[CLINICAL COMMENTARY]

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Recent Advances in the Rehabilitation of Anterior Cruciate Ligament Injuries

Injury to the anterior cruciate ligament (ACL) is potentially functionally debilitating and often requires surgical intervention followed by an extensive course of rehabilitation. Approximately 200 000 ACL injuries occur annually in the United States, leading to nearly 100 000 ACL reconstruction surgeries, one of the most common orthopaedic surgeries, which has expectations of excellent outcomes.[26,73,85,105,112,150,171,175] The surgical procedure is one aspect of a successful outcome after ACL reconstruction; however, a scientifically based and well-designed rehabilitation program also plays a vital role. Although we expect all our patients to return to unrestricted activities and preinjury levels after surgery,[5,6,162] some authors have reported some concerning results in which professional football players' careers have been altered and even shortened by approximately 2 years and their overall performance has decreased by 20%.[22,26,148]

Current rehabilitation programs following ACL reconstruction are more aggressive than those utilized in the 1980s. Current programs emphasize full passive knee extension,[101,151,155,173,179] immediate motion,[35,52,101,122,147,173,174,179] immediate partial weight bearing (WB),[145,173,176,179] and functional exercises.[29,94,95,173] This trend is due in part to the documented improved outcomes with more aggressive rehabilitation.[151] Howe et al[77] also reported improved outcomes—greater motion, improved muscular strength, and enhanced earlier function—with formal, supervised rehabilitation compared to no supervised rehabilitation.

Presently, we utilize 3 different rehabilitation programs for patients with an isolated ACL reconstruction. We have an accelerated program and a regular program for patellar tendon reconstruction and a separate protocol for hamstring reconstruction. The accelerated approach is utilized for the young and/or athletic patient. The main differences between the 2 programs are the rate of progression through the various phases of rehabilitation and the recovery time necessary prior to running and a full return to athletic activities.

SYNOPSIS: Rehabilitation following anterior cruciate ligament surgery continues to change, with the current emphasis being on immediate weight bearing and range of motion, and progressive muscular strengthening, proprioception, dynamic stability, and neuromuscular control drills. The rehabilitation program should be based on scientific and clinical research and focus on specific drills and exercises designed to return the patient to the desired functional goals. The goal is to return the patient's knee to homeostasis and the patient to his or her sport or activity as safely as possible. Unique rehabilitation techniques and special considerations for the female athlete will also be discussed. The purpose of this article is to provide the reader with a thorough scientific basis for anterior cruciate ligament rehabilitation based on graft selection, patient population, and concomitant injuries. *J Orthop Sports Phys Ther 2012;42(3):153-171. doi:10.2519/jospt.2012.3741*

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In 1990, Shelbourne and Nitz[151] reported improved clinical outcomes in patients who followed an accelerated approach rather than a conservative rehabilitation approach. These patients exhibited better strength and range of motion (ROM) with fewer complications, such as arthrofibrosis, laxity, and graft failures. Furthermore, the accelerated group had fewer patellofemoral complaints and an earlier return to sport. The senior author (K.E.W.),[172,176,179] since 1994, and others[37,88,103,183] have utilized components of the accelerated ACL rehabilitation program with excellent results.

In this paper, we will provide a scientific basis for the rationale behind our ACL rehabilitation program following a reconstruction, discuss variations in rehabilitation based on graft type and concomitant injuries, as well as discuss special considerations for the female athlete.

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PRINCIPLES OF ACL REHABILITATION

Our accelerated rehabilitation program following ACL reconstruction with an ipsilateral patellar tendon autograft is provided in the **APPENDIX**.

We begin rehabilitation before surgery when possible. It is imperative to reduce swelling, inflammation, and pain, restore normal ROM, normalize gait, and prevent muscle atrophy prior to surgery. The goal is to return the knee to its preinjury, normalized state and to obtain tissue homeostasis. Full motion is restored before surgery to reduce the risk of postoperative arthrofibrosis.[155] Patient education, a critical aspect of preoperative rehabilitation, informs and prepares the patient for the surgical procedure and postoperative rehabilitation.

The preoperative phase, which we believe is critical to a successful outcome, may require several weeks; however, 21 days are typically adequate.[110,155] We have found that patients undergoing a preoperative rehabilitation program progress more easily through the postoperative rehabilitation program, especially the earlier phases, and regain their ROM with diminished symptoms.

Postoperative rehabilitation begins with passive range of motion (PROM) and WB activities immediately following surgery. Full passive knee extension is emphasized while gradually restoring flexion motion. Immediately following surgery, WB as tolerated in a locked knee brace in full extension is allowed, and the patient is progressed to full WB without crutches after 10 to 14 days. Despite conflicts in the literature, we recommend a drop-lock knee brace during ambulation to emphasize full knee extension and assist the patient during the gait cycle while the quadriceps is inhibited.[144,150,154] The locked brace is used while ambulating and sleeping during the first 2 weeks after surgery. Studies have also shown that patients achieve improved functional knee scores and proprioception when using a brace after surgery.[20,138]

WB and non-WB activities, proprioceptive training, and strengthening exercises are also initiated during the first 2 weeks and progressed as tolerated. Neuromuscular control drills are gradually advanced to include dynamic stabilization and controlled perturbation training 2 or 3 weeks after surgery. Once satisfactory strength and neuromuscular control have been demonstrated to the rehabilitation specialist, functional activities such as running and cutting may begin 10 to 12 weeks and 16 to 18 weeks after surgery, respectively. A gradual return to athletic competition for running and cutting sports, such as baseball, football, tennis, and soccer, occurs approximately 6 months after surgery, once the patient demonstrates at least 85% of contralateral strength in the quadriceps and hamstrings.[180] Return to jumping sports such as basketball and volleyball, however, may be delayed until 6 to 9 months after surgery.

Our postoperative programs were designed according to several key principles of ACL rehabilitation to ensure satisfactory outcomes and to return the athlete to sport as quickly and safely as possible. We will discuss each of these principles in detail in the following sections.

Full Passive Knee Extension

The most common complication and cause of poorer outcomes following ACL reconstruction is motion loss, particularly loss of full knee extension.[8,60,80,143,155] The inability to fully extend the knee results in abnormal joint arthrokinematics,[17,21,89,130] scar tissue formation in the anterior aspect of the knee, and subsequent increases in patellofemoral/tibiofemoral joint contact pressure.[3] Therefore, two of our goals are to achieve some degree of hyperextension during the first few days after surgery and eventually to work to restore symmetrical motion.

Specific exercises include PROM exercises performed by the rehabilitation specialist, supine hamstring stretches with a wedge under the heel, and gastrocnemius stretches with a towel. Passive overpressure of 5 to 10 lb (2.25-4.5 kg) just proximal to the patella may be used for a low-load, long-duration stretch as needed (**FIGURE 1A**). The patient is instructed to lie supine while the low-load, long-duration stretch is applied for 12 to 15 minutes 4 times per day, with the total low-load, long-duration stretch time per day equaling at least 60 minutes.[108] We utilize this technique immediately following surgery to maintain and improve knee extension and prevent a flexion contracture.

