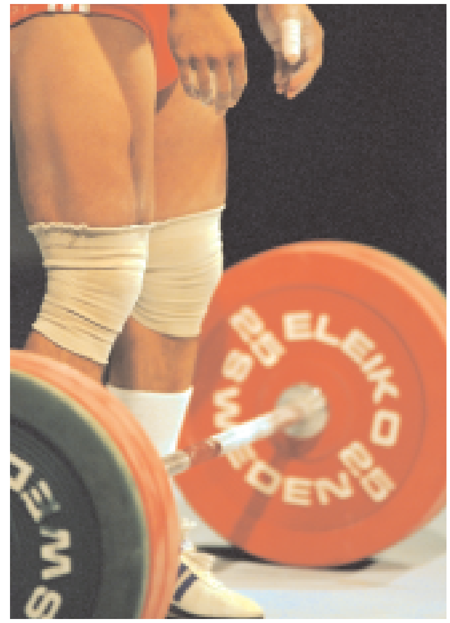
Chapter 1

Rehabilitation of Revision ACL Reconstruction



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Introduction

Reconstruction of the anterior cruciate ligament (ACL) is widely accepted as the treatment of choice for individuals with functional instability due to an ACL-deficient knee.[1] It is estimated that anywhere between 60,000 and 75,000 ACL reconstructions are performed annually in the United States, although this number may be as high as 350,000.[2] Despite the fact that nearly 90% of index ACL reconstructions are performed by surgeons who do fewer than 10 reconstructions per year, the overall success rate of the operation is high, ranging from 75% to 95%.[3,4] Nevertheless, between 3,000 and 10,000 revision ACL surgeries are performed each year, underlying the significant potential for failed ACL reconstruction (ACLR).[5] As adolescents maintain their participation in sports and older athletes extend their playing days, the number of index ACL injuries continue to escalate each year.[6] Accordingly, as patient expectations and functional demands increase, the number of ACLR failures, with subsequent revision ACL surgery, will likely show a similar trend.[7]

When evaluating a patient with persistent complaints following an index ACL surgery, the first and most important step is to define what constitutes a failure of the ACLR. Currently, there is a lack of general consensus on what criteria define a failed ACLR. A low correlation exists between the patient's perception and the surgeon's evaluation of knee stability following reconstruction.[8,9] Safran and Harner[10] proposed a definition of ACLR failure with the attempt to combine both subjective data gathered from the patient and objective data gathered by the clinician. They defined failure as "functional instability with activities of daily living or sports and the knee shows increased laxity on physical examination and instrumented testing."[10] Based on this definition, it is estimated that approximately 8% of patients undergoing primary ACLR will develop recurrent instability and proceed to graft failure.[10]

The evaluation, diagnosis, treatment and rehabilitation of failed ACLR is complex. Successful revision ACLR requires an accurate diagnosis as to the cause of failure, appropriate pre-operative work-up, careful patient selection, a well-executed surgical plan, and individualized rehabilitation protocols.[7] Patient counseling and management of pre-operative expectations are critically important. In general, it has been widely reported that the outcomes after revision ACLR are inferior to those following primary ACLR.[3,5,7] Even in the presence of objective evidence of knee stability, subjective outcomes may remain poor, possibly due to the declining status of the meniscus and articular surfaces.[3,5-7,11] Return to pre-injury level of play is also less predictable after revision ACLR.[3,5,7] Despite these challenges, the outcome of revision ACLR can be quite successful if the treating team is attentive to detail, meticulous in pre-operative evaluation, and adherent to sound operative and rehabilitative principles.[12]

Modes of Failure

Understanding the cause of failure is the pivotal first step in evaluating the failed ACLR. It is critical to differentiate between problems that can be helped by surgery, and those that are unlikely to change or improve with revision surgical intervention.[1,7] In general, patients with a failed primary ACLR may present with one of four major categories of complaints: recurrent patholaxity, decreased range of motion (ROM), extensor mechanism dysfunction, or issues with pain secondary to arthritis *(Figure 1)*. Of these categories, the most reliably treated with revision ACLR is recurrent patholaxity.[3,5-7,11] Diagnosis and treatment of recurrent patholaxity will be the focus of the majority of the chapter. The other three problems have unique presentations and treatment algorithms that do not generally involve revision ACLR. For completion, these causes of ACLR failure will be briefly discussed.

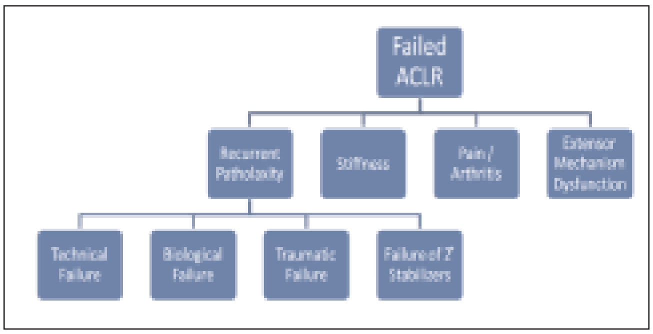

Figure 1: *Causes of failed ACL reconstruction.*

Decreased ROM

The most common complication of ACLR is loss of knee motion, which has been reported to occur in up to 35% of patients following primary ACLR.[13-15] There are several causes of postoperative knee stiffness, including arthrofibrosis, prolonged immobilization, complex regional pain syndrome (CRPS), capsulitis with ligament scarring, impingement from an inadequately debrided ACL stump, nonanatomic graft positioning, and intercondylar notch scarring.[16] Specifically, arthrofibrosis, or malignant production of fibrous tissue, is a significant challenge to the surgeon in the postoperative period. Knees reconstructed in the acute setting after ACL surgery prior to regaining full ROM pre-operatively are at greatest risk for arthrofibrosis,[15] as pre-operative ROM is the greatest determinant of postoperative knee motion.

Loss of motion can be detrimental to outcomes of primary ACLR, potentially leading to decreased athletic functional performance, altered running patterns, and increased patellofemoral contact pressures with subsequent joint degeneration.[3,5,14,16,17] Unfortunately, failures of primary ACLR due to loss of motion will not likely be corrected with a revision ACLR, making postoperative knee stiffness a potentially devastating complication, especially for high-level athletes. Stiffness is best managed prophylactically by achieving full ROM pre-operatively and adherence to sound rehabilitation principles postoperatively. Loss of motion secondary to arthrofibrosis may benefit from alternative treatment approaches such as arthroscopic lysis of adhesions, and/or manipulation under anesthesia.[7, 15]

Extensor Mechanism Dysfunction

Increased recognition and prompt treatment of postoperative extensor mechanism deficiencies have significantly decreased the incidence of extensor mechanism dysfunction over the past several years. Classically, painful rehabilitation in the early postoperative setting induced quadriceps muscle shutdown. Deficient quadriceps function coupled with poor patellar mobility may lead to infrapatellar contracture syndrome (IPCS), which is best diagnosed early and treated aggressively in rehab to prevent long-term sequelae of joint contracture and patella infera.[7,18] With the trend toward early aggressive rehabilitation protocols combined with increased awareness about the effects of painful rehabilitation on quadriceps inhibition, extensor mechanism dysfunction is now a much less common cause of failed ACLR.[7]

Pain/Arthritis

Pain as a cause of primary ACL failure can be due to many factors. These include, but are not limited to, arthritis, infection (acute septic arthritis or chronic subclinical infection), CRPS, and recurrent or ongoing instability (including meniscal or osteochondral damage).[7,10] Arthrosis should be suspected in the older patient returning with gradual onset of pain developing several years from the index procedure. Infection should be managed emergently to optimize the chance of graft survival and decrease the risk of joint degeneration. CRPS requires multimodal non-operative treatment methods for optimal outcome. Pain secondary to recurrent or ongoing instability, with or without concomitant meniscal or osteochondral injury, may require revision ACLR.[7,19] The evaluation and treatment of this subset of patients will be described in more detail in the remainder of the chapter.

Recurrent Patholaxity

Of the four main categories of postoperative ACLR failure, recurrent patholaxity is the failure mode most amenable to successful revision ACLR.[2,3,5,6] To optimize outcomes, the specific cause of failure inducing recurrent patholaxity must be determined. This will ensure a properly planned and executed revision ACLR with an individualized postoperative rehabilitation regimen. The causes of recurrent patholaxity can be further categorized into the following subgroups: Technical, Biologic, Traumatic, and Failure due to secondary instability *(Figure 1)*.

Technical

Technical error at the time of primary ACLR is the most common cause of failure requiring revision ACLR and has been implicated in 77% of the cases leading to revision surgery.[1,7] Intra-operative factors including non-anatomic tunnel placement, inadequate notchplasty, improper graft tensioning, insufficient graft material, and poor graft fixation rank amongst the major shortcomings of index procedures that eventually fail.[1] Non-anatomic tunnel placement accounts for 70-80% of all technical errors, with the femoral tunnel the most likely to be malpositioned.[1,20] Technical errors may lead to an increase in graft tension, graft impingement, or rotational instability, all of which could result in eventual failure of primary reconstruction.[1,7] More specifically, vertical placement of the femoral tunnel is the most common technical error leading to revision surgery. This error may produce a stable knee with anteroposterior excursion but poor rotational stability.[7]

Biologic

Biologic failure should be suspected in the patient with recurrent patholaxity without a history of trauma or evidence of technical errors.[1] These types of failures can be considered a failure of "ligamentization," or incorporation of the graft, as described by Amiel and colleagues in 1986.[21] Ligamentization is the process by which a collagenous substitute, such as autograft or allograft tendon, undergoes remodeling and biologic incorporation to take on the role of the absent ACL. Successful incorporation relies on a favorable biologic response from the host, which requires revascularization of the graft in addition to favorable biomechanical conditions (i.e. proper graft position and tension).[22] Avascularity, immunologic reaction, and stress shielding may impede the ligamentization process and lead to failure. Allograft use may also lead to delayed and less organized biologic remodeling.[23]

Clinically, true biological failures are rare and are a diagnosis of exclusion. Most failures classified as biologic are secondary to mechanical problems preventing a proper healing environment for the ACL graft such as altered biomechanics or abnormal strain. True biological failures result in graft necrosis secondary to poor revascularization, which may be caused by surgical factors such as overtensioning the graft, or patient factors such as smoking, cocaine use, diabetes, or peripheral vascular disease.[7]

