Current Rehabilitation Concepts for Anterior Cruciate Ligament Surgery in Athletes

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Abstract: The anterior cruciate ligament is the most commonly disrupted ligament in the knee in high-performance athletes. Most recently, advancements in surgical technique and graft fixation have enabled athletes to participate in early postoperative rehabilitation, focusing on range of motion and progressing to patellar mobilization, strengthening, and neuromuscular control. Several rehabilitation protocols exist with variations in specific exercises, progression through phases, and key components. The ultimate goal of rehabilitation is to return the athlete to preinjury performance level, including motion and strength, without injuring or elongating the graft. Each athlete is unique; thus, safe return to play should be individualized rather than follow a particular postoperative month or time line. This article provides an overview of the application and the scientific basis for formulating a rehabilitation protocol prior to and following anterior cruciate ligament surgery. [Orthopedics. 2015; 38(11):689-696.]

The anterior cruciate ligament (ACL) is by far the most disrupted ligament in the knee, with approximately 200,000 isolated injuries annually. Epidemiologic studies estimate that the prevalence of ACL injuries is approximately 1 per 3000 Americans.¹ As the management of these injuries has evolved from nonoperative treatment to extracapsular augmentation and primary ligament repair to ligament reconstruction, the rehabilitation of these injuries has also evolved. Rehabilitation after ACL reconstruction plays a major role in the functional outcomes of the extremity.² In the early surgical management of ACL injuries, full weight bearing without braces was not permitted for 6 to 8 weeks. In 1983, the program of rigid immobilization was discarded in favor of immediate continuous passive motion, and in 1990, Shelbourne and Nitz³ concluded that an “accelerated” rehabilitation program allowed athletes to return to normal function and athletic activities sooner than patients in the conventional rehabilitation program.

Most recently, advancements in surgical technique and graft fixation have enabled patients to participate in early postoperative rehabilitation, focusing on range of motion (ROM) and progressing to patellar mobilization and strengthening. Patients can bear weight on the affected limb immediately. Early weight bearing and rehabilitation do not compromise ligamentous stability and result in a lower incidence of anterior knee pain compared with non-weight bearing.³⁻⁵ Current ACL rehabilitation approaches stress the importance of immediate motion and early weight bearing, immediate muscle exercises, closed kinetic chain exercises, early functional activities, and an earlier return to sports. Proprioceptive and neuromuscular control drills are also important for high-level athletes so that they can regain the dynamic joint and functional stability needed in athletic competition.⁶⁻⁷

Numerous protocols exist for the rehabilitation of ACL injuries before and after surgery. The authors urge readers to examine the variety of sources available but understand the importance of seeing these materials as guidelines because the unique circumstances of the patient may require adjustments, particularly if the protocol is somewhat time focused in its approach.⁸ An important concept is that each athlete is unique; there-
Preoperative Phase

Before reconstructive ACL surgery, emphasis should be on establishing a normal gait pattern and active range of motion of at least 0° to 90°. Only 1 to 3 physical therapy visits are needed because patients can transition to a home exercise program. Patients may ambulate full weight bearing with the brace unlocked if they demonstrate a normal gait pattern and no instability with activities of daily living. Otherwise, it is recommended that the brace be locked to provide support to an unstable knee. Knee ROM in flexion and extension is an important predictor of postoperative ROM and therefore needs to be emphasized preoperatively. Prone hangs (Figure 1), heel slides, and prone flexion stretching are some exercises that can be used to re-establish a good ROM base after the initial injury (Table 1). Also, quadriceps sets and straight leg raises are recommended in this phase to maximize quadriceps function. However, only closed chain muscle strengthening exercises should be used and limited to ROM of 0° to 90°. Straight leg raises are helpful for quadriceps strengthening and should be performed without a lag sign. Neuromuscular electrical stimulation is another functional modality that can also be used to improve quadriceps muscle strength (Table 1).

Another important aspect of this phase is reducing the swelling and effusion in the knee joint that occurs with an ACL injury. Cryotherapy (cold with compression and el-

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**Figure 1:** Prone hang. This is done by lying on the stomach and sliding down to the end of the table or bed where the thigh is supported and the lower leg hangs off. A towel may be placed underneath the thigh, just above the patella, to decrease pressure directly on the patella. This position should be held for 30 to 60 seconds, allowing gravity to pull the lower leg down toward the floor so that the knee straightens out. This exercise should be done for 5 to 10 repetitions.