The amount of hyperextension we attempt to restore is dependent on the uninjured knee. During the first week following surgery, for patients who exhibit 10° or more of hyperextension on the uninjured knee, we will restore approximately 7° of hyperextension on the surgical side. We will gradually restore the remaining hyperextension once joint inflammation is reduced and muscular control is restored over the following several weeks. We often utilize extension devices to create overpressure into extension, as seen in **FIGURE 1B**. The authors feel that restoring hyperextension is imperative to a successful outcome and an asymptomatic knee.[150]

Restore Patellar Mobility

The loss of patellar mobility following ACL reconstruction may have various causes, including excessive scar tissue adhesions along the medial and lateral retinacula, fat pad restrictions,[3,7] and harvesting the patellar tendon for the ACL graft. The loss of patellar mobility, referred to as infrapatella contracture syndrome, results in ROM complications and difficulty activating the quadriceps.[129] Patellar mobilizations are performed by the rehabilitation specialist in the clinic and independently by patients during their home exercise program. Mobilizations are performed in the medial/lateral and superior/inferior directions, especially for those with a patellar tendon autograft, to restore the patella's ability to tilt, especially in the superior direction.

FIGURE 1. (A) A low-load, long-duration stretch to restore the patient's full passive knee extension. A 4.5-kg weight is used for 10 to 15 minutes, with a bolster placed under the ankle to create a stretch. (B) Commercial device (Extensionater; ERMI, Inc, Atlanta, GA) to improve extension range of motion and prevent compensatory hip external rotation.

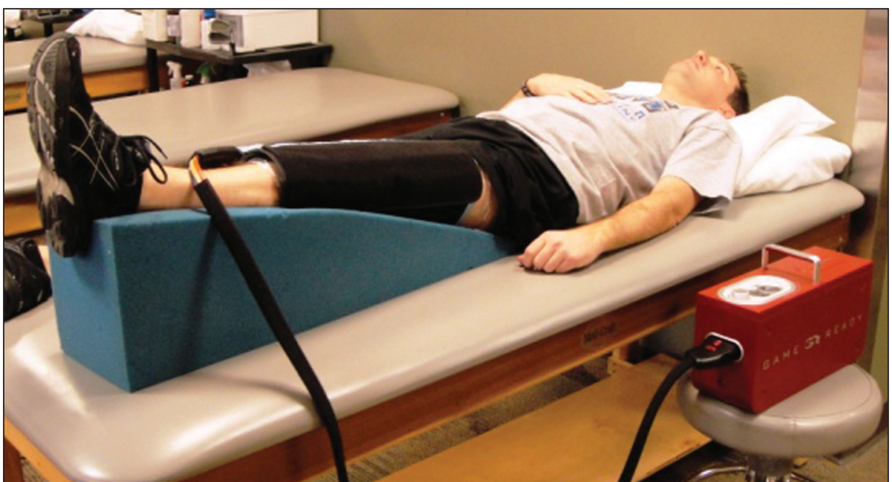

FIGURE 2. A commercial cold wrap (Game Ready, Concord, CA) applied to the knee immediately after surgery to control pain and swelling.

Reduce Postoperative Inflammation

In addition to restoring full passive knee extension and patellar mobility, it is imperative to control postoperative pain, inflammation, and swelling during the first week of rehabilitation. Pain may play a role in the inhibition of muscle activity commonly observed following ACL reconstruction. Young et al[185] examined quadriceps activity in the acutely swollen and painful knee by using local anesthesia provided during medial meniscectomy. Patients in the control group had significant postoperative pain and quadriceps inhibition (30%-76%). In contrast, patients with local anesthesia reported minimal pain and only mild quadriceps inhibition (5%-31%).

DeAndrade et al[36] reported a progressive decrease in quadriceps activity as knee joint distention was progressively increased with the injection of saline solution. Spencer et al[161] found a similar decrease in quadriceps activation with joint effusion. They reported the threshold for inhibition of the vastus medialis to be approximately 20 to 30 mL of joint effusion, and 50 to 60 mL for inhibition of the rectus femoris and vastus lateralis. Others have reported similar results.[46,62,75,83,166]

Pain after surgery can be reduced through the use of cryotherapy, analgesic medication, electrical stimulation,[38,133] and PROM.[107,124] We also utilize various therapeutic lasers to aid in the healing response.[31,58,118]

Treatment options for swelling include cryotherapy,[15,32,125,135,169] high-voltage stimulation,[74] and joint compression through the use of a knee sleeve or compression wrap.[91] A commercial cold device (**FIGURE 2**) providing continuous cold therapy and compression may also be beneficial.

The speed of progression of WB status and ROM may also affect pain and swelling in the knee. In general, our patients are allowed to bear weight, as tolerated, with 2 crutches and a brace locked into extension immediately following surgery. The brace is worn until voluntary quadriceps control is demonstrated. Typically, the patient should be able to perform a straight leg raise without a lag, have no increases in pain or swelling, and demonstrate adequate quadriceps control while present in the physical therapy clinic.

A critical goal of the second week is to train the patient to assume full WB. Two crutches are used for the first 7 to 10 days after surgery, progressing to 1 crutch

FIGURE 3. Squats performed on a tilt board to improve neuromuscular control, utilizing a Monitored Rehab Systems MR Cube (CDM Sport, Ft Worth, TX).

and finally to full WB without crutches after 10 to 14 days. This WB progression is altered as needed to ensure that increased pain and swelling do not ensue secondary to excessive WB forces. Also, WB progression is altered if concomitant surgeries are performed (meniscus repair, articular cartilage procedures, etc) or if a bone bruise is present. In such cases, WB is either delayed or slowed to allow adequate healing.

Range of Motion

Flexion ROM is also gradually progressed during the first week. Generally, the patient should exhibit 0° to 90° of knee ROM 5 to 7 days after surgery and 0° to 100° of knee ROM 7 to 10 days after surgery. However, the rate of progression is based on the patient's unique response to surgery. If a substantial effusion exists, ROM is advanced at a slower pace. We prefer to move the knee slower the first 5 to 7 days after surgery to work on reducing swelling and pain rather than aggressively pushing knee flexion at the expense of an increase in symptoms.

It should be noted that Cosgarea et al[34] compared the effects of postoperative bracing and ROM exercises on the incidence of arthrofibrosis following ACL reconstruction between 2 groups of patients. The group that was braced at 45° of knee flexion and waited 1 week prior to beginning ROM exercises had a 23% incidence of motion complications, compared to a rate of 3% in the group that was braced at 0° of knee extension and initiated ROM exercises immediately following surgery. Similarly, several authors have reported that immediate motion is essential to avoid ROM complications[34,113,114,149,155]; accordingly, failure to achieve full extension has been associated with poor postoperative results.

Thus, the primary focus at this time is on obtaining full knee extension. Over the course of the following month, flexion ROM may be progressed by approximately 10° per week, which would allow for full flexion 4 to 6 weeks after surgery. We believe that the first 2 to 4 weeks following surgery constitute a very important time to restore the knee to a level of homeostasis during ACL rehabilitation.[40]

Re-establish Voluntary Quadriceps Control

Inhibition of the quadriceps muscle is common after ACL reconstruction, especially in the presence of pain and effusion during the acute phases of rehabilitation. Electrical muscle stimulation and biofeedback[39] are often incorporated into therapeutic exercises to facilitate the active contraction of the quadriceps musculature. Kim et al,[87] based on their recent review of the literature, concluded that using neuromuscular electrical stimulation combined with exercise was more efficient than exercise alone to improve quadriceps strength after ACL surgery.

