the anterior tibialis tendon. The notch of Harty allows passage of the arthroscope posteriorly. The saphenous vein and nerve run along the anterior border of the medial malleolus. The saphenous nerve and its branches are usually located lateral to the vein and are on average 7 mm medial to the portal location. The surgeon introduces a spinal needle into the ankle joint through the anteromedial region, just medial to the anterior tibial tendon, and injects the joint with 15 to 20 mL of local anesthetic with epinephrine to insufflate the joint and to help achieve hemostasis (Fig. 48.3).

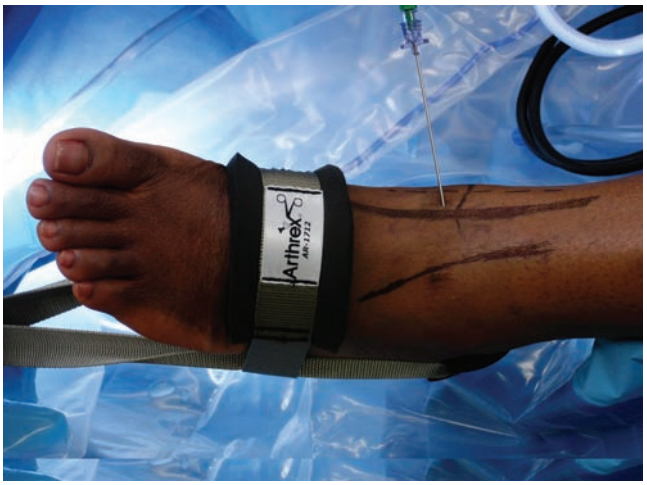

FIGURE 48.3
Anteromedial portal established just medial to tibialis anterior and joint identified with spinal needle.

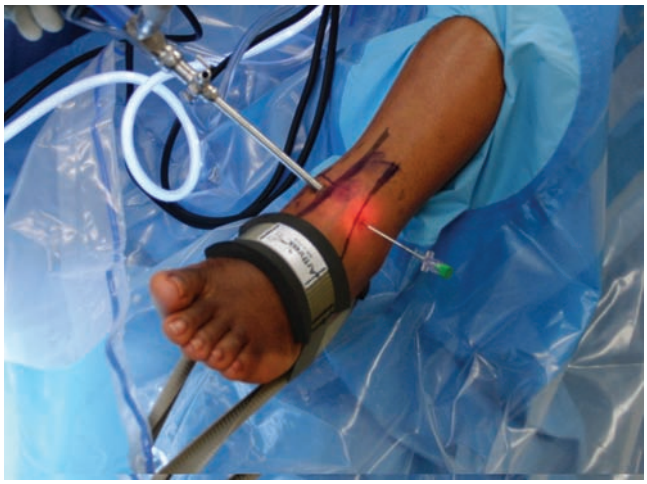

FIGURE 48.4
Lateral Portal Established while transilluminating with the scope through the medial portal.

After making a superficial skin incision with a No. 11 blade, the surgeon bluntly dissects the subcutaneous tissue and joint capsule with a curved hemostat. Next, a 30-degree, 3.5-mm arthroscope is introduced through a blunt trocar. Articular cartilage can be visualized through the arthroscope before saline inflow is started to avoid extracapsular extravasation.

The anterolateral portal is found just lateral to the peroneus tertius, entering the joint between the fibula and the talus just distal to the joint line. In this location, the lateral and medial branches of the superficial peroneal nerve may be injured if their locations are not carefully noted before a skin incision is made. Transilluminating the anterolateral region of the ankle joint with the arthroscope helps the surgeon to visualize the superficial neurovascular anatomy. A spinal needle is once again introduced in the ankle at the level of the joint just lateral to the peroneus tertius tendon. This landmark, as well as the superficial-lying intermediate dorsal cutaneous branch of the superficial peroneal nerve, can be better visualized by plantarflexing the fourth toe (3). After ensuring intra-articular placement of the spinal needle, use the needle as a probe to confirm that full mobility is possible in the joint. After accepting the position of the portal, a superficial skin incision is again made in the anterolateral region just lateral to the peroneus tertius with blunt dissection to the joint (Fig. 48.4).

DISEASE-SPECIFIC CONSIDERATIONS—ANTERIOR ANKLE ARTHROSCOPY

Comprehensive Arthroscopic Evaluation

A comprehensive arthroscopic evaluation from an anterior approach allows for an eight-point examination (Fig. 48.5). The reporting in the operating note should be consistent and mention all locations. Additional points for reporting are made by adding accessory posterior portals.

The arthroscopic exam is always done with the camera in the anteromedial portal initially and the working instruments laterally. The instruments can be switched back and forth as necessary always reintroducing the blunt trocar in the camera cannula for joint entry.

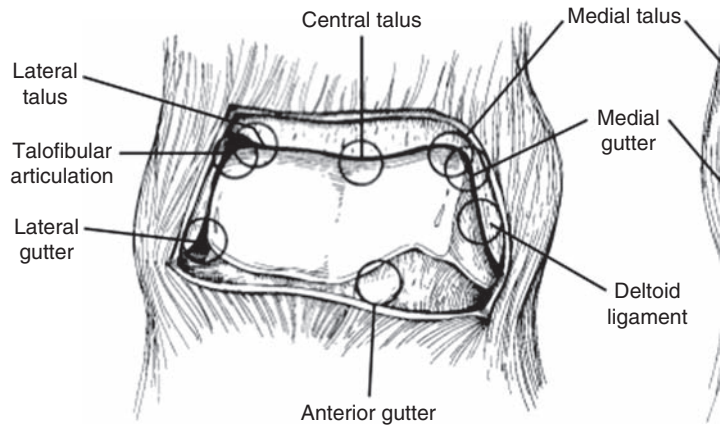

FIGURE 48.5
Eight-point anterior examination of the ankle.

Anterior Ankle Impingement

Anterior impingement lesions occur most commonly in the athletic population, particularly dancers and soccer players. These lesions can be bony or comprise soft tissue. The soft tissue lesions may be due to congenital bands, scar tissue (postsurgical or resulting from repetitive inversion injuries), synovitis, inflammatory arthritides, or infection. Etiological theories for anterior bone spurs include anterior ankle capsular strain from forced plantarflexion with resultant calcific deposits along capsular lines or repetitive dorsiflexion resulting in subchondral injury and new bone formation (4). Capsular strain likely represents the mechanism of anterior impingement lesions, which are found commonly in the chronically unstable ankle. These spurs can occur coincidentally with degenerative joint disease, although there is no conclusive evidence that chronic ankle instability leads to degenerative joint disease.

The anterior spurs do not kiss as may be expected but instead the talar spur peak lies medial to the midline, the tibial spur lies lateral to the midline, and the spurs typically do not overlap each other (5). They also found that the tibial spur is wider than the talar spur and the talar spur usually protrudes medially off the medial edge of the talar neck.

Treatment considerations must include the association of lateral ankle instability and mechanical axis deviation as comorbid factors to the patient's disability.

Anterior ankle spurs can be removed arthroscopically or via open arthrotomy. It is the authors' experience that arthroscopic intervention is successful is most cases, although the portals may need to be enlarged to accommodate large bony fragments. A comprehensive arthroscopic examination is done first with the ankle under distraction followed by spur removal. The spur removal is reserved for the end of the case as bleeding is often encountered when the bone is débrided. The spurs are best visualized with no distraction applied to the foot, because distraction tends to draw the anterior capsule close to the anterior bony structures. A 4-mm burr facilitates both the removal of the spur and the adequate fluid flow to preserve visualization. The amount of resection is set off by the anterior tibial margin developing the resection amount laterally and working in a methodical manner medially. A burr run on reverse has less potential for overly aggressive resection and can be useful for final smoothing or for less experienced arthroscopists.

Osteochondritis Dessicans of the Talus

The first-line treatment for talar osteochondritis dessicans (OCD) lesions remains an arthroscopic evaluation and treatment. Arthroscopic treatment of talar OCD involves three principles: removing loose bodies, securing the OLT to the talar dome, and stimulating development of fibrocartilage. Using a wide-angle, 2.7-mm arthroscope may provide more mobility than a 4-mm arthroscope and noninvasive joint distraction enables visualization of the entire talar dome.

Patients can expect 80% good to excellent results with a single arthroscopic treatment of symptomatic OCD of the talus (6). The cohort with the best results had débridement and microfracture of the OCD lesion.

The OCD is first converted to a stable lesion with the use of curettes. All remaining articular cartilage must be firmly anchored to the subchondral bone. Carefully define shoulder lesions trying to avoid delaminating down the gutters of the ankle. Using awls, microfractures (perforations) are made 3 to 4 mm apart in the subchondral bone while maintaining the integrity of the bone plate. A release of fat or blood indicates that the depth of penetration with the awl was of adequate depth.

The microfracture technique promotes new tissue formation by releasing substances such as mesenchymal stem cells, growth factors, and healing proteins. Ultimately, cartilage-like cells form and fill the original defect.

Arthroscopic Ankle Fusion

The technique of arthroscopic ankle arthrodesis has been associated with high fusion rates and low complication rates and can often be performed on an outpatient basis. The arthroscopic technique cannot be relied upon to correct varus/valgus deformities >5 to 10 degrees. In addition, patients with significant bone loss, compromised circulation, a history of active or prior infection or previous failed fusion are best treated by open techniques. However, when confronted with a patient who fulfills the strict criteria for an arthroscopic procedure, the results have demonstrated fusion rates that are comparable with those of open procedures, with quicker healing times, reduced narcotic use, better cosmetic results, and shorter hospital stays.

The goals of arthroscopic ankle arthrodesis are the same as for open procedures: creation of broad, viable cancellous bony surfaces that are well approximated and stabilized with internal fixation in a functional position. This goal should be accomplished with the use of motorized burrs, shavers, and hand-held curettes. The surgeon should keep in mind that excess bone resection can result in a nonanatomic reduction and should be avoided at all costs. The shape of the distal tibia and talar dome imparts inherent bony stability. Care should be taken to maintain the normal talar convexity and distal tibial concavity. However, the typical anterior tibial osteophytes must be aggressively resected so that joint visualization is maximized and an anatomic reduction is possible. The ideal position is neutral dorsiflexion and 5 degrees of hindfoot valgus, but up to 10 degrees of equinus is acceptable. Care should be taken to avoid hindfoot varus. A heel cord–lengthening procedure should be performed in the presence of a heel cord contracture in an effort to reduce the ankle to the neutral position.

Intraoperative fluoroscopy should be used to confirm concentric reduction of the bony anatomy. This is often more difficult to achieve arthroscopically compared to open procedures. Fixation is usually achieved with insertion of percutaneous transarticular cannulated screws of at least 6.5 mm diameter through the medial and lateral malleoli, or two medial screws (one into talar neck and one into talar body). Three screws are often necessary to achieve fixation in osteoporotic bone. Anterior or posterior screws are rarely needed.

COMPLICATIONS

Complications from ankle arthroscopy can be broadly classified into two main categories: failure to visualize or treat the intra-articular lesion or neurologic injury from portal placement.

Access is best determined preoperatively by the review of axial imaging (MRI or CT). Lesions in the posterior half of the talar dome are not reliably accessible with anterior ankle arthroscopy. Alternative choices of posterior arthroscopy or malleolar osteotomy should be considered.

Neurologic injury is most commonly associated with the lateral portal. Blunt dissection after skin incision, transillumination to view subcutaneous structures, and plantar flexion of the fourth toe are the best techniques to avoid inadvertent nerve injury.

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49 Posterior Ankle Arthroscopy and Tendoscopy

Mikel L. Reilingh, Peter A.J. de Leeuw, Maayke N. van Sterkenburg, and C. Niek van Dijk

INTRODUCTION

Ankle arthroscopy has been developed and improved over the last 30 years. Nowadays, this minimal invasive technique is increasingly used for dealing with a wide range of ankle pathologies. In 1931, Burman was the first orthopaedic surgeon attempting ankle joint arthroscopy in vivo and concluded that the ankle joint was unsuitable for arthroscopy, because of its narrow interarticular access (1). Technical improvements, such as smaller diameter arthroscopes and joint distraction methods, made it possible for Watanabe in 1972 to report on a series of 28 ankle arthroscopies.

Van Dijk et al. (3) were the first to describe endoscopic access to the tendons by tendoscopy. These included tendoscopy of the posterior tibial tendon, of the peroneal tendons (4,5), and of the Achilles tendon (6), which was followed by endoscopic treatment for retrocalcaneal bursitis, called endoscopic calcaneoplasty (7,8). In 2000, he introduced a two-portal endoscopic hindfoot approach (9). Recently, the results of 55 consecutive patients with posterior ankle impingement were reported on with a good to excellent outcome in 74% of patients (10). This minimal invasive technique provides excellent access to the posterior aspect of the ankle and subtalar joint. Furthermore, extra-articular structures of the hindfoot such as the os trigonum, flexor hallucis longus (FHL), and the deep portion of the deltoid ligament can be assessed (9).

INDICATIONS AND CONTRAINDICATIONS OF THE PROCEDURES

Contraindications for endoscopic/arthroscopic procedures are few but important. Relative contraindications include severe edema and a tenuous vascular status. More absolute contraindications include localized soft tissue infection and severe degenerative joint disease in arthroscopic procedures. Obesity, although not a contraindication, significantly contributes to a prolonged intraoperative surgical time and postoperative morbidity (11).

The different indications can be categorized according to the location of the pathology.

ARTICULAR PATHOLOGY

Posterior Compartment Ankle Joint

The main indications include both soft tissue and/or bony pathology. Soft tissue pathology mainly includes chronic synovitis, chondromatosis, and excessive scar tissue. Bony pathology includes loose bodies, ossicles, posttraumatic calcifications, avulsion fragments, and osteophytes of the posterior tibial rim. An osteochondral defect (OD) in the ankle joint that cannot be approached by means of anterior ankle arthroscopy with the ankle in maximum plantar flexion can be assessed through posterior ankle arthroscopy.

Osteochondral Defects

A traumatic insult is widely accepted as the most important etiologic factor of an OD of the talus. In 93% to 98% of the lateral talar lesions, trauma has been described and for medial lesions in 61% to 70% (12,13). ODs can either heal and remain asymptomatic or progress to deep ankle pain on weight bearing, prolonged joint swelling, recurrent synovitis, diminished range of motion, and formation of subchondral bone cysts. However, absence of swelling and diminished range of motion does not rule out an OD.

Routine radiographs of the ankle should be obtained after careful history taking and physical examination of the ankle. These consist of weight-bearing anteroposterior (AP) (mortise) and lateral views of both ankles (Fig. 49.1A and B). Initially, the damage may be too small to be visualized on a routine radiograph. The OD sometimes becomes apparent on radiographs at a later stage. A posteromedial or posterolateral defect may be revealed by a heelrise mortise view with the ankle in plantar flexion (14) (Fig. 49.2). Additionally, computer tomography can be performed to confirm diagnosis and to plan arthroscopic treatment (15) (Fig.49.1C and D).

In case of a symptomatic OD, arthroscopic débridement and bone marrow stimulation remain the best treatment that is currently available for defects up to 15 mm in diameter (13,16). With this technique, all unstable

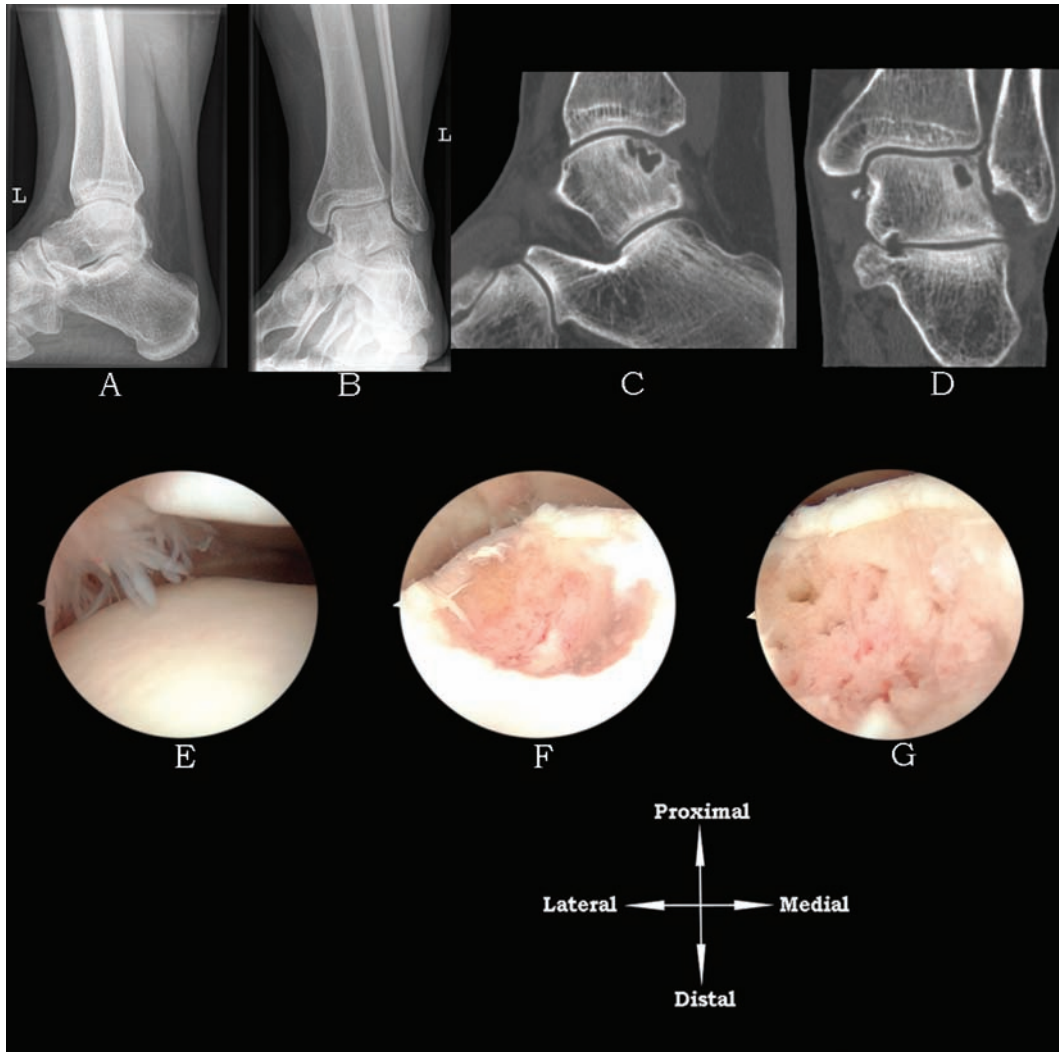

FIGURE 49.1

A 28-year-old female patient presenting with deep left ankle pain after an inversion trauma 1 year before. Physical examination revealed mild ankle swelling, no recognizable pain on palpation, and a normal range of motion.

In this case, the OD is too small to be visualized on standard weight-bearing lateral **(A)** and anteroposterior **(B)** radiographs of the left ankle. On a sagittal (**C**) and coronal **(D)** computed tomography, a posterolateral OD of the talus, with cyst formation is visible. **E:** By posterior ankle arthroscopy, the OD can be identified. **F:** All unstable cartilage including the underlying necrotic bone is removed with a shaver. **G:** Arthroscopic view of the microfractured lesion.

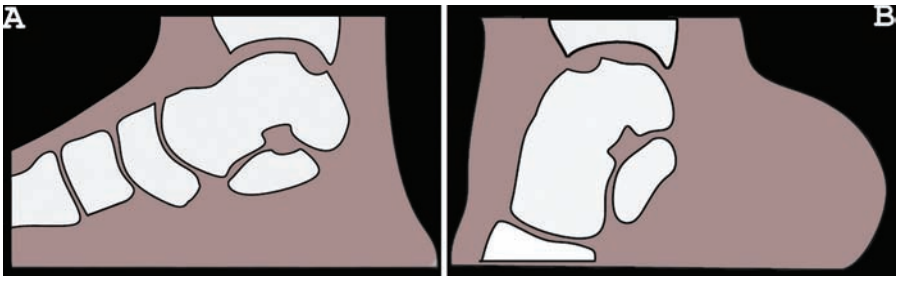

FIGURE 49.2

Talar ODs can most frequently be addressed through anterior ankle arthroscopy; nevertheless, posterior located ODs could sometimes be approached through a posterior ankle arthroscopy more easily. To determine which arthroscopic procedure is most suited, the ankle is forced in maximum plantar flexion. **A:** Posteriorly located talar OD with the foot in neutral position. **B:** By forcing the foot in maximum plantar flexion the OD moves anteriorly. In this case, the OD can be reached via anterior ankle.

cartilage including the underlying necrotic bone is removed. Any cysts underlying the defect are opened and curetted. After débridement, multiple connections with the subchondral bone are created by drilling or microfracturing. The objective is to partially destroy the calcified zone that is most often present and to create multiple openings into the subchondral bone (Fig. 49.1). Intraosseous blood vessels are disrupted and the release of growth factors leads to the formation of a fibrin clot. The growth of local new blood vessels is stimulated, marrow cells are introduced in the OD, and fibrocartilaginous tissue is formed (17).

Posterior Compartment Subtalar Joint

The main indications are removal of osteophytes; treatment of degenerative changes in the subtalar joint, including talar cystic lesions; loose body removal; and a subtalar arthrodesis in case of osteoarthritis (18–21). Intraosseous talar ganglions can also be treated arthroscopically (22).

PERIARTICULAR PATHOLOGY

Posterior Ankle Impingement

Posterior ankle impingement syndrome encompasses a group of pathologies that are characterized by posterior ankle pain in plantar flexion. The mechanism can be caused by overuse or trauma. It is important to differentiate between these two groups, because posterior impingement from overuse has a better prognosis (23) and patients are more satisfied after arthroscopic treatment (10).

The overuse group mainly exists from ballet dancers, downhill runners, and soccer players (23–25). In professional ballet, the specific dancing maneuvers force the ankle in hyper plantar flexion. The anatomical structures in between the calcaneus and the posterior part of the distal tibia thereby become compressed. Through exercise, the dancer will attempt to increase the range of motion and joint mobility, ultimately decreasing the distance between the calcaneus and the talus. The anatomical structures at the back of the ankle joint hereby become compressed. Running with more pronounced plantar flexion, such as downhill running, imposes repetitive stresses on the anatomical structures of the posterior ankle area (26). Kicking with the foot in plantar flexion results in high forces on the anatomical structures in the hindfoot. These repetitive high forces can eventually cause posterior ankle impingement.

An isolated or combined hyper plantar flexion—and supination—trauma can damage these structures and may finally lead to a chronic posterior ankle impingement syndrome. Congenital anatomic anomalies such as a prominent posterior talar process, os trigonum, or talus bipartitus (27) could facilitate the occurrence of the syndrome, especially in combination with overuse injury (28–30). An os trigonum is estimated to be present in 1.7% to 7% and occurs bilateral in 1.4% of the people (28,31,32). During plantar flexion, the soft tissue structures such as synovium, posterior ankle capsule, or one of the posterior ligamentous structures can get pinched and compressed, eventually resulting in swelling, partial rupture, or fibrosis.

The diagnosis is made by means of physical examination. The forced passive hyper plantar flexion test is positive when the patient complains of recognizable pain during the test (Fig. 49.3). A negative test rules out the posterior ankle impingement syndrome. A positive test is followed by a diagnostic infiltration with Xylocaine. Disappearance of pain following infiltration confirms the diagnosis. For radiographic detection of posterior impingement, the AP ankle view typically does not show abnormalities. On a lateral view, the posterolateral part of the talus is often superimposed on the medial talar process. Therefore, detection of a posterolateral talar process or os trigonum is often not possible. We recommend

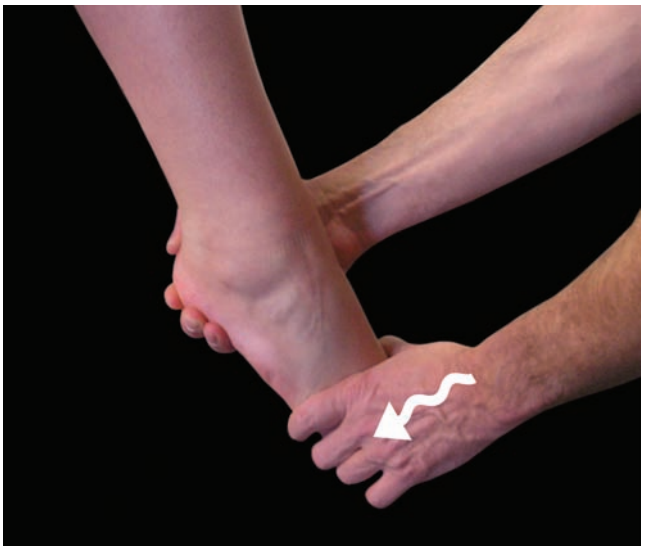

FIGURE 49.3

The forced hyper plantar flexion test is performed with the patient sitting with the knee flexed in 90 degrees. The test should be performed with repetitive quick passive hyper plantarflexion movements (*arrow*). The test can be repeated in slight external rotation or slight internal rotation of the foot relative to the tibia. The investigator can apply this rotational movement on the point of maximal plantar flexion, thereby "grinding" the (enlarged) posterior talar process/os trigonum in between tibia and calcaneus.

lateral radiographs with the foot in 25 degrees of external rotation in relation to the standard lateral radiographs (29).

In case conservative treatment fails, excision of soft tissue overgrowth and osteophytes results in good functional and clinical outcome in symptomatic posterior ankle impingement (10,33).

Deep Portion of the Deltoid Ligament/Cedell Fracture

Hyper dorsiflexion or eversion trauma can result in avulsion of the posterior talotibial ligament at its insertion into the medial tubercle of the talus. This may result in posttraumatic calcifications or ossicles in the deep portion of the deltoid ligament. These patients typically present with posteromedial ankle pain that is aggravated by running and walking on uneven grounds. Cedell was the first to report four cases of young athletes with ligament avulsion of the deep portion from the posteromedial talar process of the deltoid ligament (34).