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<table>
<thead>
<tr>
<th>Aspect of Rehabilitation</th>
<th>Treatment Goal</th>
<th>Treatment Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extension ROM</strong></td>
<td>Full extension equal to the opposite side</td>
<td>Prone hangs, working up to more than 30 minutes per day</td>
</tr>
<tr>
<td><strong>Flexion ROM</strong></td>
<td>120° or more of flexion</td>
<td>Heel slides, prone flexion stretching</td>
</tr>
<tr>
<td><strong>Quadriceps function</strong></td>
<td>Straight leg raise without a lag sign</td>
<td>Straight leg raise, quadriceps sets, neuromuscular electrical stimulation quadriceps, closed chain exercises limited to 0° to 90°</td>
</tr>
<tr>
<td><strong>Gait/brace</strong></td>
<td>Full weight bearing, brace unlocked</td>
<td>Patient may ambulate with brace unlocked if demonstrating a normal gait pattern and not reporting instability with activities of daily living; otherwise, locked brace is recommended</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>Patient understands both presurgical and early postoperative treatment goals/home exercise program</td>
<td>Integrated team approach with specific expectations and goals discussed between the athlete, physician, athletic trainer, and physical therapist</td>
</tr>
<tr>
<td><strong>Swelling</strong></td>
<td>Minimal to none</td>
<td>Cryotherapy, compressive sleeve (eg, Tubigrip [North Coast Medical, Incorporated, Gilroy, California]), limb elevation</td>
</tr>
</tbody>
</table>

*Abbreviation: ROM, range of motion.*
Elevation), compression sleeves, and limb elevation can all be used to attain this goal in preparation for surgery. Furthermore, this phase should also involve detailed and comprehensive education regarding rehabilitation goals prior to and immediately after surgery. Patient education should also include specific postoperative exercises that are necessary for successful rehabilitation, the importance of compliance, ambulation with crutches, and wound care instructions. A discussion of the postoperative rehabilitation protocol, different phases, and recommended goals before eventual return to play is imperative in managing expectations and fostering a safe and timely return to sport.

**Early Postoperative Phase**

This phase consists of the first 4 weeks (0-4 weeks) after surgery. The goals during this period are to minimize pain and swelling, establish a normal gait pattern and eventually discontinue crutch use, achieve 90° of flexion and full extension, and promote quadriceps function and good quadriceps control. It is important to ensure that the incisions are clean, dry, and intact, and appropriate wound care should be emphasized. Cryotherapy is recommended for the first 24 hours or until acute inflammation is controlled and should be used every hour for approximately 15 minutes. After acute inflammation is controlled, cryotherapy can be used 3 times a day for 15 minutes and crushed ice can be useful for reducing swelling after activity or physical therapy. Also, weight bearing as tolerated with a brace and both crutches should begin the day of surgery. This should include progressive loading of the involved limb with improved gait on a weekly basis. Early weight bearing has been shown to decrease patellofemoral pain after ACL surgery. A brace should be applied at the time of surgery and locked at 0° for weight bearing initially, but may be unlocked when seated. At 4 weeks, the brace may be shortened and unlocked if the patient demonstrates a straight leg raise without a lag and can ambulate with a normal gait pattern (Table 2). Crutches, helpful for safe ambulation

