Anterior Cruciate Ligament Reconstruction: Surgical Management and Postoperative Rehabilitation Considerations

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INTRODUCTION

Surgical techniques for anterior cruciate ligament (ACL) reconstruction have progressed in the past 20 to 30 years. In the 1970s, ACL reconstructions were done through large arthrotomies, using non-anatomic, extra-articular reconstructions, with long postoperative periods of immobilization.[1,2] In the 1980s, large arthrotomies were replaced by arthroscopic, anatomic, intra-articular reconstructions. Arthroscopy eliminated the need for prolonged postoperative immobilization, and accelerated rehabilitation protocols were established. In the 1990s, the rehabilitation protocols were advanced further to allow athletes an early return to sports.[2] Today, while there is less variability in the surgical techniques used, there remains variability in the types of surgical grafts used. The most commonly used grafts for ACL reconstruction are the bone-patellar-tendon-bone autograft, semitendinosus autograft, and the semitendinosus/gracilis autografts and allografts.[3,4] The success of a patient's recovery who has undergone an ACL reconstruction is predicated on several factors including surgical technique, graft selection, prevention of postoperative complications, patient compliance, and postoperative rehabilitation.[4,5] The postoperative rehabilitation regimen must be guided by principles such as the early return of knee range of motion (ROM), especially extension, while obtaining and maintaining a relatively stable physiological state of the knee joint (homeostasis). Strengthening, proprioception exercises, and early weight bearing have also become guiding principles.[2] The purpose of this paper is to outline current surgical and postoperative factors that should be considered when establishing the rehabilitation program for a patient following ACL reconstruction.

BASIC ANATOMY AND FUNCTION

The ACL restrains anterior translation of the tibia, and prevents tibial rotation and varus/valgus stresses to the knee. Participating in sports and activities in which pivoting occurs where the foot is planted, the knee is flexed, and a change in direction is needed puts one at a higher risk for an ACL injury. Basketball, skiing, and football are examples of sports in which a high number of ACL injuries occur.[6] The ACL is also very susceptible to injury in contact sports. It can be damaged along with the medial collateral ligament when there is an associated valgus stress. A force that results in the tibia being driven forward, the femur being driven backward, or in the knee joint being severely hyperextended may also result in damage to the ACL.

The ACL does not heal well without surgery.[7] This is most likely due to the amount of force involved in the injury, the lack of blood supply to the ligament, and its intra-articular location. However, about one-third of all patients can expect a fair to good outcome without surgery.[8] Typically, these patients who do well without surgery are older or less active, and modify their activity level following injury, including avoiding pivoting sports/activities. Generally, younger and/or active individuals do not do well with nonoperative treatment. This is due to the expectation of continuing to participate in sports that require high levels of pivoting. Active patients with an ACL deficiency are at risk for reinjury, including meniscal tears and/or articular damage, leading to subsequent degenerative changes in the knee. Patients who opt for surgical reconstruction of the ACL can expect restored stability of the knee and return to preinjury levels of activity.[9] Over the past 20 years, advances have been made with respect to graft choice and fixation, and perioperative management, including rehabilitation. These advances have led to increased functional outcomes and early return to activity.[10]

ADVANCEMENTS IN SURGICAL TECHNIQUES

Over the past 20 years, multiple scientific and empirical studies on ACL reconstruction have been completed, leading to a greater understanding of factors influencing postsurgical outcome, including patient selection and graft selection.[4,5,7,10-21] When it comes to patient selection for operative and nonoperative management, the most important factor that may lead to graft failure is noncompliance with the postoperative regimen.[4] Other factors that impact patient selection and the surgical decision-making process are the patient's physiological age, occupation, symptomatology, and desired activity level, as well as the presence of associated collateral ligament insufficiency, the presence of generalized ligamentous instability, open growth plates, or the need for rapid rehabilitation.[4,5]

The most commonly used grafts for ACL reconstruction are the bone-patellar-tendon-bone autograft, semitendinosus autograft, and the semitendinosus/gracilis autografts and allografts.[4] Using an autograft eliminates the risk of disease transmission, but can cause donor site morbidity.[18]

Bone-Patellar Tendon-Bone Autograft

The ipsilateral bone-patellar-tendon-bone autograft has been considered the gold standard graft for ACL reconstruction since it was described by Jones in 1963.[4,18] The advantages of this graft include its high ultimate tensile strength and stiffness, rapid bone to bone interface healing (6-8 weeks)[22] and revascularization, which can allow the patient to initiate an accelerated rehabilitation program and in turn, decrease risk of postsurgical morbidity.[20] Disadvantages and complications include anterior knee pain, extensor mechanism dysfunction, patellar fractures, patellar tendon ruptures, and arthrofibrosis.[9,23,24,26] Complications during graft fixation include inappropriate patellar tendon length, poor femoral fixation, poor tibial fixation, graft disruption, and femoral wall disruption.[25] Contralateral patellar tendon autografts are also used, but there is a risk of donor site morbidity in the uninvolved knee.[18,20]