Flexor Hallucis Longus Tendon pathology

Posterior ankle impingement syndrome is often accompanied by tenosynovitis or degeneration of the FHL, especially in ballet dancers (30,35,36). The patient experiences pain in the posteromedial part of the ankle (30). On physical examination, the tendon can be palpated behind the medial malleolus. By asking the patient to repetitively flex the big toe, while the ankle is in 10 to 20 degree plantar flexion, the FHL tendon can be identified in its gliding channel, in between the medial and the lateral talar process. In case of tendinitis or chronic inflammation, crepitus and recognizable pain can be provoked by the examiner putting the palpating/compressing finger just behind the medial malleolus. In some cases, a painful nodule in the tendon exists. Arthroscopic treatment can be considered when nonoperative treatment fails to improve symptoms. Débridement of the FHL and release of the flexor retinaculum and tendon sheath up to the level of the sustentaculum tali can be performed in order to achieve unrestricted movement of the tendon.

Peroneal Tendon Pathology

Peroneal tendon pathology frequently coexists with or is secondary to chronic lateral ankle instability. These disorders often cause chronic ankle pain in runners and ballet dancers (37). Posttraumatic lateral ankle pain is seen frequently, but peroneal tendon pathology is not always recognized as a cause of these symptoms. In a study by Dombek et al. (38), only 60% of peroneal tendon disorders were accurately diagnosed at first clinical evaluation. Because the peroneal tendons act as lateral ankle stabilizers, in chronic instability of the ankle more strain is put on these tendons, resulting in hypertrophic tendinopathy, tenosynovitis, and ultimately in tendon tears (4).

Pathology consists of tenosynovitis, tendon dislocation or subluxation, and (subtotal) rupture or snapping of one or both of the peroneal tendons. It accounts for the majority of symptoms at the posterolateral aspect of the ankle (39). Other causes of posterolateral ankle pain are rheumatoid synovitis, bony spurs, calcifications or ossicles, pathology to the posterior talofibular ligament, or disorders of the posterior compartment of the subtalar joint. Posterior ankle impingement can present as posterolateral ankle pain. On clinical examination, there is recognizable tenderness over the tendons on palpation. Swelling, tendon dislocation, and signs of tenosynovitis can be found in peroneal tendon pathology.

The diagnosis of peroneal tendon pathology can be difficult in a patient with lateral ankle pain. A detailed history should include the presence of associated conditions such as rheumatoid arthritis, psoriasis, hyperparathyroidism, diabetic neuropathy, calcaneal fracture, fluoroquinolone use, and local steroid injections. These can all increase the prevalence of peroneal tendon dysfunction (40). A diagnostic differentiation must be made with fatigue fractures or fractures of the fibula, posterior impingement of the ankle, and lesions of the lateral ligament complex.

Additional investigation such as magnetic resonance imaging (MRI) and ultrasonography may be helpful in confirming the diagnosis in (partial) tears of the tendon of peroneus brevis or longus (41,42). Posttraumatic or postsurgical adhesions and irregularities of the posterior aspect of the fibula (peroneal groove) can also be responsible for symptoms in this region.

In case of recurrent peroneal tendon dislocation, the primary indication for treatment is pain. After several months of conservative treatment without improvement, open or nowadays endoscopic/tendoscopic treatment options are available (4,43). An endoscopic fibular groove deepening technique, based on the posterior ankle arthroscopic portals (9), with one additional portal 4 cm proximal to the posterolateral portal (44) was recently introduced. Other peroneal tendon pathologies as for instance synovitis, adhesion, and exostosis can safely be assessed through tendoscopy, resulting in good to excellent clinical outcome (4).

Posterior Tibial Tendon Pathology

In the absence of intra-articular ankle pathology, posteromedial ankle pain is most often caused by disorders of the posterior tibial tendon.

Inactivity of the posterior tibial tendon gives midtarsal instability and is the commonest cause of adult onset flatfoot deformity. The relative strength of this tendon is more than twice that of its primary antagonist, the peroneus brevis tendon. Without the activity of the posterior tibial tendon, there is no stability at the midtarsal joint, and the forward propulsive force of the gastrocnemius-soleus complex acts at the midfoot instead of at the midtarsal heads. Total dysfunction eventually leads to a flatfoot deformity.

These disorders can be divided into two groups: the younger group of patients with dysfunction of the tendon, caused by some form of systemic inflammatory disease (e.g., rheumatoid arthritis), and an older group of patients whose tendon dysfunction is mostly caused by chronic overuse (45).

Following trauma, surgery, and fractures, adhesions and irregularity of the posterior aspect of the tibia can be responsible for symptoms in this region.

Mostly, a dysfunctioning posterior tibial tendon evolves in a painful tenosynovitis. Tenosynovitis is also a common extra-articular manifestation of rheumatoid arthritis, where hindfoot problems are a significant cause of disability. Tenosynovitis in rheumatoid patients eventually leads to a ruptured tendon (46).

Although the precise etiology is unknown, the condition is classified on the basis of clinical and radiographic findings. In the early stage of dysfunction, patients complain of persisting ankle pain medially along the course of the tendon, in addition to fatigue and aching on the plantar medial aspect of the ankle. When a tenosynovitis is present, swelling is common. On clinical examination, valgus angulation of the hindfoot is frequently seen, with accompanying abduction of the forefoot, the “too many toes” sign (47). This sign is positive when the examiner inspects the patient’s foot from behind: in case of significant forefoot abduction, three or more toes are visible lateral to the calcaneus, where normally only one or two toes are seen.

Intra-articular lesions such as a posteromedial impingement syndrome, subtalar pathology, calcifications in the dorsal capsule of the ankle joint, loose bodies, or ODs should be excluded. Entrapment of the posterior tibial nerve in the tarsal canal is commonly known as a tarsal tunnel syndrome. Clinical examination is normally sufficient to adequately differentiate these disorders from an isolated posterior tibia tendon disorder.

For additional investigation, MRI is the best method to assess a tendon rupture (48). Also, ultrasound imaging is known as a cost-effective and accurate method to evaluate disorders of the tendon (49).

Initially, conservative management is indicated, with rest, combined with nonsteroidal anti-inflammatory drugs (NSAIDs), and immobilization using a plaster cast or tape. There is no consensus whether to use corticosteroid injections; some cases of tendon rupture following corticosteroid injections have recently been described (50).

After failure of 3 to 6 months of conservative management, surgery is indicated (51). This can be performed open or endoscopically. An open synovectomy is performed by sharp dissection of the inflamed synovium, while preserving blood supply to the tendon. Postoperative management consists of plaster cast immobilization for 3 weeks with the possible disadvantage of new formation of adhesions, followed by wearing a functional brace with controlled ankle movement for another 3 weeks, and physical therapy (52).

Johnson and Strom classified tenosynovitis of the posterior tibial tendon into three stages (53): stage one, tenosynovitis where the tendon length is normal; stage two, elongated tendon with mobile hindfoot deformity; and stage three, elongated tendon with fixed hindfoot deformity. Myerson modified the classification by adding stage four: a valgus angulation of the talus and early degeneration of the ankle joint (45). Endoscopic synovectomy is our surgical modality of choice for stage I when access allows radical removal of inflamed synovium (54). Several studies have been described previously in which endoscopic synovectomy was successfully performed, offering the advantages that are related to minimally invasive surgery (3,5).

Achilles Tendon Pathology

Pathology of the Achilles tendon can be divided into noninsertional and insertional problems (55,56). The first type can present as local degeneration of the tendon that can be combined with paratendinopathy. Insertional problems are related to abnormalities at the insertion of the Achilles tendon, including the posterior aspect of the calcaneus and the retrocalcaneal bursa. The noninsertional tendinopathy can be divided into three entities: tendinopathy, paratendinopathy, and a combination of both. Isolated tendinopathy seldom occurs (6,57). General symptoms include painful swelling typically 4 to 6 cm proximal to the insertion, and stiffness especially when getting up after a period of rest.

Patients with tendinopathy can present with three patterns: diffuse thickening of the tendon, local degeneration of the tendon that is mechanically intact, or insufficiency of the tendon with a partial tear. In paratendinopathy, there is local thickening or inflammation of the paratenon. Clinically, a differentiation between tendinopathy and paratendinopathy can be made. Maffulli et al. describe the Royal London Hospital test, which is found to be positive in patients with isolated tendinopathy of the main body of the tendon: the portion of the tendon originally found to be tender on palpation shows little or no pain with the ankle in maximum dorsiflexion (57,58). In paratendinopathy, the area of swelling does not move with dorsiflexion and plantarflexion of the ankle, where it does in tendinopathy (6,58). Paratendinopathy can be acute or chronic. Differential diagnoses are pathology of the tendons of the peroneus longus and brevis, intra-articular pathology of the ankle joint and subtalar joint, degenerative changes of the posterior tibial tendon, and tendinopathy of the FHL muscle; these must be ruled out. MRI and ultrasound can be used to differentiate between the various forms of tendinopathy (59).

We normally initiate conservative management. Modification of the activity level of the patient is advised together with avoidance of strenuous activities in case of paratendinopathy. Shoe modifications and inlays can be given. Physical therapy includes an extensive eccentric exercise program, which can be combined with icing and NSAIDs (60,61). Shockwave treatment, a night splint, and cast immobilization are alternative conservative methods. Sclerosing injections of neovascularization and accompanying nerves around the Achilles tendon have initially shown promising results and are based on the observation that neovascularization is seen in the vast majority of patients with Achilles tendinopathy but not in pain-free normal tendons (62,63).

If these conservative measures fail, surgery must be considered. The percentage of patients requiring surgery is around 25% (64,65). The technique used for operative management of tendinopathy depends on the stage of the disease. Local degeneration and thickening are usually treated by open excision and curettage. An insufficient Achilles tendon due to extensive degeneration can be reconstructed. Isolated paratendinopathy can be treated by excision of the diseased paratenon.

Open surgery produces a guarded prognosis and is associated with a higher risk of complications than endoscopy (23,66,67). Open techniques are also associated with an extensive rehabilitation period of 4 to 12 months. Therefore, recently minimally invasive techniques were developed. Percutaneous needling of the tendon has been described, but until now no results have been published. Testa et al. described a minimally invasive technique consisting of percutaneous longitudinal tenotomies (68,69), which was later optimized by adding ultrasound control. Eighty-three percent of patients reported symptomatic benefit at the time of their best outcome; however, the median time to return to sports was 6.5 months (70).

In combined tendinopathy and paratendinopathy, the question is whether both pathologies contribute to the complaints. An anatomic cadaver study described degenerative changes of the Achilles tendon in as much as 34% of subjects with no complaints (71). Khan et al. (72) found abnormal morphology not only in 65% (37 of 57) of symptomatic tendons but also in 32% (9 of 28) of asymptomatic Achilles tendons assessed by ultrasound. Therefore, it is questionable whether degeneration of the tendon itself is the main cause of the pain. The authors focus mainly on management of the paratendinopathy leaving the tendinopathy untouched. The current approach for patients with tendinopathy of the Achilles tendon is an endoscopic release of the paratendon at the level of the nodule in the tendon. In presence of the plantaris tendon, this tendon is resected, since we believe it has a part in maintenance of medially located symptoms. We earlier described good functional and clinical outcome of patients treated with an endoscopic release for noninsertional tendinopathy combined with a paratendinopathy (6). Maquirriain et al. reported similar results (73).

OPERATIVE TECHNIQUES

Posterior Ankle Arthroscopy

The procedure is carried out as outpatient surgery under general anesthesia or spinal anesthesia. The patient is placed prone. The involved leg is marked by the patient with an arrow to avoid wrong side surgery, with a tourniquet inflated around the thigh. The patient's ankle is placed slightly over the distal edge of the table and a small support is placed under the lower leg, making it possible to move the ankle freely. A support is placed at the ipsilateral side of the pelvis to safely rotate the table when needed (Fig.49.4). A 4-mm arthroscope with an inclination angle of 30 degrees is routinely used.

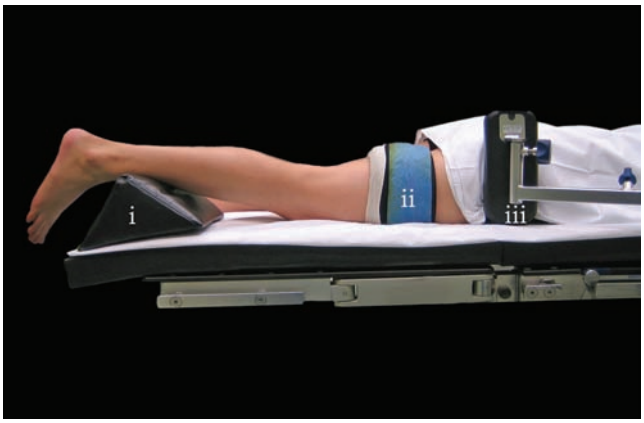

FIGURE 49.4

The patient is placed in the prone position with a tourniquet inflated around the thigh (*ii*). The affected heel is positioned slightly over the edge of the operation table and is raised with a triangular-shaped cushion (*i*) allowing free ankle movement. The ipsilateral hip is supported for safe operation table rotation (*iii*).

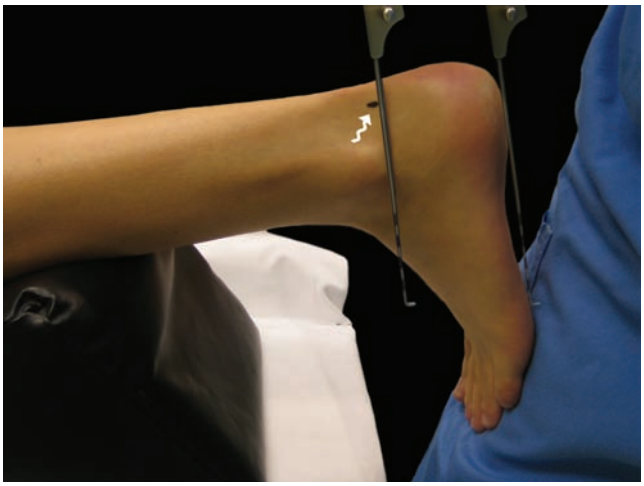

FIGURE 49.5

For marking the anatomical landmarks that are needed for portal placement, the ankle is kept in a neutral position. A hook can be useful to determine the plane in which the portal must be positioned. A straight line is drawn from the tip of the lateral malleolus to the Achilles tendon, parallel to the foot sole. The posterolateral portal (*arrow*) is made just above the line from the tip of the lateral malleolus to the interception with the Achilles tendon. The posteromedial portal is located at the same level of the posterolateral portal, medially to the Achilles tendon.

For irrigation, normal saline is used, and flow is obtained by gravity. Apart from the standard excisional and motorized instruments for treatment of osteophytes and ossicles, a 4-mm chisel and periosteal elevator can be useful.

The anatomical landmarks on the ankle are the lateral malleolus, medial and lateral border of the Achilles tendon, and the sole of the foot. The ankle is kept in a 90-degree position. A straight line is drawn from the tip of the lateral malleolus to the Achilles tendon, parallel to the sole of the foot (Fig. 49.5).

The posterolateral portal is made directly in front of the Achilles tendon just proximal of this line. After making a vertical stab incision, the subcutaneous layer is split by a mosquito clamp. The mosquito clamp is directed toward the first interdigital webspace. When the tip of the clamp touches the bone, it is exchanged for a 4.5-mm arthroscopic shaft with the blunt trocar pointing in the same direction. By palpating the bone in the sagittal plane, the level of the ankle joint and subtalar joint can often be distinguished since the prominent posterior talar process or os trigonum can be felt as a posterior prominence in between the two joints. The trocar is situated extra-articularly at the level of the ankle joint. The trocar will be exchanged for the 4-mm arthroscope with the standard direction of view 30 degrees to the lateral side.

The posteromedial portal is made medially to the Achilles tendon, at the same level as the posterolateral portal, medially to the lateral malleolus. After making a vertical stab incision, a mosquito clamp is pointed into the direction of the arthroscopic shaft in a 90-degree angle. When the mosquito clamp touches the shaft of the arthroscope, the shaft is used as a guide to "travel" anteriorly in the direction of the ankle joint, all the way down while contacting the arthroscope shaft until it reaches the bone. The arthroscopic shaft is subsequently pulled slightly backward and is lifted until the tip of the mosquito clamp becomes visible. The clamp is used to spread the extra-articular soft tissue in front of the tip of the lens. After exchanging the mosquito clamp for a 5-mm full radius resector, the fatty tissue overlying the posterior ankle capsule, lateral to the FHL tendon, is resected. The tip of the shaver is directed in a lateral and slightly plantar direction toward the lateral aspect of the subtalar joint.

Once this tissue is débrided, the ankle and subtalar joints can be entered easily by penetrating the very thin joint capsule. At the level of the ankle joint, the superficial and deep component (transverse ligament) of the posterior tibiofibular ligament is recognized as well as the posterior talofibular ligament. The posterior talar process can be freed from scar tissue and the FHL tendon is identified. This tendon

should be located first, before addressing the pathology. The FHL tendon is an important safety landmark, since the neurovascular bundle runs just medial to this tendon. After removal of the thin joint capsule of the ankle joint, the intermalleolar and transverse ligaments need to be lifted in order to enter and inspect the ankle joint.

On the medial side, the tip of the medial malleolus can be visualized as well as the deep portion of the deltoid ligament. By opening the joint capsule from inside out at the level of the medial malleolus, the tendon sheath of the posterior tibial tendon and the FHL tendon can be opened when desired, and the arthroscope may now be introduced into the tendon sheath. Inspection of both tendons is now possible.

By applying manual distraction to the calcaneus, the posterior compartment of the ankle opens up and the shaver can be introduced into the posterior ankle compartment. We prefer to apply a soft tissue distractor at this point (8). A synovectomy and/or capsulectomy can be performed. Inspection of the talar dome is possible over almost its entire surface as well as the complete tibial plafond. Identification of an OD or subchondral cystic lesion may lead to débridement and drilling. The posterior syndesmotic ligaments are inspected and débrided if fibrotic or ruptured.

Removal of a symptomatic os trigonum, a nonunion of a fracture of the posterior talar process, or a symptomatic large posterior talar prominence involves partial detachment of the posterior talofibular ligament and release of the flexor retinaculum, which both attach to the posterior talar prominence. Release of the FHL tendon involves detachment of the flexor retinaculum from the posterior talar process. The tendon sheath can now be entered with the scope, following the tendon under the medial malleolus and a further release is performed.

Bleeding is controlled by electrocautery at the end of the procedure. Wound closure and dressing are performed as in anterior ankle arthroscopy. Prophylactic antibiotics are not routinely given. After surgery, patients are instructed to weight bear as tolerated.

Posterior ankle arthroscopy is an advanced endoscopic procedure. Surgeons are advised to train themselves in cadaveric sessions to adapt the technique before treating their patients {2009 371 /id}.

Peroneal Tendoscopy

The patient is placed in the lateral decubitus position, with the operative side up. Before anesthesia is administered, the patient is asked to actively evert the affected foot. In this way, the tendon can be palpated, and the location of the portals is drawn onto the skin (Fig. 49.6). The surgery can be performed under local, regional, epidural, or general anesthesia. A support is placed under the affected leg making it possible to move the ankle freely. After exsanguination, a tourniquet is inflated around the thigh of the affected leg.

A distal portal is made first, 2 to 2.5 cm distal to the posterior edge of the lateral malleolus. An incision is made through the skin, and the tendon sheath is penetrated with an arthroscopic shaft with a blunt trocar. After this, a 2.7-mm 30-degree arthroscope is introduced.

The inspection starts approximately 6 cm proximal to the posterior tip of the fibula, where a thin membrane splits the tendon compartment into two separate tendon chambers. More distally, the tendons lie in one compartment. A second portal is made 2 to 2.5 cm proximal to the posterior edge of the lateral malleolus under direct vision by placing a spinal needle, producing a portal directly over the tendons. Through the distal portal, a complete overview of both tendons can be obtained.

By rotating the arthroscope over and in between both tendons, the whole compartment can be inspected. When a total synovectomy of the tendon sheath has to be performed, it is advisable to make a third portal more distal or more proximal than the portals described previously.

When a rupture of one of the tendons is seen, endoscopic synovectomy is performed, and the rupture is repaired through a miniopen approach.

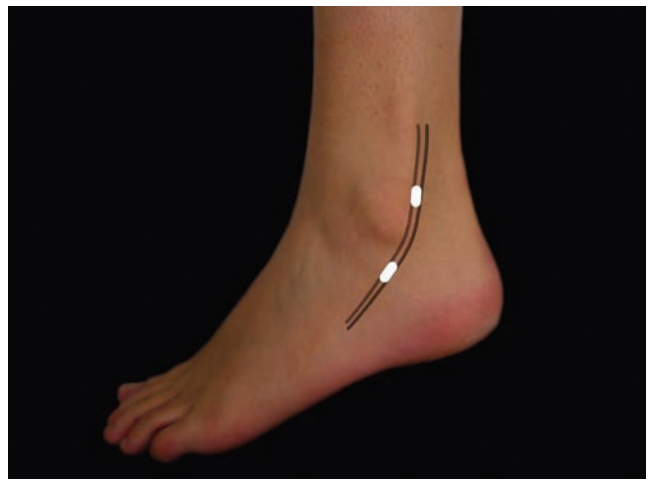

FIGURE 49.6

The patient is placed in the lateral decubitus position. Alternatively, the patient can also be placed in the supine position with the foot in endorotation. A support can be placed under the leg, being able to move the ankle freely. The patient is asked to evert the foot, hereby the peroneal tendons can usually be visualized clearly (in *black*). Its course is drawn on the skin (*white lines*) and the location of the portals is marked (in *white*).

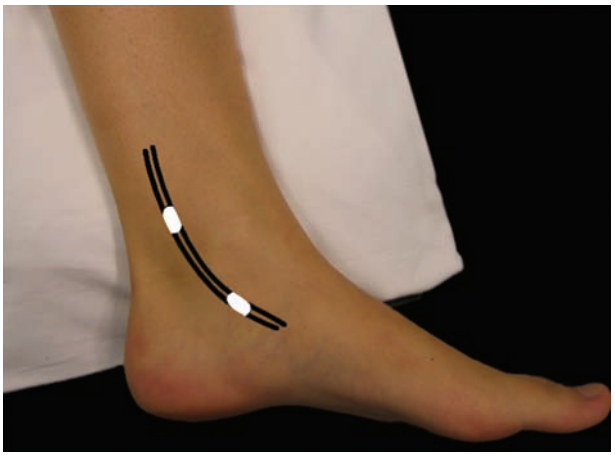

FIGURE 49.7

The patient is in the supine position. The two main portals (indicated in *white*) are made directly over the posterior tibial tendon (indicated with *black lines*) tendon 2 to 3 cm distal and 2 to 3 cm proximal to the posterior edge of the medial malleolus.

In patients with recurrent dislocation of the peroneal tendon, endoscopic fibular groove deepening can be performed through this tendoscopic approach. It is a time-consuming procedure, because of the limited working area. Groove deepening is performed from within the tendon sheath with the risk of iatrogenic damage to the tendons. We therefore prefer an approach, based on the 2-portal hindfoot technique, with an additional portal located 4 cm proximal to the posterolateral portal (44).

At the end of the procedure, the portals are sutured to prevent sinus formation, and a compressive dressing is applied. Antibiotics are not routinely given.

Posterior Tibial Tendoscopy

The procedure can be performed on an outpatient basis under local, regional, or general anesthesia. The patient is placed in the supine position. A tourniquet is placed around the upper leg. Before anesthesia, the patient is asked to actively invert the foot, so that the posterior tibial tendon can be palpated and the portals can be marked. Access to the tendon can be obtained anywhere along its course.

We prefer to make the two main portals directly over the tendon 2 to 3 cm distal and 2 to 3 cm proximal to the posterior edge of the medial malleolus (Fig. 49.7). The distal portal is made first: the incision is made through the skin, and the tendon sheath is penetrated by the arthroscopic shaft with a blunt trocar. A 2.7-mm 30- degree arthroscope is introduced, and the tendon sheath is filled with saline. Irrigation is performed using gravity flow.

Under direct vision, the proximal portal is made by introducing a spinal needle, and subsequently an incision is made into the tendon sheath. Instruments such as a retrograde knife, a shaver system, blunt probes, and scissors can be used. For synovectomy in patients with rheumatoid arthritis, a 3.5-mm shaver can be used. The complete tendon sheath can be inspected by rotating the arthroscope around the tendon.

Synovectomy can be performed with a complete overview of the tendon from the distal portal, over the insertion of the navicular bone to approximately 6 cm above the tip of the medial malleolus.

Special attention should be given while inspecting the tendon sheath, the posterior aspect of the medial malleolar surface, and the posterior ankle joint capsule. The tendon sheath between the posterior tibial tendon and the flexor digitorum longus is relatively thin: inspection of the correct tendon should always be checked. This can be accomplished by passively flexing and extending the toes; if the tendon sheath of the flexor digitorum longus tendon is entered, the tendon will move up and down.

When remaining in the posterior tibial tendon sheath, the neurovascular bundle is not in danger.

When a rupture of the posterior tibial tendon is seen, endoscopic synovectomy is performed and the rupture is repaired through a miniopen approach. Magnifying the tendon endoscopically pronounces the localization and extent of the rupture, thereby minimizing the incision for repair. At the end of the procedure, the portals are sutured to prevent sinus formation.

Achilles Tendoscopy

Local, epidural, spinal, and general anesthesia can be used for this procedure, which can be performed on an outpatient basis. The patient is in prone position. A tourniquet is placed around the thigh of the affected leg, and a bolster is placed under the foot. Because the surgeon needs to be able to obtain full plantar and dorsiflexion, the foot is placed right over the end of the table.