Traumatic

The incidence of ACLR failure secondary to trauma is unknown. It has been reported to vary from 5-10% in several series.[7,20] Traumatic failure can be further divided into early and late failure, with early failures occurring in the first six months after surgery, prior to full graft incorporation. Early failures in particular may involve overly aggressive physical therapy regimens or premature return to sport as the graft, especially at the points of fixation, is at its weakest in the acute postoperative setting.[7,20,24] Late reruptures, in contrast, may occur in an otherwise technically well-done ACLR. Trauma of similar or greater magnitude to the initial injury can potentially lead to graft failure and recurrent instability. Late rerupture usually occurs through the mid-substance of the graft, similar to the location where native ACLs fail.[7,17] The incidence of late rerupture is rare in a well-executed index autograft procedure.[7]

Failure of Secondary Stabilizers

With an ACL injury, the magnitude of energy necessary to rupture the ligament is substantial, and other structures of the knee are often injured concurrently. Unrecognized or unaddressed concomitant knee injuries from the initial injury may lead to failure of the ACLR. For example, posterolateral instability from an undiagnosed posterolateral corner (PLC) injury is the most common unrecognized injury during ACL rupture, and is present in 10-15% of chronically ACL-deficient knees.[1,17,25,26] Other concomitant injuries that may go unrecognized in the primary setting include injuries to the menisci, medial collateral ligament (MCL), lateral collateral ligament (LCL), and posterior cruciate ligament (PCL). Failure to address deficiencies in these knee stabilizers at the time of ACLR may lead to increased graft tension and eventual failure. The ACL graft may initially provide anterior restraint, but increased activity level will lead to gradual recurrence of instability.[4]

When considering revision ACLR, it is essential to evaluate these secondary restraints and address deficiencies within these structures at the time of surgery. Depending on the specific scenario, this may include combination procedures that involve revision ACLR and PLC reconstruction or other related surgical procedures that will be discussed in greater detail in the sections to follow. Careful surgical planning and individualized rehabilitation protocols will help to ensure successful outcomes in this group of patients.

Patient Selection

History

As with any surgical procedure, patient selection is perhaps the most critical determinant of surgical outcome. In evaluating a patient with a failed ACL, obtaining a thorough history is pivotal. Determining the patient's chief complaint may not only provide clues as to the etiology of the failed graft, but it may also help guide treatment options. For example, if a patient's chief complaint after ACLR is pain, but he or she demonstrates objective evidence of patholaxity on exam, even successful revision surgery may not alleviate symptoms. Next, the clinician should determine the symptoms that led the patient to have the index ACL procedure in the first place, the time between initial injury and primary reconstruction, and the mechanism of injury. As noted, gaining a thorough understanding of the patient's current symptoms, including the presence or absence of pain, swelling, giving way, locking, and stiffness will help determine both the mode of failure and the likelihood that surgery will be beneficial. Instability, rather than pain, should be identified before considering revision, as a painful knee that demonstrates some laxity on examination presents a different clinical scenario than a knee that demonstrates recurrent instability.

From a surgical perspective, an equally important piece of the history is reviewing previous medical and surgical documents to gain a better understanding of the index procedure. Reviewing the initial operative report provides important information on previous surgical technique (one vs. two incision, open, endoscopic, etc), type and source of graft, type of fixation used, and status of menisci and articular surfaces at the time of surgery.[7] Associated injuries to the articular surface and menisci are often more vital in predicting subjective outcomes than recurrent patholaxity alone.[27]

Expectations

Pre-injury and current activity level as well as patient expectations should be documented. It is crucial to recognize that results of revision surgery are not as good as those of primary ACLR,[1] and the patient, physician and therapist must set realistic postoperative goals and expectations. Kocher and colleagues clearly demonstrated the importance of expectations in the revision ACL patient. They reported that false expectations preoperatively may lead to a subjective failure of the revision procedure despite a successful revision surgery from a technical standpoint.[28] Often, the goals of revision ACLR are to allow the patient to return to activities of daily living without instability, rather than successful return to pre-injury level or sport, which may not be feasible. Rehabilitation after a revision is usually slower than after a primary reconstruction and patients need to understand that revision surgery is often considered a salvage procedure, and their postoperative rehabilitation course will be more conservative.

Physical Examination

The physical exam of a failed ACLR patient should be thorough and consistent. There are several important steps in obtaining an accurate diagnostic assessment of the knee status post primary ACLR. First, the exam begins with observation of the patient's alignment while weight bearing. Valgus or varus alignment may necessitate further imaging and prompt the clinician to consider an osteotomy procedure, which will be discussed later. The patient's gait should be observed for a dynamic varus thrust, which may be seen in chronic ACL-deficient knees indicating laxity of the PLC structures, commonly found in the revision setting secondary to diagnostic failure prior to the index operation.[26]

The examination of the knee is similar to that for an index ACL injury. Skin should be examined for evidence of infection, as well as location and healing of prior scars. ROM and patellar mobility may give an indication of cause of failure such as arthrofibrosis, joint contractures, or CRPS. Objective muscle strength and functional testing help the clinician determine if further rehabilitation, bracing, or correction of gait patterns will be necessary prior to revision surgery.[7] Specific tests include the Lachman test, pivot shift, posterior drawer and sag testing for the PCL, assessment of LCL and MCL laxity (varus and valgus stress testing, respectively), pain along the medial and lateral joint lines (meniscal injury vs. arthrosis), and integrity of the PLC using the dial test. Importantly, the pivot shift test is a reliable clinical test for ACL deficiency that correlates well with patient-oriented outcomes.[28,29] However, this test may not be tolerated in the office setting secondary to pain and guarding by the patient. Objective measures of ACL ligamentous laxity, such as the KT-1000 (MEDmetric, San Diego, CA) are useful in both the pre-operative and postoperative settings, with a cutoff for an abnormal exam at >5 mm of side-to-side difference.[11]

Imaging Studies

For all patients with persistent complaints following primary ACLR, a full set of knee radiographs should be obtained, including weight bearing anteroposterior, full-extension lateral, a 45-degree posteroanterior flexion/weight bearing view, and axial views of the patella.[7,30] Radiographs allow the clinician to assess for evidence of arthritis, type and position of existing hardware, tunnel osteolysis, and patellar abnormalities such as alta or baja that may complicate the clinical picture. Specifically, when evaluating for tibial or femoral bone loss (tunnel osteolysis), serial radiographs are helpful and should be evaluated to monitor for progression. Lateral views allow evaluation of tunnel position and size. A dedicated notch view may also be helpful in the revision setting to evaluate for inadequate notchplasty, which has been implicated in the failure of primary ACLR.[1]

Just as in primary ACL injuries, the use of advanced imaging such as magnetic resonance imaging (MRI) is not essential for the diagnosis of a failed ACLR. However, MRI is very helpful in evaluating the integrity and possible modes of failure of ACLRs previously discussed. MRI is a sensitive imaging modality in the diagnosis of concomitant injuries of the knee, most notably to soft tissue structures. Meniscal tears, articular cartilage injuries, osteochondral defects, LCL/MCL/PCL pathology, and PLC deficiency may all be diagnosed on MRI, revealing an important step in the understanding and management of revision ACL surgery.[31,32] Tunnel osteolysis, while initially picked up on radiographs, may be further evaluated by computed tomography (CT) scanning, which provides a better definition of bony architecture than does MRI. Further, if there is concern for a subclinical infection, this must be ruled out via joint aspiration and fluid culture, cell count, gram stain and crystal analysis.[7]

Indications and Contraindications

Indications for revision ACLR include instability from ACL deficiency with failed nonoperative management, normal mechanical alignment, and correctable concurrent meniscal, ligamentous, or cartilage damage. Contraindications are numerous and must be identified before proceeding with operative intervention. For example, patients complaining of instability may present with quadriceps weakness secondary to inadequate rehabilitation rather than true ACL deficiency, and this must be ruled out as a cause of instability. If the patient's chief complaint is pain, other sources of failure should be identified. If the chief complaint is pain and instability, often concurrent pathology will exist in addition to the primary ACLR failure. If the patient presents with malalignment and a failed ACL, attention must first be turned to correcting alignment before reconstructing the ACL, as it is not feasible to correct soft tissue deficiencies with an underlying bony abnormality.

Similar to primary ACLR, it is necessary to obtain full ROM pre-operatively before revision surgery to prevent postoperative stiffness. Revision surgery is associated with greater stiffness pre-operatively and postoperatively than primary ACL surgery secondary to a number of factors, including arthrofibrosis and inadequate rehabilitation.[33] If stiffness is significant and due to arthrofibrosis, then it may be necessary to stage the revision surgery to first regain ROM via arthroscopic lysis of adhesions and aggressive rehabilitation, followed by revision ACLR.[7,33]

Concomitant Conditions

During the workup and evaluation of the patient with a failed ACLR, secondary diagnoses may confound operative treatment and postoperative rehabilitation. In the revision setting, concomitant conditions are more common than with index ACL injuries. These include PLC injuries, articular cartilage injuries, MCL or PCL tears, patellofemoral problems, and varus or valgus malalignment. Whether diagnosed preoperatively or intraoperatively with subsequent procedures performed, concomitant conditions significantly affect both surgeon and physical therapist (PT) in the extended and often protracted postoperative course. Specific injuries will be discussed in greater detail in the Surgical Treatment and Rehabilitation sections of this chapter.

Surgical Treatment

Following the diagnosis of a failed ACLR and the determination of the etiology of failure, the surgeon may opt to proceed with operative intervention. Before entering the operating room, however, pre-operative planning is essential to properly manage the underlying pathology.

Graft Selection

The first step in pre-operative planning is to choose a graft for the reconstruction. This is similar to graft selection in a primary ACL; however the coexisting pathology and previous procedures must be taken into account. The ideal graft is one that retains strength at least equivalent to that of the normal ACL, allows for secure fixation, has minimal morbidity, and allows for postoperative rehabilitation.[34] The options for available grafts can be broken down into two general categories, autograft and allograft.

Autograft

There are multiple options for autograft reconstruction, including patellar, hamstrings, and quadriceps tendon grafts. Each graft has its own advantages and disadvantages in the revision setting. If the initial (failed) reconstruction was done with an allograft, then the ipsilateral patellar tendon represents an excellent option. If the patellar tendon was previously utilized, the treating surgeon has the contralateral patellar tendon available. However, this carries the significant disadvantage of operating on the patient's normal knee with the associated morbidity and additional risk of complications.

The advantages of using a patellar tendon autograft in revision surgery include excellent graft strength/stiffness, good fixation options, and predictable results in active patients. Yet, these advantages must be countered against the disadvantages, including potential anterior knee pain, the risk of donor site fracture, and complications associated with operating on a normal knee (in the case of a contralateral harvest).