Clinically, we use electrical stimulation immediately following surgery while performing isometric and isotonic exercises such as quadriceps sets, straight leg raises, hip adduction and abduction, and knee extensions from 90° to 40° of knee flexion.[177] Patients are instructed to actively contract the quadriceps musculature with the assistance of the superimposed neuromuscular electrical stimulation. Once independent muscle activation is achieved, biofeedback may be utilized to facilitate further neuromuscular activation of the quadriceps. The authors prefer electrical muscle stimulation to biofeedback for the vast majority of patients. The patient must concentrate on independently activating the quadriceps during rehabilitation.

Restore Neuromuscular Control

We routinely begin basic proprioceptive training during the second postoperative week, pending adequate normalization of pain, swelling, and quadriceps control.[10-14] Proprioceptive training initially begins with basic exercises such as joint repositioning and WB weight shifting. Weight shifts may be performed in the medial/lateral direction and in diagonal patterns. Minisquats are also performed soon after surgery. A neuromuscular training device (Monitored Rehab Systems MR Cube; CDM Sport, Ft Worth, TX) (**FIGURE 3**) may be used with weight shifts and minisquats to challenge the proprioception and neuromuscular system of the patient. We encourage our patients to wear an elastic support wrap underneath their brace, because several authors[19,91] have reported that wearing an elastic bandage after surgery has a positive impact on proprioception and joint position sense.

By approximately the end of week 2, minisquats are progressed to be performed on an unstable surface, such as foam or a tilt board, if the patient exhibits good postural control and good form during a double-leg squat on a solid surface. The patient is instructed to squat to approximately 25° to 30° and to hold the position for 2 to 3 seconds while stabilizing the tilt board. Wilk et al[177] showed that the greatest amount of hamstring and quadriceps cocontraction occurred at approximately 30° of knee flexion during the squat. Squats may be performed with the

FIGURE 4. Single-leg stance on foam while performing upper extremity movements using a 3.2-kg medicine ball. The clinician can perform a perturbation by striking the ball to cause a postural disturbance.

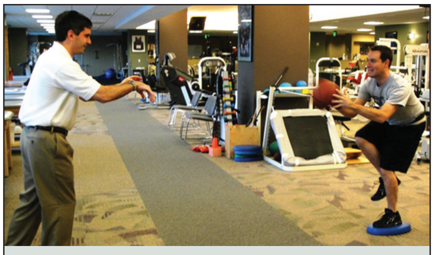

FIGURE 5. Lateral lunges performed using a sport cord for resistance while landing on a foam pad and catching a ball. The patient is instructed to land and maintain a knee flexion angle of 30° during the drill.

FIGURE 6. Single-leg stance (knee flexed at 30°) performed on a tilt board while throwing and catching a 3.2-kg plyoball. Manual perturbations are performed by tapping the tilt board with the clinician's foot to create a postural disturbance.

tilt board positioned to move in the medial/lateral or anterior/posterior direction. Based on previous studies showing that muscular contraction can decrease knee varus/valgus laxity[104] and that quadriceps-to-hamstring muscle strength imbalances lead to an increased risk of ligamentous injury,[6] we believe that improving neuromuscular coactivation enhances knee stability. As proprioception improves, drills to encourage preparatory agonist/antagonist coactivation during functional activities are incorporated. These dynamic stabilization drills begin during the first 3 weeks with a single-leg stance on flat ground and unstable surfaces, cone stepping, and lateral lunge drills.

Single-leg balance exercises, performed on a piece of foam with the knee slightly flexed, are progressed by incorporating random movement of either the upper extremity or the uninvolved lower extremity to alter the position of the center of mass. Eventually, both upper and lower extremity movements may be combined (**FIGURE 4**). These single-leg balance drills with extremity movement are used to promote dynamic stabilization and recruit various muscle groups. Medicine balls of progressively heavier weight may be incorporated to provide a further challenge to the neuromuscular control system.

The patient may perform forward, backward, and lateral cone or cup step-over drills to facilitate gait training, enhance dynamic stability, and train the hip to help control forces at the knee joint. The patient is instructed to raise the knee to the level of the hip and step over a series of cones, landing with a slightly flexed knee. These cone drills may also be performed at various speeds to train the lower extremity to dynamically stabilize with different amounts of momentum. Strengthening of the hip and knee to eccentrically control the lower extremity is imperative to a return to function. We believe that one can improve knee stability via proximal and distal stability.

Lateral lunges are also performed. The patient is instructed to lunge to the side, land on a slightly flexed knee, and hold that position for 1 to 2 seconds before returning to the start position. We use a functional progression for lateral lunges in which straight plane lateral lunges are performed first, then progress to multiple plane/diagonal lunges, lateral lunges with rotation, and lateral lunges onto foam (**FIGURE 5**). As the patient progresses, a ball toss can be added to any of these exercises to challenge the preparatory stabilization of the lower extremity with minimal conscious awareness.

Perturbation training may also be incorporated approximately 2 to 3 weeks after surgery. Fitzgerald et al[49] examined the efficacy of perturbation training in a rehabilitation program for ACL-deficient knees and reported more satisfactory outcomes and a lower frequency of subsequent giving-way episodes. Wilk et al,[176] studying female patients after ACL surgery, observed improved results when a program emphasized perturbation training. Therefore, we incorporate perturbation training while the patient performs double- or single-leg balance exercises on a tilt board or an unstable surface. While flexing the knee to approximately 30°, the patient stabilizes the tilt board and begins throwing and catching a 3- to 5-lb (1.4- to 2.3-kg) medicine ball. The patient is instructed to stabilize the tilt board in reaction to the sudden outside force produced by the weighted ball. The rehabilitation specialist may also provide perturbations by striking the tilt board (**FIGURE 6**) with the foot, requiring the patient to stabilize the tilt board with dynamic muscular contractions. Perturbations may also be performed during this drill by tapping the patient on the hips and trunk to provide a postural disturbance to the body. We typically utilize 3 levels of the tilt board to progress the patient to a more challenging level of instability.

An additional goal of neuromuscular training is the restoration of the patient's confidence in the injured knee. It has been our experience that, following a serious knee injury, patients may become afraid of reinjury and returning to high-level function.[29] We believe that restoring neuromuscular control and, in particular, perturbation skill, significantly improves the patient's confidence in the injured knee.