The authors mostly use a 2.7-mm arthroscope for endoscopy of a combined tendinopathy and paratendinopathy. This small-diameter short arthroscope yields an excellent picture comparable to the standard 4-mm arthroscope; however, it cannot deliver the same amount of irrigation fluid per time as the 4-mm sheath. This is important in procedures in which a large-diameter shaver is used (e.g., in endoscopic calcaneoplasty). When

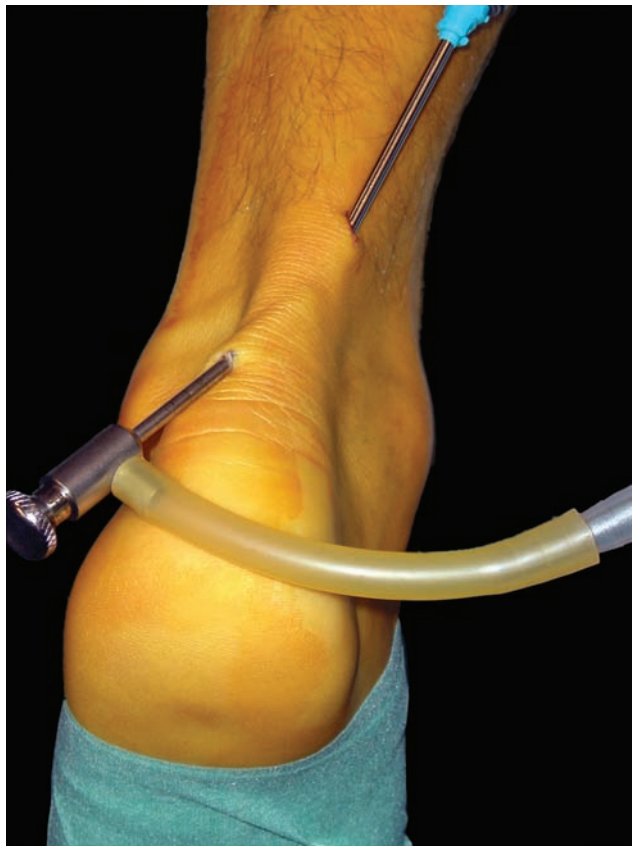

FIGURE 49.8

In case of peritendinitis of the Achilles tendon, the portals are created 2 to 3 cm proximal and 2 to 4 cm distal of the lesion. The distal portal is made first through the skin only. After introduction of a spinal needle under direct vision, an incision is made at the location of the proximal portal. Instruments like a probe or a small shaver can be introduced.

a 4-mm arthroscope is used, gravity inflow of irrigation fluid is usually sufficient. A pressurized bag or pump device sometimes is used with the 2.7-mm arthroscope.

The distal portal is located on the lateral border of the Achilles tendon, 2 to 3 cm distal to the pathologic nodule. The proximal portal is located medial to the border of the Achilles tendon, 2 to 4 cm above the nodule (Fig. 49.8). When the portals are placed this way, it is usually possible to visualize and work around the whole surface of the tendon, over a length of approximately 10 cm.

The distal portal is made first. After making the skin incision, the mosquito clamp is introduced, followed by the blunt 2.7-mm trocar in a craniomedial direction. With this blunt trocar, the paratenon is approached and is blindly released from the tendon by moving around it. Subsequently, the 2.7-mm 30-degree arthroscope is introduced. To minimize the risk of iatrogenic damage, the arthroscope should be kept on the tendon. At this moment, it can be confirmed whether the surgeon is in the right layer between paratenon and Achilles tendon. If not, now it can be identified and a further release can be performed.

The proximal portal is made by introducing a spinal needle, followed by a mosquito clamp and probe. The plantaris tendon can be identified at the anteromedial border of the Achilles tendon. In a typical case of local paratendinopathy, the plantaris tendon, the Achilles tendon, and the paratenon are tight together in the process. Removal of the local thickened paratenon on the anteromedial side of the Achilles tendon at the level of the nodule, and release of the plantaris tendon are the goals of this procedure. In cases where the fibrotic paratenon is firmly attached to the lateral or posterior border of the tendon, a release in these areas is performed. Neovessels accompanied by small nerve fibers can be found in this area and are removed with a 2.7-mm bonecutter shaver. The tendon proper remains untouched.

Changing portals can be helpful. At the end of the procedure, it must be possible to move the arthroscope over the complete symptomatic area of the Achilles tendon.

After the procedure, the portals are sutured.

Aftercare consists of a compressive dressing for 2 to 3 days. Patients are encouraged to actively perform range of motion exercises. Full weight bearing is allowed as tolerated. Initially, the foot must be elevated when not walking.

POSTOPERATIVE MANAGEMENT AND REHABILITATION

In all indications as described in this chapter, the patient can be discharged the same day of surgery. The patient is instructed to elevate the foot when not walking to prevent edema. In most cases, postoperative management consists of a pressure bandage and partial weight bearing for 2 to 3 days. Full weight bearing is allowed as

tolerated and active range of motion exercises for at least three times a day for 10 minutes are advised starting immediately post surgery.

If an OD is the indication for operation, the patient is kept non–weight bearing and placed in a well-padded short leg cast during the immediate postoperative period. At 2 weeks postoperatively, the patient is placed in a controlled action motion (CAM) walker boot. Partial weight bearing and gentle ankle range of motion exercises are permitted. Weight bearing is advanced based on radiographic evidence of osteotomy healing. At 6 weeks, the patient can discontinue the use of the CAM walker. Repetitive impact activities, such as jogging and aerobics, can be resumed after 6 to 8 months. Return to high-level sports is permitted after 12 months.

In case of an endoscopic groove deepening in order to treat recurrent peroneal tendon dislocation, partial weight bearing is advised for 5 days. A soft brace is applied for 4 to 6 weeks with the permission to fully bear weight. With satisfaction of the surgeon and the patient, no further outpatient department contact is necessary. Patients with limited range of motion are directed to a physiotherapist.

TECHNICAL ALTERNATIVES AND PITFALLS

Posterior Ankle Arthroscopy/Endoscopic Groove Deepening Technique

In the hindfoot, the crural fascia can be quite thick. This local thickening is called the Rouvière ligament (76). This ligament needs to be at least partially excised or sectioned, using arthroscopic punch or scissors, to reach the level of the ankle and the subtalar joint. The position of the arthroscope is important; the view should always be to the lateral side. At introduction, the arthroscope must be pointed in the direction between the first and the second toe to remain in a safe area. The FHL tendon is an important landmark. The working area is laterally with respect to the FHL tendon. The FHL tendon can safely be identified by shaving on top of the posterior talar process while the opening of the shaver is pointing toward the bone. While staying in contact with the bone, the tip of the shaver should be moved slowly and slightly twisted to the medial side. The shaver must be twisted approximately 45 degrees so that the opening of the shaver is directed 45 degrees distally and 45 degrees to the lateral side, and thus the blunt back of the shaverblade is turned toward the FHL tendon. The contour of the posterior talar process is followed until the shaver can be pushed in between the posterior talar process and the FHL tendon. Shaving should be stopped at this moment and the FHL tendon must be identified. The opening of the shaver should always be directed away from the tendon at this point. In case of a posterior tarsal tunnel syndrome, release of the neurovascular bundle can be performed. The FHL tendon should then be passed medially with a mosquito clamp and with caution to the neurovascular bundle. If a hypertrophic posterior talar process is removed by using a chisel, care must be taken not to place the chisel too far anteriorly. Only the inferoposterior part of the process should be removed with the chisel. The remnant of the process can be taken away with a bonecutter shaver. If initially the chisel is placed too much anteriorly, it is hard to avoid taking away too much bone at the level of the subtalar joint.

Loose bony particles can easily be created with the microfracture awl in case of puncturing the subchondral plate in ODs. They can become detached upon withdrawal of the awl. If the particles are not taken out properly, they may act as loose bodies and should therefore be removed (77).

During endoscopic groove deepening for recurrent peroneal tendon dislocation, the posterior ankle ligament is potentially at risk. Medial from the fibular groove the posterior syndesmotic ligaments and the posterior talofibular ligament are located. The contour of the groove must be followed from proximal to distal. The calcaneofibular ligament inserts more anteriorly in the most distal part of the lateral malleolus. The fibular groove must be deepened anteriorly and distally, while the shaver is directed medial from the calcaneofibular ligament insertion (44).

The depth of the fibular groove needs to be sufficient in order to prevent redislocation of the peroneal tendons and should approximately be 5 mm. At the end of the procedure, the ankle is manipulated to check whether sufficient bone is excised. Removing too much fibular bone could induce weakening, which could eventually result in a fracture of the remaining lateral rim. It is important to smoothen the created lateral edge of the groove in order to prevent it from causing peroneal tendon (length) ruptures. In fact, this is the most important pitfall and should therefore always be carefully checked.

The advantage of a two-portal procedure (9) and also of the 3-portal endoscopic groove deepening technique (44) with the patient in the prone position is the working space that can be created in between the Achilles tendon and the back of the ankle and subtalar joint. The position is ergonomic for the orthopa74edic surgeon. Soft tissue distraction can easily be applied (78).

DISCUSSION/CONSIDERATION

Arthroscopy has become an important operative technique in treating a wide variety of ankle pathology. It provides a minimally invasive approach as a good alternative to the already-existing open surgical techniques. The surgeon must be familiar with the anatomy and must try to use routine portals in ankle arthroscopy (79).

Ideally, these routine portals can be used to treat the vast majority of pathology, without the need for additional portals.

The authors feel that the posteromedial and lateral portal, as described in 2000, possess the criteria (9). Also, portals must provide a safe access, as is anatomically demonstrated to be the case for these posterior endoscopic portals (80).

Recently, a retrospective study was published in which 16 posterior ankle arthroscopies were evaluated (33). The patients all had a good functional and clinical outcome at a mean follow-up of 32 months. One patient had a temporary numbness in the region of the scar. Similar results were published in a prospective study of the senior author (10). In total, 55 posterior ankle arthroscopies were assessed. All patients had a posterior ankle impingement syndrome. Good to excellent functional and clinical outcome was reported on in 74% of the cases. One complication occurred, being a temporary sensational loss of the posteromedial heel. The two-portal endoscopic hindfoot approach compares favorably to open surgery with regard to less morbidity and a quicker recovery (10).

The technique is now expanding to other areas in the hindfoot. The endoscopic groove deepening technique for recurrent peroneal tendon dislocation, as described in this chapter, is one of these new possibilities (44). Also, subtalar arthrodesis can be successfully performed with this technique in patients who have primary degenerative joint disease of the subtalar joint without gross deformity or bone loss (21).

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50 Lateral Ankle Instability and the Modified Broström Technique

Jerome M. Benavides and Thomas O. Clanton

INDICATIONS/CONTRAINDICATIONS

Lateral ankle ligament sprain is one of the most common injuries in sport (3,16,17,18,27,31). Most injuries respond to conservative treatment with a physical therapy program emphasizing proprioceptive training, restoration of motion, and strengthening of the supportive musculature (8,12,27). Surgical correction in the patient with persistent instability and dysfunction has been described utilizing a number of anatomic and nonanatomic operations (4,9,10,14,15). Many of the historic methods of ankle stabilization sacrificed some or all of an often normal peroneal tendon to achieve stability (10,14,15). These procedures typically involved weaving half of the peroneus brevis tendon to achieve stability. Disadvantages of such procedures include sacrificing a peroneal tendon, loss of motion from nonanatomical tunnel positions, large exposures with wide dissection, increased risk of nerve injury, and increased operative time (22).

More than a half-century ago, Lennart Broström published the first in a series of articles on operative treatment of lateral ankle ligament sprains (4–9). Broström advocated direct primary repair of the lateral ligaments in patients with chronic lateral ankle instability. The operation he described was an anatomic repair formulated on the premise that the anterior talofibular ligament (ATFL) is contained in a portion of the lateral ankle capsule (4,5). He also advocated repair of the calcaneofibular ligament (CFL) when indicated. This operation restored the normal length of the lateral ligaments and respected their normal anatomical location (9). The Broström repair was advocated for the treatment of both acute ruptures and in chronic instability (4,9).

Several modifications of Broström's original procedure have been described, the most popular being reinforcement of the primary ligament repair using a portion of the inferior extensor retinaculum sutured to the periosteum of the distal fibula (20). This adds stability to the repair, limits inversion, and helps address subtalar instability (21).

Indications for primary lateral ankle ligament repair include functional instability and chronic mechanical instability that has failed to respond to an aggressive rehabilitation program. Carefully selected professional and elite athletes may benefit from the procedure in cases of acute sprain with complete rupture of the lateral ligamentous complex. For the remainder of this chapter, the focus will be the patient with chronic lateral ankle instability.

PREOPERATIVE PLANNING

Patients being considered for secondary lateral ankle ligament repair should have severe limitation from lateral ankle instability. This dysfunction persists despite completion of a standard rehabilitation and proprioception training program. Athletes describe giving way, frequent sprains, and inability to perform at their prior level of competition. Pain may be present, but it is generally less of a consideration than the instability. If pain is the major complaint, then other sources of pain should be investigated such as osteochondral lesions, peroneal

tendon pathology, an occult fracture, or nerve injury. Among the most frequent presentations is the athlete with a severe acute lateral ankle sprain who relates that this happens with an unnatural frequency or ease of occurrence.

In these situations, anatomic repair of the ligaments is an excellent choice for athletes because it does not restrict subtalar motion and is tendon sparing. It attempts to restore the normal anatomical length of the injured ligaments with preservation of normal anatomical origin and insertion sites along with a quick recovery and rehabilitation program.

Ankle instability can be evaluated by physical exam with talar tilt and anterior drawer tests. The talar tilt test compares inversion of the hindfoot with the contralateral ankle. The anterior drawer test stresses the lateral ankle ligaments by the examiner first stabilizing the distal tibia and then exerting a forward stress to a slightly plantar-flexed ankle (Fig. 50.1). Comparison with the contralateral side gives the examiner an idea of the degree of increased laxity in the affected ankle. The motion of the hindfoot should be observed closely during these examinations. Decreased motion in the transverse tarsal or subtalar joint could mean a tarsal coalition is present—a condition that predisposes to recurrent ankle sprain and instability.

A thorough evaluation of the posture of the foot and ankle is required before proceeding with surgery. A patient with hindfoot varus or cavus foot (Fig. 50.2) can be predisposed to lateral ankle ligament injury. These patients may require realignment of the foot's posture in addition to secondary ligament repair. Tarsal coalitions can also present as recurrent sprains and may be a source of ongoing difficulty after a lateral ligament repair if not addressed appropriately. These anatomical abnormalities can be associated with additional soft tissue pathology as in the case of peroneal tendon subluxation or tear, lateral impingement, synovitis, or sinus tarsi syndrome.

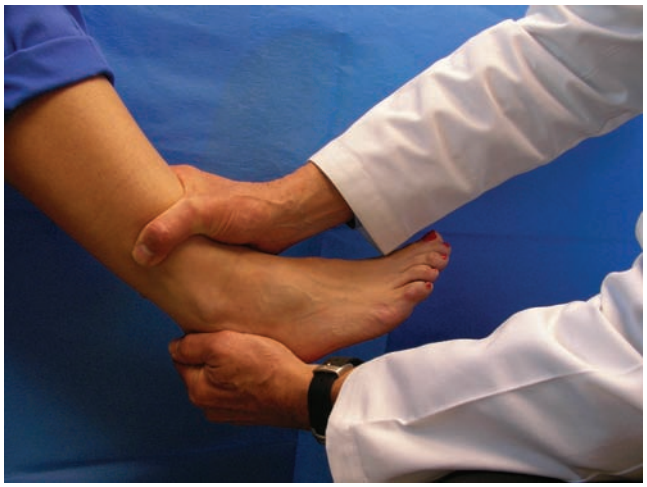

FIGURE 50.1
The talar tilt test.

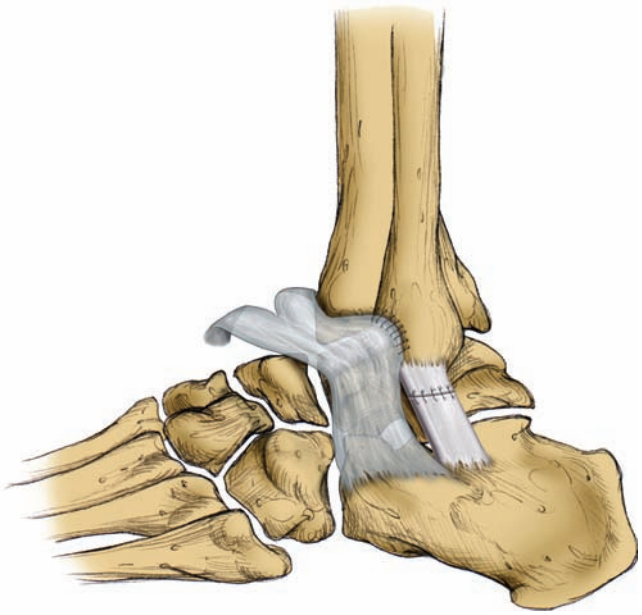

FIGURE 50.2
Hindfoot varus (cavus foot).

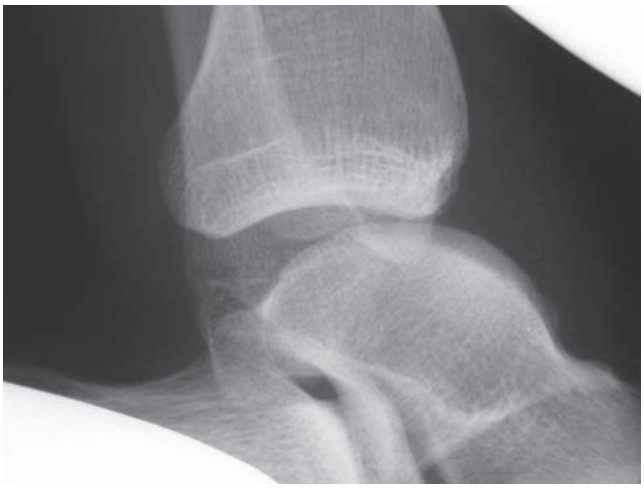

FIGURE 50.3
Stress views.

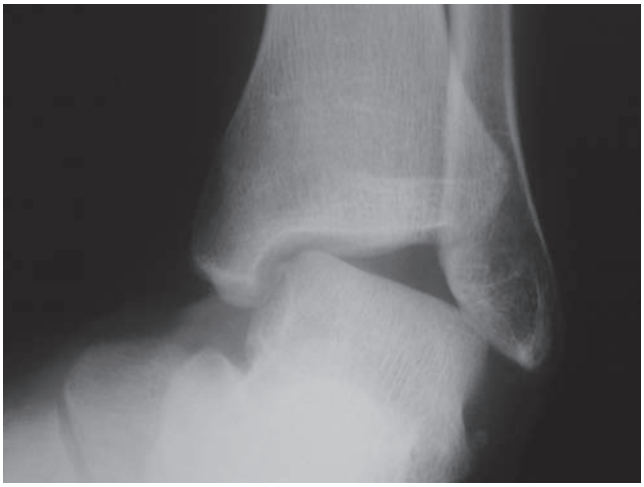

FIGURE 50.4
Stress view.

Radiographs should be evaluated for fracture, osteochondral lesions, loose bodies, cavus, and signs of coalition. Stress views can be done to evaluate and compare talar tilt and anterior drawer differences using either fluoroscopy with a mini c-arm or plain radiographs (Figs. 50.3 and 50.4). There is still controversy as to the exact degree of opening or side-to-side difference necessary to indicate the need for surgical intervention. MRI provides an anatomically specific view of the ligament injury (Fig. 50.5) as well as demonstrating additional pathology that may be important. Peroneal tendon tears, coalitions, osteochondral lesions, loose bodies, and other ankle pathology are readily apparent on MRI. All of these imaging studies should be evaluated in light of the patient's history and physical examination.

SURGERY

Lateral ankle ligament secondary repair is typically performed as outpatient surgery. The patient is placed supine on the operating table with a bump under the ipsilateral hip to slightly internally rotate the extremity. A thigh tourniquet is applied, the leg exsanguinated, and the procedure begins.

The typical incision is made at the level of the tibial plafond along the anterior border of the distal fibula, curving in a J-shape posteriorly (Fig. 50.6), and stopping at the level of the peroneal tendons. Alternative incisions can be used if concomitant pathology is to be addressed. As an example, a utility incision can be made along the course of the peroneal tendons if peroneal tendon pathology is to be addressed in addition to lateral ligament repair. Care is taken to avoid damage to the lateral branch of the superficial peroneal nerve anteriorly, and the sural nerve lying posterior to the distal margin of the incision. An anterior branch of the sural nerve can sometimes cross over the distal fibula in the middle of the incision.

The dissection proceeds down through the subcutaneous tissue to the anterolateral ankle joint capsule. During this approach, the anterior inferior tibiofibular ligament can be a useful guide at the level of the joint line and attaches to the anterior fibula proximal to the ATFL origin. The inferior extensor retinaculum is encountered superficial to the capsule and ligaments coursing from the dorsal ankle and foot into the sinus tarsi.

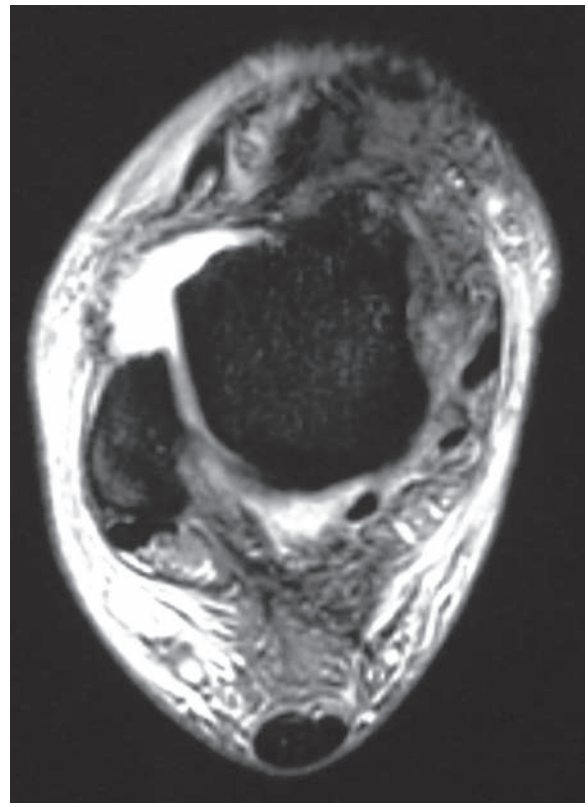

FIGURE 50.5
MRI view of ligament injury.

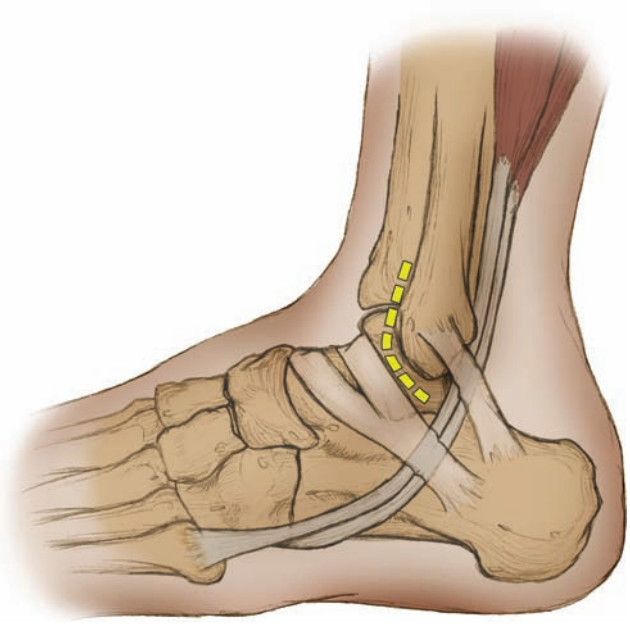

FIGURE 50.6
The typical incision is made at the level of the tibial plafond along the anterior border of the distal fibula, curving in a J-shape posteriorly.

The capsule is identified with the lax ATFL fibers running within the anterolateral capsule (Fig. 50.7). The ATFL and capsule are then divided with a small cuff of tissue attached to the lateral malleolus left to repair the imbricated ligament. Alternatively, the ATFL and capsule can be transected directly off the bone and repaired into a trough or through drill holes (Figs. 50.8 and 50.9).

The CFL can be identified by retracting the peroneal tendons below the fibula. From its origin on the distal fibula, the CFL runs posteriorly and inferiorly to insert on the calcaneus. If it appears stretched, it can be divided and imbricated. The CFL can also be completely avulsed and its loose end found anteriorly to the peroneals. If this is the case and it is avulsed from the calcaneus, it can be repaired with suture anchors. A fibular avulsion of the CFL can be repaired through drill holes or with an anchor. We prefer bioabsorbable anchors that avoid later imaging or hardware removal problems as well as difficulties with drill holes for future reconstructions.

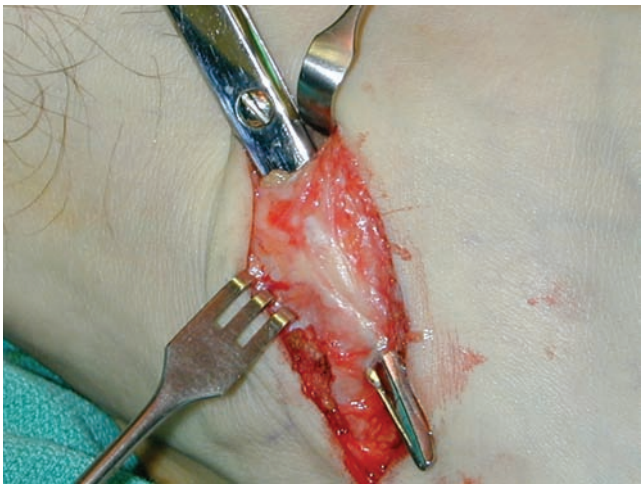

FIGURE 50.7

The capsule is identified with the lax ATFL fibers running within the anterolateral capsule.