The hamstrings represent another good source of autograft tissue for revision ACLR. The same disadvantages and advantages for autograft hamstrings in the setting of primary ACL surgery hold true in the revision situation. However, in the revision setting, the surgeon must take into account the size and location of the previous bone tunnels. Often, these tunnels will either be too large or convergent with the new tunnels. This creates a channel that is too wide to accommodate the hamstrings graft. The surgeon then has two options. If the previous tunnels were non-anatomic, new ones can be drilled in the appropriate anatomic position and the previous tunnels can be ignored. If the tunnels present are too large for the graft, a two stage procedure can be completed that includes an initial bone grafting of the previous tunnel.

Lastly, a quadriceps tendon autograft can be used. This is a less common source of autograft. The concerns regarding the quadriceps tendon are similar to those for the patellar tendon given the fact that both require a removal of a bone block from the anterior patella and can result in anterior knee pain as well as potential patellar fractures. In the revision setting, a previous bone-patellar tendon-bone graft could potentially weaken the patella, and the subsequent removal of another bone block with the quadriceps graft may cause an intraoperative fracture. However, this has not been proven in the literature and remains theoretical.

Allograft

In revision ACL surgery, allograft tissue has become an extremely popular option and is used frequently. Allografts have the advantage of being readily available and are associated with less donor site morbidity, quicker operative time, decreased surgical dissection, and are overall more cost-effective compared with autografts.[34] However, allografts will incorporate slower than autografts and may therefore require an increased period of protection, and run the risk of disease transmission.[34] Similar to autografts, there are multiple options for the revision ACL allograft. These include patellar tendon, Achilles tendon, hamstrings tendon, as well as the tibialis anterior tendon allografts. Each of these has their advantages and disadvantages, many of which are beyond the scope of this chapter. In particular, patellar tendon allografts are the most common. These grafts offer excellent tensile properties with bone blocks that can be sculpted to fit the previous tunnel, thus improving fixation. The Achilles tendon has also become a popular graft in revision procedures. It is a robust graft that has a large cross sectional area and a customizable bone block.

Surgical Techniques

The surgical techniques for a revision ACLR are both varied and based on the etiology of failure. The following sections will briefly discuss the specific surgical techniques utilized to address various mechanisms of failure.

The first subset we will discuss is the failed ACL with non-anatomic tunnels secondary to technical error, as discussed previously. It is estimated that this is the etiology of failure in 70-80% of failed ACLRs.[35] Misplacement of the initial tunnels can lead to graft impingement, ligamentous laxity, improper tensioning, and eventual graft failure.[36] In these cases, preoperative planning is essential. Complete radiographs should be ordered, and a CT scan or MRI allows further evaluation of tunnel position, tissue integrity, and any concomitant knee pathology that may need to be addressed at the time of revision.

After complete evaluation, the surgeon must determine the next course of action. If there has been significant expansion of the existing tunnels, a 2-stage procedure with bone grafting of the tunnels can be utilized. This 2-stage bone grafting technique is also useful in the setting of anticipated convergence between the old and new tunnels. If the previous tunnels are clear of the anticipated new path, the surgery can proceed in one step without bone grafting being necessary. The other issue that the surgeon faces is the hardware that was used to fix the original graft. If this hardware will be in the way, then it must be removed intraoperatively. The basic technique for a 2-stage bone grafting procedure involves clearing and identifying the ACL footprints and previous hardware on both tibia and femur, removing hardware as necessary, and bone grafting the previous tunnels using either allograft or autograft harvested from the iliac crest (Stage 1). The patient is then given 4-6 months to allow incorporation of the bone graft, after which time the second stage can be completed in the same fashion as a primary ACL reconstruction.

A technique for a one-stage revision ACLR with non-anatomic initial tunnels is listed below. In most of these cases, the graft is placed either too vertical or too anterior, with the most common technical error being vertical placement of the femoral tunnel. Therefore, the femoral, tibial, or both tunnels may require placement in new locations compared to the previous tunnels. Here, we present a brief technique guide for single bundle revision ACL reconstruction. Of note, double bundle reconstruction is more commonly used in primary ACLR than revision surgery, and is beyond the scope of this chapter.

1. Diagnostic arthroscopy with removal of the remnant ACL and identification of appropriate tunnel positions on both tibia and femur. A notchplasty is also performed at this step.
2. The tibial tunnel is drilled first from an incision on the anterior tibia. If the previous tunnel does not converge with the new path, it can be left alone with or without hardware.
3. If the exit point of the tibial tunnel is in the appropriate position, and the surgeon wishes to create a new path for the graft, the "divergent tunnel" concept can be used. In this case, the new tunnel is created at a different angle (usually more horizontal) but with the same exit point inside the knee joint.
4. Now with the arthroscope, attention is turned toward the femoral ACL footprint on the medial aspect of the lateral femoral condyle. The old ACL stump is identified and the location of the new tunnel is defined.
    a. If the new tunnel is posterior to the old insertion, the previous hardware can be left in place. However, given that the new tunnel may compromise the posterior wall, intra-articular interference screw fixation may not be possible. In these cases,

fixation is achieved using a two-incision technique. This entails making a small incision on the lateral aspect of the distal femoral metaphysis to achieve fixation of the graft on the outer cortex of the femur.

b. If the previous femoral ACL stump is in the correct location, two options exist. Either the use of the "divergent tunnel" concept as listed above, or the previous hardware must be removed and the old tunnel utilized.

5. With the technique defined and the insertion site localized, the surgeon now must determine if the femoral tunnel will be drilled through the tibial tunnel (trans-tibial), from an accessory anteromedial portal, or retrograde with the two-incision technique (special reamer required). One advantage of the accessory portal or retrograde cutter is that there is more flexibility with regard to femoral tunnel placement. This enables the surgeon to bypass the previous fixation.
6. After drilling and subsequent reaming of both tibial and femoral tunnels, the graft is passed and the choice of fixation is chosen. In general, there are two types of fixation; interference screw or fixation to the outer cortex of the tibia/femur with suspension fixation of the graft.

Concomitant conditions

Meniscal Injuries

Meniscal lesions and ACL tears commonly occur together. The medial and lateral menisci act as shock absorbers in the knee, and the posterior horn of the medial meniscus is a secondary stabilizer to anterior-posterior translation of the tibia on the femur. Removal of even a small percentage of the meniscus (16-34%) can significantly impact contact forces seen across the knee, with up to a 350% increase in contact pressures in the medial compartment.[37] It is well published that the menisci influence both stability and load transmission,[38-41] with an interdependence between the ACL and medial meniscus.[42] Patients undergoing a primary ACLR with a medial meniscal-deficient knee have poorer outcomes than those without meniscal deficiency due to an increase in contact pressures and instability of the graft, and have higher rates of ACL failure and revision surgery.[17,37,43-46]

Clinically, patients may complain of instability coupled with joint line pain and mechanical symptoms, more commonly medial than lateral with chronic ACL deficiency. Standard radiographs are obtained, with or without an MRI to further evaluate meniscal and cartilage integrity. The findings on MRI for patients with meniscal deficieny demonstrate a lack of meniscal tissue seen in the affected compartment on both coronal and sagittal images *(Figure 2A and 2B)*.

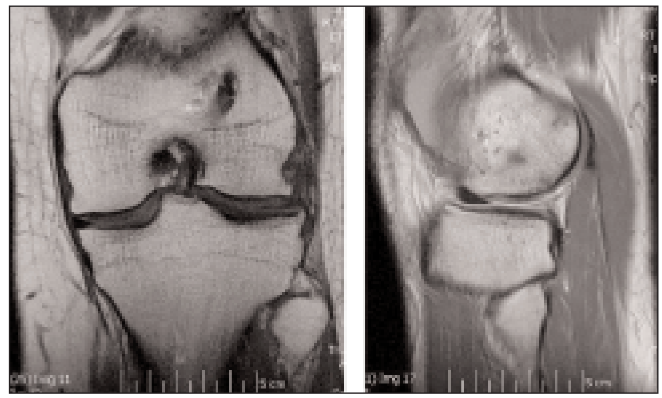

Figure 2a & b: *MRI findings in patient with previous ACLR demonstrating deficiency of posterior horn of lateral meniscus on T1-weighted coronal (2A) and sagittal (2B) images.*

To best preserve the knee joint long-term, maintaining intact menisci is of utmost importance in both index and revision ACL surgery. This creates a situation that necessitates management of both the ligament deficiency and the meniscal pathology. In the initial setting, unstable meniscal tears should be managed in conjuction with the primary ACLR. However, occasionally these tears will go undiagnosed or occur after the index surgery and can potentially contribute to the failure of the original graft. In these cases, the meniscal tear should be addressed during the revision reconstruction with one of the follow techniques: 1) Partial Meniscectomy, 2) Meniscal Repair, or 3) Meniscal Transplantation.

Meniscectomy

Meniscectomy is a straightforward procedure that requires debridement and/or removal of the affected portion of the meniscus. This provides good pain relief but will not offer additional stability to the knee. The effect of a meniscectomy on postoperative rehabilitation is minimal.

Meniscal Repair

Meniscal repairs, in contrast, will significantly influence the postoperative protocol during ACLR, resulting in limitations of ROM and weight bearing activities during the early stages of rehabilitation. In the setting of an ACLR, meniscal repair of torn menisci have been shown to have high rates of healing secondary to hematoma formation from ACLR,[47] however this depends on the type of tear. Tears involving the posterior horn of the medial meniscus can significantly affect anteroposterior stability and should be repaired in both primary and revision ACL procedures. Based on the type of tear, different techniques and instruments can be used. For example, the surgeon will choose to use either an "all-inside" or "inside-out" technique to repair the meniscus back to capsule. "All-inside" techniques use proprietary devices that secure the tear without having to make accessory incisions. "Inside-Out" techniques consist of a suture that is passed through the torn meniscus on a needle that is retrieved on the outside of the knee. Knots are then tied against the capsule through small incision. A modification of this using bone tunnels can sometimes be used to repair posterior horn avulsions of the meniscus. The ACL is then reconstructed using methods described above.