Semitendinosus/Gracilis Tendon Graft

The use of hamstring autografts has become more common due to the evolution of surgical techniques, including the use of the four strand, quadruple loop combination of semitendinosus and gracilis tendons, and due to the advancement in graft fixation options. The advantages of this graft include decreased risk of postsurgical complications found with bone-patellar tendon-bone autografts. The morbidity from harvesting the semitendinosus and gracilis tendons is minimal because flexion strength returns completely. The hamstring tendons regenerate, and extensor mechanism problems, such as anterior knee pain, kneeling pain, quadriceps weakness, patellar fracture, and patellar tendon rupture are less common and severe.[27-33] The principal disadvantage of the hamstring autograft compared to the bone-patellar tendon-bone autograft is increased anterior knee laxity, but its correlation with any functional deficits remains unclear.[5,18,21] Other disadvantages include lower returns to preinjury levels of activity and increased healing time of soft tissue to bone interface.[18,22] Surgical complications during harvesting include inadequate length or width and transection of the tendons.[25]

In 2002, Shaieb et al[21] completed a prospective, randomized study to compare the overall outcome at a minimum of 2 years after single-incision ACL reconstruction. Seventy patients, with either autogenous patellar tendon graft or hamstring tendon autografts, were studied. Both grafts were fixed with interference screws by the same surgeon using the same surgical technique with notchplasty. In addition, the same aggressive postoperative rehabilitation protocol[10,34,35] was instituted for both groups. They reported no significant difference between patellar tendon and hamstring tendon grafts with respect to the Lysholm score,[36] Lachman and pivot shift test results, thigh circumference, return to sports, reduction in activity, jumping, and ability to do hard cuts and pivots 2 years after surgery. In 2003, Feller and Webster[5] completed a prospective randomized clinical trial of 65 patients to compare both grafts as well as to assess the functional outcome at 3 years postoperatively. In this study, the same surgeon performed the procedures, but different graft fixation methods were used. They found that at 3 years after surgery, there was no significant difference between bone-patellar tendon-graft (31 patients) and combined semitendinosus and gracilis hamstring tendon grafts (34 patients) in terms of functional outcome. However, patients who had the patellar tendon graft reported pain on kneeling and had increased extension deficits compared to the patients who had the hamstring graft. In the group of patients who had the hamstring graft, there was an increase in anterior knee laxity as measured by the KT-1000 arthrometer and radiological evidence of widening of the femoral tunnel, but this did not translate into decreased function. These authors suggested that hamstring tendon grafts might be indicated for patients who still have open growth plates, whereas the patellar tendon grafts may be more suitable in a 'loose' knee. Furthermore, a patient whose occupation or sport involves kneeling may have a better long-term outcome with the hamstring graft.

Allografts

The advantages of allograft tissue are that there is no donor site morbidity and that the tissue is readily available, thus eliminating the step of graft harvesting during surgery. As a result, the patient does not experience any of the postsurgical deficits associated with either patellar or hamstring tendon harvesting. The greatest disadvantage to allograft use is the potential risk of disease transmission.[4,18,20,37] However, with proper precautions and adequate laboratory studies, the theoretical risk of processing bone from an unrecognized carrier of the human immunodeficiency virus is one in more than one million.[38] Since 1985, the Food and Drug Administration has mandated screening of all allograft tissue for viruses. Another potential disadvantage of allografts include greater failure or delay of biologic incorporation than with autografts, in turn delaying the return to activity in order to protect the graft.[18] Graft selection in practice is often based on patients' activity levels, needs, and age. Most surgeons tend to use patellar tendon autografts for patients with high-demand activities such as cutting, pivoting or jumping sports, or skiing. For patients who are older or have lower demand activities, the hamstring grafts are used. Finally, allografts may be preferred by patients who elect to have transplanted tissue, or for patients over age 45, for patients with arthritis, evidence of instability, or for patients who do not have any donor tissue.

In 2001, a survey of the American Orthopaedic Society for Sports Medicine[3] regarding current practices and opinions in ACL reconstruction yielded responses from 855 members (76% response rate). Seventy-eight percent of members preferred bone-patellar tendon-bone grafts. The respondents had an average of 17 years experience in orthopaedic practice. Of the surgeons who used multiple graft types, 75% preferred using hamstring autografts for patients with open physes around the knee, for patients with patellofemoral pathology, and in patients undergoing revision ACL reconstruction surgery. Only 3 of the respondents used allografts exclusively, but no description of the graft selection criteria was given in this case. Other allograft tissue options include the Achilles, anterior tibialis tendon, and posterior tibialis tendons.[18] No use of synthetic grafts was documented in this survey.

