Current Concepts for Anterior Cruciate Ligament Reconstruction: A Criterion-Based Rehabilitation Progression

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Synopsis:
The management of patients after anterior cruciate ligament (ACL) reconstruction should be evidence based. Since our original published guidelines in 1996, successful outcomes have been consistently achieved with the rehabilitation principles of early weight bearing, using a combination of weight bearing and non-weight bearing exercise focused on quadriceps and lower extremity strength, and meeting specific objective requirements for return to activity. As rehabilitative evidence and surgical technology and procedures have progressed, the original guidelines should be revisited to ensure the most up to date evidence is guiding rehabilitative care. Emerging evidence on rehabilitative interventions and advancements in concomitant surgeries, including those addressing chondral and meniscal injuries, is continuing to grow and greatly affects the rehabilitative care of patients with ACL reconstruction. The aim of this article is to update our previously published rehabilitation guidelines using the most recent research to reflect the most current evidence for management of patients after ACL reconstruction. The focus will be on current concepts in rehabilitation interventions and modifications needed for concomitant surgery and pathology.

Key Words: ACL, graft, surgery
More than 200,000 anterior cruciate ligament (ACL) injuries occur each year in the United States, and approximately 65% of these injuries are treated with reconstructive surgery. A consistent approach to rehabilitation after ACL reconstruction can yield predictably good outcomes, such as returning to previous levels of activity and normal knee function. The University of Delaware published criterion-based rehabilitation guidelines in 1996. In these guidelines, a progression was established with specific clinical milestones with respect to tissue healing time frames. The goal of any criterion based guideline is to maximize the patient’s response to exercise at the current level of function while minimizing the risk of injury to the healing tissue. Based on sound principles and current evidence, the original guidelines have continued to guide rehabilitative care to successful outcomes.

Advancements in surgical procedures directly impact post-operative rehabilitation. Since the original guidelines were published in 1996, considerable advancements have occurred in ACL reconstruction surgical procedures and common secondary surgical interventions to address injuries often associated with ACL tears. Rehabilitation after ACL reconstruction has continued to move from surgery modified rehabilitation, where the surgery actually constrained the rehabilitation progression, to rehabilitation modified surgery, where the reconstruction techniques are robust enough to withstand early mobilization and strengthening. Modifications of the surgery over the past 16 years, (e.g. soft-tissue fixation) warrant a reexamination of the rehabilitative management of patients after ACL reconstruction. Further literature and understanding of secondary surgeries and their impact on ACL reconstruction call for further clarification on their impact on post-surgical treatment and outcomes. The purpose of this paper is to revisit the rehabilitation guidelines to reflect the most current evidence on management of patients following ACL reconstruction.
ISOLATED ACL RECONSTRUCTION:

The original guidelines (Table 1) were developed around evidence based medicine along with consideration for biological healing time frames. As a result, the treatment of an isolated ACL reconstruction has required only minor adjustments to reflect recent advances in the rehabilitation literature and surgical techniques (Appendix A). Time frames have been included as a guide for the therapist, but it is required that the patient meet all of the clinical milestones prior to advancing to the next stage no matter the time frame. Clarification and adjustments of clinical milestones and additions of interventions are aimed at improving functional outcomes and providing a safe return to sport.

Pre-surgical Rehabilitation

Knee function prior to surgery is important in expected and final outcomes after ACL reconstruction. Preoperative milestones have been included in the updated guidelines to reflect the importance that these factors have on postoperative outcomes. Patients with full knee extension range of motion (ROM), absent or minimal effusion, and without knee extension lag during a straight leg raise (SLR) preoperatively have better outcomes, such as returning to previous levels of activity and demonstration of normal knee function, after surgery.

Quadriceps strength deficit is significant after ACL injury, ranging from 15 to 40%. Preoperative quadriceps strength is a significant predictor of knee function after ACL reconstruction. Because of the large impact that quadriceps strength has on knee function, the identification and treatment of quadriceps weakness prior to ACL reconstruction is paramount in maximizing patient outcomes. Objective measures of quadriceps
strength with isometric or isokinetic dynamometry allow the rehabilitation specialist to track the progress of this critical impairment throughout the recovery period. Preoperative rehabilitation that includes perturbation training and aggressive quadriceps strengthening should be used to reduce limb-to-limb differences and the objective should be to improve the quadriceps index (a ratio of the involved quadriceps strength to the uninvolved quadriceps strength) to greater than 90% prior to surgery.\textsuperscript{21,55}

**Immediate post-operative phase**

The milestones for the immediate postoperative phase (week 1) are to achieve active/passive ROM equal to 0-90 degrees and perform an active quadriceps contraction with superior patellar glide. Knee extension ROM loss is unfortunately a common issue, with one study showing 25.3% of patients having more than a 5 degree side-to-side difference in passive knee extension ROM 4 weeks after ACL reconstruction.\textsuperscript{61} Even small losses (3 to 5 degrees) in knee extension adversely affect subjective and objective results following ACL reconstruction with loss of normal extension and flexion being associated with weaker quadriceps.\textsuperscript{87} Early achievement of full knee extension also decreases the risk of postoperative complications such as arthrofibrosis.\textsuperscript{30,44} If full extension is not achieved by week 2, low-load long-duration stretching techniques such as prone hangs (FIGURE 1) or bag hangs are needed to effectively restore full knee extension.\textsuperscript{56,62}