Meniscal Transplant

In cases where the meniscus has been damaged beyond debridement or repair, or a significant portion was previously removed with a meniscectomy, the only way to recreate the secondary stabilizing effect of the meniscus is through a meniscal transplantation. This can be approached in either a staged or one-time fashion along with the revision ACLR. Some surgeons elect to complete the meniscal transplantation first and then come back at a later date for the ACLR. Others elect to perform a one-stage meniscal transplantation. Briefly, meniscal transplantation requires thorough pre-operative planning to determine the size of the required allograft. Diagnostic arthroscopy is then performed with removal of the remnant meniscus and ACL. The anterior and posterior insertions for the meniscus are identified and a small arthrotomy is made on the affected side for placement of the graft. Preparation is then made for allograft docking, which can be done using two different techniques. The first involves use of a bone-bridge technique that involves placing a bone block with both the anterior and posterior meniscal horns attached into a slot created in the tibia and securing the meniscus to capsule using an inside-out meniscal repair technique. A screw may be used to fix the bone block to the tibia, if needed. This approach is commonly used for lateral meniscal allograft transplant. The second technique, more common with medial meniscal transplants, utilizes bone tunnels that require the anterior and posterior meniscal allograft to be attached to two different bone plugs. These are then secured in the tibia via suture fixation. The ACL graft is then inserted, tensioned, and secured, as previously described.

Cartilage Injuries

Cartilage injuries are common in patients with an acute ACL tear (25%) or chronic ACL deficiency (50%).[48] In the ACL-deficient knee, chondral injuries are classified as one of two types. The first is an acute chondral or osteochondral injury (i.e. osteochondral fracture) that is a result of the initial traumatic event, occurs more commonly in the lateral knee, and is likely due to transient subluxation of the tibia on the femur and/or altered mechanical loading. The second type is a degenerative lesion found in a chronically unstable knee, resulting from long-term sequelae of the original insult or altered biomechanics from chronic instability.[49] The natural history of chondral lesions is largely unknown, but is thought to be more favorable in young and skeletally immature individuals and less favorable in older patients.[50]

Clinically, diagnosis is often complicated because the patient with a chondral lesion will have symptoms that overlap with ACL deficiency. In the revision setting, cartilage injuries are difficult to diagnose and should be suspected in a patient with recurrent postoperative effusions or true mechanical symptoms following ACL surgery (with no evidence of meniscal damage during first surgery). Overall alignment is important to determine whether the patient is loading one compartment over another, and may implicate the need for osteotomy to create a more favorable environment for cartilage restoration. A flexed knee radiograph can best illustrate osteochondritis dissecans, posterior condyle degenerative disease, or posterior condyle osteochondral lesions.[49] MRI is valuable to further characterize lesions suspected on x-ray and allows for evaluation of defects that may significantly affect surgical intervention.[51]

Management of articular cartilage lesions can range from benign neglect to cartilage transplantation procedures. The choice of treatment should be based on a number of factors, including patient activity, age, depth and size of lesion, and intra-articular location. The literature is not clear with regard to what procedure is best for each patient or lesion. Thus, the treatment is surgeon-specific. Some of the primary procedures that can be considered in conjunction with a revision ACLR are listed below.

1. *Benign neglect* - often symptoms induced by cartilage lesions will improve over time, and improved knee stability after ACLR can help make these defects less symptomatic.

2. *Microfracture* - This is technically the easiest procedure and some data suggests that this can be as effective as the more extensive cartilage procedures.[52-54] It consists of creating small holes at the base of the lesion in order to stimulate and release pluripotent mesenchymal cells to aid in cartilage healing. At the time of the diagnostic arthroscopy during revision ACL surgery, the lesion is identified and the calcified cartilage layer is removed from the base of the defect. A microfracture awl is then introduced arthroscopically and used to create multiple subchondral holes that are spaced approximately 2-3 mm apart. When the tourniquet is released, there should be bleeding evident from these holes.

3. *Osteoarticular Transplant System (OATS)* - In this procedure, an allograft is used to fill the cartilage defect. This technique can be used for large and deep lesions. It is often done in a staged fashion in order to prevent stiffness from occurring post-ACLR. Intraoperatively, the lesion is defined and sized, and a corresponding plug is created in a femoral condyle allograft. This plug is then inserted into the patient's knee at the site of the cartilage defect and secured with a bioabsorbable screw.

4. *Autologous Chondrocyte Implantation (ACI)* - This technique requires harvesting and incubating the patient's own chondrocytes and requires a two-stage procedure. In the first procedure, cartilage biopsies are taken from a non-articulating portion of the patient's knee and sent to a proprietary lab. In the lab, the chondrocytes are isolated and reproduced exponentially. The patient is then taken back to the operating room, at which time the harvested cells are implanted into the cartilage defect via injection. A patch or glue is placed over the top of the lesion to secure the cells in place, with the goal of cartilage restoration. This procedure is currently undergoing significant changes in contemporary orthopaedics with the introduction of novel matrices that better hold the cells and mimic the natural structure of a cartilage matrix. Some of these techniques are being used to create a one-stage process that does not require the external incubation of a patient's cells.

MCL Injuries

Concomitant ACL and medial collateral ligament (MCL) injuries frequently occur together, and have been classically termed as two-thirds of the "unhappy triad," along with medial meniscal injury.[55] Recent studies report that MCL injury in the setting of an ACL tear can be as high as 20-38%.[56,57] Biomechanically, the ACL and MCL work together to limit anterior tibial translation and valgus instability.[58] The MCL complex, including the superficial and deep MCL, resists valgus and external rotation forces of the tibia relative to the femur, and acts as a secondary stabilizer to anterior translation.[59] The mechanism of injury is usually a pivoting-type injury followed by immediate swelling and pain on the medial side of the knee. The best physical examination test for MCL assessment is valgus stress testing at 30 degrees of flexion. If the knee is unstable at both 0 and 30 degrees of flexion, classically the patient will have both an MCL and cruciate injury.

To date, treatment of MCL injuries when part of a combined ACL-MCL injury is controversial, as some studies have demonstrated that the MCL will heal well with nonoperative treatment if the knee is protected, while others report poor results following nonoperative treatment.[60-62] Nevertheless, relative indications for repair or reconstruction of MCL injuries include three or more multiligamentous knee injury, intraarticular entrapment of the MCL, failure of nonoperative treatment, and bony avulsion of the MCL insertion.[58] In these situations, the surgeon may make the decision to repair the MCL during the revision ACL procedure.

Posterolateral Corner Injuries

PLC injuries are much less common than ACL injuries and rarely occur in isolation.[63,64] Combined PLC and ACL injuries can occur in athletes, but are also often the result of a high energy trauma. A missed diagnosis of a PLC injury in a patient undergoing primary ACLR can be devastating as this has been associated with failed ACLR.[7] The PLC consists of the lateral collateral ligament (LCL), popliteus tendon, popliteofibular ligament (PFL), and posterolateral capsule. The primary function of the PLC is to resist external tibial rotation and posterior translation of the tibia on the femur.[65] The primary function of the LCL is to resist varus forces.[65] Importantly, a deficient PLC significantly increases the stress in the graft after ACLR,[66,67] and this relationship may help to explain the association between untreated PLC injuries and failed ACLR.[68]

The mechanism of injury of a patient with a PLC injury is often a result of a hyperextension varus or hyperextension external rotation injury. On exam, the patient may demonstrate a dynamic varus thrust and varus laxity with the knee in full extension. Of note, varus laxity with the knee in 30 degrees of flexion may signify an isolated LCL injury, but is usually associated with a PLC injury as well. Specific tests include the dial test and external rotation recurvatum test, and an increase in external rotation compared to the contralateral side is suggestive of a PLC injury.[68] MRI is critical in the diagnosis of PLC injuries, with T2-weighted coronal images most helpful in evaluating the PLC *(Figure 3)*.[69]

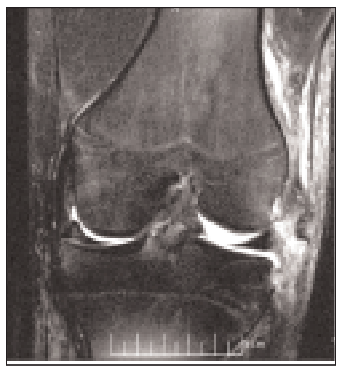

Figure 3: *T2 coronal MRI demonstrating posterolateral corner injury*

In patients with a failed ACLR and a PLC injury, operative treatment is recommended as poor outcomes, persistent instability, and early degenerative changes have been reported in patients with high-grade PLC laxity treated nonoperatively.[70] A detailed discussion of PLC injuries is beyond the scope of this chapter, but a brief overview is warranted. PLC injuries should be evaluated and potentially addressed as soon as possible after the injury. With regard to revision ACL surgery, there are a couple potential treatment algorithms:

1. Repair of the PLC in the first 2-3 weeks, aggressive physical therapy to regain knee motion, followed by a delayed reconstruction of the ACL.

2. Acute repair of the PLC and reconstruction of the ACL in the first 2-3 weeks. The risk of this treatment is postoperative stiffness.

3. Delayed reconstruction of both the PLC and ACL. This allows the patient to regain motion before operative intervention.

Malalignment

In patients with a failed ACLR, there may be associated pathology that is the result of coronal or sagittal malalignment overloading one compartment over another. A varus coronal malalignment is the most common and will briefly be addressed here. Varus malalignment will induce increased strain on the ACL graft, which may predispose either the original graft to have failed or possibly the revision procedure to fail prematurely in the future.[71] In addition to addressing the coronal deformity, it has been shown that a decrease in tibial slope (sagittal plane) can decrease anterior translation in the ACL deficient knee and possibly protect the graft, so the surgeon must keep sagittal plane deformity in mind as well.[72]

Clinically, a thorough history and physical exam should alert the clinician to alignment deformities. A full set of radiographs should be obtained, with an emphasis on standing films to determine the weight bearing axis. Sagittal plane alignment is evaluated by measuring posterior tibial slope angle on the lateral view (average 10º). MRI or CT may be ordered to look for intraarticular injuries, but are not essential in evaluating alignment.

For varus malalignment, management consists of a valgus-producing high tibial osteotomy (HTO) such as a lateral closing-wedge osteotomy or medial opening-wedge osteotomy, with both types reported to have similar outcomes.[73] In the revision setting, consideration should be given for either a staged or concomitant HTO with ACL revision procedure. Many surgeons prefer to use the medial opening-wedge osteotomy over the lateral closing-wedge osteotomy secondary to the belief that opening-wedge procedures allow for the correction of larger deformities in both the coronal and sagittal planes.[74,75]

Rehabilitation

Following revision ACLR, the ability for a patient to return to sports or pre-injury level of function depends largely on postoperative rehabilitation.[76-78] Revision ACLR poses a significant challenge to both the surgeon and PT. Rehabilitation is determined on a case-by-case basis, specific to each patient. Generally, the rehabilitation for an ACL revision will be slower than for a primary reconstruction.[74,79] To date, there is little consensus available in the literature on the content, timing, and specific goals for rehabilitation after revision ACL surgery.