Both weight-bearing exercise (WBE) and non–weight-bearing exercise (NWBE) have been shown to be effective for rehabilitation and return to sport after ACL surgery.[151] However, compared to NWBE, individuals who perform predominantly WBE tend to have less knee pain, more stable knees, generally more satisfaction with the end result, and a quicker return to sport.[151]

There are differences in ACL loading between NWBE and WBE. Through a series of studies that estimated ACL loading during WBE and NWBE using the same relative exercise intensity, Wilk et al[177] and Escamilla et al[41-45] demonstrated higher ACL loads during NWBE (seated knee extensions). With NWBE, ACL tensile loads occurred between knee angles of 0° and 30° and peaked at approximately 150 N, compared to a peak of 50 N when performing a variety of WBEs (barbell squats, single-leg squats, wall squats, forward and side lunges, and leg presses). These data are in agreement with in vivo ACL strain data reported by Beynnon and Fleming[18] and Heijne et al[63] (**TABLE 1**), who also reported a greater peak ACL tensile strain with NWBE than with WBE, occurring at knee flexion angles between 10° and 30°. For example, performing a leg press with 40% body weight resistance, climbing stairs, and lunging forward all produced less ACL strain than performing seated knee extension with no external resistance (**TABLE 1**). Interestingly, performing seated knee extension with no external resistance (quadriceps activation only) produced the same amount of ACL strain as that measured while performing a single-leg sit-to-stand (**TABLE 1**), with the latter also recruiting important hip and thigh musculature (eg, quadriceps, hamstrings, and gluteals), which helps to stabilize the knee and protect the ACL graft.

Although it has been reported that squatting with resistance produces a similar amount of ACL strain compared to performing seated knee extension with resistance,[18] it should be noted that variations in squatting and lunging techniques can affect ACL strain.[43,44,47] For example, squatting and lunging with a more forward trunk tilt recruit the hamstrings, which helps to unload the ACL by decreasing anterior tibial translation to a greater extent than squatting and lunging with a more erect trunk.[44,47,126] Also, the gluteal musculature has higher activation, which may aid in medial/lateral control at the knee. Knee flexion angles can also affect ACL loading. For NWBE and WBE, ACL loading primarily occurs between 0° and 50° of knee flexion; performing these exercises between 50° and 100° of knee flexion minimizes ACL loading. Finally, anterior knee translation beyond the toes, especially more than 8 cm, may also increase ACL loading during squatting and lunging exercises.[43,45]

TABLE 1 SUMMARY OF PEAK ANTERIOR CRUCIATE LIGAMENT STRAIN IN NON–WEIGHT-BEARING AND WEIGHT-BEARING EXERCISES[18,63]

Rehabilitation Exercise	Peak Strain at Knee Angle
Isometric leg extension seated (30 Nm torque)	4.4% at 15°
Dynamic leg extension seated with 45 N (10 lb) of resistance	3.8% at 10°
150 N (33 lb) Lachman test	3.7% at 30°
Squatting with or without 136 N (30 lb) of resistance	3.6%-4.0% at 10°
Dynamic leg extension seated without external resistance	2.8% at 10°
Single-leg sit-to-stand (tested at 30°, 50°, and 70°)	2.8% at 30°
Step-up/-down and stair climbing (tested at 30°, 50°, and 70°)	2.5%-2.7% at 30°
Leg press with 40% body weight resistance	2.1% at 20°
Forward lunge (tested at 30°, 50°, and 70°)	1.9% at 30°
Stationary bicycling	1.7%

WBEs performed on the involved extremity are also utilized to train the neuromuscular control system. Specific neuromuscular control drills designed to dynamically control valgus and varus moments at the knee include front step-downs, lateral step-downs, and single-leg balance drills. Chmielewski et al[30] evaluated several WB activities in individuals with ACL-deficient and ACL-reconstructed knees and noted a strong correlation between functional outcome scores and the ability to perform the front step-down exercise.

Plyometric jumping drills may also be performed to facilitate dynamic stabilization and neuromuscular control of the knee joint, and to train dissipation and production of forces through the muscle's stretch-shortening properties.[178,181] Hewett et al[69] examined the effects of a 6-week plyometric training program on the landing mechanics and strength of female athletes. They reported a 22% decrease in peak ground reaction forces and a 50% decrease in the abduction/adduction moments at the knee during landing. Moreover, significant increases in hamstring isokinetic strength, the hamstring-quadriceps ratio, and vertical jump height were reported. Using the same plyometric program, Hewett et al[66] reported a statistically significant decrease in the amount of knee injuries in female athletes. It must be emphasized that with plyometric drills it is important to instruct the patient on proper jumping and landing techniques as well as control and dissipation of forces.

Plyometric activities are typically initiated 12 weeks after a patellar tendon autograft reconstruction and delayed until 16 weeks after a semitendinosus autograft. The leg press machine is initially used to control the amount of weight and ground reaction forces as the athlete learns to correctly perform jumping drills. The patient is instructed to land softly on the toes, with the knees slightly flexed, to maximize force dissipation and avoid knee hyperextension. Plyometric drills are then progressed to flat ground

FIGURE 7. Double-leg plyometric jumping drills in the lateral direction, in which the patient is instructed to land on the box and flat ground with the knee in a flexed position. These activities are initiated to allow the quadriceps musculature to create and dissipate forces at a higher level prior to returning to sport.

and include ankle hops, jumping in place, and lateral, diagonal, and rotational jumping, bounding, and skip lunging. Flat-ground plyometrics are progressed to incorporate single and multiple boxes (**FIGURE 7**). We usually begin plyometric activities with double-leg jumps, progressing to single-leg jumps. We are cautious with plyometric training because of its potential negative effects on articular surfaces, bone bruises, and the meniscus. We do not advocate the use of plyometrics for the recreational athlete.

Finally, proprioceptive and neuromuscular control has been shown to diminish once muscular fatigue occurs.[92,93,159] Therefore, we frequently recommend performing neuromuscular control drills toward the end of a treatment session, after cardiovascular training, to challenge neuromuscular control of the knee joint when the dynamic stabilizers are fatigued.

Gradually Increase Applied Loads

The next principle of ACL rehabilitation is a gradual increase in the amount of stress applied to the injured knee. The majority (70%-92%) of individuals who sustain an ACL injury also have sustained a bone bruise to the lateral femoral condyle and lateral tibial plateau,[55,84] which can result in an increase in postoperative swelling, pain, and muscle inhibition.[84]

FIGURE 8. Progressive loading treadmill (AlterG Anti-Gravity Treadmill; AlterG, Fremont, CA) utilized to initiate a walking or running program to minimize impact loading on the knee joint.

We believe that such a bone bruise could also lead to articular cartilage defects in the long term,[123] and we therefore attempt to control WB forces after surgery until the bone bruise has subsided.

This simple concept is applied to the progression of ROM, strengthening exercises, proprioceptive training, neuromuscular control drills, functional drills, and sport-specific training. For example, exercises such as weight shifts and lunges are progressed from the straight-plane anterior/posterior or medial/lateral direction to multiplane and rotational movements. Double-leg exercises, such as leg presses, knee extensions, balance activities, and plyometric jumps, are progressed to single-leg exercises. This progression will also gradually increase applied loads on the ACL graft, which are believed to result in tissue hypertrophy and better tissue alignment. Persistent or increasing pain, inflammation, or swelling at any time during the rehabilitation program is an indication of an overaggressive approach.

The athlete's return to sport is achieved through a series of transitional drills. The athlete is allowed to run in the pool prior to flat-ground running as a way to initiate a jogging program. We have found that the pool and an unloading treadmill (**FIGURE 8**) are excellent options prior to dry-land activities. Furthermore, backward and lateral running is performed prior to forward running to decrease stress on the knee. Plyometric activities are performed prior to running and cutting drills, followed by sport-specific agility drills. The decision to return to running is based on a complex sequence of evaluations by the rehabilitation specialist and the athlete's ability to tolerate the functional progression without an increase in pain and swelling, while demonstrating good knee and hip control. Each decision regarding progression is also determined by the known concomitant injuries addressed during surgery and by adequate healing of the involved tissues.