Deficits in quadriceps strength after ACL reconstruction have been reported to be present months to years after surgery and at various isokinetic testing speeds.\textsuperscript{43} The largest extent of quadriceps weakness occurs in the first months after reconstruction.\textsuperscript{17,43,47} Neuromuscular Electrical Stimulation (NMES) (FIGURE 2) is utilized to augment quadriceps strengthening
activities and has been shown to improve outcomes.\textsuperscript{49,91,92} The quadriceps muscles are often affected by arthrogenic muscle inhibition after ACL reconstruction, which limits volitional contraction. A benefit of NMES is that it directly recruits the motor neurons to produce better quadriceps strength gains than voluntary exercise alone.\textsuperscript{75} Functional outcomes are improved with increased strength gains of the quadriceps.\textsuperscript{75}

**Early post-operative phase**

The milestones of the early post-operative phase (week 2 post surgery) are knee flexion greater than 110 degrees, walking without crutches, the use of a cycle/stair climber without difficulty, walking with full knee extension, reciprocal stair climbing, SLR without an extension lag, and a Knee Outcome Survey – Activities of Daily Living Subscale (KOS-ADLS) score greater than 65%. When recently reviewed, the average KOS-ADLS score for our patients at the end of week 2 was 60.2% with a median of 64% (unpublished data, 2009). The median score more accurately reflected the data with the presence of large outliers, therefore 65% was chosen as our suggested criteria. Crutches and an immobilizer may be used early after an ACL reconstruction. Crutches may be discontinued once a patient is able to ambulate without pain and use of the immobilizer can be discontinued once the patient has demonstrated a SLR without an extension lag. If a functional brace was ordered pre-operatively, patients may use the brace once the immobilizer has been discontinued.

In this phase, treatments incorporate weight bearing (closed chain) activities (**FIGURE 3**) such as wall slides and step ups in pain free ranges (typically 0-60 degrees). Weight bearing activities are safe and effective and may place less stress on the healing graft as well as cause less patellofemoral pain.\textsuperscript{11}
Mikkelsen et al. found higher quadriceps strength and rates of return to sports but no difference in laxity when comparing the use of a combination of non-weight bearing and weight bearing exercises versus weight bearing exercises alone. Based on this systematic review, it appears that non-weight bearing exercises can be safely incorporated with weight bearing exercises into the rehabilitation process without deleterious effects on the healing ACL graft as long as undue strain on the healing graft is avoided (i.e. limiting knee ROM from 90 to 45 degrees for the non-weight bearing exercises, progressing to knee ROM from 90 to 10 by week 12).

**Immediate postoperative phase**

The milestones for the intermediate post-operative phase are knee flexion within 10 degrees of the uninvolved side and quadriceps index greater than 60%. Balance and neuromuscular re-education exercises begin in this time frame (FIGURES 4 and 5). Neuromuscular alterations (i.e. muscle inhibition, impaired sensorimotor function) around the ACL-reconstructed knee may contribute to clinical impairments, such as strength loss, atrophy, and altered function. The use of balance and neuromuscular re-education activities has shown no effects of increased joint laxity or decreased strength when compared to standard rehabilitation methods. Self-reported knee function after ACL reconstruction improves with a neuromuscular rehabilitation program.

**Late postoperative phase**

The frequency of treatment during the late postoperative time frame is based on the remaining impairments. The milestones are quadriceps index greater than 80%, a normal gait
pattern, full knee ROM, and knee joint effusion equal to a grade of trace or less. The quadriceps index of 80% represents a minimal deficit in strength\textsuperscript{72, 100}, and has been previously used to distinguish between poor and good quadriceps strength.\textsuperscript{53, 73, 88} The quadriceps index of 80% has also been used as a cut off for the use of NMES to augment quadriceps strengthening.\textsuperscript{92} Effusion can be assessed using the modified stroke test (TABLE 2) as a reliable method of rating knee effusion in the outpatient setting.\textsuperscript{96}

**Transitional Phase**

Once a patient is 8 weeks post-surgery and meets the criteria of 80% quadriceps index, effusion of trace or less, and demonstrates an understanding of the soreness rules\textsuperscript{24} (TABLE 3), a running progression may commence (TABLE 4). All active patients after ACL reconstruction, including non-runners, are encouraged to perform the running progression for the benefits of unilateral strengthening during the running gait and increased force generation from the dynamic nature of running. The running progression begins as a two mile activity with alternating jogging and walking. The ratio of jogging to walk distance is gradually increased and beginning at level 6 distances and pace are increased.

During this transitional phase patients should progress their strengthening program at a fitness facility if no longer treated in a clinical setting. Patients who have not met the 80% quadriceps index milestone should continue quadriceps strengthening and NMES, while those patients with at least an 80% quadriceps index can continue with a gym strengthening program if no other impairments persist. Exercise prescription should continue to focus on unilateral lower extremity strengthening and neuromuscular control. Patients may have a desire to begin
exercising the uninvolved side and an individual plan should be designed to foster strength gains aiming for bilateral limb symmetry.

Hop tests are a functional assessment of dynamic stability of the knee\textsuperscript{26, 71, 79} and patients can undergo hop testing as early as 12 weeks after ACL reconstruction if all criteria are met. Quadriceps strength, assessed with dynamometry, should be at least 80\% quadriceps index. Additional criteria to meet for hop tests are trace or less effusion, full knee ROM, and no pain with single leg hopping. Low to moderate correlations were found between hop test performance and lower extremity muscular strength, and between hop test performance and self-report outcome measures.\textsuperscript{26} Because no single test has been established that captures all of the essential components necessary for return to sport, the use of several measurements of limb impairments may capture different constructs of physical function and are necessary to gauge a patient’s function at a given time point.\textsuperscript{26} Four single limb hop tests commonly used in patients after ACL reconstruction are the single hop for distance, the crossover hop for distance, the triple hop for distance, and the 6-meter timed hop (Instructions and milestones are detailed in Appendix A).