To fully comprehend the rationale for developing patient-specific rehabilitation goals after revision surgery, it is important to understand the history and progression of primary ACLR rehabilitation over time. From a historical perspective, rehabilitation of ACLR has changed dramatically since the introduction of the surgery in the early 1900s. Inconsistent and poor patient outcomes throughout the twentieth century led to the formation of standardized protocols in the preoperative and postoperative periods of primary ACL surgery. In the 1970s and early 1980s, many authors recommended conservative rehabilitation with 6-8 weeks of immobilization, 8-12 weeks of crutch use, and an early emphasis on flexion rather than extension.[80-83] Some recommended avoiding early quadriceps contraction to protect the knee,[80,81] and many prohibited return to sport for at least 12 months postoperatively.[81,82] Throughout the 1980s, complications following ACLR such as arthrofibrosis, quadriceps weakness and graft failure, in addition to a lack of preoperative therapy to regain full ROM, led to changes resulting in the protocol-based system in place today for primary ACLR.

Rehabilitation Goals for Revision ACLR

Currently, goals of rehabilitation following revision ACLR are similar to those following primary surgery but at a slower pace and more individualized. While the long range goals following revision ACLR are similar to primary ACLR, a number of reports indicate a return to preinjury level of function may be unrealistic.[6,11,84] Basic principles of primary ACLR rehabilitation are well-reported in the literature.[85-88] Rehabilitation following primary ACLR emphasizes immediate postoperative weight bearing and ROM exercises, obtaining full passive knee extension, restoration of neuromuscular control, and utilizing perturbation exercises with the goal of improving overall outcome.

Postoperative rehabilitation for patients following revision ACL should be individualized and take into account a multitude of factors. Factors to consider revolve primarily around surgical techniques and graft selection, physical performance factors, occupational demands, patient characteristics (age, body mass index, etc.), and patient goals/expectations. The presence of concomitant procedures in revision ACLR is another key component that will impact postoperative rehabilitation. It has been reported that less than 10% of patients undergoing revision ACLR have normal meniscal or articular cartilage at the time of their revision surgery.[89] Therefore, reconstruction of secondary stabilizers and articular cartilage serve as the most common factors necessitating individualization and modifications beyond a standard primary ACLR.

Rehabilitation for patients following revision ACLR can be broken into general time lines focusing on key rehabilitation goals respective of tissue healing guidelines. While aggressive rehabilitation and expected early recovery following index ACLR has become the norm, this is the absolute wrong approach to take following revision ACLR. Multiple reports indicate that overaggressive rehabilitation can result in early graft failure (during the first six months) as well as the late onset (beyond six months) of laxity.[90-92] The revision ACL patient will benefit from a slower, more cautious rehabilitation program for several reasons. First, as previously stated, there is an increased utilization of allograft tissue for revision ACLR, which negates harvest site morbidity but takes longer for bone-to-graft healing and revascularization compared to autografts,[93] and the sterilization process for allografts can cause delayed graft incorporation.[94] Therefore, to ensure adequate biological fixation, a slower rehabilitation program is recommended.[74,79] In addition, depending on the mechanism of injury, a failed ACLR may have been a result of premature return to activity and/or lack of adequate neuromuscular control following the index surgery, and an overly cautious approach may conceivably decrease the risk of a second ACL failure. Finally, the vast majority of revision patients have concomitant intra-articular injuries that will either be addressed surgically and need time to heal, or are not amenable to surgery and therefore require a slower rehabilitation approach. In the following sections, a general protocol for postoperative rehabilitation following revision ACLR will be discussed. It must be stressed again that, in clinical practice, treatment progression should be determined on a case-by-case basis, specific to the patient's pathology, treatment, rehabilitation needs, and long-term goals.

Rehabilitation Protocol (Table 1)

Phase I: Initial postoperative phase (0-4 weeks)

The initial post-op rehabilitation phase focuses on minimizing arthrogenic muscle inhibition (AMI) by way of pain modulation and effusion reduction, attainment of neutral extension, and early quadriceps activation. The general time line for this phase of rehabilitation is two to four weeks following surgery. A knee ROM brace, locked in full extension, is advised for weight bearing as tolerated (WBAT) crutch ambulation. ROM exercises can be performed passively or actively with assistance. Critical to early attainment of desired 0º-0º-90º ROM is educating the patient on resting with the knee fully extended as opposed to the often desired position of resting with a pillow under the knee. While full passive extension is a key goal in the early post-op period following index ACLR, this is not aggressively pursued following revision ACLR, settling for neutral extension and protecting the graft. Effective effusion management during this early stage will promote easier attainment of knee ROM. Conversely, an over-aggressive attempt to gain ROM in this early stage is

Table 1: *General progression of exercise*

	PHASE I 0-4 WKS	PHASE II 2-8 WKS	PHASE III 6-12 WKS	PHASE IV 12-20 WKS	PHASE V 20-36 WKS	PHASE VI 36-54 WKS
EXERCISES						
Weight bearing[a]	o	o	o			
ROM[b]	0-0-110	0-0-120	0-0-130	0-0-135	Symmetrical knee flexion	
Joint mobilizations	o	o	o			
Modalities	o	o	o	o		
Gait Training	o	o	o	o	o	
OKC exercises	o	o	o	o	o	
CKC exercises	o	o	o	o	o	o
Proprioceptive exercises		o	o	o	o	o
Core exercises		o	o	o	o	o
Cardio exercises		o	o	o	o	o
Plyometric exercises					o	o
Agility exercises					o	o
Reaction drills						o
Sprinting						o
ROM Brace[c]	o	o	o			
Functional brace				o	o	o

a. **Weight bearing modifications will be necessary for patients following concomitant repair or reconstruction procedures.**
b. **ROM modifications will be necessary for patients following concomitant repair or reconstruction procedures.**
c. **ROM bracing will most commonly be utilized during the first six weeks. In the case of concomitant procedures ROM brace wear may be extended into the 3rd phase of rehabilitation.**

likely to produce increased pain, effusion, and resultant increased AMI/reduced volitional quadriceps activation.

Weight bearing status during the first six to eight weeks following revision ACLR will be delayed and begin with toe touch weight bearing (TTWB) or non weight bearing (NWB) for patients with special situations such as repair of complex meniscal tears, repair of an osteochondral lesion, or meniscal transplant, which are discussed in another section. Progression of ROM during this phase may also be restricted during the early recovery period. Communication with the orthopedic surgeon is essential for the therapist to ensure non-deleterious progression of knee flexion during the early healing period.

Muscular activation exercises during this stage are typically focused on quadriceps setting (QS), straight leg raises (SLR), and hamstring activation. The ability to perform an effective quadriceps contraction in full extension is an important early step in promoting patellofemoral joint mobility and preventing infrapatellar contracture. There is a growing body of evidence on regional interdependence and the impact of an injury at one location impacting neuromuscular control and activation at locations proximal and distal to the injury. For this reason, the authors recommend screening of prior musculoskeletal injuries of the lumbar spine and lower extremities to minimize the potential for compensatory, and potentially deleterious, movement patterns due to limited mobility and/or neuromuscular control in these areas. For example, limitations of motion in the ankle or hip are likely to contribute to abnormal movement and loading patterns imposed upon the knee. The early stages of rehabilitation are the preferred time periods to correct these deficits before moving on to activities of greater demand on the lower extremities. Early activation of the hip and ankle musculature may be helpful in preventing indirect deleterious impact from knee surgery. This may be achieved by performing SLRs, prone hip extension with the knee bent to 90 degrees, and resisted ankle dorsiflexion and plantarflexion exercises either in standing with reduced weight bearing or utilizing resistance bands. Active heel slides or standing knee flexion to encourage hamstring activation may also be instituted during this period.

Closed kinetic chain (CKC) exercises during this stage of rehabilitation will be predicated on weight bearing limitations for the patient. If the surgery did not entail concomitant ligamentous, meniscal, or osteochondral procedures, then early weight bearing may progress from TTWB to WBAT. Additional CKC exercises will consist of standing weight shifts while wearing the knee brace in order to ready the leg for full weight bearing. Additional CKC exercises may include heel raises, mini-squats, or limited range squatting beginning on a reduced weight bearing device (i.e. Total Gym).

With the exception of ice and neuromuscular electrical stimulation, there is a lack of evidence regarding utilization of modalities during the early stages of rehabilitation. Ice application has been shown to reduce AMI,[95] but has not been demonstrated to reduce the use of oral pain medications.[96] Neuromuscular electrical stimulation is commonly employed in the early stages of rehabilitation and has been shown to accelerate quadriceps femoris recovery and normalization of gait parameters.[97,98]

Patient education throughout rehabilitation must be emphasized. There is significant patient variability in the early postoperative phases with regards to degree of knee effusion, pain, and ease of gaining ROM. Regardless of how well a patient is doing at this early stage, it is paramount that they follow prescribed weight bearing, ROM, and exercise limitations to prevent undue stress on the healing soft tissues. Given the impaired knee joint neurophysiology, excessive strain imposed on the repaired tissue(s) may not manifest in an immediate increase in pain or swelling, but a latent resultant loss of knee stability or persistent mechanical symptoms that may contribute to suboptimal outcomes.

Phase II: Subacute postoperative phase (2-8 weeks)

Moving into the subacute phase, which typically spans from two to eight weeks, rehabilitation can be carefully advanced assuming the patient's pain is well controlled and knee joint effusion diminishes over time. This period is marked by progressive increase in weight bearing, mobility (ROM), incorporation of low level cardiovascular conditioning exercises, and neuromuscular control exercises.

Barring weight bearing limitations due to concomitant soft tissue or osteochondral restorative procedures, full weight bearing ambulation should be tolerated beginning around two weeks postoperatively. Gait training with the knee ROM brace (using a 90º block) is advocated to limit non-sagittal plane stresses on the knee joint and to protect against forceful knee flexion should the patient experience an uncontrolled knee flexion movement. Gait training exercises are focused on patient awareness of normal lower kinetic chain movement, in particular the swing phase of gait where many postoperative patients demonstrate movements of the hip and ankle to compensate for limited knee flexion. Exercises that can assist in regaining this swing phase movement include marching in place with progressive increases in knee flexion, and treadmill walking with verbal feedback from the therapist or visual feedback using mirrors. If the patient's gait is altered due to pain, walking in a reduced weight bearing condition is recommended. Options include aquatic therapy or body weight reduced treadmill training (i.e. Harness unweighting or Alter-G treadmill). While gait training in a pool is effective at unweighting the patient, the forces on the limb moving through the water do not mimic those of normal gait and therefore may not result in optimal carry-over to normal land-based walking. Gait training on the Alter-G cannot be done with the ROM brace as the compression shorts are unable to maintain the required seal necessary to enable the build-up of air pressure for unweighting.