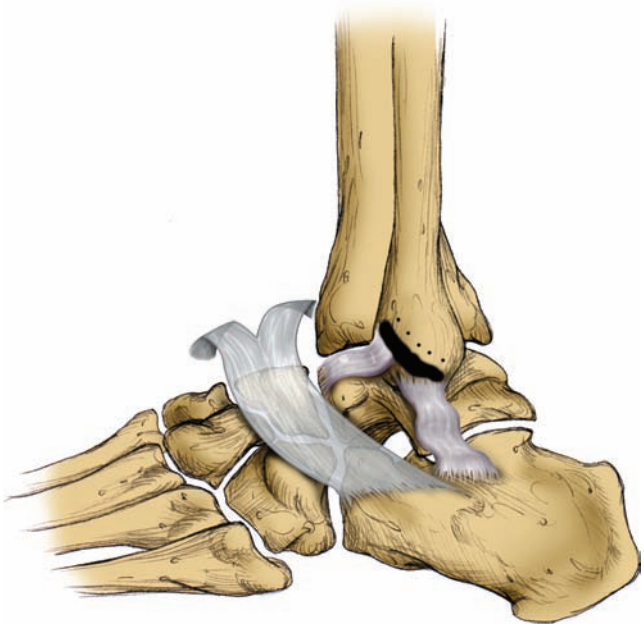

FIGURE 50.8

The ATFL and capsule are then divided with a small cuff of tissue attached to the lateral malleolus left to repair the imbricated ligament.

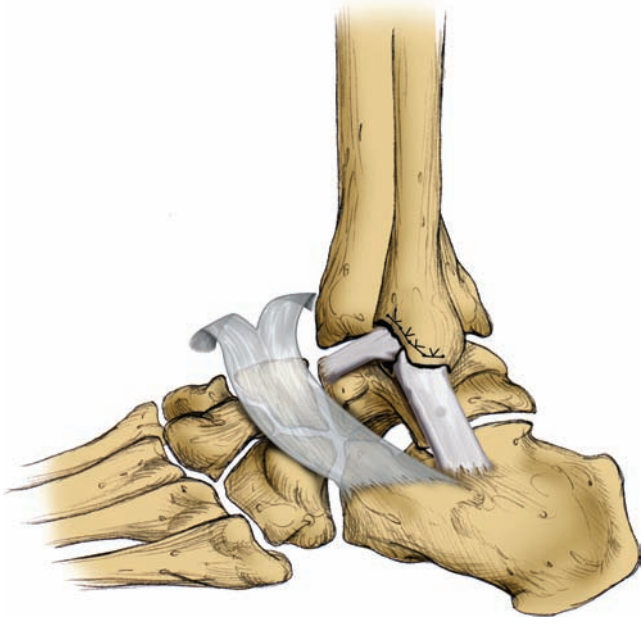

FIGURE 50.9

Alternatively, the ATFL and capsule can be transected directly off the bone and repaired into a trough or through drill holes.

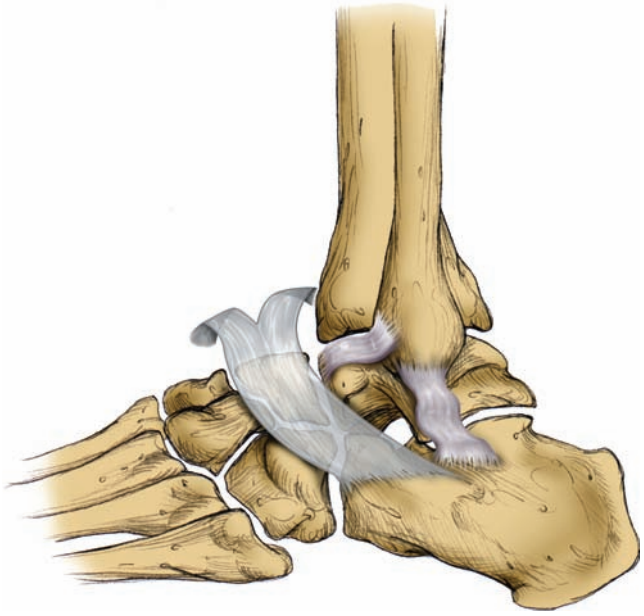

FIGURE 50.10

The ligaments are repaired in an isometric, anatomic position preserving a normal range of motion.

The ligaments are repaired in an isometric, anatomic position preserving a normal range of motion (Figs. 50.10 and 50.11). After the ligaments are sutured, redundant tissue can be excised or used as reinforcement over the substance of the repair. The CFL should be repaired first, since it is the more difficult to visualize. There are many ways to repair the ligaments, including end to end, into a trough created in the fibula, through drill holes, or using suture anchors. Regardless of the method chosen, the ankle must be in the reduced position of neutral dorsiflexion and slight eversion while tensioning the repairs of the ligaments. Placing a small stack of towels under the distal tibia allows the heel to float freely in order to avoid anterior displacement of the ankle during repair.

The previously identified extensor retinaculum can then be imbricated or sutured over the ATFL repair with absorbable sutures to the periosteum of the distal fibula (20) (Fig. 50.12). This reinforces the primary repair. The stability of the ankle is carefully examined and the incision is closed in layers. The patient is sent home in a walking boot or splint and allowed to weight bear with crutches until the first postoperative visit.

Some authors advocate augmenting the modified Broström with an Evans procedure (modified Broström-Evans) in particular cases such as revision surgery, obesity, laborers, neurogenic conditions, peroneal dysfunction, or large athletes (19). To date, there have been no studies comparing the modified Broström with combined Broström and augmentation procedures. Due to inadequate local tissues, a revision procedure may require a reconstruction of the lateral ligaments with autograft or allograft tendon. Several methods for reconstruction have been described and numerous options for graft fixation exist (30,11). The ultimate goal is a functionally stable ankle in the athlete with speedy return to sport.

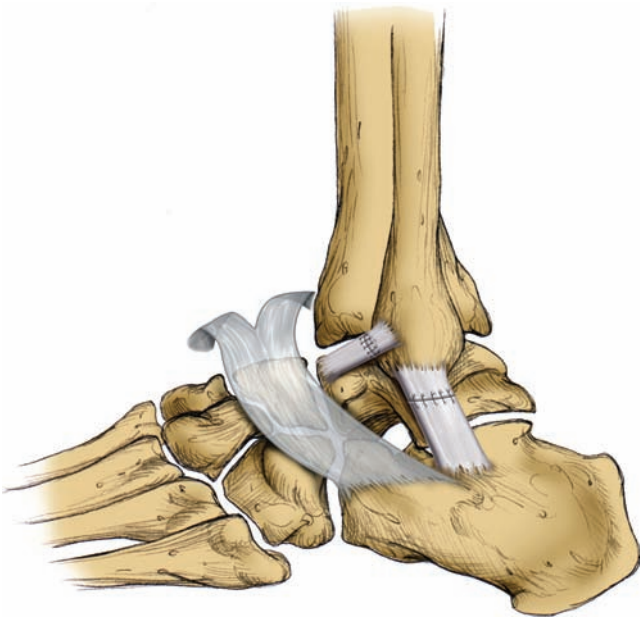

FIGURE 50.11

The ligaments are repaired in an isometric, anatomic position preserving a normal range of motion.

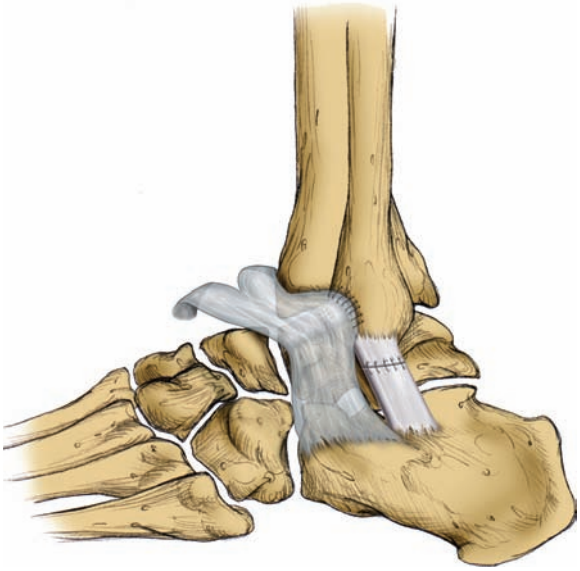

FIGURE 50.12

The previously identified extensor retinaculum can then be imbricated or sutured over the ATFL repair with absorbable sutures to the periosteum of the distal fibula.

Patients undergoing lateral ankle ligament secondary repair have a high incidence of associated intra-articular pathology (24,32). Ankle arthroscopy is a useful adjunct to lateral ligament repair as it allows evaluation and treatment of the full spectrum of concomitant intra-articular pathology (13). Loose bodies, synovitis, impingement, osteochondral lesions, and osteophytes can all be addressed with arthroscopy at the time of surgery. The procedure has the disadvantage of fluid extravasation into the soft tissues, making dissection more challenging when trying to find and repair torn lateral ligaments that are contiguous with the capsule.

POSTOPERATIVE MANAGEMENT

A short leg walking boot or cast that maintains the foot in neutral dorsiflexion and slight eversion allows the athlete to bear weight as tolerated. The immobilization is discontinued at 3 to 4 weeks and an air stirrup is used. At the first dressing change 7 to 10 days after surgery, gentle active dorsiflexion and eversion are instituted. Active inversion is started at 4 weeks along with Achilles stretching. At 4 to 6 weeks post-op, swimming exercises, proprioception training, and resistance training with rubber tubing begin.

The athlete is gradually transitioned from walking to straight line running. In the absence of pain or swelling, figure-of-eights and cutting exercises can be brought into the rehabilitation program, followed by sport-specific rehabilitation activities. When these activities can be performed, the athlete is allowed to return to their sport. This can take 4 to 6 months. The athlete is advised to use a protective brace or taping for the first 6 months after resuming competition.

RESULTS

The modified Broström procedure has stood the test of time. Hamilton reported 93% successful results after surgical repair of the lateral ankle ligaments, with athletes and dancers returning to previous competitive levels (21). Review studies of the modified Broström typically show an 85% to 95% success rate (2). Biomechanical studies have shown ligamentous force patterns most similar to normal ligaments after Broström repair as compared to nonanatomical tenodesis procedures (1). Long-term studies comparing anatomic reconstruction with tenodesis have shown inferior results in functional and mechanical stability and overall patient satisfaction with tenodesis procedures (26). Additionally, compared with nonanatomic techniques, the Broström repair has shown less evidence of osteoarthritis 15 to 30 years after surgery (25). Other studies have cited a higher complication rate and nerve injury with nonanatomic procedures (22,23) and greater restraint to anterior talar translation and talar tilt with anatomic repairs (28).

COMPLICATIONS

Nerve injury, although rare, is the most common complication of secondary lateral ankle ligament repair. Hypersensitivity or hyposensitivity has an incidence of 7% to 19%. Most of these occur in tenodesis procedures, with the sural nerve at the highest risk. The superficial peroneal nerve can be harmed with an incision either too proximal on the fibula or distally over the dorsum of the foot. The sural nerve also can be injured if the incision extends too far beyond the margin of the peroneal tendons. Delayed wound healing, deep infection, stiffness, and DVT have also been reported (29).

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51 Posterior Tibial Tendon Release and Stabilization

Mollie Manley, Alex Kline, and Dane Wukich

Posterior tibial tendon dysfunction (PTTD) is a relatively common problem of middle-aged adults; however, it is relatively uncommon in younger adults, adolescents, and athletes (1–4). Awareness of the condition and early diagnosis are important to prevent disability and prolonged time away from sports. Rupture of the posterior tibial tendon (PTT) results in a progressive, painful flatfoot deformity as it progresses through well-defined stages. Unlike the Achilles tendon, the PTT does not typically undergo acute rupture, and the orthopaedic literature regarding treatment in athletes and young adults is based on small case series or case reports (5–7). Idiopathic inflammation and rupture of the PTT can be a manifestation of seronegative inflammatory disease, especially when PTTD presents in younger patients (8).

ANATOMY

The tibialis posterior (PT) muscle originates proximally on the posterior surface of the tibia, fibula, and interosseous membrane. The muscle is contained in the deep posterior compartment of the leg and transitions to tendon in the distal third of the leg. The tendon passes directly posterior to the medial malleolus where the course becomes more horizontal. This is the most anterior of the three flexor tendons posterior to the medial malleolus, the other two being the flexor digitorum and flexor hallucis longus (FHL). The PTT has a broad insertion on the plantar aspect of the foot with its major insertion point attaching to the inferior navicular. Other sites of attachment are the bases of the second, third, and fourth metatarsals, all three cuneiforms and the sustentaculum tali. The PT is innervated by nerve roots L5, S1 forming the tibial nerve. The posterior tibial artery provides the blood supply; however, there is a zone of hypovascularity in the tendon approximately 4 cm from its insertion (9).

BIOMECHANICS

The primary actions of the PT are plantar flexion of the ankle and inversion of the subtalar joint. It is also vital to maintaining the integrity of the longitudinal arch. During heel strike and the flatfoot phase of the gait cycle, the subtalar joint is everted and the transverse tarsal joint is flexible. This allows the foot to adapt to the contour of the terrain, especially during heel strike. During the midstance phase of gait, the PT inverts the hindfoot, thus locking the transverse tarsal joints. This action brings the foot into neutral position of the hindfoot and increases its mechanical advantage for the toe off phase of gait. The PT controls the mobility of the transverse tarsal joints (i.e., talonavicular and calcaneocuboid) locking these joints prior to heel rise. At the beginning of toe off phase, the transverse tarsal joint becomes rigid and the subtalar joint is inverted. The rigidly inverted hindfoot and tension of the plantar fascia convert the longitudinal arch into a rigid lever to aid in toe off. The PT is also a structure that helps to maintain this arch (10). Large demands are placed on the tendon during high impact activities and running, especially in patients with a pronated foot. The peroneal tendons are the primary antagonists to inversion force and the tibialis anterior tendon antagonizes plantar flexion force.

INJURIES

Sports related injuries to the TP tendon include those injuries common to athletics in general such as complete or partial ruptures, tenosynovitis, and overuse syndrome. Anterior dislocation of the TP superficial to the medial malleolus can occur with inversion and dorsiflexion of the foot; however, this is relatively rare (11). Patients with preexisting flatfoot deformity and hindfoot valgus are at increased risk of developing PTTD during athletic activities. Patients with tenosynovitis are typically women in their 40s to 60s with careers that require prolonged standing. They complain of pain and weakness that are increased with activity and decreased with rest and anti-inflammatory medication. Most patients with tendon rupture have a previous history of tenosynovitis, usually without a specific history of trauma. These patients develop insidious deformity, resulting in hindfoot valgus and abduction of the forefoot on the midfoot (Fig. 51.1). Patients with a ruptured PT initially complain of pain that begins medially between the navicular and the medial malleolus but eventually develop lateral pain in the region of the sinus tarsi (12). The lateral pain is due to the valgus position of the hindfoot with the calcaneus abutting the fibula, also known as subfibular impingement. Os subtibiale is a rare but reported cause of PTT dysfunction. The os subtibiale, an anatomic bony variant near the tip of the medial malleolus, can impinge the PTT in dorsiflexion and eversion (13). Magnetic resonance imaging studies have demonstrated longitudinal tears and inflammation from the os subtibiale impinging on the PTT (Fig. 51.2).

PTT pathology in adolescents and athletes is rarely discussed in the literature. Tenosynovitis and tendon laceration are the most common pathologies in these groups (2–4). Direct penetrating injury is almost always the cause of tendon rupture in this young group of patients, which is a distinction from adult disorders (14) (Fig. 51.3). A case reported by Jacoby describes an athlete without direct medial laceration who sustained an ankle sprain. Two weeks later while training under unusually high loads, the patient experienced another twisting injury to his ankle causing rupture of the PTT (15). Masterson et al. reported on three young patients who developed unilateral pes planus after old undiagnosed lacerations of the tendon. Transfer of the FHL to the distal stump of the tibialis posterior tendon achieved good results in all three cases (4). Brodsky et al. (3) reported on two teenagers who experienced closed posterior tears during athletic activities. Both patients were able to resume normal athletic activities after reconstruction using the flexor digitorum longus (FDL) tendon.

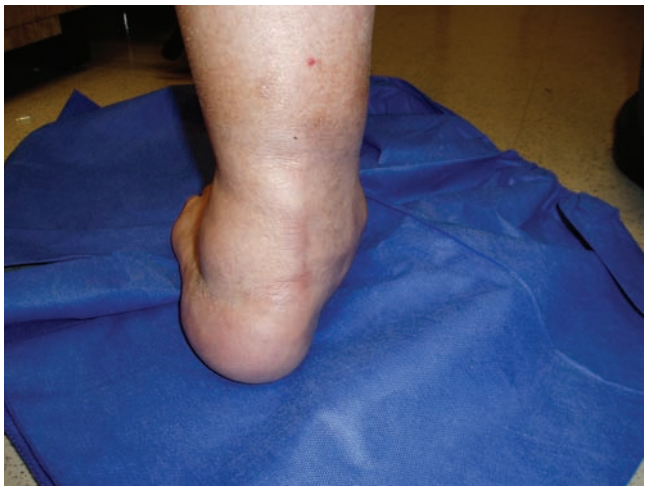

FIGURE 51.1
Hindfoot valgus.

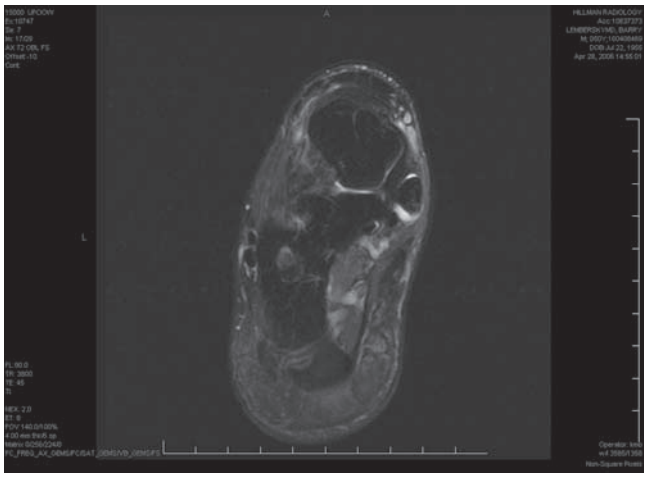

FIGURE 51.2
Magnetic resonance imaging study.

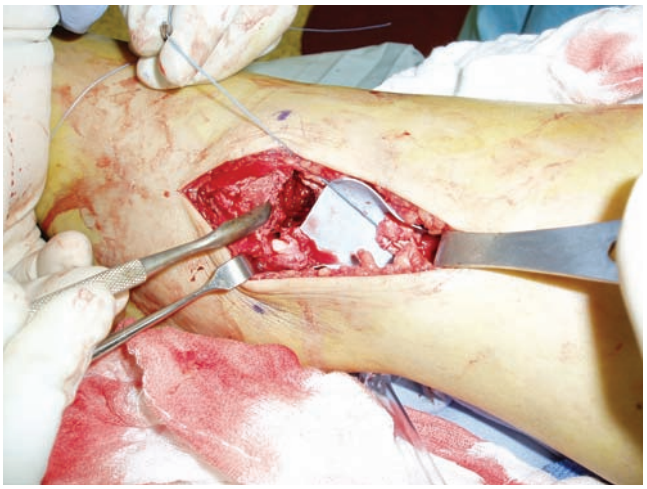

FIGURE 51.3
Direct penetrating laceration.

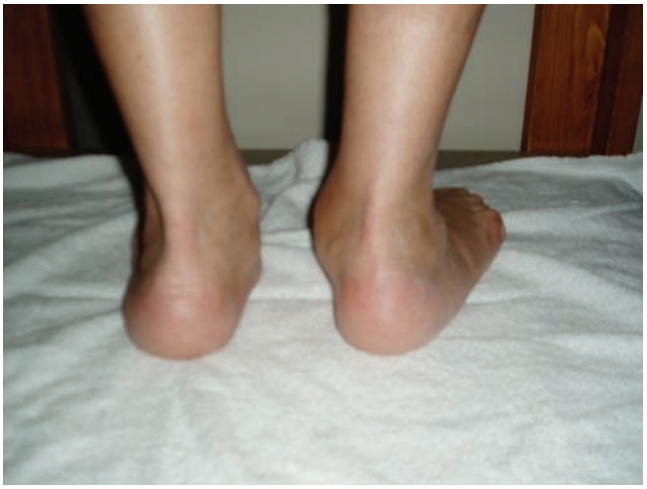

FIGURE 51.4
"Too many toes" sign.

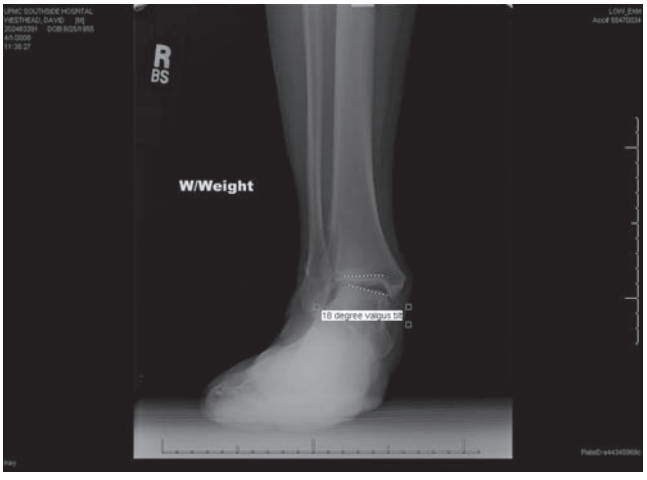

FIGURE 51.5
Stage IV PTTD.

A classification system has been developed by Johnson and Strom to aid in the staging and treatment plan (16). Although it was originally three stages, Myerson expanded this classification to include a fourth (17). Stage I describes a normal alignment of the foot with pain medially around the TP tendon with inflammation. A stage II foot has a flexible hindfoot valgus with a positive "too many toes" sign (Fig. 51.4). An important finding in stage II is the ability to be able to reduce the deformity. These patients complain of weakness and are unable to do a single leg heel raise. Stage III is present when a fixed valgus deformity of the hindfoot occurs. As a result of the hindfoot deformity, the forefoot supinates to maintain a plantigrade foot. Lastly, stage IV has had long-standing PTT insufficiency with associated ankle arthritis (17) (Fig. 51.5).

PHYSICAL EXAMINATION/EVALUATION/IMAGING

Physical examination may reveal swelling and tenderness about the medial malleolus and the course of the PT. Typically, there is an associated flatfoot deformity. The "too many toes" sign is a description of inspecting a patient's foot from a posterior view when standing and observing more toes on the impaired side than the contralateral uninjured side. This is a result of a valgus hindfoot and abducted midfoot. When inspecting the foot from a medial position, a loss of the longitudinal arch can be seen. The heel rise is another test used to evaluate TP function; for this test, the patient attempts to elevate to the ball of the foot from standing on one leg with knee extended. A positive test (i.e., the patient unable to do a single heel rise) is indicative of TP dysfunction since the hindfoot cannot invert and come into varus (Fig. 51.6). Without this varus position, the gastrocnemius muscle is not able to raise the heel off the ground due to a lack of mechanical advantage.

Standard weight-bearing radiographs of ankles and foot should be obtained to assess the dynamic or static bony deformity (18) (Fig. 51.7). Hindfoot alignment or axial calcaneal views are also required to assess the degree of hindfoot valgus (Fig. 51.8). Radiographic changes vary in severity depending on the duration of symptoms. In stage IV disease, dorsolateral peritalar subluxation, increased talo-first metatarsal angle (on ap and lateral of foot), increased tibiotalar tilt, decreased calcaneal pitch, and loss of talar head coverage of the navicular can be demonstrated (17). Tibiotalar angulation measurement originally described by Karlsson (19) is found by drawing a line parallel to the articular surface of the talus and another parallel to the tibial articular surface. Ideally, these lines should be parallel; however, up to 2 degrees is acceptable (20). Meary angle, talo-first metatarsal angle, is measured on the lateral radiograph and directly demonstrates medial column disease. Angle measurements >30 degrees is significant of severe disease and 15 to 30 degrees moderate.

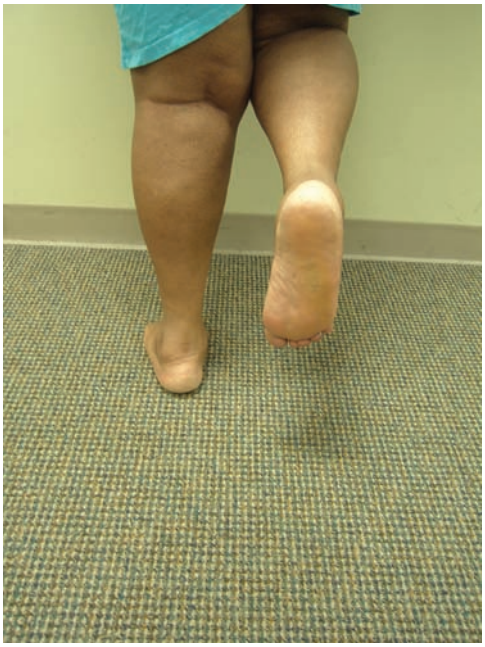

FIGURE 51.6
Heel rise test.

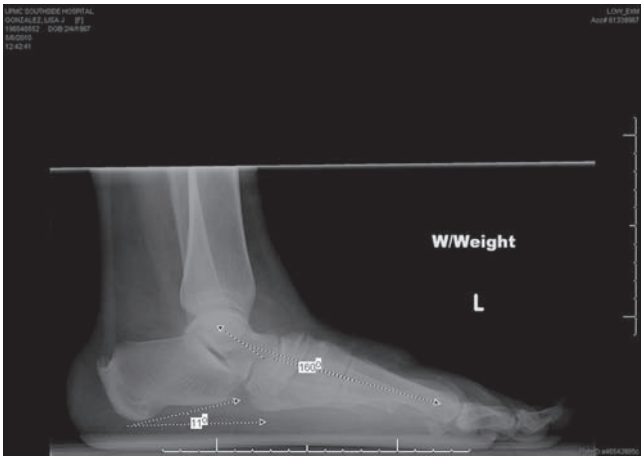

FIGURE 51.7
Standard weight-bearing radiograph of ankle and foot.