Quadriceps weakness can exceed 20\% at 6 months after ACL reconstruction and 10-15\% at 1 year.\textsuperscript{75} Recent research from our clinic indicate that limb-to-limb asymmetries are reduced and limb symmetry indexes are restored to greater than 90\% and return to preoperative levels by 6 months after ACL reconstruction when following these clinical guidelines.\textsuperscript{55} Previous research utilizing these clinical guidelines have found a quadriceps index of 90\% or greater in patients at 3, 6, and 12 month follow up in 55\%, 65\%, and 73\% of subjects respectively.\textsuperscript{36} The mean quadriceps index at the 3, 6, and 12 month follow up looking at groups who received either perturbation or strength training prior to surgery were 88.7\% and 92.7\%, 95.7\% and 93.0\%, and
98.7% and 98.1% respectively. These quadriceps index values reflect good restoration of
quadriceps and limb symmetries utilizing these clinical guidelines as an essential component of
safe return to activity. We recommend that all patients should continue to strengthen the
involved lower extremity until 90% quadriceps index is obtained.

Agility, plyometric, and sport specific activities can be added to the patient’s home
exercise program, provided that they have shown no adverse effects (i.e. increased effusion or
pain) to the running progression and that they can demonstrate pain-free performance of loading
activities. Patients should be instructed by the therapist and should be able to demonstrate proper
technique under supervision prior to adding these higher level activities to a home program.

Agility drills during a rehabilitation program can assist patients by allowing them to adjust to
sport specific activities, such as changing directions, accelerating, and decelerating.

Plyometrics can improve neuromuscular control in athletes, which can become a learned skill
that will transfer to return to competitive play. Additionally, neuromuscular control of dynamic
lower extremity valgus is enhanced with plyometric training, which may be critical for the
prevention of ACL re-injury. Athletes participating in jumping activities may benefit from
education on proper jumping and landing technique. High school female athletes in basketball,
volleyball, and soccer in a pre-season jumping program with instruction on proper landing
technique showed a significantly lower incidence of knee injury rates compared to untrained
females. The effects of plyometrics, however, have not been investigated in the functional
return of patients after ACL reconstruction.

Patients return for functional testing between 3 and 6 months as needed based on their
ability to meet the milestones (TABLE 5) and their time frame or desire to return to sport. If any
of the criteria are not met the patient is not cleared to begin return to sport activity. While
returning to preinjury levels or back to sport may be a short-term goal after reconstruction,\textsuperscript{19} intent to return to sports is not predictive of actual return to play.\textsuperscript{4} Patients may reduce their activity levels for a variety of reasons, including: social reasons, knee problems, or fear of re-injury.\textsuperscript{70, 99} Additionally, not all athletes choose or have the opportunity to return to previous activity levels or sports.

For those who do desire to return to their previous level of sports, strict return to sports criteria has been developed to ensure normal limb symmetry and knee function. Limb symmetry indexes of 90% have previously been suggested as the milestone for determining normal limb symmetry in quadriceps strength\textsuperscript{72, 92, 100} and functional testing.\textsuperscript{26, 36, 71, 79, 69} Additionally, the cut-off of 90% is used for 2 self-reported outcome measures in this population. Athletes must pass all the criteria in order to begin returning back to sports. Following these rehabilitation guidelines and using the return to sport criteria (performance-based and self-report outcomes), 40% of athletes classified as noncopers preoperatively passed return to sport criteria at 6 months after ACL reconstruction and 73% by 12 months.\textsuperscript{37} When examining the 3, 6, and 12 month follow up for the self-report outcomes, the percentage of patients with 90% or greater was 70%, 92.5% and 92.5% for the KOS-ADLS, and 37.5%, 72.5% and 87.5% for Global Rating Score of Knee Function (GRS).\textsuperscript{36} Using the age- and sex-matched norms on International Knee Documentation Committee 2000 subjective knee form,\textsuperscript{1, 31} 75% of patients had knee function within normal ranges at 6 months after surgery and 87% by 1 year.\textsuperscript{55} While we have not examined return to previous level of activity using these guidelines as of yet, the current data suggests that it improves self-report and performance-based knee function. Athletes not meeting the criteria continue rehabilitation focused on the areas in which they did not achieve the desired return to sport score.
Once cleared, patients do not directly return to competition. Athletes begin with lower level sports participation in practice and gradually build up to competition while monitoring pain, effusion, and ROM. A systematic approach for return to sport participation is recommended that accounts for pain and apprehension (FIGURE 6). If post-operative bracing is used, our evidence shows they may discontinue use of the brace at 1 year. The patient’s activity level should be monitored utilizing the soreness guidelines to minimize the potential of impairments recurring.

**GRAFT TYPES**

Graft selection is an important consideration to the rehabilitation specialist. Certain factors should be considered when rehabilitating patients with different graft types. With a bone-patellar tendon-bone autograft, donor site morbidity can occur and the rehabilitation specialist should be aware of patellar tendon pain during quadriceps strengthening. Although no difference in anterior knee pain has been consistently shown between patients having a bone-patellar tendon-bone compared to a hamstring autografts, an increased incidence of pain with kneeling has been found in those with the bone-patellar tendon-bone procedure. Patellar taping and pain modalities may be effective in decreasing patellar tendon pain that patients may experience.