Pursuit of greater knee flexion can be achieved by performing supine wall slides, active-assisted heel slides, and prone or standing hamstring curls. When performing the wall slide it is important to advise the patient in proper performance of the exercise, emphasizing return to the starting position by using the uninvolved leg to avoid unwanted anterior tibial shear stress imposed by open chain quadriceps contraction while extending the knee from 30º to full extension. Utilization of each of these methods is recommended to encourage active knee flexion. Aggressive passive knee flexion exercises, i.e. pulling the knee into flexion with a strap or assisted flexion by a PT, should not be necessary to advance knee flexion. These techniques commonly result in transient increases in knee flexion followed by counterproductive increases in pain and effusion and no sustained ROM improvement. Neutral knee extension should have been achieved in the acute postop period but must continue to be emphasized during this phase. Passive extension with a towel under the ankle is preferred but caution must be exercised in preventing passive hyperextension, as mentioned in the acute phase of rehabilitation. For this reason, the authors do not advocate use of the prone hang or extension boards, both of which are commonly employed following index ACLR to ensure symmetrical bilateral knee extension. This is also a good time to screen the adjacent joints in the lower extremity (hip and talocrural), as well as the lumbar spine, for mobility limitations. Such limitations would be best addressed early in rehabilitation to enable effective loading of the adjacent joints and prevent potential compensatory movement at the tibiofemoral joint.

The implementation of neuromuscular conditioning exercises is dependent upon weight bearing status. In patients requiring limited weight bearing throughout this phase of rehabilitation, the neuromuscular conditioning exercises remain the same as in phase I. If the patient is able to advance with WBAT throughout this phase then a greater variety of neuromuscular training exercises can be introduced. Exercises may include open kinetic chain (OKC) exercises, CKC exercises, integration of core strengthening, and gait training.

Closed kinetic chain exercises may be implemented with progression centered on awareness of soft tissue healing time lines and close observation of quality of patient movement. Enabling a patient to progress CKC exercises through greater ROM, volume, and/or resistance without strict adherence to proper technique can produce compensatory movement patterns that become difficult to correct. Initial CKC exercises include terminal extension with therband resistance *(Figure 4)*, split squat *(Figure 5)*, heel raises, hip dominant squatting, and leg press (limiting ROM from 0º to 90º of knee motion). Forward and lateral step-ups and step-downs beginning with a two to four-inch step height may also be implemented. Balance exercises, beginning with static single leg stance with eyes open, may begin when the patient demonstrates good volitional quadriceps control (i.e. SLR without extension lag and solid QS), hip and core stability of the pelvis (i.e. absence of Trendelenburg sign on single-leg stance), and is pain free with full weight bearing.

Open kinetic chain exercises may, in addition to continuation of SLRs, QS, and hamstring curls from

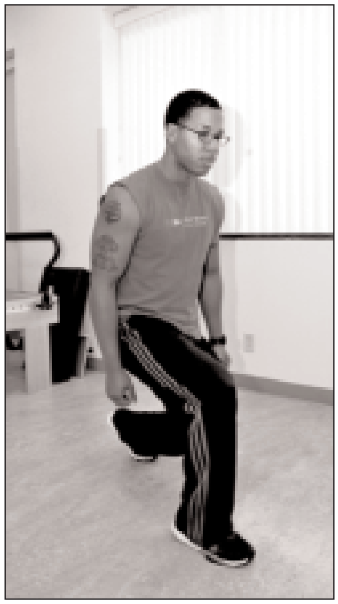

Figure 4: *Closed kinetic chain terminal extension*

Figure 5: *Split squat.*

Phase I, include isometric knee extension exercises in the 90º-60º of knee flexion position and active knee extension from 90º-45º. Research indicates that OKC knee extension exercises performed in a limited ROM (from 90º-35º) do not produce injurious levels of strain on the ACL graft.[99] OKC knee extension from 30º to 0º with a load applied at the ankle, on the other hand, has been demonstrated to produce unwanted levels of strain on the ACL graft.[100,101] Incorporation of OKC knee extension exercises beginning around six weeks has been associated with better outcomes in comparison to rehabilitation focused solely on CKC exercises.[102] Therefore, the authors recommend incorporating OKC knee extensions only following patient demonstration of adherence to the limited range and understanding of the potential adverse effects should they proceed outside the 90º-45º range of knee flexion.

Core strength and stability play an important integrated role in optimizing return to high level activities and diminishing the risk of reinjury.[103,104] In this phase of rehabilitation, patients may begin with hook lying side planks *(Figure 6)* progressing to standard side planks, front plank, and bridging. In performing the bridge exercise, the therapist should emphasize gluteal muscle activation and control of the movement, not hamstring activity. When the patient can effectively perform a standard bridge, progression forward with therapy may include shifting to single-leg support *(Figure 7)* or performing a single-leg bridge.

Figure 6: *Hook lying side plank.*

Figure 7: *Bridging with single leg support.*

Low level cardiovascular conditioning exercises are important to initiate in this subacute phase to minimize unwanted deconditioning. Upright stationary cycling can be initiated with an emphasis on quality of movement and a gradual progression of volume (time) and intensity (speed and resistance). While the stationary bike can be utilized to gain knee flexion, this should be done with caution (i.e. performing careful 1/2 to 3/4 revolutions in a controlled manner), rather than employing aggressive and compensatory movement patterns. Aquatic therapy can be effectively implemented during this stage as well. Buoyancy provided by pool-based exercises can enable improved quality of weight bearing exercises (i.e. gait training and neuromuscular exercises) and advancing knee ROM. The upper body ergometer (UBE) is another recommended conditioning exercise and the only one that can be safely utilized during this early rehabilitation period for patients who are relegated to NWB status due to concomitant meniscal, osteochondral restoration, or ligamentous repair.

Phase III: Initial neuromuscular conditioning phase (6-12 weeks)

Rehabilitation from approximately six to twelve weeks is usually focused on increasing variation and intensity of strengthening exercises, pursuit of end range flexion mobility, and preparation for jogging and early agility exercises. Paradoxically, it is during this same time period wherein the ACL graft is entering its weakest stage in regards to resistance to strain and greatest risk of lengthening (stretch out). It is for this reason, as well as the need for an extra measure of caution in the revision ACLR patient, that the authors take a slightly different approach during this phase of rehabilitation. Since most patients undergoing revision ACLR have a concomitant procedure or altered intra-articular tissue, delaying impact loading exercises during this stage is recommended until adequate neuromuscular control (strength and endurance) can be developed. This slight delay in impact loading should also improve knee joint homeostasis, which has been reported to take longer than one year in many patients following index ACLR.[105]

The ROM brace will be discharged early on during this stage except in the most severely involved cases (i.e. multiple ligamentous repair/reconstruction and large osteochondral repair). Knee ROM during this period should be neutral extension and greater than 120° of flexion by the 12-week mark. While symmetrical knee extension is not stringently pursued, when hyperextension is present on the uninvolved knee, it is important to regain neutral extension. Inability to regain neutral extension will result in an aberrant pattern of quadriceps contraction (quadriceps recruitment coupled with knee flexion). If this persists, the patient is likely to experience sustained quadriceps atrophy and anterior knee pain due to the increase in patellofemoral joint forces when the knee remains in the flexed position. Passive stretching by the rehabilitation specialist into end range knee flexion is not recommended. Delays in gaining knee flexion are most commonly due to residual knee effusion which frequently worsens with overaggressive end range stretching. Resolution of knee effusion coupled with the patient's performance of stretching into knee flexion is usually effective in regaining symmetrical knee flexion.

Normal walking gait should be achieved during this time period. Exercises to assist in this goal include forward and lateral walking using a floor ladder, cones, or small hurdles (6-8″). Gait training during this period may also advance to include lateral stepping and backward stepping. Additional gait training should include critical observation and progression of the step-up and step-down exercises to ensure appropriate mechanics.

Progression of neuromuscular training will become more diverse during this period, emphasizing neuromuscular control and endurance at a low intensity of loading in order to protect the weakened graft. Continued progression of core and proximal lower extremity exercises will be emphasized. Core exercises such as front planks, side planks, bridging on a physioball, and planks with altered base of support *(Figure 8)* may be incorporated. Exercise progression is focused on increasing the duration of exercises (i.e. 10 x 10 second hold on side planks to 10 x 20-30 seconds). Quad setting and straight leg raises (SLRs) may be part of a very brief warm-up but in general the patient

Figure 8: *Static core exercise on an unstable base of support.*

should be advanced beyond these exercises and, in the interest of maximizing time spent on rehabilitation, these are usually not a part of this phase of rehabilitation. OKC exercises will consist of hamstring (HS) curls, leg extensions (isometrics or 90°-45°, and the 4-way hip machine. CKC exercises will be the focus of this phase.

Emphasis on CKC exercises include 1/2 to 3/4-depth hip dominant body-weight squatting, rear step lunges, and leg press (limiting ROM to 0°-90° of knee motion). As long as the patient demonstrates normal step-up and step-down mechanics with a 4″ step, the step height may increase to 6-8″. Eccentric loading has been demonstrated by Gerber et al[106] to be an effective and safe means of increasing lower extremity strength following ACLR, and may be implemented in this stage. Performing eccentric squatting with a device that allows limited body weight/resistance enables the patient to get the technique correct before increasing intensity. This may be done using a Total Gym, Shuttle trainer, or strap system in standing *(Figure 9)*. While eccentric loading has been imposed earlier in the rehabilitation with leg presses, hip dominant squatting, and step downs, this focused eccentric loading will occur through a larger ROM and return to the starting position will be performed by using the uninvolved lower extremity or the upper extremities. The PT should closely observe the eccentric loading in single leg stance to ensure avoidance of dynamic knee valgus and maintenance of the hip dominant squatting technique. Single leg stance balance exercises are progressed to include standing with eyes closed and open accompanied with head movements in various directions.