Synthetic Grafts

In the late 1970s and early 1980s, synthetic materials were used to substitute tissue grafts with an objective of developing a graft that would be stronger, more rigid, and therefore would allow early mobilization and rapid return to sports. These synthetic materials included permanent (true), scaffold (ingrowths), and stents (augmentation devices).[20,37] In 1997, Frank et al[15] reported that 40% to 78% of the 855 synthetic ligaments tracked over a period of 15 years had failed over time. They failed secondary to debris, tissue reactions, and mechanical limitations of the grafts. The Gore-Tex ACL is a true prosthetic that was designed to allow immediate fixation, therefore accelerate mobilization and weight bearing, leading to earlier return to activity. It failed because of lack of tissue ingrowth, fraying at the bone tunnels, and chronic effusions. The Dacron ligament was developed as a scaffold prosthesis intended to prevent problems with stiffness that had been associated with other materials. However, complications from this prosthesis included rupture of the femoral or tibial insertion of the ligament, rupture of the central body of the prosthesis and elongation of the ligament.[39] The Kennedy Ligament Augmentation Device (LAD) was designed to provide protection to a primary ACL repair or to a patellar tendon graft while it healed. In 2002, Weitzel et al[37] stated that the LAD was predominantly of historic interest because primary repair of the ACL is not routinely performed. Kumar and Maffulli[40] note that excellent results can be obtained in primary ACL reconstructions without LAD.

TREND TOWARDS ACCELERATED REHABILITATION PROTOCOLS

Rehabilitation following ACL reconstruction is very important to restore range of motion, strength, proprioception, and function to allow return to preinjury levels of activity. In the 1970s and early 1980s, postsurgical rehabilitation for patients recovering from ACL reconstruction consisted of immobilization in long leg casts for 2 to 4 weeks, followed by the use of a postoperative knee brace. Weight bearing was restricted for approximately 6 weeks, followed by a gradual progression from partial weight bearing to weight bearing as tolerated, with the use of a brace. By 12 to 14 weeks after surgery, patients were allowed to progress to full weight bearing. Typically, the postoperative brace was not discontinued for daily activities until 4 months. Isokinetic evaluations began at 6 months postoperatively and continued through the 9th to 12th months.[41,42] It was typically the standard for patients to be released to full, unrestricted activity once they had full ROM, no pain or swelling, had completed a very structured functional progression including agility drills, and their quadriceps strength was greater than 80% of the uninvolved knee. In 1983, Shelbourne and Nitz[10] discontinued the use of rigid immobilization and began using continuous passive motion immediately postoperatively. They began to note that patients who were advancing or progressing their activities earlier than recommended (and therefore were noncompliant with the rehabilitation protocol), were actually demonstrating improved functional outcomes without an increase in knee instability compared to the patients who had been compliant with the recommended rehabilitation protocol. Follow-up of the noncompliant patients over a 2-year period revealed that there were no long-term adverse consequences of early weight bearing and full extension ROM. As a result, they developed the first accelerated rehabilitation protocol by the end of 1986.

REHABILITATION

Basic Principles

The rehabilitation process for patients having undergone ACL reconstruction is multifaceted. It includes patient education, pain control, edema management, ROM, strengthening exercises, gait training, agility drills, sport-specific drills, proprioception, and endurance exercises. The goal of these interventions is to restore the patients' preinjury levels of function. Tissue healing stages and graft fixation protection must be very carefully considered, especially in the early postoperative phase.

The speed at which the above interventions are progressed depends on a number of basic principles. In the immediate postoperative period (0-2 weeks), emphasis is placed on patient education, edema and pain control, early protected weight bearing, and ROM. In order to decrease the risk of arthrofibrosis and extensor mechanism dysfunction, full extension (equal to that of the uninvolved knee) and 90° of flexion should be achieved by 7 to 10 days following surgery.[2] Range of motion goals are achieved with the use of continuous passive motion (CPM), passive and active-assisted ROM exercises, active ROM exercises (with early activation of the quadriceps and hamstring muscles), patellar mobilizations and mobilization of the soft tissues, and weight bearing. In some cases, the use of a brace is recommended to assist in achieving full extension. Early recognition and management of motion deficits are crucial to prevent the sequelae of arthrofibrosis such as patella baja and progressive joint degeneration.[24] Once motion has been restored and knee homeostasis has been controlled, strength training can be progressed as tolerated. Electrical stimulation can be used to facilitate the active contraction of the quadriceps.[2,24,26,43-46]

It is crucial to initiate proprioception exercises once pain and swelling are controlled. Neuromuscular re-education is essential in the prevention of knee injuries and in the protection of the ACL graft.[47] Muscular endurance is important and can be addressed with the use of a stationary bicycle, elliptical trainer, treadmill, and aquatherapy for long durations with low resistance.[24]

As the patient advances through the weeks following ACL reconstruction surgery, the loads being applied to the knee can be gradually increased through the progression of therapeutic exercises, providing that knee homeostasis is maintained. There are several post-ACL rehabilitation protocols in the literature.[2,10,26,48]

Factors that Guide Rehabilitation

Patellar tendon autografts

A number of prospective and retrospective studies have demonstrated the success of accelerated rehabilitation protocols for patients who have undergone an ACL reconstruction with a patellar tendon autograft.[2,10,26,41] Clinical pathways or protocols have been developed because of these studies, but the clinician must also consider the underlying pathology and modify the pathway accordingly, while respecting basic rehabilitation principles (Table 1).