If a hamstring autograft is used, resisted hamstring activities are not performed for 12 weeks after surgery. After hamstring graft harvest, the hamstring muscles retract, although most tendons eventually regenerate and muscle force improves by 6 to 12 months after ACL reconstruction. Resisted hamstring strengthening is delayed to allow for appropriate soft tissue healing and to limit irritation to the hamstring donor site. After 12 weeks the patient can

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**FIGURE 6**

A systematic approach for return to sport participation is recommended that accounts for pain and apprehension. If post-operative bracing is used, evidence shows they may discontinue use of the brace at 1 year. The patient’s activity level should be monitored utilizing the soreness guidelines to minimize the potential of impairments recurring.
begin a resisted hamstring strengthening progression and activities according to the soreness rules. The use of hamstring autografts does not appear to limit the recovery of hamstring strength.\textsuperscript{13, 102} Additionally, bone-patellar tendon-bone and hamstring autograft procedures do not differ in clinical and functional outcomes in terms of laxity, clinical outcome, time to return to sports, patellofemoral crepitations, one-legged hop test, ROM, thigh muscle circumference, or anterior knee sensory deficit.\textsuperscript{86} Because the use of hamstrings autograft do not influence clinical or functional outcomes and demonstrate good strength recovery,\textsuperscript{3, 86} the 12 week restriction is used to allow for necessary hamstring recovery after harvesting.

Recent advances in surgical technique include use of a double bundle graft to attempt to replicate the anatomical nature of the ACL. Double bundle grafts have shown some advantage in decreasing anterior and rotational laxity after surgery,\textsuperscript{90} but no modifications to the rehabilitation guidelines are warranted when compared with single bundle grafts.

Clinical and functional outcomes after ACL reconstruction using allograft tissue compared to autograft tissue appear to be similar.\textsuperscript{12, 97} An allograft selection has the advantage of no graft donor-site morbidity and donor-site precautions are not necessary during the rehabilitation process.\textsuperscript{32} Despite that non-irradiated allografts are equal in strength to autografts, allograft healing is delayed regarding graft incorporation and remodelling.\textsuperscript{32} An increased risk for graft failure has been proposed as a potential limitation to allograft utilization. Individuals with an allograft were 5 times more likely to have an ACL graft failure than those with an autograft.\textsuperscript{9, 52} In patients participating at a high activity level after reconstruction, the odds of allograft failure was 14.1 times more likely than autograft failure.\textsuperscript{9} Patients following allograft ACL reconstruction have faster immediate postoperative recovery and less operative pain, suggesting that they may be more likely to attempt return to high-level sports prematurely.\textsuperscript{9, 15}
Combined with delayed healing of the allograft, premature return to sports may place these athletes at greater risk for graft failure. Recent evidence indicates that it may be more beneficial in younger patients to use an autograft\textsuperscript{93}, but there is no evidence that delaying return to sport will decrease the likelihood of re-rupture if an allograft is used. Therefore, all individuals, despite graft selection, should be required to meet the criteria at each phase before being able to progress to the next phase. Rehabilitation specialists should maintain the latest knowledge of the effect of graft selection as evidence continues to emerge to determine the effect on return to sport.

MENISCAL INURY

The meniscus plays a large role in the integrity of the knee with contributions to shock absorption, load transmission, joint nutrition, and stability.\textsuperscript{5} Typically, when a partial arthroscopic meniscectomy is performed concurrently with an ACL reconstruction, no modifications to rehabilitation are necessary unless specified by the surgeon.

Meniscal repairs have become increasingly more common with the introduction of arthroscopic fixation techniques.\textsuperscript{98} Meniscal repairs performed at the time of the ACL reconstruction have superior healing rates and better outcomes in comparison to isolated meniscal repairs.\textsuperscript{77} Toman et al\textsuperscript{98} showed a greater than 90\% clinical success rate in patients who had meniscus repaired in conjunction with ACL reconstruction. In the study by Toman et al surgeons were allowed to select the post-operative rehabilitation program, but other studies that included more aggressive rehabilitation as typically used following ACL reconstruction rehabilitation have shown similar success rates.\textsuperscript{6, 60} The clinical practice guidelines for Knee pain and mobility impairments: meniscal and articular cartilage lesions published by the Orthopaedic
Section, APTA suggests that clinicians can consider early weight bearing and mobilization.\textsuperscript{57} If a meniscal repair is performed concurrently with ACL reconstruction, modifications include no weight bearing activities at knee angles greater than 45 degrees of flexion for 4 weeks with no restrictions on weight bearing in full extension. After the initial 4 weeks, weight bearing knee flexion, as in a deep squat, is limited to less than 90 degrees. Because meniscal repairs are commonly performed on the posterior horn of the meniscus,\textsuperscript{95} increased knee flexion greater than 90 degrees can irritate and potentially damage the healing meniscal repair site. After 8 weeks the rehabilitation specialist should resume normal ACL guidelines. Therefore, there are no additional restrictions on running progressions for an ACL reconstruction with meniscal repair.