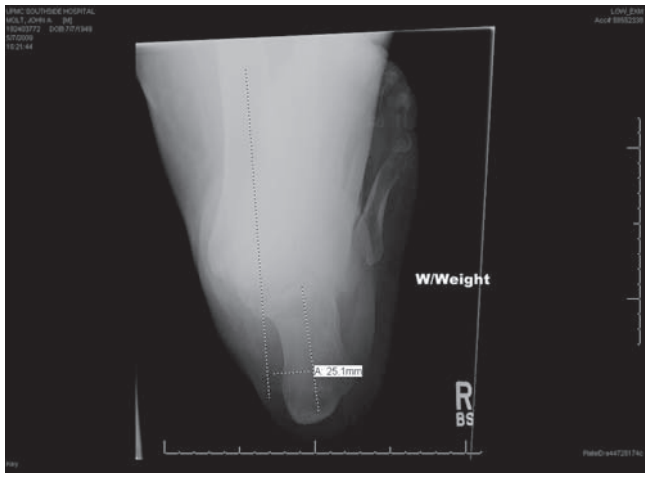

FIGURE 51.8
Hindfoot alignment view.

NONOPERATIVE TREATMENT

Nonoperative treatment can be used with reasonable success in patients with stage I or early stage II disease who have low physical demands or medical problems that preclude undergoing reconstructive surgery (1). Conservative treatment plans begin with an orthosis supporting the medial longitudinal arch. Immobilization for 4 to 6 weeks in short leg cast or cast boot can also be used, followed by a structured exercise program. When bracing a flexible foot, the calcaneus is supported in a neutral position to decrease forefoot abduction. A rigid deformity is braced to accommodate the bony deformity (21). Corticosteroid injections are controversial, because they may lead to increased tendon rupture. If an injection is performed, protection and immobilization in walking boot are recommended for 2 to 3 weeks postinjection.

Orthotics are useful in PTT dysfunction for two reasons, namely to unload the normal ground reactive force of the body and to restore nonanatomic alignment of the foot (22). Three orthotics are used to unload the ground reactive force transmitted through the forefoot: rocker bottom shoes, torque absorbing AFO, and proximal weight-bearing AFO (22). Restoring alignment can be achieved with three-point molded orthotics. In addition to bracing, Alvarez et al. demonstrated that patients with stage I or II PTTD could be treated in orthotics and strengthening the posterior tibial, gastrocnemius, peroneus brevis, and anterior tibial muscles. After roughly 4 months, many patients did not need their orthotic and did quite well (1). Strengthening with eccentric and concentric exercise programs have been used to improve function in PTT dysfunction. When performing eccentric exercises, the muscle groups experience forces that can be 50% higher than during isometric exercises. Kulig et al. reported that patients with early stages of tibialis posterior tendinopathy who participated in a 12-week exercise study benefited from a program of orthotic wear and stretching. Eccentric and concentric progressive resistive exercises further reduced pain and improved perceptions of function (23).

Treatment of stage II PTTD with a double upright ankle foot orthosis has been shown to be a viable alternative to surgery with a high likelihood of adequate function, avoidance of surgery, and being brace-free at 7- to 10-year follow-up (24). It is important to realize that the studies regarding the nonoperative treatment were in patients with traditional adult PTTD. It is not currently unknown whether active young adults or athletes will benefit from nonoperative treatment to the same degree as less active patients.

SURGICAL TREATMENT

Surgical treatment is reserved for those patients who fail a trial of conservative therapy. Much like conservative treatment, surgical procedures vary based on flexibility of the foot. Tendon transfers are a commonly employed procedure in tandem with bony procedures. The ideal tendon for transfer and substitution of the diseased PT functions in the same phase as the PTT, has a similar anatomic course, and provides equivalent strength (25). Unfortunately, none of the available tendons match all three parameters; however, the FHL and FDL have been used successfully. Isolated tendon transfer has provided initial pain relief; however, they ultimately did not fare well with longer periods of follow-up (26,27). Consequently, tendon transfer is typically done in concert with an osseous procedure, such as medial displacement osteotomy of the calcaneus or lateral column lengthening. FDL transfer is currently the most commonly used tendon for stage II PTT dysfunction (26,28,29) (Fig. 51.9). In a gait study by Brodsky, patients who underwent FDL transfer with medial calcaneal osteotomy and spring ligament reconstruction had significant improvement in cadence, velocity, step length, and ankle push-off power compared to preoperative evaluation (30). The procedure consists of a medial incision corresponding to the PTT, and the diseased portion of the tendon is then excised. The FDL is identified and harvested in the

FIGURE 51.9
FDL transfer.

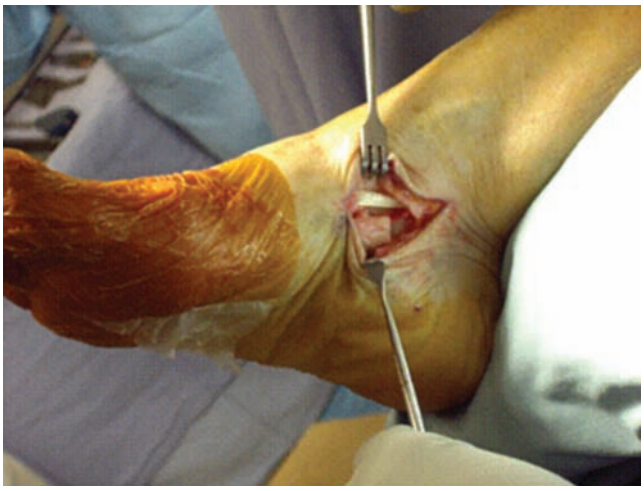

FIGURE 51.10
Post-transfer.

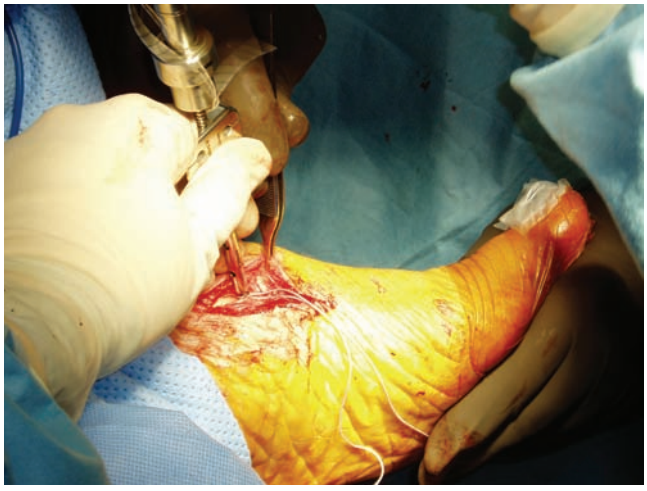

FIGURE 51.11
Biotenodesis screw.

midfoot. Traditionally, the FDL has been amputated distal to the knot of Henry and looped through the medial navicular and sutured back to itself (25) (Fig. 51.10). Recently, utilization of biotenodesis screws has permitted a slightly smaller incision (31) (Fig. 51.11). Although the FDL is most commonly used, its relative strength is only 28% of the PTT, whereas the relative strength of the FHL is 56.3% of the PT (32). A potential problem of using the FDL as a transfer FDL is a resultant intrinsic muscle deficit since the lumbricals attach to the FDL tendons.

Medial displacement osteotomy of the calcaneus is typically performed at a 45-degree angle to the weight-bearing surface. The posterior tuberosity is then displaced medially approximately 1 cm (Fig. 51.12). This

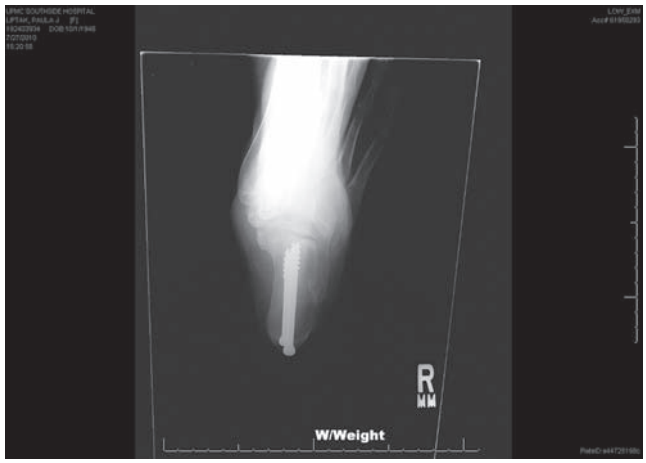

FIGURE 51.12
Hindfoot view after surgery.

osteotomy helps correct hindfoot valgus and restores the normal inversion moment of the Achilles tendon (33). Anterior calcaneal lengthening osteotomy, also known as the Evans procedure, corrects midfoot and forefoot abduction and is also a powerful restorer of the longitudinal arch. Lateral column lengthening can also be performed by a distraction arthrodesis of the calcaneocuboid joint. A recent study suggests that the use of allograft in the lateral column lengthening component of operative correction of adult stage II PTTD appears to be a viable alternative to the use of iliac crest autograft and eliminates the morbidity and increased cost associated with autograft harvest (34). Achilles tendon lengthening and gastrocnemius muscle recession are soft tissue procedures that are commonly used in addition to the bony procedure. Many patients with adult or pediatric flatfoot deformity have associated Achilles tendon or gastrocnemius contracture (28).

Plantar flexion opening wedge osteotomy of the medial cuneiform, known as a Cotton procedure, may be necessary to correct forefoot supination/varus deformity (35). In PTT dysfunction, the Cotton osteotomy is most commonly used in stage II disease. Forefoot supination/varus can also be addressed with arthrodesis of the medial column (naviculocuneiform and first tarsometatarsal joints) (35). In some patients with painful flatfoot, realignment and arthrodesis of the medial naviculocuneiform and first tarsometatarsal joints can be done to correct alignment and relieve symptoms (36,37). Triple arthrodesis is typically reserved for use in rigid deformity, since long-term studies have demonstrated deterioration of adjacent joints. Triple arthrodesis is also indicated when the previous procedures have failed and degenerative changes are found in these joints (28,33,38).

Tenosynovitis, a well-known ailment of the PTT, can also successfully be treated with surgery after failure of conservative therapy. For this débridement of the inflammatory tissue, a medial incision is made and the PTT identified. The tendon sheath is opened, and any areas of stenosis are excised along with the inflamed synovium (14). If patients do not have a planovalgus osseous deformity, then osteotomy is not necessary in this group.

SUMMARY

Disorders of the PTT are more common in older patients, although middle-aged, active patients are susceptible to this problem. Nonoperative treatment can be successful prior to permanent deformation of the tendon. Once elongation or rupture occurs, most patients require surgery to improve pain and function. PTT reconstruction utilizing calcaneal osteotomy and/or lateral column lengthening with FDL transfer can be successful in the higher functioning, younger patients (39).

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52 Peroneal Tendon Injuries

Alex Kline, Mollie Manley, and Dane Wukich

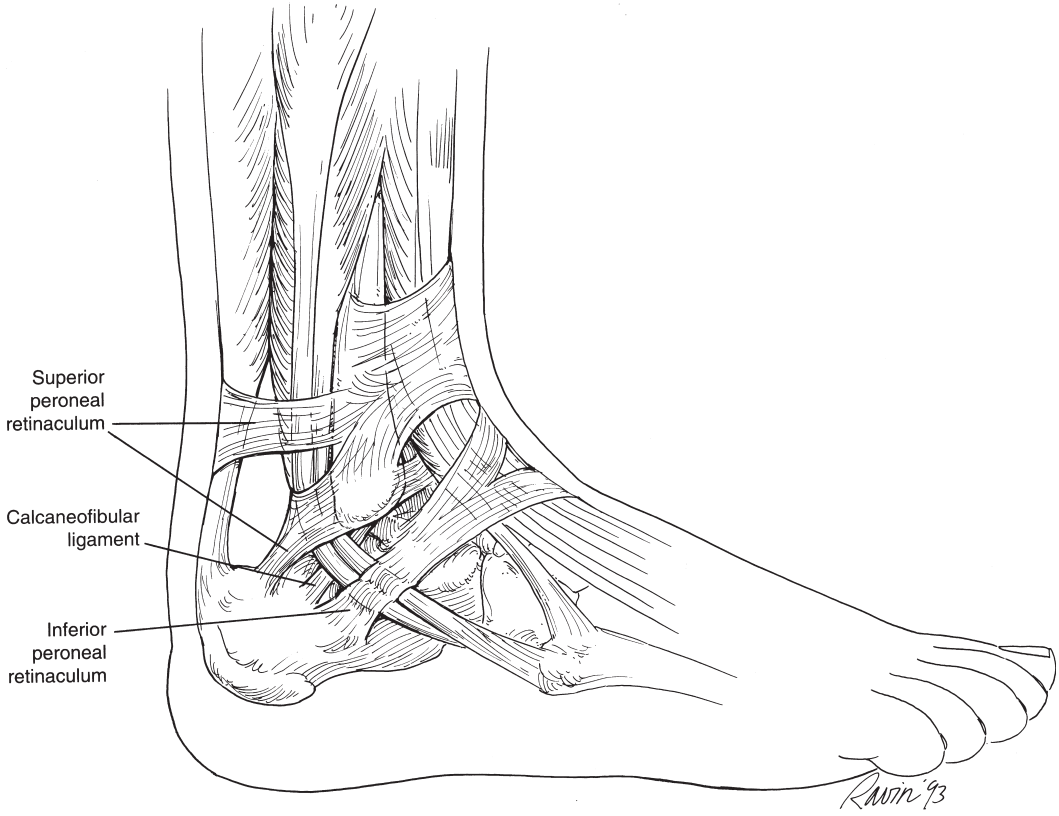
BACKGROUND/ANATOMY

Peroneal tendon disorders are frequently missed and can be a source of lateral ankle pain in athletes (1). Several common pathologies can affect the peroneal tendons in the athletic population, including tendonitis, tears, and instability. The peroneus longus and brevis muscles form the lateral compartment of the leg and are innervated by the superficial peroneal nerve. The peroneus brevis originates from the lateral surface of the middle one third of the fibula and intermuscular septum and inserts at the peroneal tuberosity at the base of the fifth metatarsal. It acts primarily as an everter of the ankle joint and also provides some lateral ankle stability. Its primary antagonist is the tibialis posterior. The peroneus longus originates from the lateral condyle of the proximal tibia and the head and lateral aspect of the fibula. Distal to the tip of the fibula, it crosses the peroneal tubercle and turns sharply to obliquely cross the plantar aspect of the foot, inserting on the plantar aspect of the first metatarsal base. Its primary action is to plantarflex the first ray and also to assist in eversion of the foot. Its primary antagonist is the tibialis anterior. In its muscular portion, the peroneus longus lies posterolateral to the peroneus brevis. At the level of the ankle joint, the longus tendon lies posterior to the peroneus brevis, which hugs the posterior aspect of the fibula (Fig. 52.1).

Approximately 4 cm proximal to the distal end of the fibula, the peroneal tendons enter a common synovial sheath. At the level of an ankle, the tendons course through a fibroosseous tunnel bordered anteriorly by the fibula; medially by the calcaneal fibular ligament, the posterior inferior tibiofibular ligament, and the posterior talofibular ligament; and posterolaterally by the superior peroneal retinaculum. The superior peroneal retinaculum acts as the primary restraint to subluxation and dislocation of the peroneal tendons and is always torn in an acute peroneal tendon dislocation (Fig. 52.2). In the majority of patients, the posterior aspect of the distal fibula forms a recess or groove (the retromalleolar groove), and this concavity deepens the area available for the peroneal tendons. Flattening or convexity of this groove may predispose patients to subluxation and tearing (2) (Fig. 52.3). Approximately 1 cm distal to the tip of the fibula, the peroneal tendons enter distinct synovial sheaths and head to their respective insertion sites.

Several distinct pathologic processes can affect the peroneal tendons in the athletic population. These include tenosynovitis/tendonopathy, tendon tears, tendon subluxation, and ganglion cyst formation (Fig. 52.4). Tendonitis or tenosynovitis of the peroneal tendons involves inflammation within the tendon sheath of either the peroneus longus or peroneus brevis. Generally, it results from prolonged repetitive activity such as that seen with dancers and distance runners. They develop chronic lateral ankle pain, with swelling and tenderness along the course of the involved tendon. This is also commonly seen concomitantly with lateral ankle instability. Subluxation or frank dislocation of the peroneal tendons can occur acutely as the result of athletic endeavors when a sudden dorsiflexion inversion injury of the ankle is sustained with a simultaneous violent peroneal muscle contraction. This generally causes the superior peroneal retinaculum to peel off of its fibular insertion. This has been classically described in the skiing population but also occurs in football, tennis, basketball, soccer, and ice skating.

Longitudinal tendon tears may affect either the peroneus longus or the peroneus brevis (Fig. 52.5). Acute tears in the athletic population generally result from sudden inversion injuries. Theoretical mechanisms of the injury include impingement of the peroneus brevis between the longus tendon and the posterior aspect of the fibula, split tears that occur in the setting of instability as the tendons sublux out of the retromalleolar groove, and a low-lying peroneus brevis that "overstuffs" the retrofibular groove. Peroneus brevis tears tend to occur in the retromalleolar sulcus, while longus tears often occur distal to the tip of the fibula near the peroneal tubercle.



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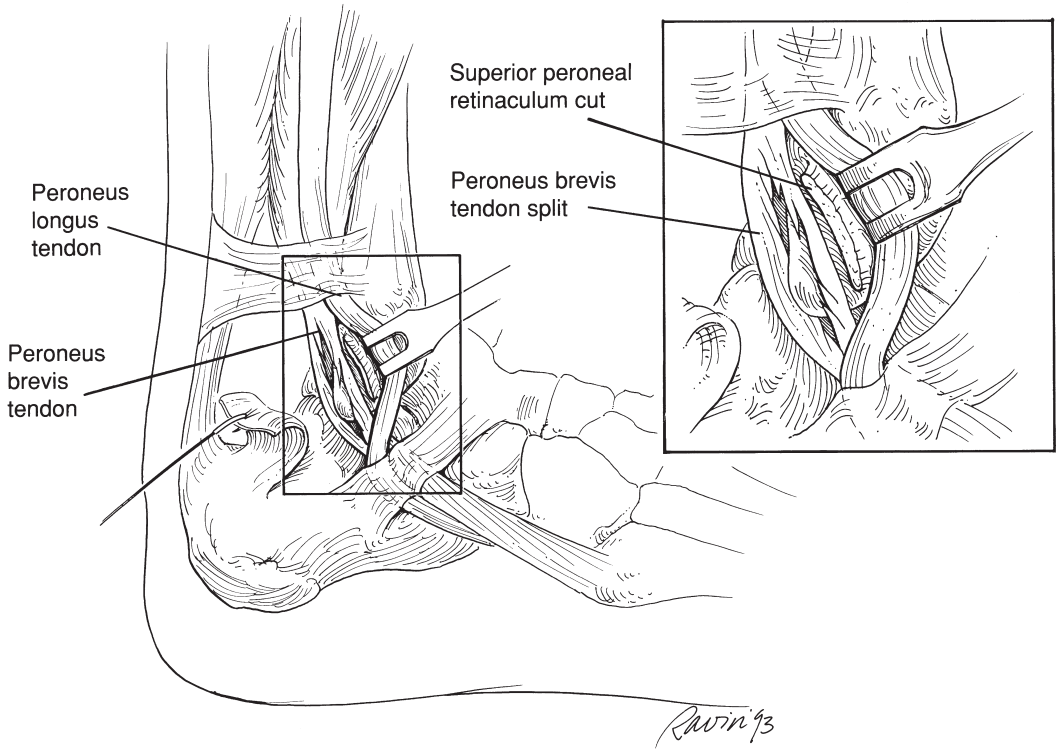


B

FIGURE 52.1

A: Normal anatomy of the tendons and ligaments of the lateral ankle and hindfoot. **B:** Course of the peroneal tendons along the lateral aspect of the ankle and foot. Retraction of the peroneus longus shows the split tear of the peroneus brevis. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle.* 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:294, with permission.)

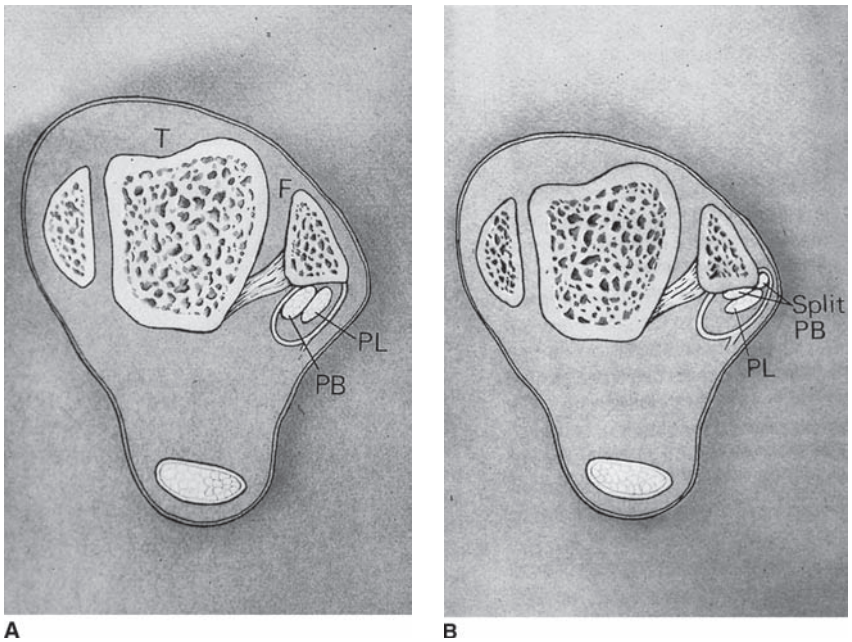


FIGURE 52.2

A: Schematic drawing of normal peroneal anatomy without redundant fascia and pseudopocket. Note the retinacular attachment on the posterior edge of the fibula. **B:** Schematic drawing showing the redundant fascia and pseudopocket that forms with chronic subluxing peroneal tendons. The peroneus brevis usually is caught against the sharp posterior ridge of the fibula. (From Chang TJ. *Master Techniques in Podiatric Surgery: The Foot and Ankle*. Philadelphia, PA: Lippincott Williams & Wilkins, 2005:292.)

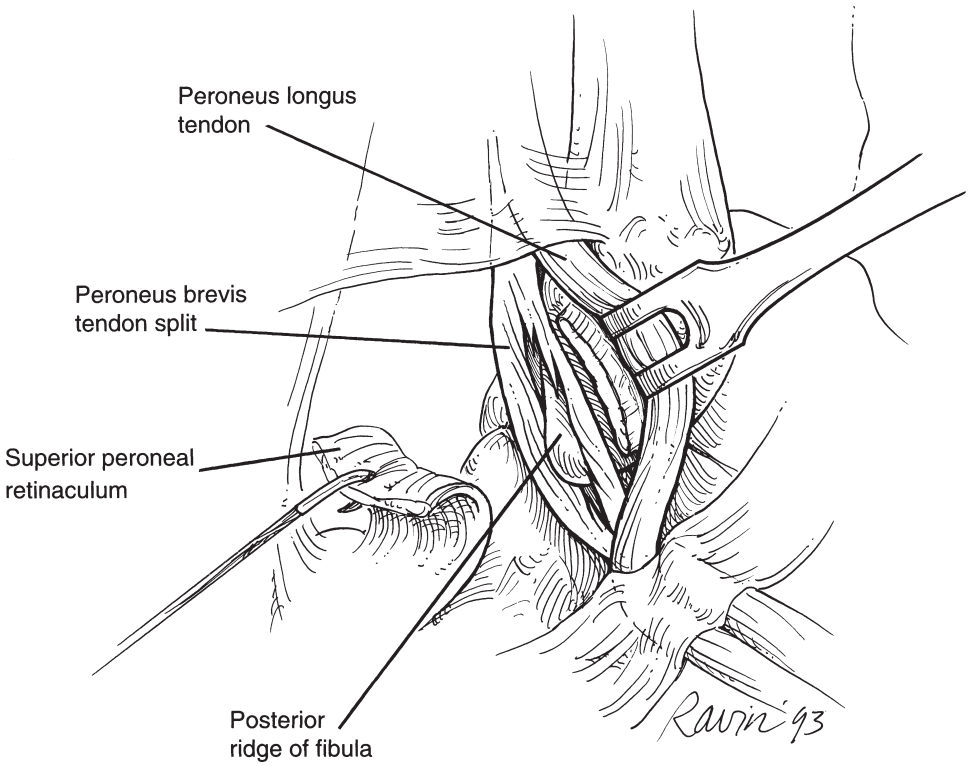


FIGURE 52.3

A: Exposure of the peroneus brevis tendon tear is achieved by retraction of the superior peroneal retinaculum posteriorly and the peroneus longus tendon anteriorly. **B:** Through a posterolateral incision, the retinaculum is incised at the posterior margin of the malleolus, revealing a partial tear of the flattened brevis tendon. **C:** A closer view shows dislocation of the anterior third of the brevis tendon over the fibro-osseous ridge of the lateral malleolus. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:298, with permission.)

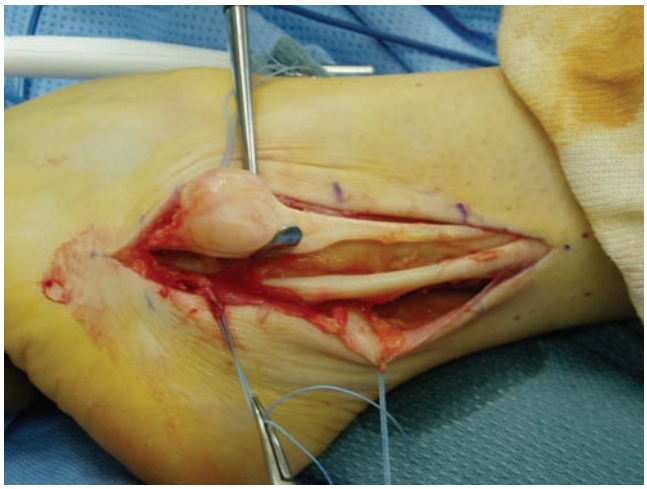


FIGURE 52.4

Ganglion cyst formation from torn tendon.