Hamstring tendon autografts

Howell and Taylor[49] demonstrated the safety of an accelerated rehabilitation protocol, without the use of a brace, for patients with a hamstring tendon autograft. As described earlier, the hamstring autografts have been associated with increased anterior-posterior laxity compared to patellar tendon grafts, but this increased laxity has not been correlated to decreased function or increased pain. The patients in this study returned to sports at 4 months after brace-free rehabilitation. Stability was measured at 4 months, prior to patients returning to sports, and

Table 1. Treatment Parameter based on Graft Type

Graft Type	Weight-bearing (WB) status	Use of Postoperative brace	Passive range of motion (PROM) and active range of motion (AROM)	Strength training/ proprioception exercises	Return to running/sports
Patellar tendon (accelerated rehab protocol); Wilk et al[95]	Progression to full WB without crutches by 10-14 days.	Immobilizer locked at 0° ext during ambulation for 2-3 weeks.	0°-100° PROM in week 1; 0°-115° PROM in week 3; 0°- 125°AROM by week 10.	Isometric knee extension and closed kinetic chain and proprioception exercises as of week 1. Progressive resistance extension exercises as of week 2.	Backward running as of week 4. Forward running as of week 6. Gradual return to sports as of weeks 16-22.
Hamstring Tendon; Wilk et al[95]	Progression to full WB without crutches by 10-14 days.	Immoblizer locked at 0° ext for ambulation until week 3. Then unlocked to 0°-125° until weeks 4-7.	0°-90° PROM in week 1; 0°-105° PROM in week 2; 0°-115° PROM in week 3; 0°-130° PROM by weeks 4-7; 0°-125°AROM by weeks 7-12.	Delay hamstring strengthening until 4 weeks after surgery. At 5-6 weeks, start submaximal isometric hamstring contractions. At 6-8 weeks, start light resistance exercises. At 8 weeks, start progressive resistance exercises.	No running for 12 weeks, no jumping for 12-14 weeks, no twisting and hard cutting for 16 weeks and return to sports in 5.5-6 months.
Hamstring Tendon; Howell and Taylor[36]	Restricted WB with crutches for 3 weeks, with progression to full WB without crutches by 6 weeks.	None.	Cited Shelbourne and Nitz's[79] accelerated protocol: 0°-110° AROM in weeks 2-3; 0°-130° AROM in weeks 5-6.	Unrestricted open and closed kinetic chain exercises started at week 4.	Running in a straight line at 8-10 weeks. Return to to sports by 4 months.
ACL reconstruction with meniscal repair; Brotzman & Wilk, Wilk et al[13,95]	Immediate WB	Hinged brace or immobilizer locked in full extension during ambulation until weeks 2-3.	Flexion ROM: Peripheral tears: 90°-100° by week 2; 105°-115° by week 3; 120°-135° by week 4; Complex tears: 90°-100° by week 2; 105°-110° by week 3; 115°-120° by week 4.	No isolated hamstring contraction for 8-10 weeks. No squatting past 60° of knee flexion for 8 weeks. No squatting with rotation or twisting for 10-12 weeks. No lunges past 75° knee flexion for 8 weeks.	5-7 months.
ACL reconstruction with articular cartilage pathology; Wilk et al[95]	Microfracture Technique: Non-WB or toe-touch WB for 2-4 weeks; 50% WB in weeks 5-6; 75% WB in weeks 7-8.	No Recommendation specified.	ROM goals same as with accelerated rehab protocol for isolated ACL reconstruction.	No excess loading for 3-4 months.	6-9 months.
ACL reconstruction with articular cartilage pathology; Wilk et al[95]	ACI Technique: NWB for 2 weeks. Toe-touch WB weeks 3-6. 50% WB by week 6. Progression to full WB by week 8	Locked in extension for 2 weeks.	0°-90° in week 2; 0°-105° by week 4; 0°-125° by week 6; 0°-135° by week 8.	Open kinetic chain exercises including proprioception, closed chain exercises and aquatherapy by week 6.	Low-impact activities by 8 months. High-impact activities by 12 months.
Combined ACL-MCL injuries/ repair; Irrgang & Fitzgerald[41]	Partial WB to full WB within 6 weeks.	Locked in extension for week 1, then unlocked for ambulation. Discontinue after 4-6 weeks when 90°-100° of flexion.	Full AROM and PROM extension by weeks 1-2. 90°-100° flexion by week 4. Full flexion by week 8.	Closed kinetic chain exercises performed in 0°-45° of flexion. Medial hamstring to increase anteromedial stability of knee. Caution with hip adduction exercises (i.e. valgus stress imposed on the MCL)	Running at 6 months. Return to sports by 9-12 months.
Combined ACL-MCL injuries/repair; Wilk et al[95]	Full WB by week 2	No postoperative brace. Functional brace in presence of varus movement during gait.	No Recommendation specified.	No Recommendation specified.	No Recommendation specified.
Combined ACL/LCL injuries/repair; Irrgang & Fitzgerald[41]	Partial WB for 6 weeks	Locked in extension for 6 weeks.	0° knee ext week 1(avoid hyperextension); 0°-90° for weeks 1-6; at week 6: full AROM.	Quad sets and straight-leg raises for 6 weeks. Progress to open and closed chain exercises-caution with hip abduction exercises.	Running by 6 months. Return to sports by 9-12 months.
Combined ACL/PCL reconstruction; Irrgang & Fitzgerald[41]	Partial WB in week 1. WB as tolerated in week 2.	Locked in extension weeks 1-4. Unlocked for gait training weeks 5-8.	0°-90° for 4-6 weeks. Passive knee flexion by lifting proximal tibia. Full flexion ROM by weeks 8-10.	No active hamstring contraction for 6 weeks. Quad sets and straight-leg raises. Open kinetic chain exercises from 75°-60° knee flexion. Closed kinetic chain exer-cises from 0°-45° knee flexion. Stationary bike-no toe clips.	Walking program weeks 8-12. Running by 6 months. Return to sports by 9-12 months.
Combined ACL/PCL reconstruction; Wilk et al[95]	50% WB on day 7; 75% WB day 12; Full WB by week 4.	Used for 7-8 weeks, then may need functional brace.	0°-65° on day 5; 0°-75° on day 7; 0°-90° on day 10; 0°-100° week 2; 0°-115° week 6; 0°-125° week 7.	Closed kinetic chain exercises in week 3. Leg press week 4.	Walking program week 12. Light running week 16. Agility drills by 5 months.