Meniscus transplantation is also now being performed more often. It is still considered a joint preserving surgery without return to sports as a goal. Meniscus transplant is complex; each procedure is different. Often, meniscus transplantation is performed with a concomitant tibial or femoral osteotomy. Meniscus transplantation and ACL reconstruction are often staged. The rehabilitation guidelines for meniscal transplantation are therefore beyond the scope of this paper and these guidelines should not be used for patients with staged or concomitant ACL reconstruction and meniscus transplantation.

CHONDRAL DEFECTS

Addressing chondral defects of the knee has been an area of significant advancement in recent years. With the increased understanding of articular cartilage lesions and the development of chondral repair interventions (e.g. autologous chondrocyte transplantation), these situations present unique tissue healing dilemmas. Similar to meniscus transplant, articular cartilage repair
is often performed with a concomitant tibial or femoral osteotomy and articular cartilage repair and ACL reconstruction are often staged.\textsuperscript{54} 

A patient who undergoes a chondral debridement may be weight bearing as tolerated with crutches for 3 to 5 days after surgery and have no other modifications made to the post ACL reconstruction rehabilitation guidelines.\textsuperscript{78} Microfracture procedures are performed arthroscopically, usually in conjunction with ACL reconstruction and the cartilage surgical site requires additional protection. Patients are non-weight bearing with crutches from 2 to 8 weeks depending on knee pain, effusion, the surgeon’s preference, and the location and size of the lesion. Lesions that are larger in size and in weight bearing zones will require additional precautions.\textsuperscript{78} 

Procedures aimed at repairing the damaged articular cartilage are becoming more popular. The influence of articular cartilage in the prevention of degenerative changes and generation of pain is more widely appreciated,\textsuperscript{2} and the preservation of the cartilage is encouraged when possible. Procedures, such as osteochondral autograft transplantation (OATS) and autologous chondrocyte implantation (ACI), challenge the rehabilitation specialist to further enhance rehabilitation techniques. Recent literature has aimed at identifying the most beneficial intervention and the individuals most likely to benefit from cartilage repair. Few of the studies are higher level evidence and they are often without control groups. ACI and OATS have been shown to lead to better outcomes than microfracture surgery. Microfracture, OATS, and ACI procedures have all shown the ability to return athletes to sport with rates of return of 59 to 66%, 91 to 93%, and 67 to 78% respectively.\textsuperscript{34, 65} The patients who were younger, had shorter preoperative duration of symptoms, had no prior surgical intervention, and higher pre-injury and postsurgical levels of sports had better outcomes and higher rates of return to sport.\textsuperscript{34}
Rehabilitation after isolated chondral repair surgery is highly individualized based on factors such as the size and location of the lesions and rehabilitation guidelines can be found for the different isolated chondral repair surgeries. Due to the complexity of the surgeries and specific needs of post-operative management, the most conservative guidelines following chondral repair procedures should be followed with concomitant ACL reconstruction.

Return to sports after chondral injuries is controversial and studies to assess the effectiveness of chondral surgeries are becoming more readily available. The authors of a systematic review on articular cartilage repair in the athletes’ knee examined 20 studies on clinical outcomes and return to competition. With an average of 42 month follow-up, 79% of patients reported good to excellent results using self-report outcome measures. Seventy-three percent returned to sports participation 7 to 18 months post-surgery, depending on the surgical technique. A decline in continued sports participation at the same preinjury level was observed at 2 to 5 years after surgery. For microfracture and OATS procedures, we use the same criteria-based guidelines for progression of exercise and determination of readiness for return to sports. Our guidelines for ACI procedures are typically surgeon-specific due to the nature of the technique, larger lesion size, and length of healing time and rehabilitation. However, soreness and effusion guidelines are still used to direct the rehabilitation process and readiness to return to sport testing.

LIGAMENTOUS

When there is a tear of the medial collateral ligament (MCL) combined with an ACL rupture, the MCL is typically treated non-surgically. The severity of the MCL injury may contribute to the outcome of a combined ACL-MCL injury when the MCL is treated non-
Much of the current histologic and mechanical healing literature on non-operative management of the MCL has been done on animals and this should be considered when interpreting the literature. ACL reconstruction is usually delayed to allow for the MCL to heal and to correct any additional impairments the patient may exhibit. Petersen and Laprell evaluated the effects of early (within 3 weeks of the original injury) versus delayed (minimum of 10 weeks after injury) ACL reconstruction in patients with combined ACL-MCL injuries. They found that patients that had late ACL reconstruction had significantly lower rates of ROM complications in both flexion and extension and lower rates of re-arthroscopies to address extension ROM losses, as well as significantly better outcomes in Lysholm scores.

When combined ACL-MCL injuries occur, during the pre-operative stage, modifications to the rehabilitation process are warranted. Treatment should be restricted to the exercises/movements performed in the sagittal plane for 4 to 6 weeks to allow for MCL healing. Tibial internal rotation, to minimize valgus stresses on the healing MCL, should also be maintained during resisted strengthening exercises (TABLE 6).

For individuals with chronic MCL insufficiency and failed conservative management, it may be indicated to perform an MCL repair with ACL reconstruction. With this scenario, patients use crutches for 5 weeks, wear an immobilizer with the knee in full extension (0 degrees) for 6 weeks, and weight bearing as tolerated immediately post-operative day 1. Except for these modifications, these patients will continue with the ACL reconstruction guidelines for the isolated ACL reconstruction (Appendix A).