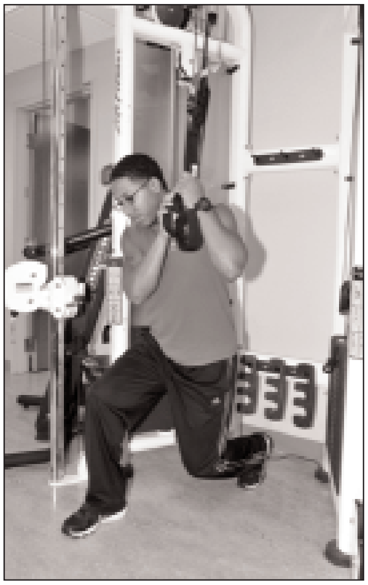

Figure 9: *Eccentric squats in single leg stance with off-loading.*

Cardiovascular training during this period may include free-style swimming (no breaststroke kicking), stationary cycling of increasing difficulty (varying the intensity or pre-set program), and the UBE. If the patient exhibits good neuromuscular control and absence of effusion, s/he may be allowed to begin using the elliptical or stair machine. During the initial attempt at all new exercises, the PT should observe for quality of movement and absence of effusion as indicators for readiness to progress with exercises. Subtle joint effusion often manifests as a decreased comfort, or a feeling of tightness, at the available end range of knee flexion or extension. Patient report of this symptom necessitates a reduction in exercise volume and intensity.

Phase IV: Intermediate neuromuscular conditioning phase (12-20 weeks)

During this phase, neuromuscular conditioning exercises will be further advanced with respect to soft tissue healing and knee joint homeostasis (pain and effusion). The ACL graft will be gaining in both strength and tolerance to loading during this stage; however, the graft remains susceptible to stretch-out from overaggressive rehabilitation. While standard ACL rehabilitation typically advances to impact loading exercises such as jogging and agility training, during this phase a more conservative approach is recommended following revision ACLR.

Regardless of the concomitant procedures performed, ROM during this phase can be advanced as tolerated to include pursuit of symmetrical knee flexion. It is the authors' recommendation to continue with gentle end range knee flexion stretching by the patient, avoid rotational moments (i.e. the hurdler's stretch), and maintain neutral knee extension.

Normal walking gait should be present by the early period of this phase. Further gait analysis may include feedback on gait quality during stair ascent and descent. Also, observation of changes in gait following neuromuscular fatigue (in clinic rehabilitation) can provide an indication of key areas (movements or muscles) that should be focused on in further neuromuscular training. Form-walking exercises are incorporated to include high knee walking, hurdle walking, and lateral stepping. Useful training aids may include an agility ladder, cones or hurdles. Resisted walking with an elastic band place around the patient's torso or lower extremity can also effectively increase the demand for neuromuscular control.

Strength training during this phase will continue to incorporate OKC and CKC exercises. OKC knee extensions should still be performed in a limited ROM (90º-45º) to minimize anterior tibial translation stress on the healing ACL graft. Hamstring curls and the 4-way hip machine may continue to be utilized, but the focus of the neuromuscular training during this phase is on CKC exercises. Throughout performance of CKC exercises, the patient's focus should be on avoidance of dynamic knee valgus and quality, over quantity, of movement. To implement this approach, the authors recommend performing three to five sets of each exercise beginning with a duration of 20 seconds.

Progression of the exercise may be done by manipulating numerous training variables. Manipulation of training variables may include increasing the duration (i.e. from 20 to 30 seconds without exceeding 45 seconds), increasing the amount of joint excursion (i.e. step length on lunges, depth of leg press/squatting, or height of steps), increasing speed of movement, incorporation of multiple movement patterns in the same exercise (i.e. multi-directional lunges), and adding greater amounts of resistance to the exercise (i.e. holding a medicine ball or dumbbells).

Hip dominant squatting continues to be emphasized during this period and is progressed to include holding of dumbbells or other weights. Lunges performed in multiple directions are recommended for increased neuromuscular demand. While the forward lunge is most commonly performed, the addition of lateral lunging, 45° anterolateral and posterolateral lunges, and rear step lunges are effective means to further develop movement awareness and neuromuscular control in preparation for greater functional demands. Toward the later period of this stage, if there is no effusion and minimal pain, patients may begin training in jump landing. This will prepare them for the next phase of recovery. The authors' preferred method for this type of training involves use of a Total Gym or Shuttle device to enable limited weight bearing, followed by a progression to stepping off of a four to eight-inch step and focusing on a soft landing, double-leg landing, and avoidance of dynamic knee valgus.

External resistance utilizing free weights, medicine balls, or resistance bands can serve as additional training stimuli to further develop neuromuscular control. Increased resistance during squatting has been shown to result in no greater strain on the ACL graft than unweighted squatting.[107] Exercises start with the patient holding weights at hip level (arms extended at the side) and progress to holding the weights at shoulder level while performing the CKC exercises. Traditional back squats (barbell across the back) during this phase are not recommended since they often result in altered movement patterns and potential injurious stress on the healing graft. To further increase the neuromuscular demand, weights may be utilized unilaterally (i.e. squatting or lunging with a weight held only on one side) or asymmetrically (i.e. holding 10 lbs in one arm and 25 lbs in the other arm). This asymmetrical training will increase the demands for integrated core and proximal neuromuscular control while performing sound technical movement patterns.

Progression of core exercises may include wood chopper and diagonal woodchoppers, physioball exercises to include hamstring curls and knees to chest *(Figure 10)*, squatting or lunging with over head reaching or forward reaching, and push-ups with three points of support. These exercises will create additional demands for core stabilization while performing coordinated movement of the extremities. Continuation of swimming, elliptical, biking, and the stair climber machine are the primary means for increasing general conditioning during this phase. In order to vary the training stimulus, frequent changes in exercise selection and/or changing the pre-selected exercise program on the machines are advised.

Figure 10: *Core exercise with lower extremity movement demand.*

Phase V: Late stage neuromuscular conditioning phase (20-32 weeks)

This late stage of rehabilitation is characterized by the beginning of more complex movement training and exercises that will mimic the demands of the patient's chosen occupation, recreation, or competitive sport. Until this stage, rotational forces about the knee have been avoided, as have exercises likely to impart dynamic valgus stress on the knee. For patients with extensive meniscal repair, meniscal allograft, and extensive articular cartilage repair, we will delay incorporation and progression of these exercises until the around the 24 week mark.

While ROM of the knee should be near symmetrical at this stage, it is important to continue gentle stretching to achieve end range flexion. As was noted in the early rehabilitation phase, it is also important to ensure good ROM in the adjacent joints (talocrural and hip) as well as the lumbar spine. Limitations in these locations are likely to contribute to subtle and potentially cumulative adverse stresses on the knee joint.

Neuromuscular training during this latter phase will include increasing resistance and volume of the previously mentioned exercises. Variations frequently added include walking lunges with trunk and upper extremity movement (i.e. torso rotation or overhead reaching), split squat stance with overhead presses, and stair climbing while holding weights. OKC exercises may continue to be utilized for isolated muscle strengthening. The OKC leg extension exercises will now advance to a 90º-30º ROM. CKC exercises may include the star excursion exercise and anteromedial lunging. These exercises will produce valgus forces to the knee so the PT must ensure patient understanding and adherence to avoidance of knee valgus.

Figure 11: *Core exercise with increased lower extremity stability demand.*

Core and lower extremity stability training will continue throughout this phase *(Figure 11)*. Primary modifications include an increase in single leg support exercises and modification of the training surface. Examples of exercises include the inverted hamstring *(golfer's lift, Figure 12)*, Nordic hamstring *(Figure 13)*, and single leg balance while performing upper body exercises (i.e. plyoback toss, overhead pressing, or woodchoppers). Perturbation exercises may be incorporated during this phase as well. Methods include use of resistance bands, standing on an unstable surface (i.e. foam pad), and modification of visual and vestibular input. Resistance band perturbation can include application of carefully imposed valgus stress to the lower extremity by placing

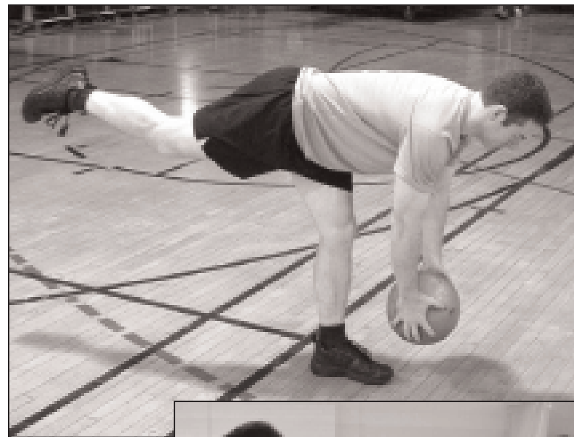

Figure 12: *Inverted hamstring*

Figure 13: *Nordic hamstring*

a resistance band above or below the knee joint while performing squatting or lunging movements or around the trunk during the performance of gait training activities (forward walking/high stepping or lateral stepping). Visual and vestibular modifications can include single leg balance exercises with eyes open or closed or incorporation of rotational, diagonal or vertical movement of the head and neck while performing lunges or single leg stance exercises to further enhance integrated neuromuscular control.

Endurance exercise training may advance to include a walk-jog progression. For patients with concomitant meniscal repair, meniscal transplant, or osteochondral repair, jogging will be initiated in a pool or using a reduced weight bearing device (i.e. Alter G treadmill). Full weight bearing jogging will not commence until 24-28 weeks. The authors prefer initiation of jogging on a treadmill to enable visual and auditory feedback for the patient. Focus is on a symmetrical gait pattern as research has demonstrated a high prevalence of persistent gait asymmetry for up to one year following ACLR.[108] Form running drills will also be incorporated to include high knee walking progressing to high knee jogging, side shuffle, and skipping. Toward the latter period of this phase, change of direction running drills (i.e. figure-of-eight jogging, T-drill, 45° and 90° turns) may be incorporated.

Phase VI: Return to unrestricted activity phase (32-54 weeks)

The final phase of rehabilitation is marked by analysis of the sport and occupational demands ("needs analysis") that will be required for the patient to return to their desired level of activity. While numerous return to play guidelines have been reported, questions remain regarding the time line for safe return to preinjury activity levels and the long-term ramifications of high demand activities on the knee joint.[109] Research indicates that asymmetrical movement patterns with squatting and jumping often persist for over a year following ACL surgery.[110,111] Therefore, emphasis continues to be placed on quality of movement and attaining the necessary neuromuscular control and endurance to promote safe return to activities. Functional testing is recommended in the early portion of this phase to provide feedback on areas of deficiency. Example of functional testing may include, but are not limited to, single-leg hop tests, vertical jump, the Functional Movement Screen, and agility tests. Isokinetic testing may also serve as a useful adjunct in evaluating symmetry of hamstring and quadriceps strength and endurance. The inclusion of functional (performance) testing following fatiguing activities has been shown to provide insight to true limb symmetry, altered loading patterns of the lower extremity and readiness for return to sport; therefore, this should be considered when making return to sport determinations.[112,113]

Neuromuscular training may include a return to traditional weight training exercises (i.e. front or back squats, deadlifts, and Olympic style lifting) depending on the patient's occupational/sport demands. Jump (plyometric) training may be advanced during this phase to include box jumps of progressive levels of difficulty or incorporation of changes in jumping direction if necessitated by the needs analysis.