then at 2 years following surgery. The 2-year evaluation revealed that 90% (37/41) of patients' knees were stable and functional. The authors state that an increase in instability between 4 months and 2 years would have implied that the composite hamstring graft was not mature enough to tolerate the early return to sports and work activities. The 4 patients' knees that were unstable had been detected at the 4-month follow-up evaluation. The authors were unable to determine a specific cause of graft failure for these cases (Table 1).

Allografts

A comparison studies of nonirradiated, fresh-frozen patellar tendon autografts and patellar tendon autografts has revealed few differences in outcomes using similar rehabilitation protocols.[2]

ACL reconstruction with meniscal repair

Meniscal injuries are commonly seen in combination with ACL injuries. The rehabilitation protocol should be modified based on whether the meniscus was surgically repaired or if a partial menisectomy was performed. In the presence of a partial menisectomy, Wilk et al[26] suggest that running and jumping be delayed to protect the healing meniscus. With a meniscal repair, modification of the rehabilitation protocol is more important. Range of motion is progressed more slowly with complex tears than with peripheral tears. In some large meniscal repairs, where the posterior horn is involved, it may be preferable to limit flexion for 4 to 6 weeks in order to avoid excessive load on the posterior horn of the meniscus. As with the standard rehabilitation protocol, full passive extension is crucial in the early postoperative period (Table 1).

Articular cartilage pathology

Articular cartilage defects occur very commonly in the setting of an ACL injury. Johnson et al[50] reported an incidence of up to 80%, with most defects presenting as bone bruises. It is important to delay high shear or repetitive loading exercises to protect the healing tissue. Patients with bone bruises also demonstrate antalgic gait for longer periods, and may complain of more pain and swelling than patients with isolated ACL injuries. It is important to obtain and maintain knee homeostasis prior to progressing activities.

Some patients with this injury may undergo a procedure involving microfracture or autologous chondrocyte implantation (ACI). The goal of these procedures is to stimulate healing and repair. After the procedure involving the microfracture, the ROM goals remain the same as with the standard rehabilitation protocol, with emphasis on early return of passive knee extension. When the cartilage defect is on the load bearing surface of the femur or tibia, weight bearing is delayed to decrease the compression forces on the healing articular tissues (Table 1).