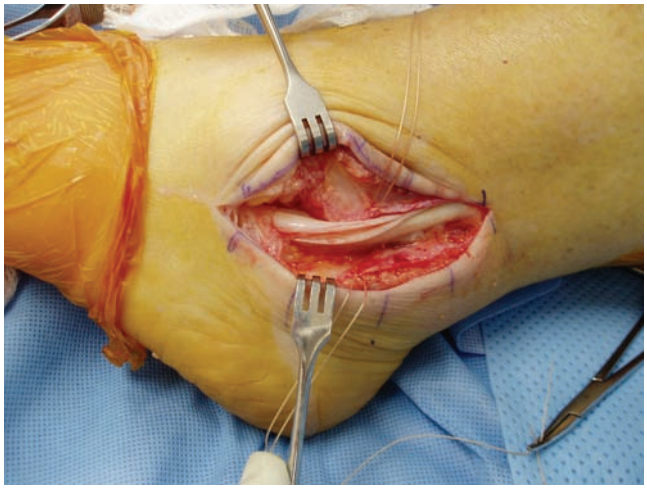


FIGURE 52.5

Longitudinal tear of the peroneus brevis.

PREOPERATIVE EVALUATION

A detailed history and physical examination are the cornerstone of diagnosing peroneal tendon injuries in the athlete. Specific questions should focus on the mechanism of injury, the chronicity of the injury, and the sport that the athlete is involved in. The specific symptoms the patient is experiencing are important, as is what seems to aggravate or alleviate the symptoms. It is also important to ask about any systemic diseases that could predispose the patient to tendon disorders, including diabetes, psoriatic arthritis, or rheumatoid arthritis. The differential diagnosis of the athlete with a lateral-sided ankle injury is broad. This would include acute or stress fractures of the lateral malleolus, base of the fifth metatarsal, the anterior process of the calcaneus, or cuboid. Additionally, acute ankle sprains or chronic ankle instability can either mimic or coexist with peroneal tendon pathology. Other potential causes of lateral-sided ankle pain in the athlete include osteochondral lesions of the talus, tarsal coalition, sinus tarsi syndrome, and degenerative joint disease.

A complete physical examination of the entire ankle and foot should be completed. Any areas of swelling, warmth, or tenderness to palpation should be carefully correlated with the underlying anatomy. It is important to note the position of the hindfoot, as even a subtle cavovarus hindfoot can lead to lateral column overload and a propensity for peroneal tendon injuries (Fig. 52.6). Focused examination of the peroneal tendons should include palpation along the entire course of the tendons. Pain with resisted active eversion/dorsiflexion may suggest peroneal pathology. Additionally, clicking, snapping, or crepitus with resisted movement may suggest tendon subluxation. As the patient ambulates, it is important to note any visual evidence of tendon subluxation. As peroneal tendon pathology often coexists with ankle instability, a full evaluation of the lateral ankle liga-

FIGURE 52.6

Peek a boo sign indicating hindfoot varus: Notice the visibility of the medial aspect of the calcaneus which is usually not visible.

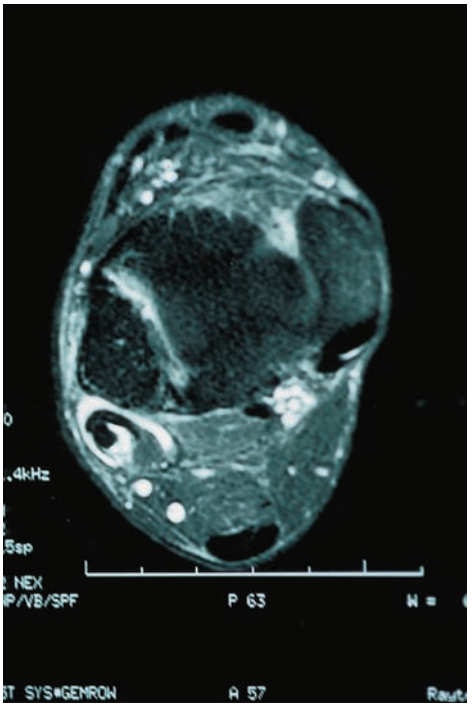


FIGURE 52.7

Example of a MRI for evaluation of peroneal pathology. Significant inflammation is noted within the peroneal sheath with flattening of the brevis tendon. The transverse slices are usually the most useful, but sagittal plane slices also can capture longitudinal tears and tendon inflammation. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:493, with permission.)

ments including talar tilt and drawer testing should be performed. A complete neurovascular examination of the foot should be undertaken, looking closely for any subtle peroneal weakness.

Initial imaging studies should consist of a full series of plain radiographs of the foot and ankle. Anteroposterior, lateral, and mortise views of the ankle and anteroposterior, lateral, and oblique views of the foot should be closely examined for any boney abnormality. Plain radiographs may also demonstrate subtle cavovarus deformity such as double talar dome sign (see radiograph). In addition to examination for any fractures, a small avulsion off of the lateral cortical border of the distal fibula should heighten the suspicion of a superior peroneal retinacular injury. In some instances, other radiographic views may be useful. If there is a concern for ligament injury, stress radiographs of the ankle may be helpful. Additionally, the hindfoot alignment films may be of use in patients with cavovarus deformity.

Magnetic resonance imaging (MRI) remains the gold standard when advanced imaging is required for the evaluation of peroneal tendon disorders (3,4). Axial cuts with the ankle in slight plantar flexion allow for the best tendon visualization. Tendonitis can be seen as fluid surrounding the tendons within the sheath or edema within the tendons (Fig. 52.7). Frank tears may be seen either directly or as increased signal within the tendon

on T2 imaging sequences. Longitudinal tears of the peroneus brevis may show a clear longitudinal tear and an apparent doubling of the brevis tendon against the posterior aspect of the fibula. Additionally, MRI can be used to evaluate for associated lateral ligamentous injuries of the ankle and for any associated bony pathology including osteochondral lesions or fractures associated with superior peroneal retinacular disruption.

Recently, ultrasound has become increasingly popular in the evaluation of peroneal tendon disorders at some centers. This can reveal fluid around the tendons, thickening of the tendon, and partial tendon ruptures. Dynamic ultrasound also may be a useful adjunct, as it can give a real-time view of peroneal tendon subluxation (5). Overall, ultrasound has a steep learning curve and remains very operator dependent.

NONOPERATIVE MANAGEMENT

In most cases of peroneal tendonitis, initial nonoperative management is appropriate. However, in the high-level athlete with a peroneal tendon tear or traumatic subluxation, surgical intervention should be considered early secondary to a very high failure rate of conservative management (1). Mainstays of nonoperative treatment include nonsteroidal anti-inflammatory medications, rest, and activity modifications. In patients with hindfoot varus heel position, orthotics with a lateral heel wedge may be beneficial to correct the deformity and unload the lateral side of the foot. In patients who fail to respond to initial nonoperative measures, a trial of immobilization with either a short leg walking cast or a CAM walker boot is appropriate. It is our general recommendation not to inject around the peroneal tendons, to avoid the potential complication of tendon rupture.

OPERATIVE MANAGEMENT

For refractory cases of peroneal tendonitis that are not relieved by conservative measures, as well as in cases of peroneal tendon tears or subluxation in the athlete, surgical intervention is warranted. A specific surgical plan should be tailored to each individual patient depending on the specific pathology. Anesthesia may be performed with either general or regional anesthesia. A thigh tourniquet may be placed. The patient may be placed either in a full lateral or "sloppy lateral" utilizing a sandbag or a large bump under the ipsilateral hip. A lateral curvilinear incision is made just posterior to the fibular border (Fig. 52.8). This starts approximately

FIGURE 52.8

A lateral skin incision is used for peroneal repair and reconstruction. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:297, with permission.)

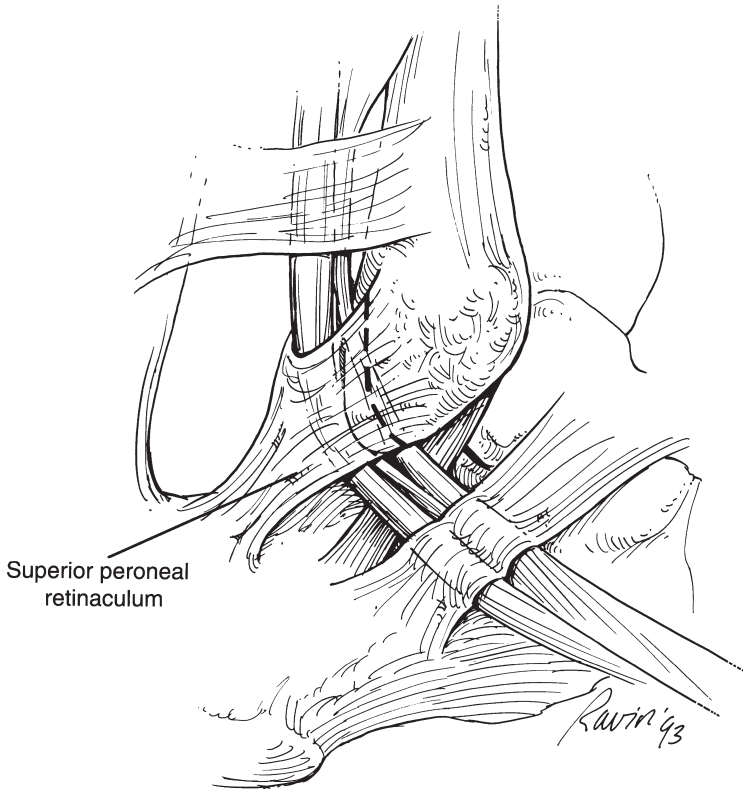


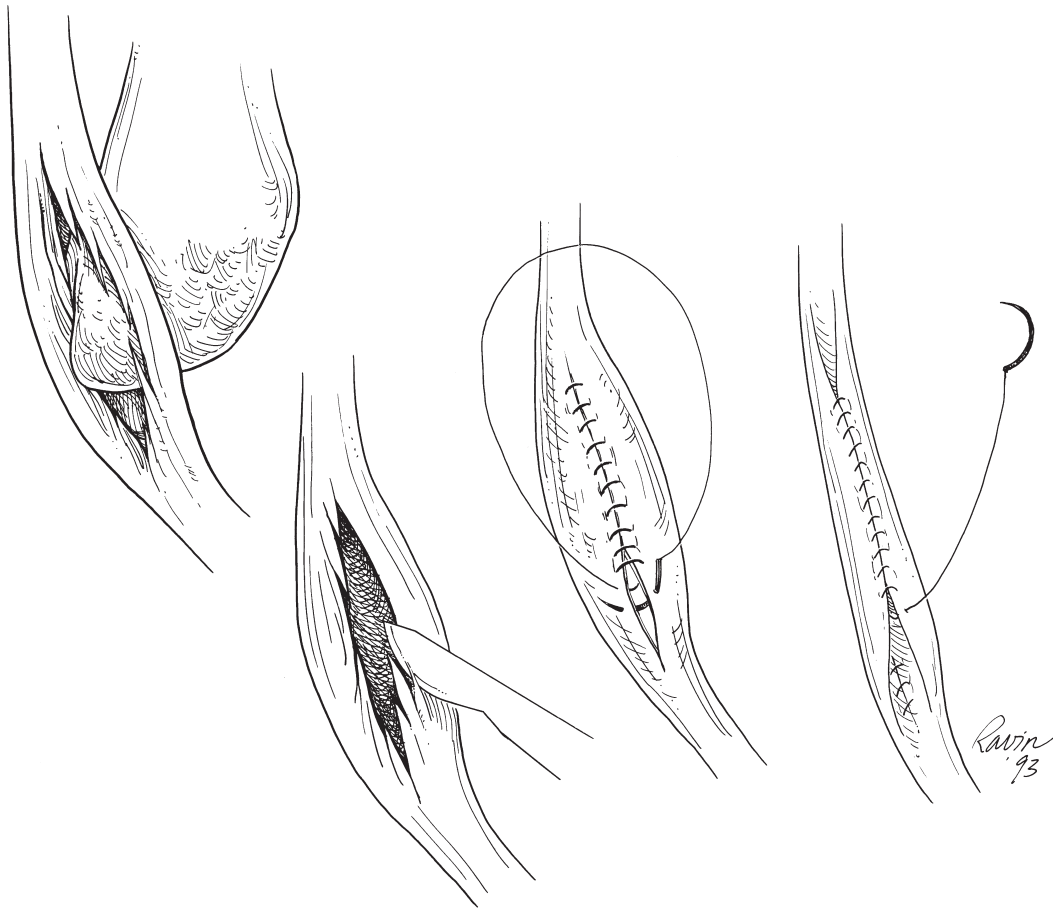
FIGURE 52.9

The retinaculum is incised close to the border of the fibula. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:298, with permission.)

4 to 5 cm proximal to the tip of the fibula and extends distally approximately 2 cm beyond the tip of the fibula toward the base of the fifth metatarsal along the peroneal tendon course. Depending on the exact pathology, only a portion of this incision may be required. Full-thickness flaps should be created, and care should be taken to avoid the sural nerve, particularly distally where it generally crosses over the peroneal tendons. In cases of acute traumatic tendon subluxation, this will have already been torn away from the posterolateral border of the fibula and a hemorrhage may be present. Chronic tendon subluxation may demonstrate a false pouch superficial to the lateral aspect of the distal fibula.

The superior peroneal retinaculum should be incised close to the fibular border, taking care to leave a sleeve of tissue to allow for reattachment. We prefer to leave at least 4 mm to allow for a primary repair on closure (Fig. 52.9). Subsequently, the sheath surrounding the peroneal tendons should be incised close to the posterior border of the fibula. Note should be made of any fluid within the sheath, and any tenosynovitis should be thoroughly débrided. The peroneal tendons may now be subluxed out of their sheath and should be meticulously inspected. Any evidence of tendon degradation, fraying, or longitudinal tearing should be identified and addressed. In general, tendon tears involving <50% of the tendon should be treated with débridement of the poor tissue involving the tear and subsequent tubularization of the remaining healthy tendon. We perform tubularization with a running 4-0 vicryl suture (Fig. 52.10). In cases of extensive degeneration involving >50% of the tendon, consideration should be given for tenodesis of the brevis tendon to the longus both proximally and distally, with excision of the degenerated segment. Any low-lying muscle bellies should be resected. If present, accessory muscles or low-lying muscle belly may be also excised to reduce crowding of the peroneal sheath (Fig. 52.11).

In cases of peroneal tendon dislocation, careful attention must be paid to the chronicity of the injury and the patients' individual morphology. Strategies to address peroneal dislocation include direct repair of the superior peroneal retinaculum, reconstruction of the peroneal retinaculum, rerouting procedures, groove deepening procedures, and bone block procedures (2,6). In the athlete with an acute peroneal dislocation, it is our preference to perform a primary repair of the superior peroneal retinaculum when at all possible. We utilize a small rongeur and rasp to roughen the surface of the posterolateral fibula. Subsequently, two small suture



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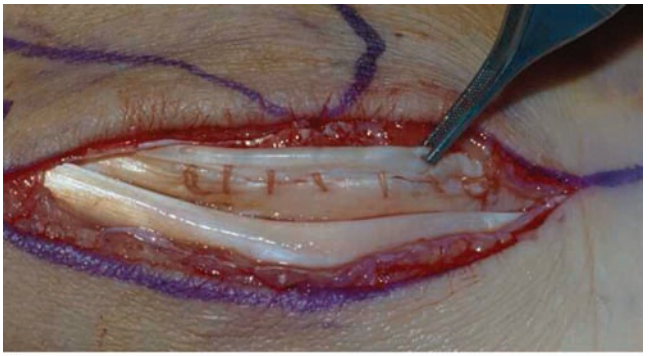

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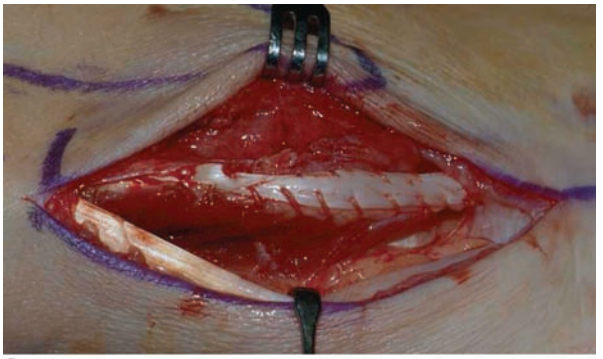

C

FIGURE 52.10

A: Dèbridement and repair of the peroneus brevis tendon and tubulation. Approximately one half of the anterior portion of the peroneus brevis tendon can be resected. **B:** Intraoperative photograph after resection of the degenerated one third of the tendon and tubulation with running suture. **C:** Closer view of the repaired tendon. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:300–301, with permission.)

anchors or sutures passed through drill holes are directed obliquely into the posterolateral fibula (Fig. 52.12). Utilizing a horizontal mattress-type stitch, the superior peroneal retinaculum is securely reattached to the fibula. Subsequently, any cuff of residual tissue on the posterior fibula is also incorporated into the repair for extra security.

Postoperatively, we place the patient into a non–weight-bearing cast for 2 weeks to allow for soft tissue and incisional healing. Subsequently, the patient is placed into a removable CAM walker boot for another month and can resume weight bearing as tolerated in the boot. At 3 to 4 weeks, we allow removing the boot for passive and active assisted range of motion of the ankle and foot to prevent stiffness. After 4 to 6

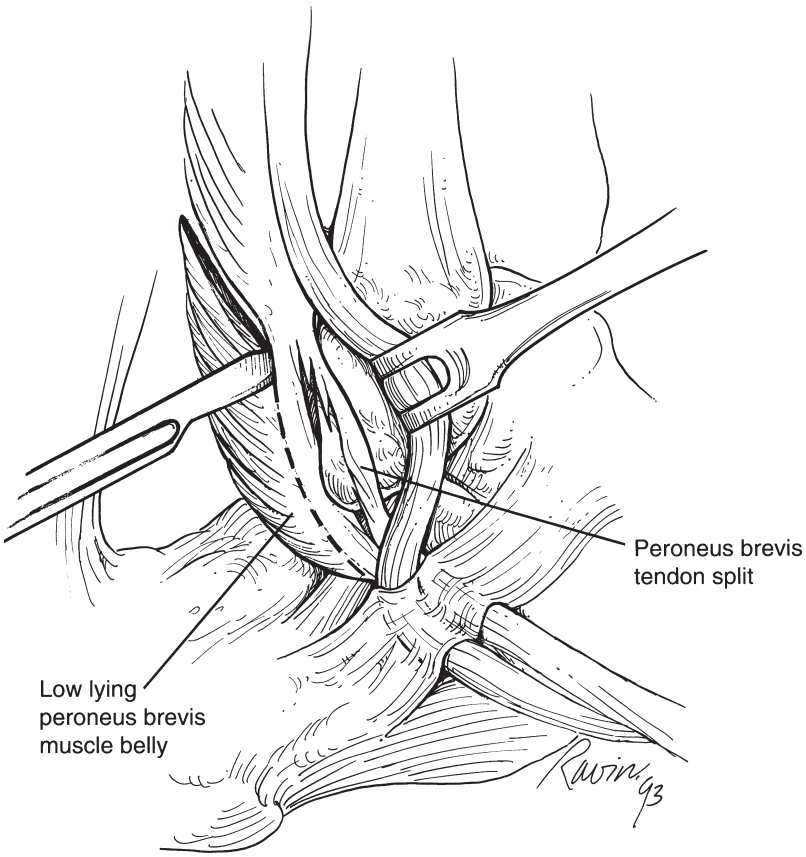

FIGURE 52.11

An abnormally low-lying portion of the muscle belly of the peroneus brevis should be resected. (From Kitaoka HB. *Master Techniques in Orthopaedic Surgery: The Foot and Ankle*. 2nd Ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002:302, with permission.)

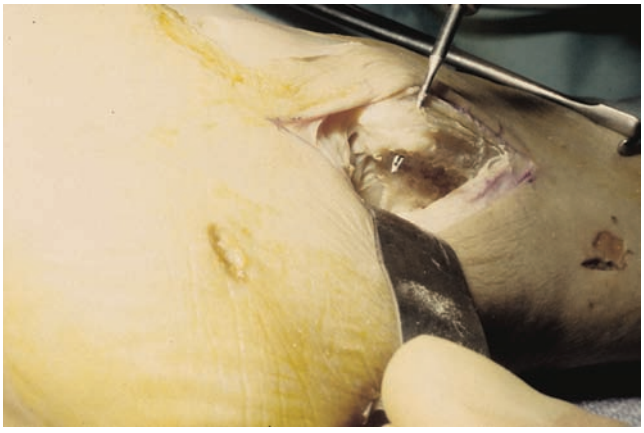

FIGURE 52.12

A wire pass drill being used on the posterior fibular ridge to secure the superior peroneal retinaculum with suture. Be careful not to fracture the drill holes by drilling too close to the edge. (From Chang TJ. *Master Techniques in Podiatric Surgery: The Foot and Ankle*. Philadelphia, PA: Lippincott Williams & Wilkins, 2005:495.)

weeks, the boot may be removed and physical therapy may be gradually advanced. In general, the return to athletics will require 3 to 6 months. A recent report indicated that a substantial number of patients had residual symptoms, including scar tenderness (58%) and lateral ankle swelling (54%). Only 46% were able to successfully return to sports. Although operative treatment was very effective in allowing these patients to return to work, only half of the patients were able to return to sports at an average follow-up of 31 months (7). Another author reported that groove deepening and peroneal reconstruction were reliable for preventing recurrent peroneal tendon instability. All patients returned to daily activities and sports within 3 months of surgery (2).

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53 Achilles Tendon Repair

James D. Granata and Jason Calhoun

The Achilles tendon is the most commonly ruptured tendon of the lower extremity (5,7), with an overall incidence of 18 per 100,000 people (1,11,18). Middle-aged recreational athletes are particularly susceptible, accounting for 40% of all surgical repairs (4,18). The majority of ruptures are indirect injuries that occur during sports and recreational activities involving rapid acceleration and deceleration movements at the ankle.

The tendons of the gastrocnemius and soleus muscles, collectively known as the triceps surae, combine to form the Achilles tendon. The combined tendon rotates 90 degrees from proximal to distal, with the medial fibers rotating posteriorly, and the posterior fibers rotating laterally (16). The tendon is extrasynovial and receives its blood supply from three different sources: the paratenon, the musculotendinous junction proximally, and the osseotendinous junction distally. This leaves the central portion of the tendon the least vascularized. The majority of Achilles tendon ruptures are midsubstance tears within this relatively avascular zone, 2 to 6 cm proximal to the calcaneal insertion (13).

Although the Achilles tendon is the strongest tendon in the body, a number of factors make it susceptible to complete rupture. Most patients with acute ruptures have no preceding Achilles tendon symptoms, yet histopathology of ruptured tendons shows the presence of degenerative tissue in the vast majority of cases (4,5,8,13). Rapid loading of the degenerated tendon can then lead to a complete tear, with running and jumping transmitting forces up to eight times body weight through the Achilles tendon. Other risk factors for acute ruptures include previous corticosteroid injections, use of fluoroquinolone antibiotics, and high longitudinal arches with a decrease in the pronation range of the foot and ankle (16).

INDICATIONS/CONTRAINDICATIONS

The choice between operative and nonoperative management of an Achilles tendon rupture remains controversial. The best form of treatment depends on patient characteristics and expectations. Age, activity level, and medical comorbidities help guide treatment recommendations. Patients should be educated about the risks and benefits of both treatment options so that an informed mutual agreement can be reached.

Nonsurgical management offers the advantages of decreased cost and the absence of surgical complications, although the overall complication rate may be higher (4). Traditional treatment includes immobilization in a plaster cast for 6 to 8 weeks. Nonsurgical management is recommended for patients with sedentary lifestyles, heavy tobacco use, poor skin quality, and medical comorbidities, which increase the risk of wound healing problems.

Operative management offers the potential benefit of a decreased rerupture rate, restores the length and tension of the muscle-tendon unit, and may result in earlier return to sport as well as increased strength and endurance (1,4,5,7,11,13,18). We recommend surgery for active patients with minimal risk factors for wound healing complications. Surgery may also benefit chronic Achilles tendon tears that have failed conservative management and remain symptomatic.

PATIENT EVALUATION AND PREOPERATIVE PLANNING

The diagnosis of acute Achilles tendon ruptures can usually be made with a thorough history and physical exam. Patients often describe acute pain in the back of the calf while participating in an athletic activity, followed by an inability to fully bear weight. A subjective feeling of being kicked in the back of the leg and hearing a loud pop is common. Physical exam findings include soft tissue swelling and ecchymosis around

the distal posterior leg and ankle. A tender palpable defect is often appreciable along the course of the tendon (Fig. 53.1). Active plantar flexion may still be intact due to the long flexors, but strength is decreased compared to the contralateral side.

The Thompson test, also known as the calf squeeze test, is the most reliable part of the physical exam used to assess the continuity of the Achilles tendon (12). The calf musculature is squeezed, and in a normal individual the ankle will plantar flex (Fig. 53.2A). In Achilles tendon tears, plantar flexion is absent or significantly decreased compared to the normal side (Fig. 53.2B). The squeeze test can be quite painful and patients may not allow it.