Multi-ligament instability (i.e. knee dislocation) occurs when the ACL, posterior cruciate ligament (PCL) and either the medial structures or the lateral and posterolateral structures of the knee are ruptured. This injury typically occurs with high energy forces such as a motor vehicle...
accident or in a catastrophic sports injury. Typically a 6 to 8 week period of non-weight bearing is recommended after multi-ligament stabilization surgery. Individuals who had a PCL reconstruction concomitantly with ACL reconstruction should follow the more conservative PCL post-surgical rehabilitation guidelines. With posterolateral corner repair/reconstruction the rehabilitation specialist should minimize tibial external rotation and varus stresses. These patients should also avoid hyper-extension and resisted knee flexion for 12 weeks.

Limited studies have been published on the effective management of an ACL revision. The current literature has shown worse outcomes after ACL revisions in comparison to primary ACL reconstruction. In a study by Fox, an identical rehabilitation program was used for revision and primary ACL reconstruction. Although the rehabilitation program itself could not be directly associated with a higher failure rate in those with revision surgeries, future studies should try to determine the best rehabilitation program for ACL revisions. Following a revision ACL reconstruction, modifying the rehabilitation guidelines to account for possible fixation concerns and complications from previous procedures may be needed by slowing the progression. Patients should use crutches and an immobilizer for an additional 2 weeks after surgery. The initiation of a running progression and functional testing is delayed to 12 and 16 weeks, respectively, after surgery.

**SUMMARY**

The goal of the original guidelines was to create a criterion based progression to protect healing structures and ensure appropriate progression of activities for maximizing patient outcomes. Upon revisiting the original guidelines with a look at the current evidence, we have shown continued support for the foundation of the guidelines. The principles of early weight-
bearing, incorporation of weight bearing and non-weight bearing exercises at the appropriate
time frames, and the use of objective measures for determining progression and return to
activities continue to have growing support. The role of concomitant injury and subsequent
intervention necessitate rehabilitation modification to protect the integrity of the knee. Chondral
surgical techniques and continued understanding of the role of the menisci are areas of
expanding knowledge that a rehabilitation specialist should familiarize themselves with in order
to provide the most up to date evidence based practice. With ACL reconstruction rehabilitation
guidelines reaffirmed by the latest evidence and continued understanding of concomitant injuries
the rehabilitation specialist can ensure the best postsurgical outcomes.
References


### Table 1. Original ACL rehabilitation practice guidelines

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Clinical Milestones</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days 1-3</td>
<td>Passive ROM/active ROM 0-90°</td>
<td>Wall slides</td>
</tr>
<tr>
<td></td>
<td>Quadriceps contraction</td>
<td>Patellar mobilizations</td>
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<tr>
<td></td>
<td>Walking without crutches</td>
<td>Active superior glide</td>
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<td></td>
<td></td>
<td>Neuromuscular electrical stimulation</td>
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<tr>
<td></td>
<td></td>
<td>Gait training</td>
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<tr>
<td>Week 2</td>
<td>Full knee extension*</td>
<td>Cycle/stairclimber</td>
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<tr>
<td></td>
<td>Flexion &gt; 110°</td>
<td>Step exercises</td>
</tr>
<tr>
<td></td>
<td>Use of cycle/stairclimber without difficulty</td>
<td>Kinetron intervals</td>
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<td></td>
<td>Walking with full extension</td>
<td>Portal/incision mobilization</td>
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<tr>
<td></td>
<td>Use of stairs foot-over-foot</td>
<td>Prone hangs if necessary</td>
</tr>
<tr>
<td>Week 4</td>
<td>Flexion within 10°*</td>
<td>Tibiofemoral mobilization with rotation</td>
</tr>
<tr>
<td></td>
<td>Quad strength &gt;50%*</td>
<td>Patellofemoral mobilization in flexion</td>
</tr>
<tr>
<td>Week 6-8</td>
<td>Normal gait pattern</td>
<td>Progress exercise in intensity and duration</td>
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<tr>
<td></td>
<td>Full ROM*</td>
<td>Begin running progression</td>
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<tr>
<td></td>
<td>Quad strength &gt;80%*</td>
<td>Transfer to fitness facility</td>
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<tr>
<td>Week 12</td>
<td>Maintaining or gaining quadriceps strength</td>
<td>Agility exercises</td>
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<tr>
<td></td>
<td>Hop tests &gt;85%*</td>
<td>Sports specific exercises</td>
</tr>
<tr>
<td></td>
<td>KOS-ADL &gt; 85%</td>
<td></td>
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</tbody>
</table>

*Compared with uninvolved.

NOTE: Discontinue treatments when goals are met. Recheck monthly until 6 months after surgery.

### Table 2. Stroke Test Effusion Grading

<table>
<thead>
<tr>
<th>Grade</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>No wave of fluid produced with downstroke</td>
</tr>
<tr>
<td>Trace</td>
<td>Small wave of fluid on medial side with downstroke</td>
</tr>
<tr>
<td>1+</td>
<td>Larger wave of fluid on medial side with downstroke (fills the sulcus)</td>
</tr>
<tr>
<td>2+</td>
<td>Effusion spontaneously returns to medial side after upstroke</td>
</tr>
<tr>
<td>3+</td>
<td>So much fluid that it cannot be moved out of the medial aspect of the knee</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Soreness Rules</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soreness during warm-up that continues</td>
<td>2 days off, drop down 1 level</td>
</tr>
<tr>
<td>Soreness during warm-up that goes away</td>
<td>Stay at level that led to soreness</td>
</tr>
<tr>
<td>Soreness during warm-up that goes away but redevelops during session</td>
<td>2 days off, drop down 1 level</td>
</tr>
<tr>
<td>Soreness the day after lifting (Not muscle soreness)</td>
<td>1 day off, do not advance program to the next level</td>
</tr>
<tr>
<td>No soreness</td>
<td>Advance 1 level per week or as instructed by healthcare professional</td>
</tr>
</tbody>
</table>

Table 4. Running progression. Reprinted by permission of Tara Manal, University of Delaware Physical Therapy Clinic. (Progress to next level when patient is able to perform activity for 2 miles without increased effusion or pain. Perform no more than 4 times in one week and no more frequently than every other day. Do not progress more than 2 levels in a 7 day period.) *Conversion: 1 mile = 1.6 km.