ACL RECONSTRUCTION IN SETTING OF MULTILIGAMENT INJURIES

Combined ACL-MCL Injuries

Patients with a combination ACL-MCL (medical collateral ligament) injury may or may not require repair of the MCL to restore knee stability and function. Reconstruction of the ACL alone may provide adequate knee stability to allow the MCL to heal. It has been reported that individuals who underwent ACL reconstruction and conservative management of the MCL had superior ROM and faster strength gains in the short-term compared to those who had both ligaments repaired. Long-term follow-up revealed that patients with ACL reconstruction and conservative management of MCL tear had excellent knee stability and functional outcomes.[51] The timing of ACL reconstruction has been a controversial subject. The standard of care has been to delay ACL reconstruction for 3 weeks postinjury in order to decrease the incidence of postoperative arthrofibrosis, one of the most common complications following this surgery.[24,52-54] In 2004, Millett et al[55] reported on their retrospective study of early ACL reconstruction in combined ACL-MCL injuries in 19 knees. Early reconstruction was defined as being within 3 weeks of the initial injury. The candidates for this early reconstruction had to meet certain preoperative criteria, such as 0-120° knee ROM, good quadriceps control (as measured by the ability to perform a straight leg raise), and near-normal appearance of the knee.[56] Early reconstruction of the ACL in these injuries facilitates the healing of the MCL by decreasing valgus instability. In this study, the rate of subsequent surgery was 5.2%, where only 1 out of 19 knee surgeries needed a second intervention for arthroscopic debridement and lysis of adhesions. A study by Peterson and Laprell[57] in 1999 had revealed a 15% rate of subsequent surgery for arthrofibrosis or cyclops lesions. Millett et al[55] believe that their preoperative protocol, which involves restoring motion, quadriceps control, and appearance of the knee may exclude patients who would be at risk of developing motion problems.

If medial laxity is still present after ACL reconstruction, a MCL repair may be warranted.[48] Combined ACL-MCL injuries are often managed postoperatively with a brace to limit valgus rotation forces, whether or not a MCL repair has been performed. The risk of postoperative loss of motion and excessive scar tissue formation is greater following MCL injuries due to the increased effusion that occurs with combined tissue damage and with extra-articular vascularity. Therefore, range of motion exercises should be progressed more rapidly providing that homeostasis of the joint is maintained. The use of the continuous passive motion machine may also be especially beneficial in these cases. Strengthening of the medial hamstrings is crucial for anteromedial stability of the knee, but hip adduction exercises should be performed with caution because of the valgus stress imposed on the MCL, especially if the resistance is placed distal to the knee joint.

Shelbourne and Patel[51] suggest that the location of the injury along the MCL should also be considered during the rehabilitation process. The MCL tears at the proximal origin or within the midsubstance of the ligament tend to heal without residual laxity but with increased stiffness. However, MCL injuries at the distal insertion site tend to have a lesser healing process and residual valgus laxity. In this case, rehabilitation should be progressed more slowly to allow for tissue healing. In the former case, the ROM exercises should be accelerated to prevent excessive scar tissue formation and stiffness (Table 1).

Combined ACL/LCL Injuries

An injury to the LCL (lateral collateral ligament) may result in varus instability, and the LCL may be reconstructed using an Achilles tendon graft. Irrgang and Fitzgerald[48] propose guidelines outlined in Table 1.

Combined ACL/PCL Injuries

Irrgang and Fitzgerald[48] describe rehabilitation following a PCL (posterior cruciate ligament) reconstruction using an Achilles tendon graft and they suggest that the same guidelines should be used in the combined ACL/PCL reconstructions. In 2000, these authors stated that the maturation process of the PCL graft and the loads that it can withstand remain unclear. They have based their rehabilitation protocol on known knee biomechanics to incorporate exercises that would reduce the strain on the PCL with respect to tibial translation. For example, they recommend that open kinetic chain knee flexion and hip extension exercises be avoided in the early postoperative period because of the posterior translation of the tibia during unopposed hamstring contraction and the associated strain on the healing PCL. In the event of a combined ACL/PCL reconstruction, they recommend that open kinetic chain knee extension exercises be limited to the range of 75° to 60° of flexion. In contrast, closed kinetic chain exercises are indicated because compression forces on the joint and co-contraction of the hamstring and quadriceps decrease tibial translation (Table 1). Following surgery in the setting of single or multiligament injury, it is crucial to restore full extension that is symmetrical to the uninvolved knee. Irrgang and Fitzgerald[48] indicate that caution must be taken with respect to gaining gross hyperextension in the PCL reconstructed knee because this can lead to elongation or failure of the graft and repair. They suggest a goal of 0° of extension for the patients having undergone this type of surgery, even if the extension ROM of the uninvolved knee is greater.