This progression of applied and functional stresses is used to provide a healthy stimulus for healing tissues without causing damage. Our goal is to return the knee joint to its preinjury status and to the level of homeostasis described by Dye and Chew.[40]

Progress to Sport-Specific Training

The last principle of ACL rehabilitation involves the restoration of function through sport-specific training for athletes returning to competition. Many of the previously discussed drills, such as cone drills, lunges with sport cords, plyometric drills, and the running and agility progression, can be modified for the specific functional movement patterns associated with the patient's unique sport. Some sport-specific running and agility drills include side shuffling, cariocas, sudden starts and stops, zigzags, 45° cutting, and 90° cutting. The specific movement patterns learned throughout the rehabilitation program are integrated to provide challenges in a controlled setting. Clearance tests, such as an isokinetic strength test,[54,106,180] the International Knee Documentation Committee Subjective Knee Evaluation Form,[71,109] and hop tests,[56,136] have been advocated. Our criteria for return to play are outlined in **TABLE 2**. The athlete must also demonstrate sufficient confidence in the affected extremity to successfully return to sport without any fears or limitations.[29,170] Finally, we only return the athlete to sport participation once the knee has returned to its normal

TABLE 2 Criteria for Return to Play[120,180]

1. Satisfactory clinical examination
2. Symmetrical range of motion without pain
3. Isokinetic test parameters
   - Quadriceps bilateral comparison (80% or greater)
   - Quadriceps torque-body weight ratio (65% or greater)
   - Hamstrings-quadriceps ratio (>66% for males, >75% for females)
   - Acceleration rate at 0.2 s (80% of quadriceps peak torque)
4. KT 2000 test within 2.5 mm of contralateral leg
5. Functional hop test (85% or greater of contralateral side)

state and reached the level of homeostasis described by Dye and Chew.[40] If the patient's knee is still sore or exhibits swelling after running, stiffness, or localized pain, the activities are reduced to a level that does not produce these effects.

REHABILITATION OF THE FEMALE ATHLETE

An increasing number of females are participating in athletics, and this group warrants special consideration.[64,65,67,70,79,137,158] Malone et al[100] reported that female college basketball players were 8 times more likely to injure their ACL than their male counterparts. Lindenfeld et al[98] reported that female soccer players were 6 times more likely to sustain an ACL injury than male soccer players. There are similar data for other sports, such as volleyball and gymnastics.[28,48] It is also noteworthy that in female athletes, the vast majority of ACL injuries occur without contact.[176]

Females have some unique characteristics that may predispose them to injury, including increased genu valgum alignment, a poor hamstring-quadriceps strength ratio, running and landing on a more extended knee, quadriceps-dominant knee posture, and hip/core weakness. It has also been postulated that hormonal changes associated with the female menstrual cycle may play a role.[64,79]

Because a common mechanism of noncontact ACL injury is a valgus stress with rotation at the knee, it is important for the female athlete to learn to control this valgus moment.[64,69,137] In addition to education on optimal knee alignment (keeping the knee over the second toe), exercises designed to control this moment at the knee include front step-downs (**FIGURE 9**), lateral step-downs with resistance (**FIGURE 10**), and squats with resistance around the distal femur (**FIGURE 11**). Rehabilitation should train the patient to stabilize the knee through coactivation of the quadriceps and hamstrings using various exercises, including tilt board balance exercises while performing a throw and catch. Because females tend to land with increased knee extension and decreased hip flexion after jumping, dynamic stabilization drills should be performed, with the knee flexed approximately 30° to promote better alignment and activation of the quadriceps and hamstrings.[66,69] A key rehabilitation aspect for the female athlete is to train the hip extensors, external rotators, abductors, and core stabilizers, while emphasizing a flexed knee posture during running, cutting, and jumping. We instruct the female athlete to control the knees via the hip/pelvis[68,86,132] and foot position.[86] Furthermore, we emphasize strength training of the hip abductors, extensors, and external rotators. We take special consideration to eccentrically train these muscle groups to help control excessive adduction and internal rotation of the femur during WB activities. Moreover, core stabilization exercises are utilized to aid in controlling lateral trunk displacement during sport movements.[66,68,117,186,187]

FIGURE 9. Front step-down movement: during the eccentric or lowering phase, the patient is instructed to maintain proper alignment of the lower extremity to prevent the knee from moving into a valgus moment.

We believe that after ACL surgery it is important that female athletes undergo a specific rehabilitation program that addresses the predisposing factors that potentially led to the injury.

VARIATIONS IN REHABILITATION BASED ON GRAFT TYPE

Graft selection has some impact on the rehabilitation program used following ACL reconstruction. Today, the most commonly utilized sources of graft tissue are the autogenous patellar bone-tendon-bone[33,149] and autogenous

FIGURE 10. Lateral step-down with resistance bands. A resistance band is applied around the inner knee to provide resistance and to control the valgus moment at the knee by recruiting hip abductors and rotators.

FIGURE 11. Lateral stepping with resistance bands around the distal femur to further recruit hip musculature.

hamstring tendons.[1,99,184] Some physicians use allografts[4,51,157] and others use the quadriceps tendon.[53,61] Postoperative rehabilitation needs to be adapted based on differences in graft tissue strength, stiffness, and fixation strength.

The ultimate load to failure of various tissues has been reported by several investigators (**TABLE 3**).[59,134,164,182] Hamner et al[59] reported that the quadrupled hamstring tendon graft is approximately 91% stronger than the native ACL and 39% stronger than the patellar tendon. The patellar tendon graft is approximately 37% stronger than the native ACL. Although all potential grafts listed in **TABLE 3** are stronger than the native ACL, graft fixation strength and graft size must be factored into the equation when developing a rehabilitation program. The healing of bone to bone in the osseous tunnel (patellar tendon autograft), which occurs in approximately 8 weeks in most instances, is faster than the healing of tendon to bone (hamstring autograft), which takes approximately 12 weeks.[140,165] The theoretical advantage of a larger, stronger allograft that allows more aggressive rehabilitation remains unproven.[111]

TABLE 3 Ultimate Load to Failure and Stiffness of Various Graft Selections

Graft Selection	Ultimate Strength to Failure (N)	Stiffness (N/m)
Native anterior cruciate ligament[182]	2160	240
Patellar tendon[134]	2977	455
Quadrupled hamstring[59]	4140	807
Quadriceps tendon[164]	2353	326

The potential disadvantage of using hamstring autograft or patellar tendon allograft tissue is increased graft laxity or graft failure due to delayed or inappropriate healing.[96] Conversely, the potential disadvantage of using a bone-patellar tendon–bone autograft is the higher rate of arthrofibrosis and anterior knee pain.[96] Both issues can be minimized or avoided by using the appropriate supervised rehabilitation program.

Our clinical approach to developing and designing a rehabilitation program based on the type of ACL graft is to be initially less aggressive with soft tissue grafts such as the quadrupled hamstring/semitendinosus graft. Therefore, the return to running, plyometrics, and sports is slightly slower with a semitendinosus graft. Additionally, we do not allow isolated hamstring strengthening for approximately 8 weeks, to allow appropriate graft site healing to occur.