Uncommon injury patterns and chronic tears may be difficult to diagnose with history and physical exam alone. Imaging studies can be helpful when the physical exam is equivocal. Avulsion injuries may include a portion of the calcaneal tuberosity and are well visualized with lateral plain radiographs (Fig. 53.3). MRI can be helpful in detecting partial tears, proximal tears, and direct avulsions of the tendon off the calcaneus

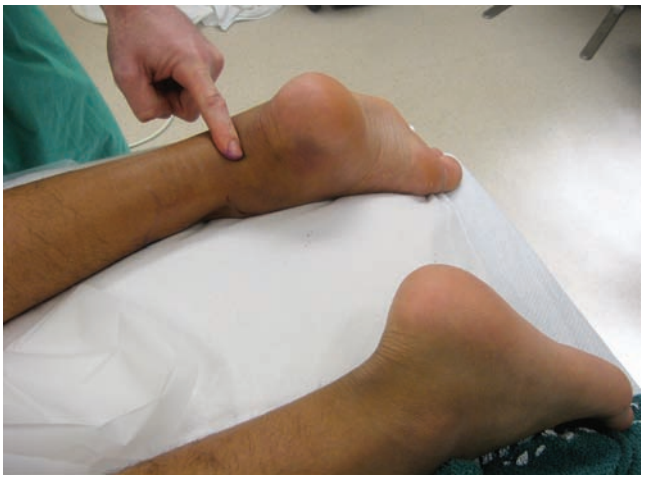
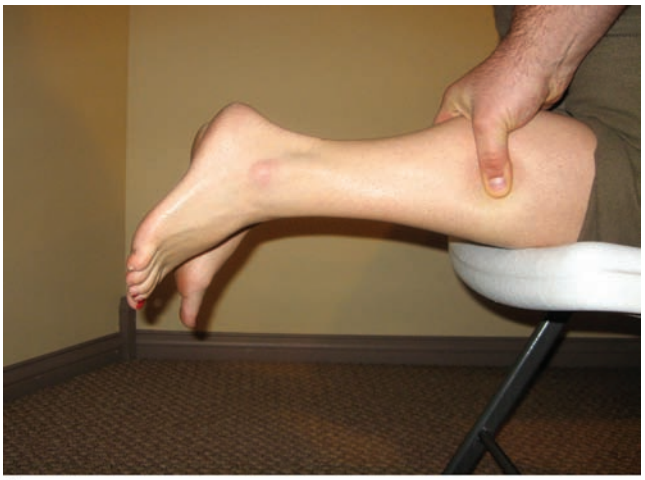


FIGURE 53.1

A palpable defect is noted along the middle portion of the Achilles tendon.



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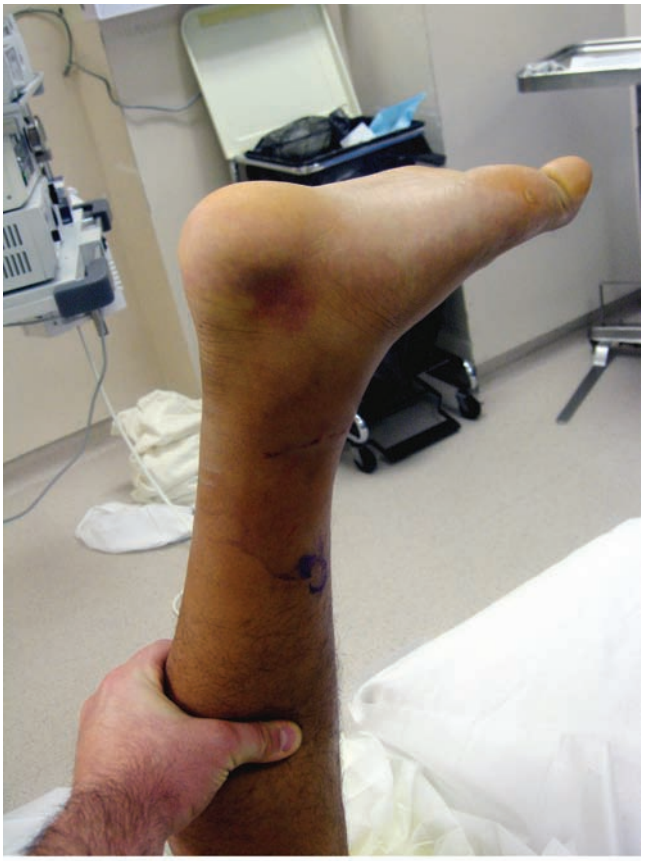

B

FIGURE 53.2

A: Negative Thompson test: intact plantar flexion with calf squeeze. **B:** Positive Thompson test: absent plantar flexion with calf squeeze.

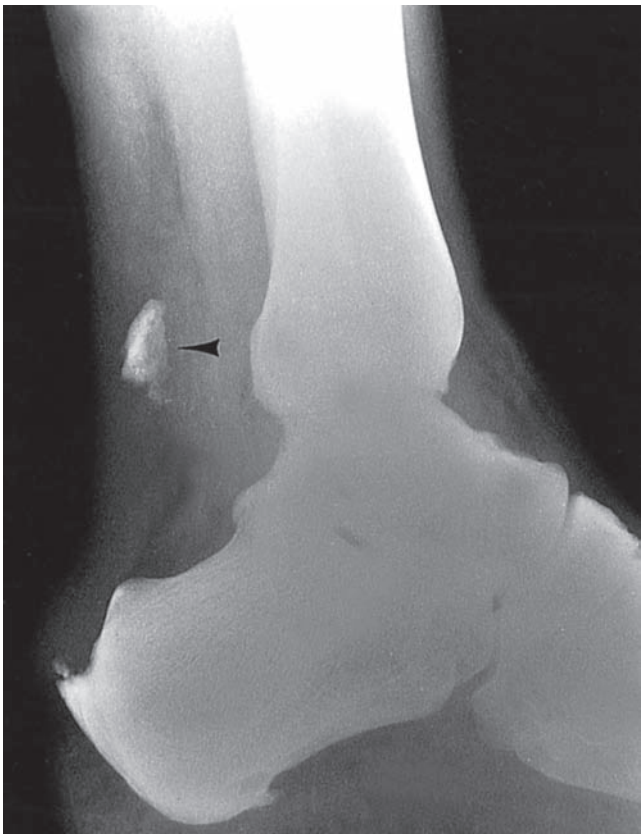

FIGURE 53.3
Lateral radiograph of the calcaneus demonstrating a displaced calcaneal tuberosity fracture.

(sleeve avulsion). MRI can confirm the diagnosis in delayed presentations or chronic tears and provide relevant information for preoperative planning, including the length of tendon involved.

After the initial evaluation, the ankle should be immobilized in plantar flexion with a well-padded posterior splint. Patients are encouraged to ice and elevate the affected extremity to minimize swelling. In order to minimize scar formation and contracture of the tendon, surgery should be performed within 2 weeks of the initial injury. Delaying surgery beyond the acute period may decrease the chance of a direct end-to-end repair.

Three main surgical techniques are used for Achilles tendon repair: traditional open, percutaneous, and limited open technique. The limited surgical dissection associated with minimally invasive techniques has the potential advantage of decreased surgical wound complications. Reported complications specific to these procedures include inadequate fixation and sural nerve injuries. Excellent results have been reported with all three techniques, and the method of choice is ultimately determined by surgeon familiarity and experience.

Open end-to-end repair of acute Achilles tendon ruptures is recommended. Open repair has excellent long-term functional results, and the complications are minimized by proper patient selection, meticulous surgical technique, and appropriate rehabilitation. Delayed or chronic Achilles tendon injuries may require additional techniques to augment the surgical repair and to restore the normal resting tension and length of the tendon.

SURGERY

Patient Positioning

Prone positioning with general anesthesia is preferred. Careful positioning is important to avoid potential complications such as pressure necrosis and nerve and eye injury. Adequate padding is used for all bony prominences including the face and extremities, with eye goggles and axillary rolls for the chest. Brachial plexus injury is minimized by avoiding shoulder extension and limiting arm abduction to <90 degrees (6).

A surgical timeout is taken and administration of preoperative antibiotics is verified prior to inflation of the thigh tourniquet. The resting tone of the contralateral ankle is evaluated and used as a reference when fixing the ruptured tendon; the unaffected limb may also be prepped and draped into the sterile field for direct comparison. The skin is prepped with surgical scrub. The extremity is draped, and the toes are covered with a sterile glove or occlusive wrap.

Surgical Approach

Approaches to the Achilles tendon include posterior-medial, direct posterior, and posterior-lateral. To help avoid sural nerve injury and minimize surgical scar irritation with shoe wear, the posterior-medial approach is preferred.

The Achilles tendon is palpated and a posterior-medial surgical incision is made from the insertion on the calcaneus to the musculotendinous junction (Fig. 53.4). To protect the blood supply to the overlying skin, full-thickness skin flaps are developed down to the paratenon. If the paratenon is intact, it is carefully incised in line with the skin incision for later repair. The defect in the Achilles tendon is identified. Typically, a mop handle–type tear of the Achilles tendon is encountered (Fig. 53.5). Although present in 90% of cadaver dissections, the plantaris tendon is found in only 40% of Achilles ruptures, as it may be ruptured also (Fig. 53.6) (3). Occasionally, it can be used to augment the repair. The edges of the Achilles rupture are conservatively debrided to maintain length of the tendon. The proximal end of the tendon can be mobilized with blunt finger dissection to gain length for the repair.

Surgical Repair

The strength of a tendon repair is determined by the suture technique, the diameter and type of suture material used, and the overall number of strands crossing the repair site. Common suture techniques include the Krackow, Kessler, and Bunnell stitches (Figs. 53.7A–C). Although suture failure and rerupture rates are low with surgical repair, gapping and elongation at the repair site may be more common. Gaps may delay healing and result in a weaker repair. Functional outcome may also be adversely affected by weakness in end range plantar flexion (14). With this in mind, strong suture material is chosen and augmented with multiple reinforcement sutures across the repair.

The knee is flexed and the ankle is plantar flexed to bring the tendon edges together. A four-strand Krakow stitch is performed with a 5 and 2 braided nonabsorbable polyester suture (Figs. 53.7A and 53.8). There are published reports and anecdotal evidence of silicone-coated suture (FiberWire, Ticron) causing foreign body

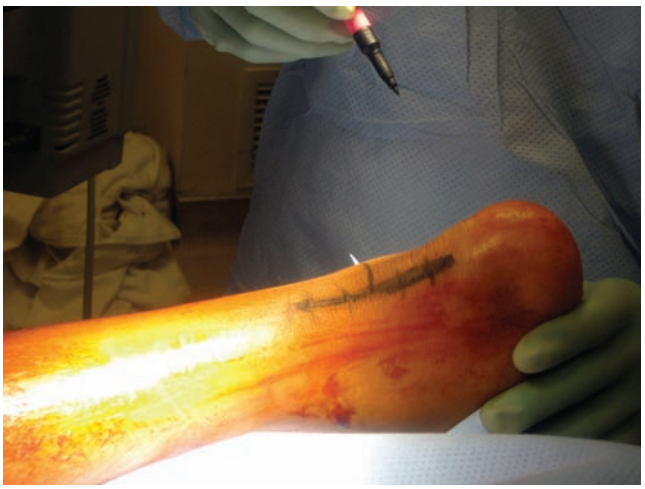

FIGURE 53.4
Skin incision: posteromedial.

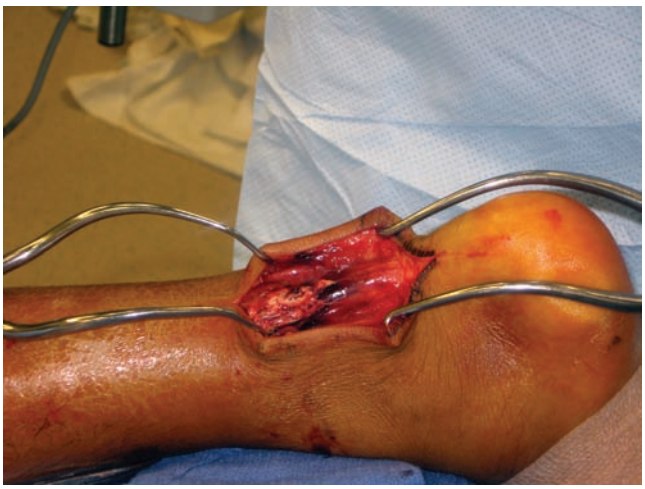

FIGURE 53.5
Achilles tendon rupture exposure: mop handle midsubstance tear of the Achilles tendon.

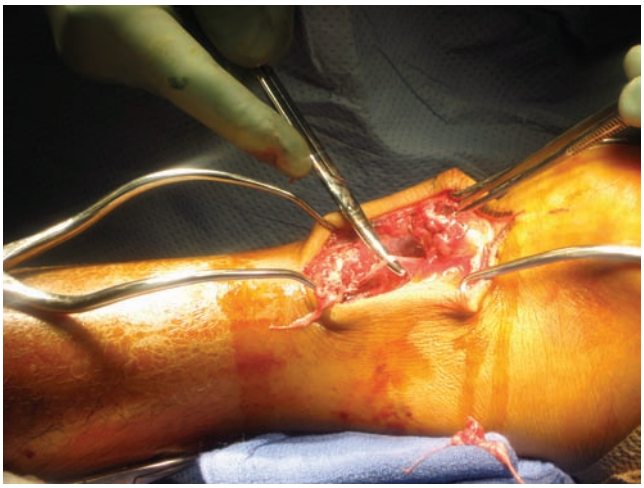

FIGURE 53.6
Plantaris tendon.

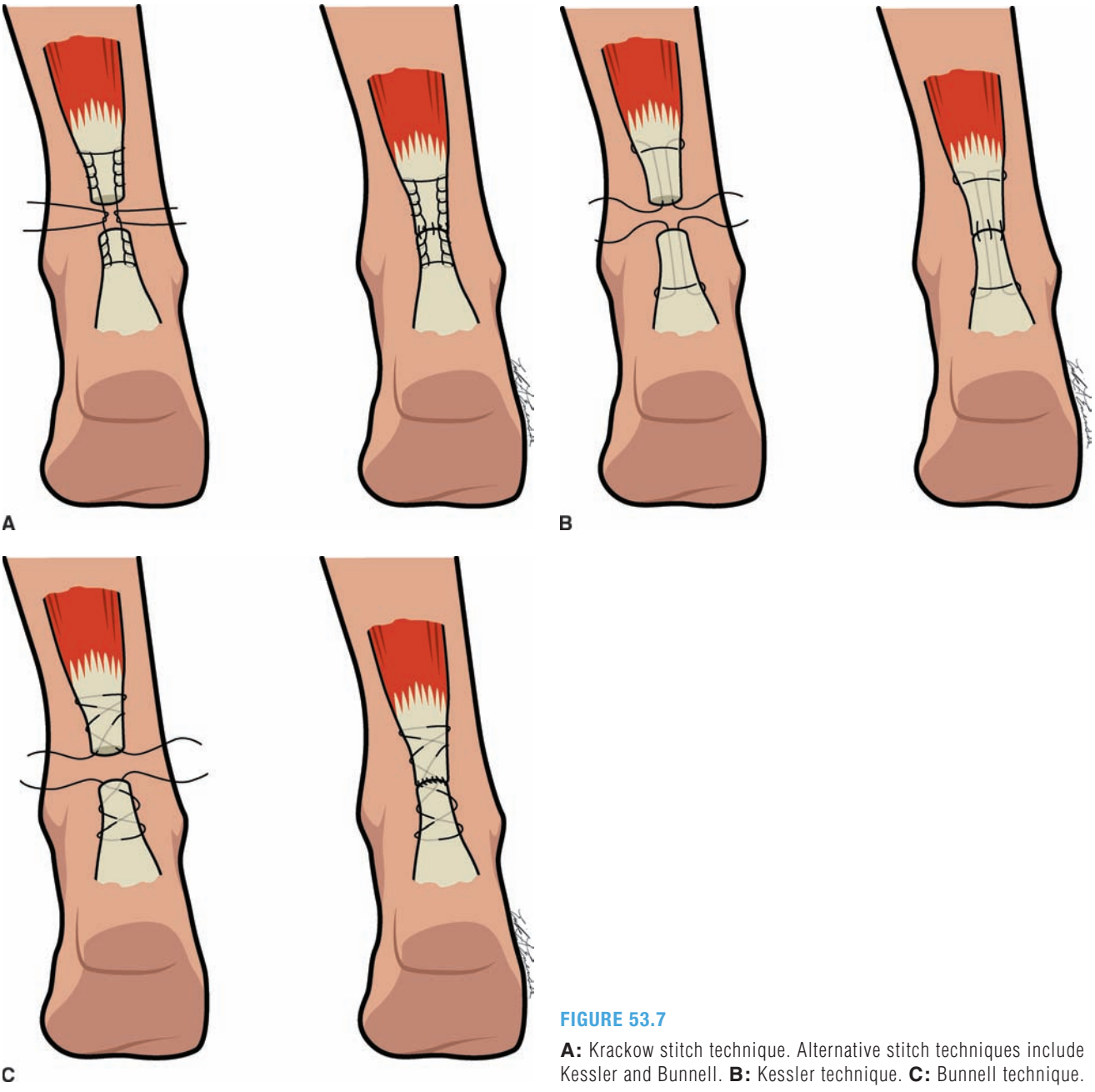

FIGURE 53.7
A: Krackow stitch technique. Alternative stitch techniques include Kessler and Bunnell. **B:** Kessler technique. **C:** Bunnell technique.

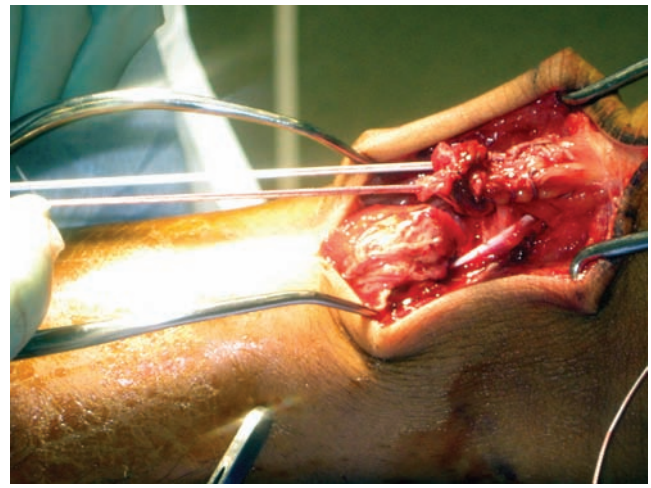

FIGURE 53.8
The distal portion of the Achilles is secured with sutures.

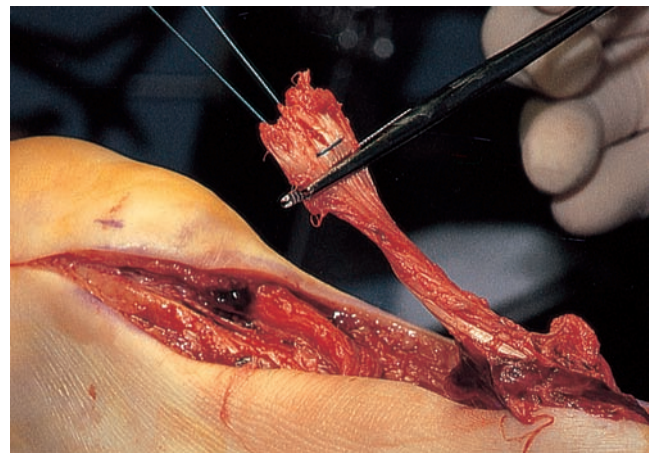

FIGURE 53.9
The avulsed bony fragment is identified and heavy nonabsorbable suture is used to gain fixation into the Achilles tendon.

reactions and wound drainage (9). Histology of retrieved granuloma specimens has shown silicone particles in the cytoplasm of multinucleated giant cells. This appears to be a rare reaction related to placing prominent knots in areas of high friction.

Augmenting the core repair with an epitenon stitch is recommended. Both simple running and cross-stitch sutures have been shown to increase the resistance to gap formation at the repair site, with the cross stitch resulting in higher loads to failure (10,17).

Alternative fixation methods are required for distal avulsion injuries, including the sleeve avulsion and bony avulsion of the calcaneal tuberosity (Fig. 53.3). Displaced bony avulsion injuries may compromise the surrounding soft tissue and require urgent open reduction and internal fixation to prevent full-thickness skin necrosis. When an avulsion injury is encountered, the skin incision is continued distally to provide exposure of the tuberosity. After identification of the bone fragment, fixation is achieved in the distal Achilles tendon with a 2 braided nonabsorbable suture (Fig. 53.9). Drill holes are placed into the tuberosity (Fig. 53.10), and the suture is placed through the drill holes and tied down to reduce the bone fragment and tendon (Fig. 53.11).

If the avulsed fragment is large, then screw fixation can be used, making sure that the screw heads are not prominent and potentially painful. Suture anchors can be helpful for augmenting repairs and gaining fixation in the sleeve avulsion–type injuries; nonabsorbable anchors are preferred to biodegradable systems due to the granuloma reactions sometimes seen with the latter.

Delayed Repairs

Delayed repairs of the Achilles tendon may require resection of a substantial amount of degenerative tendon and scar tissue. When >4 cm of scar tissue is debrided, direct end-to-end repair is difficult and augmentation is usually required. Delayed repairs (after 2 weeks) requiring augmentation have a higher risk of surgical complications (4,15) with inferior outcomes compared to acute repair (5), but overall function and pain often improves after surgical intervention.

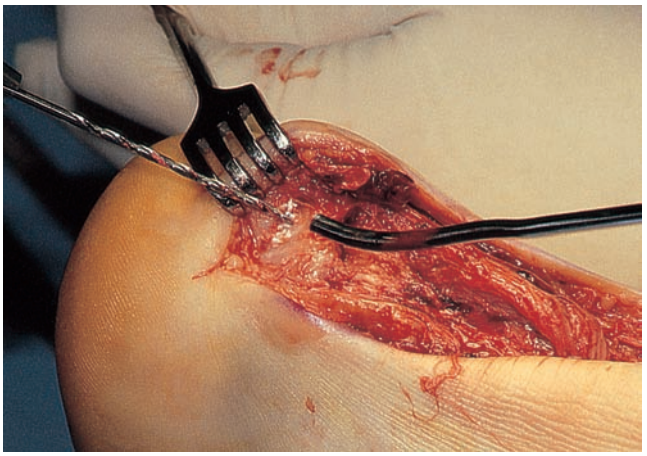

FIGURE 53.10
Drill holes are made into the calcaneal defect.

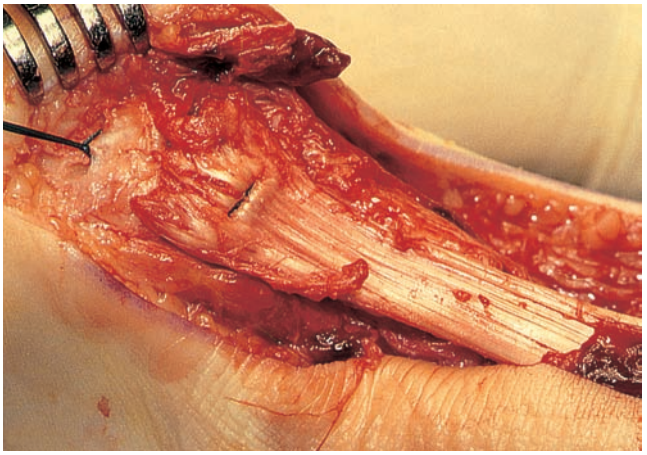

FIGURE 53.11
The avulsed fragment and Achilles tendon are brought down into the defect and the suture is tied distally.

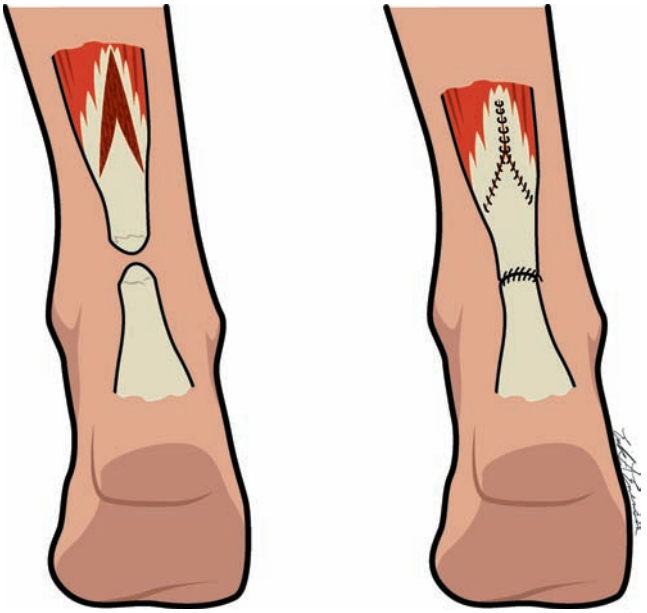

FIGURE 53.12
Inverted V-Y advancement.

There are many different techniques available for delayed repairs, including augmentation and reconstructive options. Local tissue and tendon transfers utilizing the plantaris, Achilles fascia, peroneus brevis, flexor hallucis longus, and flexor digitorum longus can be used to augment and reconstruct the tendon. The choice between the many options available depends on the size of the defect, the integrity of the soft tissues, and surgeon preference. Lengthening of the Achilles tendon can be done with an inverted V-Y advancement (Fig. 53.12). The V-Y advancement may allow for gap closure of up to 7 cm. For the larger defects, increasing the acuity of the inverted V will maximize lengthening.

Closure

The tourniquet is deflated and hemostasis is obtained to prevent postoperative hematoma formation and potential wound complications. The wound is copiously irrigated prior to closure. The paratenon is closed with 3-0 absorbable suture. The diameter of the repaired tendon often exceeds that of the native tendon and it may be difficult to fully close the paratenon. In that case, a full-thickness stitch that incorporates both the paratenon and the subcutaneous fascia can be used. Buried subcutaneous 3-0 sutures and simple 3-0 nylon skin sutures complete the closure. Patients are placed in a bulky posterior splint with the ankle resting in plantar flexion.