POTENTIAL COMPLICATIONS FOLLOWING ACL RECONSTRUCTION

As previously mentioned, problems can occur during the surgical procedure. In addition, there are numerous potential complications that are commonly seen by physical therapists during the rehabilitation process, such as anterior knee pain, arthrofibrosis, quadriceps weakness, extensor mechanism dysfunction, and donor site pain. Early motion and decreased restrictions on weight bearing are now being advocated to prevent the risk of arthrofibrosis. Arthrofibrosis can be caused by a variety of factors other than immobilization, such as infection and graft malpositioning. Physical therapists play an important role in the early detection of motion loss in the immediate postoperative phase. Possible causes of motion loss are the presence of ACL nodules, fat pad scarring, and/or adhesions. In some cases, motion loss can be managed with conservative, nonoperative treatment such as physical therapy and possibly manipulation of the knee under anesthesia. Millett et al[24] have outlined the risks and complications associated with manipulation under anesthesia, such as articular damage and fracture due to excessive joint compression forces during the procedure. Because of these risks, the surgical author prefers to treat the majority of patients with knee arthrofibrosis with arthroscopic surgery to release adhesions and distend the capsule as indicated. However, Dodds et al[58] reported success in managing knee arthrofibrosis with manipulation. They stated that manipulation might prevent the deterioration of articular cartilage that can be caused by gait deviations associated with persistent flexion contractures. The majority of the 42 patients studied experienced hemarthrosis following the manipulation, but this did not delay the initiation of physical therapy. Whether they've undergone manipulation under anesthesia or arthroscopic release of adhesions, patients should initiate or resume physical therapy in order to ensure good functional outcomes and return to preinjury levels of activity.

FUTURE DIRECTIONS OF ACL RECONSTRUCTION AND REHABILITATION

New Approaches in ACL Reconstruction

Quadriceps tendon graft

Bone-patellar-tendon-bone and hamstring autografts are the most used autografts for ACL reconstruction at this time.[3,4,5,14,17,59] Another autograft that is gaining popularity is the quadriceps tendon graft, with 1 bone plug. Fu et al[7] described donor site morbidity with quadriceps tendon grafts to include quadriceps muscle atrophy, articular surface damage at harvesting, scar size, and location. In 2003, Theut et al[59] reported on the use of a central quadriceps free tendon graft (CQFT), without a patellar bone plug, for both primary and revision ACL reconstruction. This graft is sometimes augmented and fixed by various methods, including bone disk taken from the tibia. An advantage of this graft is its cross-sectional area that is nearly double the central third of the patellar tendon. In addition, biomechanical studies have shown that its mechanical properties are similar to that of the patellar tendon.[60-62] Theut et al[59] report that they use the CQFT graft because it is easily harvested and seems to cause very little morbidity. Their retrospective postoperative assessment of 29 patients who had undergone ACL reconstruction with CQFT graft, with a minimum follow-up of at least 2 years, revealed that these patients had good knee stability as assessed by Lachman, pivot shift tests and single leg hop tests. They had 25 patients complete the 1999 International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form[63] to assess symptoms of instability, activity level, and overall knee function. They also used the visual analog score to document preinjury and postoperative pain. Eighty-four percent of these patients reported tolerating very strenuous activities without 'giving way' of the knee. Seventy-two percent of these patients reported being able to perform strenuous or very strenuous activities such as basketball, soccer, skiing, tennis, or heavy physical work. No patients in the study had signs or symptoms of patellofemoral pain.

These positive findings led to the development of a second study to assess the postoperative stability of the knee more specifically. This was done using the KT-1000 arthrometer on 45 patients at a mean of 20 months (range 12-29 months) following ACL reconstruction with CQFT graft. Twenty-three patients were excluded from the study for reasons including concomitant injuries, lack of normal contralateral knee for comparison, known graft failures prior to their study, or inability to participate in the testing at the time. The goal was to objectively measure anterior tibial translation on both knees. The acceptable range in side-to-side difference of a fully functional graft was defined as 0 to 3 mm.[59,64] A value of more than 3 to 5 mm defined a partially functional graft. Values greater than 5 mm were defined as arthrometric failure.[59] They found that 84% of patients presented with a side-to-side difference of –2 to 3 mm, and 16% presented with a difference of more than 3 mm but less or equal to 5 mm. No patients had a side-to-side difference greater than 5 mm, therefore there were no patients with an arthrometric graft failure. The authors state that these values are comparable with other KT-1000 values at a minimum of 2 years following surgery as documented in the literature.[12,17,19,34,49,65] Theut et al concluded that their patients with CQFT ACL reconstructions had stable, highly-functional knees with little morbidity such as patellofemoral pain 2 years following surgery, leading to a high rate of patient satisfaction.