<table>
<thead>
<tr>
<th>Aspect of Rehabilitation</th>
<th>Week 1</th>
<th>Week 4</th>
<th>Treatment Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension ROM</td>
<td>Symmetric to opposite side</td>
<td>Symmetric to opposite side</td>
<td>Prone hangs, working up to more than 30 minutes per day, extension mobilization in clinic; splinting for patients unable to reach 0° after 1 to 2 weeks</td>
</tr>
<tr>
<td>Flexion ROM</td>
<td>90°</td>
<td>120° or more</td>
<td>Heel slides, prone flexion stretching, stationary bike</td>
</tr>
<tr>
<td>Quadriceps function</td>
<td>Able to isolate quadriceps contraction</td>
<td>Straight leg raise without lag sign</td>
<td>Neuromuscular electrical stimulation quadriceps (home/clinic), quadriceps sets, straight leg raise; if appropriate, open brace at week 2 in clinic to start 0° to 45° closed chain exercises, including leg press, half squats, terminal knee extensions</td>
</tr>
<tr>
<td>Weight bearing</td>
<td>WBAT with both crutches</td>
<td>Full weight bearing; discontinue crutches</td>
<td>Progressive loading of involved limb with gait on a weekly basis</td>
</tr>
<tr>
<td>Brace use</td>
<td>Brace locked at 0° for weight bearing; otherwise, may be unlocked</td>
<td>Brace unlocked for gait</td>
<td>Unlock brace at 4 weeks if patients demonstrate a straight leg raise without a lag and can ambulate with a normal gait pattern; patients still may be asked to lock their brace for uneven terrain or inclement weather (eg, ice and snow)</td>
</tr>
<tr>
<td>Patellar mobility</td>
<td>Has active superior glide with quadriceps set</td>
<td>Minimally restricted</td>
<td>Teach the patient self-mobilizations at first postoperative visit; therapist mobilizes patella at all treatments</td>
</tr>
<tr>
<td>Swelling/wound care</td>
<td>Incisions are clean, dry, intact</td>
<td>Minimal swelling</td>
<td>Swelling; cryotherapy, use of compression stockings, including TED hose or Tubigrip (North Coast Medical, Incorporated, Gilroy, California); use of home units, including Game Ready (CoolSystems, Incorporated, Concord, California)</td>
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Abbreviations: TED, thromboembolic deterrent; WBAT, weight bearing as tolerated.
initially, should only be discontinued when a normal gait pattern without limp has been established and the patient is able to safely ascend/descend stairs without noteworthy pain or instability (reciprocal stair climbing).

Furthermore, this phase is important for establishing ROM and quadriceps function, and 2 to 3 physical therapy visits per week along with a focused daily home exercise program is recommended. The extension ROM goal by week 4 is for the limb to be symmetrical to the contralateral side. For flexion, ROM should progress from 90° initially to approximately 120° by week 4. Specific ROM exercises that are helpful in achieving these goals include prone hangs (Figure 1), heel slides, and prone flexion stretching; a stationary bike can also be used.

Regarding quadriceps function during this phase, neuromuscular electrical stimulation, quadriceps sets, and straight leg raises are important and should be done with a brace on and locked until the patient can demonstrate performance without a lag sign. The physical therapist should emphasize closed chain exercises and the patient should be able to isolate quadriceps contraction. Additionally, “patellar mobility exercises” or “patellar mobilizations” (Figure 2) are important for facilitating normal active extension mechanics. This includes attainment of a symmetric superior glide of the patella during quadriceps activation seen during quadriceps sets (Table 2). There are also specific graft considerations that are important to note during this phase. Anterior cruciate ligament reconstructions with bone-patellar tendon-bone autografts are more prone to patellar hypomobility; therefore, if the wound is healing well, progressive patellar mobilizations (Figure 2) are important. Patients with hamstring autograft ACL reconstructions will be limited in hamstring strengthening activities for the first month.

**Strengthening Phase**

The strengthening phase of ACL rehabilitation occurs from 4 weeks until approximately 6 months postoperatively, but can last longer if necessary. The brace should be shortened and unlocked. It is typically used outside of the clinic, but can be removed at the physical therapist’s or physician’s discretion depending on the type of activity the patient is performing. The advancement of strengthening is dictated by the patient’s response. There must be no increase in either swelling or articular pain. Short-term articular soreness after exercises should be limited to less than 6 to 12 hours in general and should not require medication for reduction. In this phase, the primary focus should be on proper technique and avoiding substitution via compensatory mechanisms. Full ROM and patellar mobilization are to be attained as early as possible if they were not achieved in the first month postoperatively. There is a strict limit on strengthening ROM during closed chain activity to 0° to 90°; however, earlier in the phase, it may be best to limit ROM to shallower depths such as 45° to 60° to limit patellofemoral stress.

Specific exercises that should be stressed during strengthening of the limb include mini-squats, mini-lunges, leg press, hamstring curls, step downs (Figures 3-4), wall sits, one-legged deadlifts, 4-way hip exercises, TheraBand (Performance Health, Akron, Ohio) hip rotator exercises, shuttle, and wall squats (Table 3). As a general guideline, repetitions are higher (10-15 per set) and
lower weights are used earlier in the phase; later in the phase, as strength improves, repetitions may be reduced (6-8 per set) with heavier weights. For the best outcomes, weights should be gradually increased. Multidirectional movements may also be incorporated to mimic functional and athletic activity.