Aglietti et al[2] compared the outcomes of using hamstring tendon grafts versus bone-tendon-bone grafts in a consecutive series of 60 patients. The results indicated no significant difference in outcomes between the 2 types of grafts. In the patellar tendon graft group, compared to the semitendinosus group, there was a trend toward better objective stability; however, there was more knee extension motion loss and more patellofemoral complaints. These results are similar to the findings of Marder et al.[102]

Our rehabilitation program for allograft reconstruction is slower than the regular program for autogenous grafts. When using allograft tissue, the limiting factor to consider is fixation of the soft tissue as it is healing within the bone tunnels. It is believed that this can take longer than 4 to 6 months[76,81,82] and therefore may limit the patient's progression to higher-level functional activities. Several authors have described the rehabilitation program following allogenous patellar tendon bone-tendon-bone grafts.[51,78,81,82,122] Although the initial progression is similar, the rehabilitation program for allograft tissue should be slower to progress to aggressive activities such as running, jumping, and cutting.

VARIATIONS BASED ON CONCOMITANT PROCEDURES

Medial Collateral Ligament Injury

Hirshman et al[72] reported a 13% incidence of combined ACL and medial collateral ligament (MCL) injuries in acute knee ligament injuries. Isolated MCL injuries are often treated nonoperatively; however, when combined with ACL disruption, grade

III MCL injuries may require surgical intervention due to the loss of the ACL as a secondary restraint to valgus stress. Although individuals with grade I and grade II MCL sprains may not require surgical intervention for the MCL, they may require special attention during the rehabilitation process due to increased pain and potential for excessive scarring of the medial capsular tissues.

The treatment approach for an ACL reconstruction and a nonoperative MCL is similar to that used for isolated ACL reconstruction, with some noteworthy special considerations. Due to increased pain, the extent of tissue damage, and extra-articular vascularity, combined ACL and MCL injuries often present with excessive scar tissue formation[139]; thus a slightly more accelerated progression for ROM should follow, with particular emphasis on achieving full passive knee extension. Restoring motion can be a challenge for the clinician due to the increase in pain associated with this injury.

MCL tears from the proximal origin or within the midsubstance of the ligament tend to heal with increased stiffness without residual laxity. In contrast, MCL injuries at the distal insertion site tend to have a lesser healing response, often leading to residual valgus laxity.[152] Therefore, the location of ligament damage may also affect the rehabilitation program. Injuries involving the distal aspect of the MCL may be progressed more cautiously to allow for tissue healing; in some instances, these individuals may be immobilized in a brace to allow MCL healing prior to ACL reconstruction. In contrast, injury to the midsubstance or proximal ligament may require a slightly accelerated restoration of ROM to prevent excessive scar tissue formation, and early motion is encouraged and beneficial to the healing of the MCL. The expected goal of an ACL reconstruction with an MCL sprain of any degree is full passive knee extension. Oftentimes, the patient may find it difficult to obtain full knee extension due to the increase in pain associated with the concomitant MCL injury.

Lateral Collateral Ligament Injury

The incidence of concomitant lateral collateral ligament (LCL) injuries is far less than that of concomitant MCL injuries, with Hirshman et al[72] reporting a 1% incidence of combined ACL and LCL injuries in acute knee injuries. ACL injuries with concomitant LCL pathology or posterolateral capsular damage usually do not exhibit the same scarring characteristics as combined ACL and MCL injuries and, in the case of grade III sprains, require surgery to restore normal knee stability and function. Thus progression for concomitant ACL and LCL injuries is usually slower than for combined ACL and MCL injuries to allow adequate healing. The restoring of ROM is not altered, although WB may progress slightly slower, with full WB occurring approximately 4 weeks following surgery. Similar to the MCL, where excessive valgus stress is avoided, exercises that produce excessive varus stress are progressed with caution and should be carefully monitored for symptoms. Furthermore, if the patient exhibits a varus thrust during ambulation, then a functional medial unloader brace may be useful to control the varus moment, and isolated isotonic hamstring strengthening may be delayed for 6 to 8 weeks.

It should be noted that the varus and valgus stresses observed during these combined collateral injuries will often result in bone bruises and articular cartilage lesions. Rehabilitation progression, particularly with impact loading, should be delayed to allow adequate bone healing.

Articular Cartilage Lesions

Articular cartilage lesions of the knee or bone bruises occur in approximately 70% to 92% of traumatic ACL injuries,[55,84,142,163] with 1 study reporting 100% incidence.[115] Generally, bone bruises occur on the lateral femoral condyle and lateral tibial plateau.[50,55,142,160,163] With lesions on a WB surface and extending into the subchondral bone, deleterious compressive forces early in the rehabilitation process must be avoided. The rehabilitation specialist should also consider delaying impact activities, such as jogging and plyometrics, to allow for sufficient bone healing. Follow-up magnetic resonance imaging is not routinely performed due to cost constraints; but it may be beneficial to determine the extent of bone healing to assist in patient progression toward higher-level WB activities. Oftentimes, the rehabilitation specialist must rely on symptoms when progressing the patient.

Two of the most important considerations of rehabilitation following ACL reconstruction on someone with an underlying articular cartilage injury are WB restrictions and progressive ROM. Unloading and immobilization have been shown to be deleterious to healing articular cartilage, resulting in proteoglycan loss and gradual weakening.[16,57,167] Therefore, controlled WB and ROM are essential to facilitate healing and prevent degeneration. This gradual progression has been shown to stimulate matrix production and improve the tissue's mechanical properties.[23,24,168] Controlled compression and decompression forces observed during WB may nourish articular cartilage and provide the necessary signals to the repair tissue to produce a matrix that will match the environmental forces.[16,57,167] A progression of partial WB with crutches is used to gradually increase the amount of load applied to the WB surfaces of the joint. A progressive loading program that utilizes a pool or unloading treadmill can also be extremely beneficial in the progression following ACL reconstruction in a patient with a bone bruise.

PROM activities, such as continuous passive motion machines or manual PROM performed by a rehabilitation specialist, are also performed immediately after surgery with a limited ROM to nourish the healing of articular cartilage and prevent the formation of adhesions.[116,147] Motion exercises may assist in creating a smooth, low-friction surface by sliding against the joint's articular surface, and may be an essential component of cartilage repair.[147,156] It is the authors' opinion that PROM is a safe and effective exercise to perform immediately after surgery and has minimal disadvantageous shear or compressive forces when performed with patient relaxation. This ensures that muscular contraction does not create deleterious compressive or shearing forces. Furthermore, the use of continuous passive motion has been shown to enhance cartilage healing and long-term outcomes following articular cartilage procedures.[141,146]

The importance of communication between the surgical team and the rehabilitation team to ensure the highest quality of care for each individual cannot be overemphasized, especially when a concomitant articular cartilage procedure, such as a microfracture, is performed. Knowledge of the healing and maturation processes following these procedures will ensure that the repair tissue is gradually loaded and that excessive forces are not introduced too early in the healing process. Long-term studies are needed to better understand whether these articular cartilage lesions can lead to degenerative osteoarthritis and functional disability, although some studies reported that 40% to 90% of ACL patients will exhibit radiographic knee osteoarthritis 7 to 12 years following surgery.[97,119,131]

Meniscal Pathology

Meniscal injuries occur in approximately 64% to 77% of ACL injuries.[27,111] Shelbourne et al[153] stated that meniscal tears in the ACL-injured knee typically occur traumatically and are nondegenerative in nature compared to meniscal tears in ACL-intact knees. If meniscal pathology is present, a partial meniscectomy or meniscus repair may be necessary to alleviate symptoms. An arthroscopic partial meniscectomy does not significantly alter the rehabilitation protocol. However, additional time may be required before initiating a running or jumping program, depending on the amount of meniscal injury. If surgical repair of the meniscus is required, alteration to the rehabilitation program is warranted; although controversy exists regarding the duration of immobilization, WB progression, and the timing for return to pivoting sports.[9] Cannon and Vittori[25] and others[90,121,128] reported an increase in meniscal healing when a concomitant ACL reconstruction was performed.