Double Bundle ACL

There is growing interest in this technique with an attempt to recreate anatomy more precisely. This technique involves placing femoral tunnels at the insertions of both the antero-medial and postero-lateral bundles of the ACL with separate grafts. This placement could restore knee kinematics and in situ force of the ACL reconstructed graft to approximate those of an intact ACL.[66] Therefore, anatomical double-bundle reconstruction may have biomechanical advantages over the single ACL graft used today.[67]

Bioengineered ACL

As previously discussed, prosthetic grafts have had high failure rates. In order for the next generation of prosthetic grafts to achieve long-term success, many factors need to be considered. The prosthesis should cause minimal patient morbidity and no risk of infection or disease transmission. It should produce and maintain immediate stabilization of the knee to allow aggressive rehabilitation and rapid return to preinjury levels of function. It should support and direct host tissue ingrowth but also biodegrade at a rate that will still provide mechanical stability as the extra-cellular matrix is laid down. This tissue ingrowth and organization should also lead to maintaining the mechanical integrity of the ACL for the patient's lifetime.[37] The use of silk as a biomaterial for use in ACL tissue bioengineering is now being studied. Its advantages include low manufacturing costs, availability, high mechanical strength, and slow biodegrading rate. The immune response becomes negligible once the sericin, a gelatinous protein, is removed. The use of such a prosthetic graft would eliminate some of the morbidity and complications associated with autogenic and allogenic grafts. The use of bioengineered grafts should therefore allow for more aggressive rehabilitation and early return to sports, especially in high-level athletes, if the mechanical tensile strength and viability of these grafts can be optimized at the time of surgery.

ACL Repair

There is also a growing interest in primary repair of the injured ACL. Improved arthroscopic surgical techniques and a better understanding of the ACL's healing process may contribute to the development of procedures which may effectively help the native ACL 'heal' into a functionally significant ligament.

CLINICAL OUTCOMES AND COST-EFFECTIVENESS

The success of ACL reconstruction surgery depends on many variables. Surgical variables include graft selection, and the proper harvesting, positioning, tensioning, and fixation of graft.[4,15,18,20,25] Rehabilitation constitutes a very important perioperative variable. Several postoperative protocols have been published in the literature[2,10,26,48] but much controversy remains regarding frequency and duration of physical therapy visits following ACL reconstruction.[26,68-71]

This has become increasingly apparent in the setting of reimbursement issues/constraints and of managed care costs. In the past, it was common for patients to attend physical therapy sessions weekly for as long as 4 to 6 months following ACL reconstruction.[69] Such close monitoring by physical therapists was crucial in order to decrease the high incidence of postoperative complications. The incidence of these complications has been decreasing with the advancements of surgical techniques and with the development of accelerated rehabilitation protocols. The question should then arise as to how physical therapy clinical practices should be revised to optimize patients' postoperative function in the most cost-effective manner. Several studies have looked at the outcomes of home-based versus clinic-based rehabilitation programs for patients having undergone ACL reconstruction with patellar tendon autografts or allografts.[68-70,72] Since there are countless variables that influence outcomes, no conclusion can be made with respect to the optimal number of physical therapy visits for either group.

The randomized prospective study by Fischer et al[70] revealed that the patients in the home-based program had an average of 5 physical therapy visits in a 6-month period, whereas the clinic-based group had an average of 20 visits. At the 6-month follow-up, no statistical differences were found between the 2 groups with respect to range of motion, thigh atrophy, stability tests, KT-1000 values and overall functional impact on health status as assessed by general health-status questionnaires. However, the rehabilitation protocols and exercise instructions weren't reported in detail; hence it would be difficult for clinicians to model their practice after either group. Other studies[68,69,72] have better outlined the rehabilitation protocols that were followed. They all differ slightly in terms of the rate of progression of ROM, weight bearing, strengthening, and return to sports activities. Nevertheless, there is consensus that in properly selected groups of patients, a well planned, home-based rehabilitation program should yield excellent clinical and functional outcomes. The challenge resides in the selection of these patients and in the development of a home exercise program. A goal-based approach to rehabilitation would most likely simplify this process. These goals include restoration of ROM, progressive strengthening and proprioception, and improvement of agility to facilitate early return to preinjury levels of function, while maintaining knee homeostasis. Periodic reassessments by physical therapists are imperative for exercise progression and modification as indicated. Physical therapists' clinical judgment, knowledge of rehabilitation guidelines, and ongoing communication with the patient and surgeon are key elements to the success of such programs.

CONCLUSION

We recommend that clinicians consider the vast array of principles and factors that affect the success of ACL reconstruction when developing patients' treatment plans. For example, the indications and timeframes for initiating open kinetic strengthening exercises vary based on the type of graft used and/or the presence of concomitant injuries. Structured, individually based programs will contribute to the patients achieving an expeditious return to preinjury levels of function, while protecting the integrity of the grafts in the early postoperative stages and preventing complications such as patellofemoral pain.

Collaboration between surgeons and physical therapists in setting up clinical trials and/or in investigating the optimal postoperative care is essential in the quest for maximizing patients' function in a cost-effective manner. This collaboration is especially important in the setting of ever evolving surgical procedures, societal expectations for the early return of function and return to sports, and managed care constraints.

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