Also, neuromuscular and cardiopulmonary training are important aspects of this phase. Balance cushions or other proprioceptive devices (wobble board or roller board) can be used during exercises to emphasize neuromuscular control of the extremity and mimic functional activities such as catching, throwing, or kicking. Regarding cardiovascular endurance, straight line running on a treadmill or exercise on a bike, elliptical machine, or StairMaster (StairMaster, Vancouver, Washington) in a protected environment should be performed (Table 3). To protect the graft, there should be no cutting or pivoting during these exercises.

**RETURN TO ACTIVITY PHASE**

This phase starts at 3 months postoperatively and continues until an athlete returns to sport. Activity is progressed via patient response. It is not unusual for patients to experience mild joint discomfort after starting functional activities; however, this soreness should improve within 6 to 12 hours with cryotherapy and without medication. The presence of swelling indicates how the knee is responding to activity. There should be little to no swelling following activity in this phase of rehabilitation. During this phase, athletes must continue with their strengthening program in addition to performing phase-specific exercises. Throughout training, athletes must receive proper instruction to ensure good form. Additional focus should be on landing softly on the affected extremity as well as maintaining a neutral hip rotation to minimize rotatory forces on the knee joint.

Exercise suggested for this phase includes aggressive strengthening with squats, lunges, and plyometrics as well as agility drills including shuffling, hops, vertical jumps, and running patterns. Additionally, neuromuscular training should continue to promote neuromuscular control and proprioception. Early in this phase, the focus is on low-impact activity that encourages double limb support. Softer surfaces may be used to diminish joint reaction forces. Running progression should include walk/jog intervals, agility ladder drills at 50% to 75% speed, dynamic activities with skipping and high knees, and 90° to 180° turns in the air. Initial sport-specific drill patterns can also be done with 50% to 75% effort. Late in this phase, cutting and pivoting training should be introduced as well as advanced plyometrics and team participation without contact (Table 4).

The end of this phase involves the return to sport aspect of ACL rehabilitation. Because each athlete is different, safe return to play should be individualized rather than follow a strict time line. An athlete should be able to perform maximal vertical jump without pain or instability before return to sport. Full ROM is needed and muscle strength and balance must be achieved to provide the required dynamic stability for high-level sports performance. Also, the athlete should have a greater than 90% score on the Limb Symmetry Index, particularly the single leg hop, 6-m timed hop, triple single leg hop, crossover single leg hop, and single leg vertical hop. Strength assessment should also be greater than 90% of the opposite limb using either dynamometry or clinical tests such as the number of step downs in 1 minute (Table 4). Furthermore, the athlete should be progressed to sport-specific activity and drills in a controlled environment at full speed. If these activities can be performed without pain, swelling, or instability complaints and athletes have developed confidence with

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**Table 3**

**Strengthening Phase (Months 1-6+)**

<table>
<thead>
<tr>
<th>Aspect of Rehabilitation</th>
<th>Early Phase</th>
<th>Advanced Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthening</td>
<td>Focus primarily on double limb exercises and progression to single limb exercises (eg, mini-squats, mini-lunges, leg press, hamstring curls, step downs, wall sits, band walks, one-legged deadlifts, 4-way hip exercises, TheraBand [Performance Health, Akron, Ohio] hip rotator exercises)</td>
<td>Advance earlier phase activities with gradual increase in weights or range of motion; may also attempt to incorporate multidirectional movements to mimic functional activity (eg, Y balance and lunge matrix); open chain leg extensions: 90° to 40° range of motion</td>
</tr>
<tr>
<td>Cardiovascular/endurance</td>
<td>Bike, elliptical machine, StairMaster (StairMaster, Vancouver, Washington), NordicTrack (Icon Health &amp; Fitness, Logan, Utah), retro treadmill</td>
<td>Can start walking for exercise if normal gait pattern and no swelling</td>
</tr>
<tr>
<td>Proprioception</td>
<td>Single limb stance, standing 4-way TheraBand kicks</td>
<td>Use of balance cushions or other proprioceptive devices during exercises; start to mimic functional activity, including catching, throwing, or kicking</td>
</tr>
</tbody>
</table>
Rehabilitation protocols have undergone a drastic change in the past 15 years. The conservative approaches that emphasized healing of the graft and stability of the knee were based largely on concepts that both time and control of the forces across the knee were necessary for ligament healing and a good outcome. Long periods of immobilization postoperatively have fallen out of favor and have been replaced by accelerated protocols that have been proven to improve athlete functional outcomes and to result in fewer complications.