POSTOPERATIVE MANAGEMENT

Surgical repair is generally done on an outpatient basis with routine follow-up 1 to 2 weeks after surgery. Strict non–weight bearing with crutches or a walker is recommended for the immediate postoperative period. The surgical wound is inspected at the first follow-up visit. If the wound is healing nicely, then a fracture boot with heel wedges can be used. The boot can be removed for daily bathing as long as the patient is compliant and does not scrub, rub, or scratch the wound. Ice, compression, and elevation are encouraged to decrease postoperative swelling. Sutures are only removed when the wound is well healed with good bridging skin after 2 to 4 weeks. Sutures are removed beginning with those at the ends of the wound and then alternating with every other suture until all are removed. Leaving sutures in too long is better than taking them out too soon.

Traditional postoperative protocols have consisted of non–weight-bearing immobilization with serial casting to bring the ankle out of equinus. Prolonged immobilization may be detrimental to overall function and healing, with side effects including muscle atrophy, scar formation, and joint stiffness. Tendon healing can benefit from intermittent loading conditions and gentle motion. Tensile stress can optimize collagen fibril orientation and may increase the size and number of fibrils present (16). Plantar flexion exercises have been found to increase blood flow sevenfold around the Achilles tendon (2). This knowledge has led to more recent Achilles tendon rehabilitation protocols that emphasize early range of motion and weight bearing to help hasten recovery. Patients report better subjective outcomes with early functional treatment with no increase in complications or rerupture rates (2,15,16).

Rehabilitation

An early functional rehabilitation protocol is encouraged for compliant patients with acute repairs. Regular scheduled follow-up is necessary to ensure that patients are progressing appropriately. For unreliable or noncompliant patients, a more traditional rehabilitation protocol is recommended with short-leg cast immobilization. Cast changes can be performed every 2 weeks for a 6- to 8-week period, with a goal of correcting plantar flexion to neutral. Physical therapy is then initiated with a 1-in heel lift in a tennis shoe, gradually progressing with stretching and strength exercises.

In the early functional rehabilitation protocol, patients begin active range of motion exercises from neutral to full plantar flexion after the surgical wound is healed. This is generally around 2 weeks after surgery, but may be longer in some patients. Weight bearing in a fracture boot with three 10-degree heel wedges is then initiated. Heel wedges are important to protect the Achilles tendon. A 1-in heel wedge can reduce the load on the Achilles tendon by nearly 50% (14).

After week 3, one 10-degree heel wedge is removed per week and progressive weight bearing is continued. Active range of motion is emphasized with dorsiflexion limited to neutral and full plantarflexion. By week 6, the boot is discontinued and patients are allowed to wear a tennis shoe with a ½-in heel lift.

Rehabilitation goals at week 7 include transitioning to a normal gait. This includes light stretching and resistance exercises to achieve a full range of motion. The heel lift is discontinued at week 10 or when at least 10 degrees of dorsiflexion is obtained. By 3 months, once full range of motion is achieved, brisk walking is initiated and may progress to jogging. Release to full activity is restricted until full strength and motion is achieved, usually 4 to 6 months after surgery. Patients are encouraged to continue stretching on a continual basis prior to all workouts and athletic activities.

The rehabilitation for delayed repairs is generally more conservative. Depending on the technique used and the perceived strength of the operative repair, rehabilitation may lag behind the above protocol by one to 2 weeks or the traditional casting protocol is used. If there is a considerable amount of tension on the repair, the initial cast may be a long leg cast with the knee bent and ankle in plantarflexion.

COMPLICATIONS

Risks associated with surgical repair of the Achilles tendon include wound healing problems (necrosis, dehiscence, superficial and deep infection), calcification, adhesions and scar formation, nerve injury, and rerupture.

The overall wound infection rate after surgical repair of the Achilles tendon is estimated to be 4.7% (1). Smoking, diabetes mellitus, obesity, and steroid use significantly increase the infection rate. Wound healing

problems can be minimized with a gentle soft tissue surgical technique, full-thickness skin flaps, adequate hemostasis to prevent hematoma formation, delicate closure, and postoperative immobilization in a well-padded splint. When skin necrosis occurs, treatment options range from local wound care to encourage granulation tissue, to local and free flap coverage.

Intratendinous and peritendinous calcifications have been reported after surgical repair, causing pain, swelling, and decreased range of motion of the ankle joint (9). Early rehabilitation and the use of postoperative nonsteroidal anti-inflammatory agents may help decrease symptomatic calcifications.

Painful scar formation can be problematic in certain individuals, especially those predisposed to keloid formation. Placing the incision posteromedial rather than directly posterior helps prevent shoe wear irritation. The risk of adhesions after surgical repair is decreased with early motion and rehabilitation.

Sural nerve injuries have been reported with both minimally invasive and open techniques. The sural nerve runs along the lateral border of the Achilles tendon approximately 10 cm proximal to the calcaneal insertion and continues along the lateral border of the Achilles tendon. Identification of the nerve and careful surgical technique will help decrease potentially painful neuromas and complex regional pain syndrome.

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54 Treatment of Osteochondral Lesions of the Talar Dome with Osteochondral Autograft Transplantation

Victor R. Prisk

INDICATIONS/CONTRAINDICATIONS

Osteochondral lesions of the talus (OLTs), otherwise known as osteochondritis dissecans or flake fractures of the talar dome, include a variety abnormalities of the articular cartilage and underlying subchondral bone (1). This may involve separation of a fragment of the articular surface with subsequent loose body formation. The talus is the third most common location for osteochondral lesions following the knee and the elbow (2). The OLTs may occur in up to 6% of all ankle sprains (3–5). Most patients with symptomatic OLTs are in their 20s or 30s and are active in sports.

It was previously believed that most lesions were either anterolateral with a high association with trauma or posteromedial with a less consistent history of trauma (2,6,7). In contrast to this thinking, a study in 2007 reviewed MRIs from 424 patients with OLTs and found that most lesions were found at the midtalar dome medially or laterally (8). The most commonly affected site was the medial equator at 53% of cases with 26% of cases involving the lateral equator. Also, medial lesions tended to be deeper and involve more surface area.

Pettine and Morrey (9) suggested that the surgeon should initially attempt to treat nondisplaced OLTs with a period of immobilization as these have a chance of healing. Elias et al. (10) reviewed MRIs of non–surgically treated OLTs and found that 45% showed MRI progression with an average follow-up of 13.7 months, 24% improved, and 31% remained unchanged. Bone marrow edema and subchondral cysts noted on the initial MRI were not reliable indicators of lesion progression.

The indication for surgical treatment of OLTs includes failure of conservative management of any stage of lesion. Regardless of the radiographic appearance of a lesion, if the patient is asymptomatic after conservative management they do not necessarily require surgical intervention, even if radiographs fail to show complete

healing. However, patients with loose fragments on plain films, MRI, or CT are candidates for surgery. Acute dome fractures with displacement may be fixed acutely by open reduction and internal fixation with bioabsorbable screws.

The use of osteochondral autograft transplantation (OAT) is indicated in large or cystic lesions and those who have failed previous débridement or marrow stimulating techniques (11). Caution should be exercised in patients with an age >45 (12) because of poor surrounding recipient cartilage and greater donor site morbidity documented with advancing age (11). Also, caution should be taken with lesions >1.5 cm^2 or cases with avascular necrosis of the talus (11). Defects related to septic arthritis and malignancies are also contraindications. Relative contraindications for using the knee as a donor site include existing arthritic changes, patellofemoral symptoms, and limited range of motion (13).

PREOPERATIVE PLANNING

Patients with OLTs may present after an acute injury, such as an inversion plantarflexion sprain, but more commonly present with a gradual onset of symptoms. These symptoms may include pain, clicking, catching, locking, or giving way. Patients may or may not have signs of ligamentous laxity. The joint line may be tender in the region of the OLT; however, medial lesions are less likely to be directly tender because of their protection by the medial malleolus.

Plain radiographs should be obtained first. Standing anteroposterior, lateral, and mortise radiographs should be obtained. More posterior lesions may be better visualized with plantarflexion of the ankle. Conversely, anterior lesions may be better visualized with dorsiflexion of the ankle.

Berndt and Harty's radiographic classification of OLTs is commonly used for classification of these lesions; however, correlations with arthroscopic findings are poor (14). Thus, Ferkel and Sgaglione proposed a four-stage classification of these lesions based on CT scan findings (15) (Fig. 54.1). This classification system correlated better with arthroscopic findings than plain radiographs. Stage I lesions are cystic, within the dome of the talus, and have an intact roof. Stage IIA lesions show communication to the talar dome surface. Stage IIB lesions demonstrate an open articular surface with an overlying, nondisplaced fragment. Stage III OLTs are nondisplaced with lucency under the entire fragment. Stage IV involves a displaced fragment.

Mintz et al. (16) developed an MRI grading system because MRI has the advantage of better visualizing the articular cartilage (Fig. 54.2). Stage I OLTs have articular cartilage injury only. Stage IIa involves cartilage injury with bony fracture with edema. Stage IIb has no edema. Stage III has a detached osteochondral fragment remaining in the native bed. Stage IV involves a displaced and detached osteochondral fragment. Stage V involves a deep subchondral cyst formation.

Based on the CT scan or MRI, the location and size of the lesion can be determined. This will help with planning the surgical approach to be used. OAT is indicated for stage III or IV lesions. Medial lesions will often require a medial malleolar osteotomy unless the lesion is very anterior and the patient has good plantarflexion motion. Lateral OLTs may need an arthrotomy, anterior tibial osteotomy, or fibular osteotomy to reach the lesion with a bone plug. Digital imaging allows for accurate measurement of the lesion size such that the plug size or need for mosaicplasty can be predicted.

In the preoperative planning for an OAT procedure, care should be taken to evaluate the knee for signs of articular cartilage degeneration both on exam and by imaging. AP, lateral, and Merchant view radiographs should be obtained to look for any irregularities of the joint surface. If there is any question about the quality of the donor cartilage sight at either the trochlea or the lateral femoral condyle, an MRI may be needed.

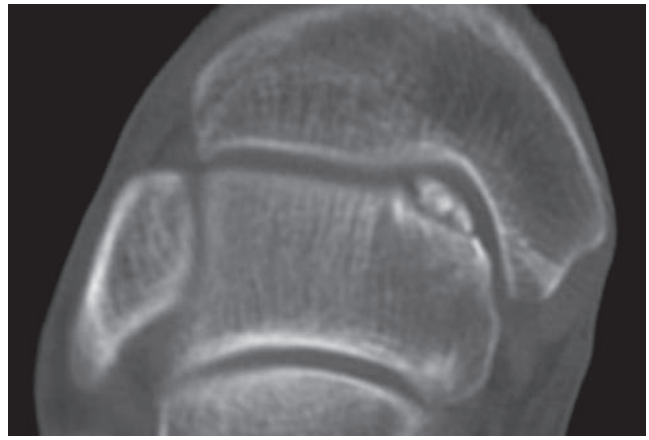

FIGURE 54.1

Coronal CT scan demonstrating a Ferkel and Sgaglione stage III medial OLT that has lucency and is nondisplaced.

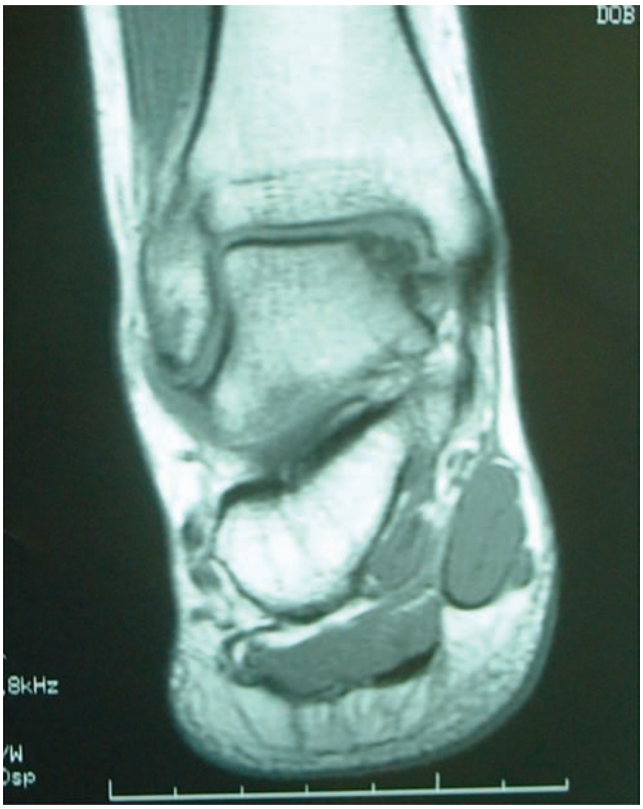

FIGURE 54.2

Coronal MRI image demonstrating medial OLT.

SURGERY

If it has not been performed previously, ankle arthroscopy can be beneficial to define the anatomy and location of the lesion prior to making a malleolar osteotomy. Surgery can be performed under general or spinal anesthesia supplemented with a regional nerve block catheter. The patient is positioned supine on a radiolucent operating table with the ipsilateral hip and knee flexed on a well-padded leg holder placed behind the knee. A thigh tourniquet is applied with cotton padding and is draped out of the operative field.

After skin preparation with chlorhexadine and betadine, the sterile drapes are applied above the knee. The noninvasive ankle distractor strap is applied to the foot and connected to the table with a sterile bar and clamp attachment. Tension can be carefully applied to distract the ankle joint. Care must be taken to limit the tension and time under distraction to avoid skin necrosis and nerve compression injuries.

The ankle joint can be dilated using an 18-gauge needle and normal saline through an approach medial to the tibialis anterior tendon at the medial joint line. The skin is superficially incised and blunt dissection is performed into the joint with a small curved hemostat. This minimizes injury to the superficial nerves. A cannula with a blunt obturator is used to penetrate the joint capsule. An 18-gauge spinal needle is introduced to the ankle joint from posterolateral just lateral to the Achilles tendon to establish an outflow portal. The anterolateral portal is made after identifying the subcutaneous superficial peroneal nerve. This can be marked out with a pen. An 18-gauge needle can localize the portal so as to avoid the nerve and be just lateral to the peroneus tertius. Again, blunt dissection techniques are used to avoid branches of the superficial peroneal nerve.

A shaver may be introduced to clear hypertrophic synovium and allow for comprehensive examination of the joint's articular surfaces with a 30- and 70-degree arthroscope. A probe can be introduced to palpate the articular cartilage and look for unstable defects. An understanding of the consistency of the surrounding cartilage can provide important prognostic information.

Medial lesions are often at the equator and cannot be reached via an anteromedial capsular arthrotomy. Only the anterior one fifth of the medial talus can be treated with this approach. Thus, a medial malleolar osteotomy is often needed for OAT treatment of these OLTs. To expose the medial ankle, a curvilinear incision is centered over the medial malleolus. Blunt dissection is performed and care is taken to protect the saphenous vein and nerve with gentle retraction. The anterior capsule is incised to visualize the location of the lesion and the medial notch. The posterior tibial tendon is identified through incision of the flexor retinaculum and protected with a blunt Hohman retractor. The Hohman protects the medial tendons and neurovascular bundle from the saw blade.

The medial malleolar screw holes are predrilled prior to making the osteotomy. The angle of the screws and the osteotomy are confirmed by fluoroscopy (Figs. 54.3 and 54.4). If a more vertical osteotomy is needed to reach the lesion, one must consider use of a semitubular plate with perpendicular screws for compression and

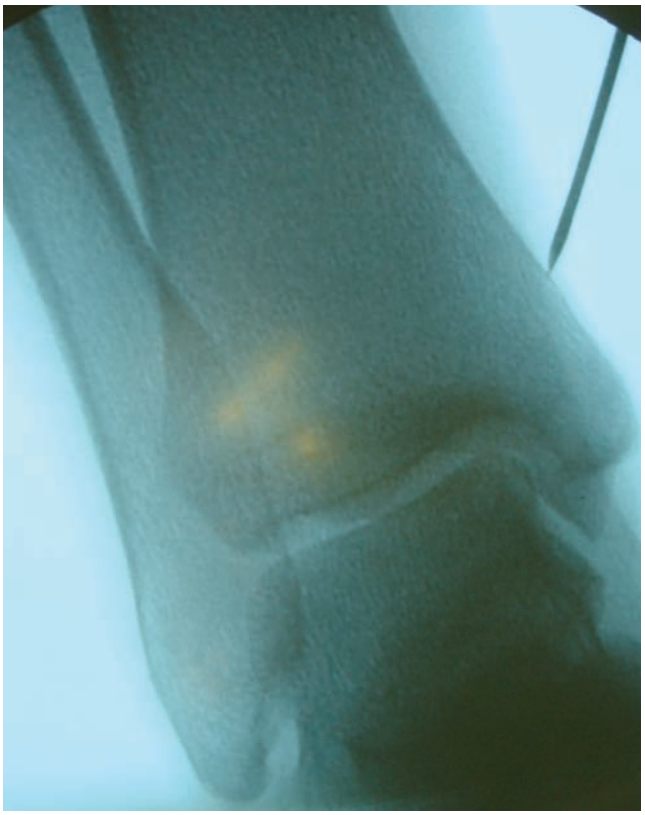

FIGURE 54.3

Fluoroscopy and a 1.6 K-wire is use to localize the medial malleolar osteotomy orientation.

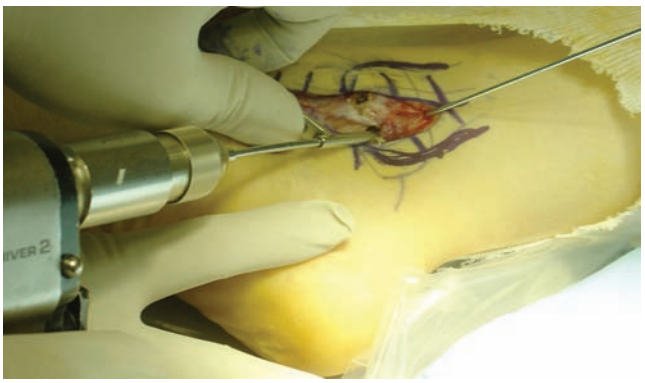

FIGURE 54.4

The screw holes for fixation of the medial malleolus are predrilled prior to making the osteotomy.

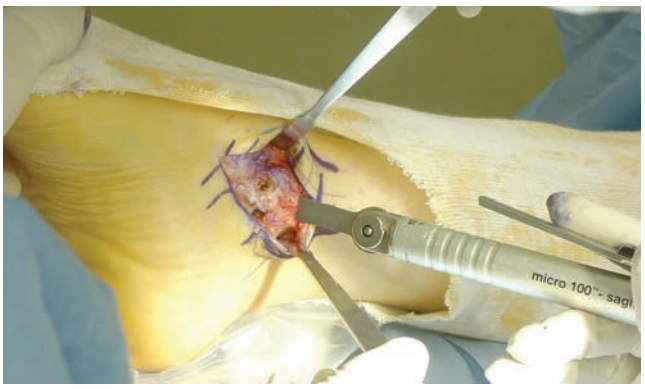

FIGURE 54.5

A microsagittal saw is used to make the medial malleolar osteotomy with blunt Hohman retractors protecting the medial structures.

antiglide. A microsagittal saw is used to create the osteotomy and is finished with a small osteotome to hinge the malleolus (Fig. 54.5). A pin distractor or a suture placed through the drill holes may be used to hinge open the osteotomy for exposure of the joint surface.

After the lesion is identified, further débridement and preparation of the recipient bed are performed. The ankle must be held stable during the drilling and dilating of the recipient hole. The lesion is drilled perpendicularly

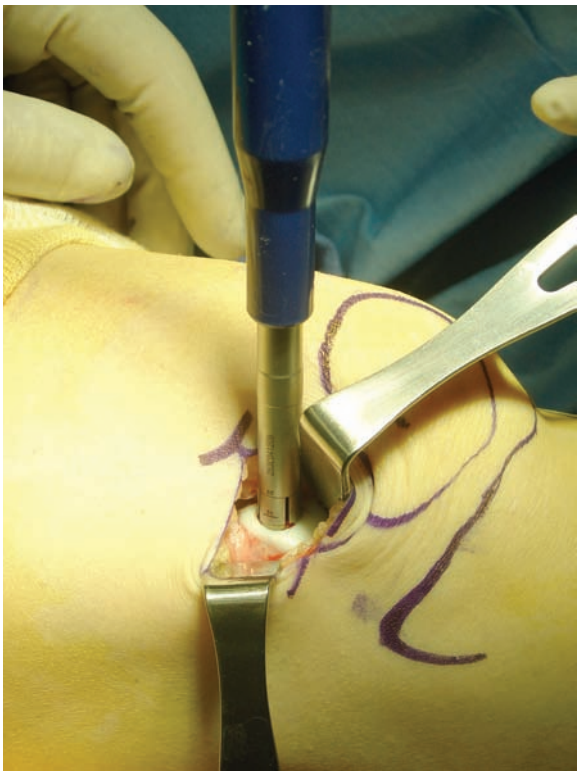

FIGURE 54.6

The donor plug is harvested from the supracondylar ridge of the lateral femoral condyle.

and centrally with a guide pin. Lesions in the dome can be drilled straight down. If a lesion is on the shoulder, the pin may be placed at up to a 45-degree angle. The guide pin is overdrilled to the appropriate size reamer to a depth of at least 12 mm. If multiple plugs are needed, as in mosaicplasty, there should be at least 1 mm of intervening bone between holes. The depth of the drill hole is confirmed and the retractors are removed and the wound is covered with a saline-damped sponge while attention is directed to the osteochondral plug harvest from the knee.

Attention is directed to the supracondylar ridge of the lateral femoral condyle (Fig. 54.6). The ridge offers a large surface area of cartilage and the quality and curvature closely matches the talus. A mini-arthrotomy is used to expose the lateral ridge. If a patient has an increased Q-angle, one may consider arthroscopic notch harvests or medial ridge harvest. The donor harvester is malleted to a depth of 15 mm and twisted under pressure to withdraw the graft. The graft can be partially extruded from the harvester to a size of 11.5 to 12 mm, and the cancellous bone is rongeured to the appropriate size with some bulleting of the tip for easier insertion.

Exposure at the ankle is obtained once again and the graft is tapped into place. It is firmly seated using a tamp (Fig. 54.7). The malleolar osteotomy is closed with two 4.0-mm partially threaded cancellous lag screws (Fig. 54.8). Rotation can be controlled with finger pressure or k-wires. An antiglide plate or a transverse screw is used if any gapping occurs proximally. Fixation is confirmed with fluoroscopy and ankle motion is tested.

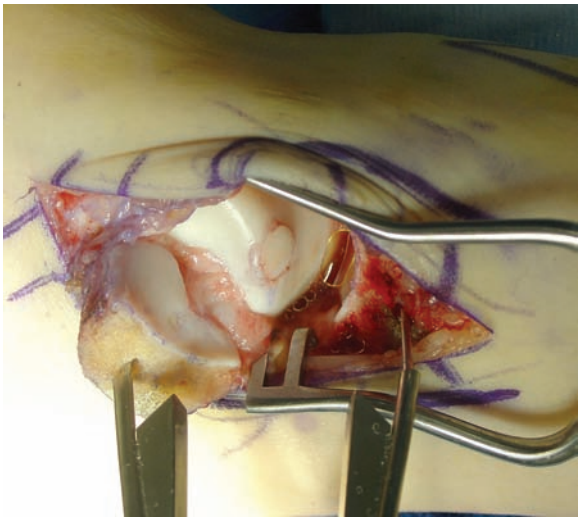

FIGURE 54.7

The osteochondral autograft plug flush with the articular surface of the talus.

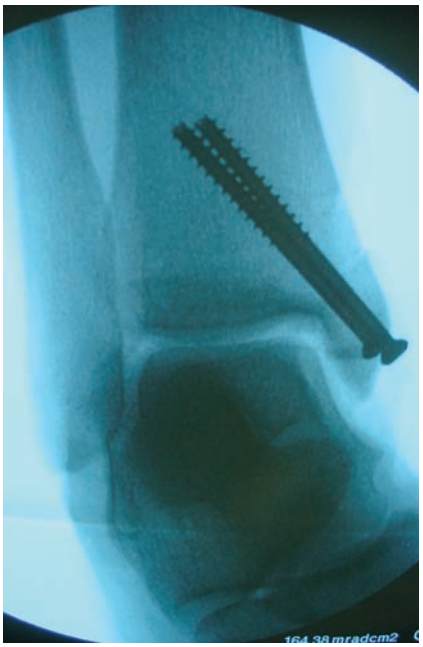

FIGURE 54.8

Screw fixation of the medial malleolus confirmed by fluoroscopy.

POSTOPERATIVE MANAGEMENT

The patient is placed in a well-padded short leg splint and is kept overnight for elevation, pain control, and postoperative antibiotics. Aspirin or low molecular weight heparin may be used for deep venous thrombosis prophylaxis.

The patient remains non–weight bearing on crutches for up to 6 weeks. Early active knee motion is encouraged. The splint is taken down at 2 weeks and active motion of the ankle is allowed when the incisions are healed. Strict elevation is adhered to in the first 2 weeks. If the osteotomy is healed, progressive partial weight bearing is advanced by 25 lb/wk in a CAM walker boot for 4 weeks. Physical therapy is initiated at 6 weeks postoperatively to work on ankle and subtalar motion with progressive resistance exercises. When painless full weight bearing is achieved in the boot and the patient has regained strength, the patient is transitioned out of the boot. Sometimes, an ankle-support orthosis is used to help with this transition. When painless walking is achieved, proprioceptive and agility training is initiated with the goal of returning to sport by 6 months postoperatively.

COMPLICATIONS

In general, infection, thrombophlebitis, nonunion, malunion, and stiffness are known complications that can be limited by good patient care and attention to detail during before and during surgery. Orientation of the malleolar osteotomy and various fixation techniques help minimize the risks of malunion and nonunion. Knee symptoms may occur and are generally mild. Complications such as infection, hemarthrosis, and patellofemoral pain have a rate of 2% to 36% (17,18). Rarely pain with squatting, instability, and knee pain after long distance walking has been noted.

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