For patients undergoing concomitant ACL reconstruction and meniscus repair, ROM and WB progressions are slightly slower, depending on the extent of meniscus repair or location of meniscal injury. Although there is very limited research, we allow immediate WB on meniscus repairs with the knee brace locked in full extension. WB with the knee locked in full extension produces a hoop stress on the meniscus, which may aid healing capacity. Repair of complex tears is progressed much slower than repair of peripheral tears of the meniscus. Moreover, isotonic hamstring strengthening is limited for 8 to 10 weeks to allow adequate healing of the repaired meniscus, due to the close anatomical relationship of the joint capsule to the meniscus and hamstrings. The patient is not allowed to squat past 60° for 8 to 12 weeks and needs to avoid squats with twisting motions for at least 16 weeks.

Specific ROM guidelines differ based on the extent and location of meniscal damage, although immediate motion with emphasis on full passive knee extension is universal. Patients with repair of a tear isolated at the periphery of the meniscus should exhibit approximately 90° to 100° of flexion by week 2, 105° to 115° by week 3, and 120° to 135° by week 4. Patients with repair of complex meniscal tears follow a slightly slower approach, with 90° to 100° of knee flexion by week 2, 105° to 110° by week 3, and 115° to 120° by week 4. Patients with complex meniscus repairs may also need to use crutches and partial WB for an additional 1 to 2 weeks.

Barber and Click[9] evaluated the efficacy of an accelerated ACL rehabilitation program for patients with concomitant meniscus repair. At follow-up (24-72 months after surgery), 92% of repairs exhibited successful meniscal healing, while only 67% of meniscus repairs performed in ACL-deficient knees and 67% of meniscus repairs performed in stable knees exhibited successful healing. The authors suggested that the hemarthrosis and simulated inflammatory process associated with ACL reconstruction may enhance meniscal healing and improve long-term results of meniscus repair.

CONCLUSION

The rehabilitation process begins immediately following ACL injury, with emphasis on reducing swelling and inflammation, regaining quadriceps control, allowing immediate WB, restoring full passive knee extension, and gradually restoring flexion. The goal of preoperative rehabilitation is to mentally and physically prepare the patient for surgery. Once the ACL surgery is performed, it is important to alter the rehabilitation program based on the type of graft used, any concomitant procedures performed, and the presence of an articular cartilage lesion. This aids in the prevention of several postoperative complications, such as loss of motion, patellofemoral pain, graft failure, and muscular weakness. Current rehabilitation programs focus not only on strengthening exercises but also on proprioceptive and neuromuscular control drills to provide a neurological stimulus so that the athlete can regain the dynamic stability that is needed in athletic competition. We believe that it is also important to address any pre-existing factors, especially for the female athlete, that may predispose the individual to future injury. Our goal in the rehabilitation program following ACL surgery is to restore full, unrestricted function and to assist the patient to return to 100% of the preinjury level while achieving excellent long-term outcomes.

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APPENDIX

ACCELERATED REHABILITATION FOLLOWING ACL-PTG RECONSTRUCTION

Preoperative Phase

Goals
- Diminish inflammation, swelling, and pain
- Restore normal range of motion (especially knee extension)
- Restore voluntary muscle activation
- Provide patient education to prepare patient for surgery

Brace:
- Knee brace or sleeve to reduce swelling

Weight bearing:
- As tolerated with or without crutches

Exercises:
- Ankle pumps
- Passive knee extension to 0°
- Passive knee flexion to tolerance
- Straight leg raises (flexion, abduction, adduction)
- Quadriceps setting
- Weight-bearing exercises: minisquats, lunges, step-ups

Muscle stimulation:
- Electrical muscle stimulation to quadriceps during voluntary quadriceps exercises (4-6 hours per day)

Cryotherapy/elevation:
- Apply ice for 20 minutes of every hour and elevate leg with knee in full extension (knee must be above heart)

Patient education:
- Review postoperative rehabilitation program
- Review instructional video (optional)
- Select appropriate surgical date

Immediate Postoperative Phase (Day 1-7)

Goals
- Restore full passive knee extension
- Diminish joint swelling and pain

APPENDIX

- Restore patellar mobility
- Gradually improve knee flexion
- Re-establish quadriceps control
- Restore independent ambulation

Postoperative Day 1

Brace:
- Postoperative brace/immobilizer applied to knee, locked in full extension during ambulation

Weight bearing:
- 2 crutches, weight bearing as tolerated

Exercises:
- Ankle pumps
- Overpressure into full, passive knee extension
- Active and passive knee flexion (90° by day 5)
- Straight leg raises (flexion, abduction, adduction)
- Quadriceps isometric setting
- Hamstring stretches
- Weight-bearing exercises: minisquats, weight shifts

Muscle stimulation:
- Use muscle stimulation during active muscle exercises (4-6 hours per day)

Continuous passive motion:
- As needed, 0° to 45°/50° (as tolerated and as directed by physician)

Ice and elevation:
- Apply ice for 20 minutes of every hour and elevate with knee in full extension

Postoperative Day 2-3

Brace:
- Knee brace/immobilizer, locked at 0° of extension for ambulation and unlocked for sitting

Weight bearing:
- 2 crutches, weight bearing as tolerated

Range of motion:
- Remove brace to perform ROM exercises 4 to 6 times per day

Exercises:
- Multi-angle isometrics for knee extension at 90° and 60°
- Knee extension 90° to 40°
- Overpressure
- Patellar mobilization
- Ankle pumps
- Straight leg raises (3 directions)
- Minisquats and weight shifts
- Standing hamstring curls
- Quadriceps isometric setting

Muscle stimulation:
- Electrical muscle stimulation to quadriceps (6 hours per day)

Continuous passive motion:
- 0° to 90°, as needed

Ice and elevation:
- Apply ice for 20 minutes of every hour and elevate leg with knee in full extension

Postoperative Day 4-7

Brace:
- Knee brace/immobilizer, locked at 0° of extension for ambulation and unlocked for sitting

Weight bearing:
- 2 crutches, weight bearing as tolerated

Range of motion:
- Remove brace to perform ROM exercises 4 to 6 times per day; knee flexion of 90° by day 5 and approximately 100° by day 7