The authors believe that knees undergoing ACL reconstruction ultimately require a comprehensive rehabilitation that emphasizes the return to symmetrical knee motion, symmetrical quadriceps strength, and neuromuscular control. Significant deficits in quadriceps strength are evident after ACL reconstruction. Kline et al. found a lower rate of torque developments and a lower rate and timing of extensor moments after surgical reconstruction. Therefore, the quadriceps musculature must be rehabilitated to improve the rate of torque developments and prepare the limb for the demands of sport performance. This also serves to restore muscular balance in the extremity and aids in neuromuscular control. Furthermore, full ROM is necessary for a return to sports, as decreased motion will place the extremity at a mechanical disadvantage and increase the risk for reinjury. A systematic rehabilitation program that emphasizes the return to symmetrical motion aids in muscle strength and balance that must be achieved to provide dynamic stability.

Current level I evidence from randomized controlled trials shows no overall difference in outcome between bone-patellar tendon-bone and quadrupled hamstring grafts in postoperative laxity, clinical outcome, return to sport, one leg hop test, and ROM. However, regarding rehabilitation, some differences exist between the graft choices. Bone-patellar tendon-bone autograft ACL reconstructions are more prone to patellar hypomobility; therefore, progressive mobilizations (Figure 2) are important and need to be emphasized in the rehabilitation program. Also, with quadrupled hamstring autograft ACL reconstructions, athletes are limited in hamstring strengthening activities for the first month. A quadriceps tendon autograft ACL reconstruction will cause deficits in the quadriceps musculature; this should be expected and managed appropriately in rehabilitation. Furthermore, the overall rehabilitation process is slower for allografts than autografts and therefore protocols should be modified to account for the longer process to return to play. Thus, athletes and physical trainers must be well educated about graft type used so that protocols may be easily modified to achieve the best outcome.

Regarding return to sport, no standard or objective criteria are currently available to determine when a patient is ready to return to competitive sport or unrestricted activity after ACL reconstruction. Functional testing provides an inaccurate marker for risk of injury because tests are performed under nonfatigued conditions. In the protocol discussed here, full ROM, limb strength symmetry, and neuromuscular control are important for an athlete to safely and effectively return to full sport. However, it may also be important to incorporate weight bearing and fatigue testing into the postoperative rehabilitation program before clearing patients for full return to activity. Currently, athletes’ rate of return to sport at...
the same level or higher is reported to be between 70% and 90%.15,19,20

Some factors that can affect rehabilitation after reconstructive ACL surgery include concomitant injuries, timing of surgery, graft selection, concomitant surgeries, quality of rehabilitation, and the goals and desire of the athlete. However, a comprehensive and appropriate protocol with input from the surgeon, athlete, and physical trainer can lead to a successful outcome where the return to a high-performance preinjury level is possible. The authors believe that there are several pearls for a successful outcome in ACL reconstruction rehabilitation: (1) prevent problems rather than treat them whenever possible, (2) obtain extension in the first few days and be protective of requestive function (do not “beat” a dead extremity), (3) know which graft is used and possibly modify the rehabilitation protocol, (4) quadriceps activation is facilitated by working in flexion and not attempting to activate initially in full extension, (5) do not have patients discard assistive devices until they are able to activate the quadriceps effectively and demonstrate a normal gait, (6) integrate both open and closed chain exercises to gain complete rehabilitation, and (7) avoid large loads in terminal extension (particularly open chain) during the initial months postoperatively.8

CONCLUSION

The concepts discussed in this article provide an integrative and comprehensive approach to the rehabilitation of a reconstructed ACL in an athlete. A variety of exercises and protocols exist in the literature; however, there are specific concepts that must be emphasized to achieve a successful outcome. Initial knee flexion gains, followed by full extension, and finally terminal flexion is a guide to achieving full ROM. Also, the quadriceps and hamstring musculature must be strengthened to achieve muscular balance in the affected extremity. Furthermore, neuromuscular training and proprioception aid in returning athletes to a high performance level in their sport. Progression through a protocol using distinct phases allows for a complete rehabilitation while reducing the risk of reinjury. Understanding that athletes differ in rehabilitation and progression is also important in guiding a safe return to play that accounts for a fear of reinjury component.

An integrated approach with input from the physician, athlete, and physical trainer is important to define the phases, progression, and ultimate goals of a rehabilitation program. Education and communication are vital in managing expectations and progressing through a protocol safely and successfully. Emphasis should be on the rehabilitation of the entire knee joint and not just the ACL to achieve a successful outcome. Further research is needed to validate reliable progression guidelines and time lines to facilitate and foster a safe return-to-play process.

REFERENCES