Transitioning from pre-planned to reactionary movement drills should also be incorporated. Research has shown that neuromuscular activity, and the associated stresses imposed on the joints of the lower extremity, change when performing reactive drills versus pre-planned movement patterns.[114] Therefore, in order to maximize readiness for return to full function and minimize risk of re-injury, reaction drills should be implemented. Reaction drills may include change of direction drills with jogging/running and incorporation of jumping and hopping.

Final return to running activities during this phase should be focused on the needs analysis of the individual patient and consider each patient's psychological readiness for return to preinjury levels of activity.[115, 116] Considerations should include the surface or terrain the patient will be running on and the need for inclusion of sprinting, high speed lateral movements (i.e. basketball), and backwards running.

Rehabilitation in Special Situations: Concomitant Injuries

While isolated ACL revision surgery requires similar, but slower, rehabilitation to that of primary ACL surgery, the majority of revision surgery is associated with concomitant injuries. Previously, a thorough protocol for the specific phases of revision ACLR rehabilitation was presented. Here, special situations associated with revision surgery will be discussed, with a brief description of unique rehabilitation techniques for concomitant injuries.

Meniscal Injuries

Following meniscal repair or transplantation, the patient is typically made NWB for the first two weeks after surgery, with the initiation of full weight bearing at four weeks in extension only.[38,44,117] Open chain exercises are avoided, and ROM is limited from 0°-90° for the first six weeks to prevent excessive strain on the healing tissue.In patients with extensive medial meniscus repair, resisted hamstring work during the first 8-10 weeks is cautioned due to the insertion of the semimembranosus into the posterior horn of the medial meniscus. Progression of knee flexion beyond 90° will usually start at about the six-week mark and an increase of approximately 10° per week is within expectations. For patients with extensive meniscal repair or meniscus allograft, often Phase V (see above) of the postoperative rehabilitation stages will be delayed until the around the 24th week. Ultimately in patients undergoing meniscal transplantation, return to full activities is limited to light sports as meniscal allograft transplantation with ACL revision is a salvage procedure. This should be emphasized during the preoperative education period and reiterated by both surgeon and PT throughout the postoperative course.

Cartilage Injuries

The decision to perform revision surgery concurrently with a chondral resurfacing procedure such as microfracture, OATS or ACI, has a profound impact on rehabilitation protocol. Following microfracture, rehabilitation should focus specifically on 1) immediate motion, and 2) protected weight bearing. Continuous passive motion is typically started on the day of surgery and is continued for a minimum of eight hours per day for six weeks (machine set at 1 cycle per minute, beginning at 45° of flexion and advancing as tolerated). Weight bearing is protected for the first six weeks, after which time it may be progressed as tolerated. If the patient undergoes microfracture to the patellofemoral joint, the patient may occasionally be allowed immediate full weight bearing in a hinged knee brace that allows limited motion from full extension to 20° of flexion.[49] General strengthening exercises begin at six weeks. Just as in patients with extensive meniscal repair or meniscal allograft, often Phase V of the previously described postoperative rehabilitation course may be delayed until the around the 24th week. High impact activities such as running, jumping and pivoting should be avoided for four months, and return to athletic activity is often delayed until 6-9 months postoperatively. This delayed return to sport provides the articular surface with a more gradual exposure to sport-specific forces, avoiding damage to healing and maturing cartilage.

Following OATS or ACI procedures, weight bearing is typically protected for approximately six weeks, followed by six weeks of progressive weight bearing. Following ACI in particular, flexion will be limited to <90° for the first six weeks. High impact activities in these patients are to be avoided for six months.[49]

MCL Injuries

Regardless of the specific management of the MCL (operative versus nonoperative), postoperative management of the patient with ACL revision reconstruction and a torn MCL is usually dictated by the ACL.[58] The knee is protected in a hinged knee brace (+/- varus mold) for six weeks and follows a similar protocol as for revision isolated ACLR. If restoration of medial stability is asymmetrical at the six-week mark, the authors recommend continuation of protective knee bracing for an additional six weeks and strict avoidance of exercises that impart valgus strain on the knee.

Posterolateral Corner Injuries

The primary goal following operative fixation of the PLC in revision ACLR is to protect the repair or reconstruction of the PLC with the use of a hinged knee brace locked in extension throughout the immediate postoperative period.[68] In these patients, strict avoidance of varus stresses to the knee and limitation of knee extension past neutral (i.e. avoidance of hyperextension) is paramount to prevent unwanted laxity. The physical therapy program is advanced gradually to return the patient to unrestricted activity over a 10-12 month period. In the first four weeks, patients can bear roughly 20-30% of their weight while wearing the hinged knee brace locked in extension. No active flexion is typically allowed during this time, and passive knee flexion is performed prone to prevent posterolateral gravity forces on the PLC repair/reconstruction. By the end of four weeks, the patient should obtain approximately symmetric extension compared to the contralateral knee. From 1-3 months, bracing is still recommended but may be unlocked to allow full ROM, and the patient may gradually begin WBAT to become free from crutches between 8 and 12 weeks. The focus during this time period is on gait and balance, as well as isometric strengthening via CKC quadriceps exercises. Some will utilize a stationary bike program with no resistance at around 8 weeks. From 3-5 months, closed-chain exercises are advanced, resistance is begun on the bike, and the patient may begin fast walking on a treadmill. From 5-7 months, weights and a slow jogging program are started. Finally, from 7-10 months, patients begin functional and return to sport training with plyometric exercises, jumping and pivoting as indicated, with an emphasis on return to pre-surgery activity level.[68]

Malalignment

For a concurrent HTO and ACLR, the patient will typically be kept NWB or TTWB until there is radiographic evidence of osteotomy healing (usually 6-8 weeks). At this time, the patient will continue with progressive weight bearing, and follow the standard revision ACLR protocol described above. For a staged

HTO followed by revision ACLR, rehabilitation focuses initially on healing of the osteotomy (NWB for 6-8 weeks) and early ROM exercises via the use of continuous passive motion for 2-4 weeks postoperatively.[74] The ACL revision rehabilitation is similar to the aforementioned protocol.

Conclusion

Revision ACL surgery should be considered salvage surgery, and a less aggressive rehabilitation program is warranted compared to primary ACLR. Weaker initial graft fixation, bone loss, laxity of secondary restraints, and the high likelihood of concomitant injuries are all integral parts in the evaluation, management, and post-operative care of the revision ACL patient. A rehabilitation program following revision ACL surgery is influenced by a number of surgical and patient variables. Therefore, an accelerated, "cookbook" type of rehabilitation program should not be used in the revision setting; rather, an individualized, slower, more cautious rehabilitation approach taking all variables into account is essential to provide satisfactory surgical outcomes.

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Review questions

1. What is the most common reason that revision ACL reconstruction is performed?
    a. Infrapatellar contracture
    b. Postoperative stiffness
    c. Recurrent patholaxity
    d. Tibiofemoral arthritis

2. Observation of varus thrust during gait is suggestive of injury to what structures about the knee joint?
    a. Lateral meniscus
    b. Posteromedial corner
    c. Posterolateral corner
    d. Lateral femoral condyle

3. Concomitant conditions associated with acute ACL tears include all of the following except:
    a. Posterolateral corner injury
    b. Osteochondral defect
    c. Lateral meniscal tear
    d. Patellofemoral arthrosis

4. The "ligamentization" process takes the longest for which of the following graft sources?
    a. Hamstring autograft
    b. Patellar tendon allograft
    c. Patellar ligament autograft
    d. Quadriceps tendon autograft

5. At what time period following revision ACLR with meniscal repair is knee flexion ROM advanced beyond 90 degrees?
    a. 2-4 weeks
    b. 4-6 weeks
    c. 6-8 weeks
    d. 8-12 weeks

6. What is the best determinant of post-operative knee ROM?
    a. Preoperative ROM
    b. Quadriceps mechanism function
    c. Pain severity rating
    d. Arthrogenic muscle inhibition

7. What is the most common unrecognized concomitant injury during ACL rupture?
    a. Lateral meniscus tear
    b. Medial meniscus tear
    c. Posterolateral corner
    d. Posteromedial corner

8. What clinical test best assesses the integrity of the posterolateral corner?
   a. Dial test
   b. Lachman test
   c. Pivot shift test
   d. Posterior drawer test

9. What soft tissue structures are most likely to be injured in a patient with valgus laxity at both 0 and 30 degrees of knee flexion?
   a. ACL and medial meniscus
   b. ACL and MCL
   c. ACL and PCL
   d. ACL and PMC

10. What soft tissue factor(s) primarily influence the rate at which early rehabilitation is progressed?
   a. Choice of graft tissue
   b. Concomitant meniscus and osteochondral procedures
   c. Degree of patellofemoral joint arthrosis
   d. Type of ligament fixation

Test questions

1. The most common technical error made during primary ACL surgery that requires revision surgery is:
   a. Malpositioned femoral tunnel
   b. Inadequate notchplasty
   c. Improper graft tensioning
   d. Inadequate screw fixation

2. When should high impact activities and pivoting sports commence following revision ACLR with meniscal transplant?
   a. 8-12 weeks following surgery
   b. 16-20 weeks following surgery
   c. 24-36 weeks following surgery
   d. These activities are not recommended following this procedure

3. What physical findings best characterize knee joint homeostasis during postoperative rehabilitation?
   a. Improving ROM with increasing pain
   b. Limited ability to flex the quadriceps muscle due to joint effusion
   c. Transient knee effusion following exercise routine which resolves in 1-2 days.
   d. Patient report of declining pain intensity

4. Integration of jump landing training should focus on what key technical aspect?
   a. Avoidance of dynamic knee valgus
   b. Heel landing
   c. Increase depth of knee flexion upon landing
   d. Keeping the knees wider than shoulder width

5. What ROM of open kinetic chain exercises can be safely utilized during the 6-12 week period of rehabilitation?
    a. 0-30 degrees
    b. 0-45 degrees
    c. 90-45 degrees
    d. OKC exercises are not advised for revision ACLR rehabilitation