<table>
<thead>
<tr>
<th>Running Progress</th>
<th>Treadmill</th>
<th>Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>0.1 mile* walk/0.1 mile Jog repeat 10 times</td>
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<td>Jog full 2 miles</td>
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<td>Increase workout to 2 ½ miles</td>
<td>Increase workout to 2½ miles</td>
</tr>
<tr>
<td>Level 7</td>
<td>Increase workout to 3 miles</td>
<td>Increase workout to 3 miles</td>
</tr>
<tr>
<td>Level 8</td>
<td>Alternate between running/jogging every 0.25 miles</td>
<td>Increase speed on straights/jog curves</td>
</tr>
</tbody>
</table>
Table 5. Return to Sport Criteria. All criteria must be met prior to beginning a return to sport progression. Knee Outcome Survey – Activities of Daily Living (KOS-ADLS)

<table>
<thead>
<tr>
<th>Return to Sport Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>minimum 12 weeks post-operative</td>
</tr>
<tr>
<td>90% or greater on Quadriceps Index</td>
</tr>
<tr>
<td>90% or greater on all Hop Tests</td>
</tr>
<tr>
<td>90% or greater on KOS-ADLS</td>
</tr>
<tr>
<td>90% or greater on Global Rating Score of Knee Function</td>
</tr>
</tbody>
</table>

Table 6. Medial collateral ligament range of motion restriction guidelines for non-operative management of MCL injuries

<table>
<thead>
<tr>
<th>MCL Injury ROM Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
</tbody>
</table>
Figure 1: Prone Hang. (Begin without weight for 10 minutes and progress to increased weight around the ankle and longer duration as needed for the desired result. Belting the patient above the hips to the table may also avoid compensations at the hip during the activity.)

Figure 2: Neuromuscular Electrical Stimulation (NMES). (NMES is applied with the patient in a seated position and the knee in 60 degrees of flexion (varying angles are used based on pain and co-morbidities). The patient relaxes while electrical stimulation is applied to achieve 50% of their maximal volitional isometric contraction against a fixed resistance.)
Figure 3: Wall squats. (The patient begins with their back against the wall with their legs shoulder width apart and goes down into a squat position up to 90 degrees of knee flexion as pain and strength allow. The exercise is progressed by adding a hold time in the squat position and progressing to 90 degrees knee flexion if not achieved initially.)

Figure 4: Single leg balance. (Single leg balance should be performed with the stance knee slightly flexed and avoiding excessive genu valgum. Increasing time and adding distractions, such as a ball toss, will progress the difficulty.)
Figure 5: Single leg cone pick up. (Single cone pick up is a single leg squat while touching cones in a semi-circle using the same hand. Proper knee alignment should be maintained, especially as the trunk rotates to reach the cones. Decreasing the height of the cones and placing the stance leg on an unstable surface will progress the difficulty of the exercise.)
Figure 6. Progression to sports-related activities (adapted from Fitzgerald et al25).

1

2

3
Appendix A:

**Rehabilitation Practice Guidelines for Anterior Cruciate Ligament (ACL) Reconstruction**

Primary surgery: ACL reconstruction

Assumptions:
1. Isolated ACL injury
2. Autograft (See specific graft types for precautions)

Expected # of visits: 25-38

Secondary surgery (possible): See precautions section for modifications related to

**Neuromuscular Electrical Stimulation (NMES) Guideline:**

1. Electrodes placed over proximal lateral quadriceps and distal medial quadriceps. (Modify distal electrode placement as needed to avoid covering superior medial arthroscopy portal until the stitches have been removed and skin is healed)

2. Stimulation parameters: 2500Hz, 75 bursts, 2 sec. ramp, 12 sec. on, 50 sec. rest, intensity to maximum tolerable [at least 50% Maximal Volitional Isometric Contraction (MVIC)(see note at end)], 10 contractions per session. Three sessions per week until quadriceps strength MVIC is 80% of uninvolved side.

3. Stimulation performed **isometrically at 60°** (dependent on graft site)

Pre-operative Goals: Full Knee Extension range of motion (ROM), absent or minimal effusion, and no knee extension lag with straight leg raise (SLR)

**Immediate Post-operative phase:** (week 1) Total visits: 1-3

**Milestones**

1. Knee active/passive ROM = 0-90°
2. Active quadriceps contraction with superior patellar glide

**Treatment**

- Wall slides, patellar mobilization, gait training, NMES (see guidelines) Bike for ROM
- Home Exercise Program: supine wall slides, self patellar mobs 30 to 50 times per day, Quadriceps set, Long Arc Quads (90-45°), and SLR 3x10 (3 times per day)

**Early Post-operative phase:** (week 2) Total visits: 4-6

**Milestones**

1. Knee flexion >110°
2. Walking without crutches
3. Use of cycle/stair climber without difficulty
4. Walking with full knee extension