Exercises:
- Multi-angle isometrics for knee extension at 90° and 60°
- Knee extension of 90° to 40°
- Overpressure into extension
- Patellar mobilization
- Ankle pumps
- Straight leg raises (3 directions)
- Minisquats and weight shifts
- Standing hamstring curls
- Quadriceps isometric setting
- Proprioception and balance activities

Muscle stimulation:
- Electrical muscle stimulation (continue for 6 h daily)

Continuous passive motion:
- 0° to 90°, as needed

Ice and elevation:
- Apply ice for 20 minutes of every hour and elevate leg with knee in full extension

Early Rehabilitation Phase (Week 2-4)

Criteria to Enter Phase 2

1. Quadriceps control (ability to perform good quadriceps set and straight leg raise)
2. Full passive knee extension
3. PROM of 0° to 90°
4. Good patellar mobility
5. Minimal joint effusion
6. Independent ambulation

Goals
- Maintain full passive knee extension
- Gradually increase knee flexion
- Diminish swelling and pain
- Muscle training
- Restore proprioception
- Patellar mobility

Week 2

Brace:
- Discontinue brace or immobilizer at 4 weeks

Weight bearing:
- As tolerated (goal is to discontinue crutches 10 days after surgery)

Range of motion:
- Self-ROM stretching (4-5 times daily), emphasis on maintaining full passive extension ROM

APPENDIX

KT 2000 test:
- 15-lb anterior/posterior test only

Exercises:
- Muscle stimulation to quadriceps with exercise
- Isometric quadriceps sets
- Straight leg raises (4 planes)
- Leg press
- Knee extension 90° to 40°
- Half squats (0°-40°)
- Weight shifts
- Front and side lunges
- Hamstring curls
- Bicycle (ROM permitted)
- Proprioception training
- Overpressure into extension
- Passive range of motion from 0° to 90°
- Patellar mobilization
- Well leg exercises
- Progressive resistance extension program: start with 1 lb and progress 1 lb per week

Swelling control:
- Ice, compression, elevation

<u>Week 3</u>

Brace:
- Continue use pending quadriceps control

Range of motion:
- Continue ROM stretching and overpressure into extension

Exercises:
- Continue all exercises as in week 2
- PROM of 0° to 115°
- Bicycle for ROM stimulus and endurance
- Pool walking program (if incision is closed)
- Eccentric quadriceps program (40°-100°; isotonic only)
- Lateral lunges
- Lateral step-ups
- Front step-ups
- Lateral step-overs (cones)
- Stair-stepper machine
- Progress proprioception drills, neuromuscular control drills

Controlled Ambulation Phase (Week 4-10)

<u>Criteria to Enter Phase 3</u>

1. Active ROM of 0° to 115°
2. Quadriceps strength greater than 60% of contralateral side (isometric test at 60° of knee flexion)
3. Unchanged KT test bilateral values (+1 or less)
4. Minimal to no joint effusion
5. No joint line or patellofemoral pain

<u>Goals</u>

- Restore full knee ROM (0°-125°)
- Improve lower extremity strength
- Enhance proprioception, balance, and neuromuscular control
- Improve muscular endurance
- Restore limb confidence and function

Brace:
- No immobilizer or brace; may use knee sleeve

Range of motion:
- Self-ROM (4-5 times daily using the other leg to provide ROM); emphasis on maintaining 0° of passive extension

KT 2000 test:
- Week 4: 20-lb anterior and posterior test

<u>Week 4</u>

Exercises:
- Progress isometric strengthening program
- Leg press
- Knee extension 90° to 40°
- Hamstring curls
- Hip abduction and adduction
- Hip flexion and extension
- Lateral step-overs
- Lateral lunges
- Lateral step-ups
- Front step-downs
- Wall squats
- Vertical squats
- Toe calf raises
- Biodex Stability System (balance, squats, etc) (Biodex Medical Systems, Shirley, NY)
- Proprioception drills
- Bicycle
- Stair-stepper machine
- Pool program (backward running, hip and leg exercises)

<u>Week 6</u>

KT 2000 test:
- 20-lb and 30-lb anterior and posterior test

Exercises:
- Continue all exercises
- Pool running (forward) and agility drills
- Balance on tilt boards
- Progress to balance and board throws

<u>Week 8</u>

KT 2000 test:
- 20-lb and 30-lb anterior and posterior test

Exercises:
- Continue all exercises listed in week 4-6
- Plyometric leg press
- Perturbation training
- Isokinetic exercises (90°-40°) (120°/s-240°/s)
- Walking program
- Bicycle for endurance
- Stair-stepper machine for endurance

<u>Week 10</u>

KT 2000 test:

APPENDIX

- 20-lb and 30-lb and manual maximum tests

Isokinetic test:

- Concentric knee extension/flexion at 180°/s and 300°/s

Exercises:

- Continue all exercises listed in week 6, 8, and 10
- Plyometric training drills
- Continue stretching drills

Advanced Activity Phase (Week 10-16)

Criteria to Enter Phase 4

1. AROM of 0° to 125° or greater
2. Quadriceps strength greater than 79% of contralateral side; knee flexor-extensor ratio of 70% to 75%
3. No change in KT values (comparable with contralateral side, within 2 mm)
4. No pain or effusion
5. Satisfactory clinical exam
6. Satisfactory isokinetic test (values at 180°/s)
   a. Quadriceps bilateral comparison: 75%
   b. Hamstrings equal bilateral
   c. Quadriceps peak torque/body weight: males 55% to 60%; females 45% to 50%
   d. Hamstrings-quadriceps ratio of 66% to 75%
7. Hop test (80% of contralateral leg)
8. Subjective knee score (ie, Cincinnati Knee Rating System) of 80 points or higher

Goals

- Normalize lower extremity strength
- Enhance muscular power and endurance
- Improve neuromuscular control
- Perform selected sport-specific drills

Exercises:

- Continue all exercises

Return to Activity Phase (Week 16-22)

Criteria to Enter Phase 5

1. Full ROM
2. Unchanged KT 2000 test (within 2.5 mm of opposite side)
3. Isokinetic test that fulfills the criteria listed below (180°/s)
4. Quadriceps bilateral comparison (80% or greater)
5. Hamstring bilateral comparison (110% or greater)
6. Quadriceps torque-body weight ratio (55% or greater)
7. Hamstrings-quadriceps ratio (70% or greater)
8. Proprioception test: Biodex Stability System test[127] (100% of contralateral leg)
9. Functional hop test (85% or greater of contralateral side)
10. Satisfactory clinical exam
11. Subjective knee score (Cincinnati Knee Rating System) of 90 points or higher

Goals

- Gradual return to full, unrestricted sports
- Achieve maximal strength and endurance
- Normalize neuromuscular control
- Progress skill training

Tests:

- KT 2000, isokinetic, and functional tests before return

Exercises:

- Continue strengthening exercises
- Continue neuromuscular control drills
- Continue plyometric drills
- Progress running and agility program
- Progress sport-specific training

6-Month Follow-up

- Isokinetic test
- KT 2000 test
- Functional test

12-Month Follow-up

- Isokinetic test
- KT 2000 test
- Functional test

Abbreviations: AROM, active range of motion; PROM, passive range of motion; PTG, patellar tendon graft; ROM, range of motion.