5. Reciprocal stair climbing
6. SLR without a knee extension lag
7. Knee Outcome Survey Activities of daily living (KOS ADL) > 65%

**Treatment**

- Step ups in pain free range (if skin is healed)
- Portal/incision mobilization as needed
- Stairmaster, Wall squats/sits
- Progress to functional brace as swelling permits
- Prone hangs if lacking full extension
- Patellar mobilization in flexion (if flexion limited)

**Intermediate Postoperative phase:** (weeks 3-5) Total visits: 7-15

**Milestones**

1. Knee flexion ROM to within 10 degrees of uninvolved side
2. Quadriceps strength >60% of uninvolved side
Treatment

- Tibiofemoral mobilizations with rotation for ROM if joint mobility is limited
- Progress bike and Stair master duration (10 minute minimum)
- Begin balance and proprioceptive activities

Late Post-operative phase: (weeks 6-8) Total visits: 16-25

Milestones

1. Quadriceps strength >80% of uninvolved side
2. Normal gait pattern
3. Full knee ROM (compared to uninvolved side)
4. Knee Effusion of trace or less

Treatment

- Progress exercises in intensity and duration
- Begin running progression**: on treadmill or track with functional brace (may vary with physician)*
- Transfer to fitness facility*

*(If all milestones are met)
**(see running progression below)

Transitional Phase: (weeks 9-12) Total visits: 25-38

Milestones

1. Maintaining or gaining quadriceps strength (>80% of uninvolved side)
2. Hop tests >85% of uninvolved side (see attached) @ 12 wks
3. KOS Sports questionnaire >70%

Treatment

- Sports specific activities
- Agility exercises
- Functional testing (see description below)

Follow up Functional Testing: 4 month, 5 month, 6 month, 1 year post-op.

Milestones

1. Maintaining gains in strength (> or = 90% to 100%)
2. Hop Test (> or = 90%)
3. KO Sports (> or = 90%)
4. return to sport criteria see below

Recommending changes in rehab as needed. Progression may include one-legged emphasis in gym, explosive types of activities (cutting, jumping, plyometrics, landing training)

MVIC: Maximum Volitional Isometric Contraction

Patient is asked to volitionally extend the involved leg as hard as possible while knee is maintained isometrically at 60° knee flexion. Side to side comparison: (involved/uninvolved X 100 = % MVC)
Precautions:

- Patellar tendon autograft technique
  - Be aware of patellofemoral forces and possible irritation during progressive resistive exercises.
  - Treat patellofemoral pain if it arises with modalities, possible patellar taping.
  - Consider alteration of knee flexion angle to most comfortable between 45°-60° for MVIC and NMES treatments.

- Hamstring tendon autograft technique
  - No resisted hamstring strengthening until week 12.

- Partial meniscectomy
  - No modifications required; progress per patient tolerance and protocol.

- Meniscal repair
  - No weight-bearing flexion beyond 45° for 4 weeks.
  - Weight bearing in full extension is allowed.
  - Seated Kinetron and multi angle quadriceps isometric can substitute for weight-bearing exercises.

- Concomitant Abrasion Chondroplasty
  - Weight bearing as tolerated (WBAT) with Axillary crutches 3-5 days
  - No modifications required, progress per patient tolerance and protocol

- Concomitant Microfracture
  - Non-weight bearing- 2-4 weeks with Axillary crutches
  - No weightbearing activities in treatment for 4 weeks
  *Consider location and size of lesion for exercise specific alterations*

- Chondral Repair (OATS, ACI, MACI)
  - Follow procedure specific protocol if done concomitantly

- Meniscal Transplantation
  - Follow procedure specific protocol if done concomitantly

- Medial Collateral Ligament (MCL) injury
  - Restrict motion to sagittal plane until week 4-6 to allow healing of MCL.
  - Perform PRE’s with tibia in internal rotation during early post-op period to decrease MCL stress.
  - Consider brace for exercise and periods of activity if severe sprain and/or patient has pain.
  - Non Repaired ROM restrictions: Grade 1 no ROM restrictions; Grade 2 0-90° week 1, 0-110° week 2; Grade 3: 0-30° week1, 0-90° week 2, 0-110° week 3

- Posterior Cruciate Ligament (PCL) injury
  - Follow PCL rehabilitation guidelines. (Not ACL protocol)

- Posterolateral corner Repair
  - Minimize external rotation torques and varus stress 6-8 weeks
  - Avoid hyper-extension
  - No resisted Knee flexion 12 weeks

- ACL Revision
  - Delay progression of running, hop testing, agility drills, and return to sport by 4 weeks.
  - Crutches and immobilizer are used for 2 weeks following surgery. Otherwise follow same milestones
Running Progression: (requires: trace or less effusion, 80% or > strength, understand soreness rules)

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Progress to next level when patient is able to perform activity for 2 miles without increased effusion or pain. Perform no more than 4 times in one week and no more frequently than every other day. Do not progress more than 2 levels in a 7 day period.

Functional Testing (Week12)

Testing: Patient performs two practices on each leg for each hop sequence. Patient performs 2 timed or measured trials on each leg for each hop sequence. Measured trials are averaged and compared involved to uninvolved for single, triple, crossover hop. Compare uninvolved to involved for timed hop.

Passing Criteria for Return to Sport: Greater than or equal to 90% on: quadriceps MVIC, hop testing, KOS-ADLS score, and Global Rating of knee function score.

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