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Clinical Commentary/Current Concept Review

# A Criterion Based Rehabilitation Protocol for ACL Repair with Internal Brace Augmentation

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The anterior cruciate ligament (ACL) is one of the main stabilizing structures of the knee and its rupture is a common injury in young active adults. ACL reconstruction has been the preferred operative management of an ACL rupture for several decades; however, success rates are variable. Recently, interest in arthroscopic primary repair of the ligament has increased. The repair is augmented with an Internal Brace (IB), which is an ultra-high strength suture tape that bridges the ligament. This technique protects the ligament during the healing and the ligament is encouraged to heal naturally, whilst not requiring any external braces. It acts as a stabiliser to permit early mobilization and optimise rehabilitation.

As understanding of rehabilitation has progressed, there has been an increased focus on early weight-bearing and achieving full range of movement. While detailed criterion-based rehabilitation protocols exist for ACL reconstruction, this is not the case for ACL repair. The purpose of this commentary is to present a novel criterion-based rehabilitation protocol following ACL repair surgery augmented with an IB.

## Level of Evidence

V

## INTRODUCTION

The anterior cruciate ligament (ACL) is one of the main stabilizing structures of the knee, acting to prevent excess anterior tibial translation and internal rotation.[1] Rupture of the ACL is a common injury with an incidence of up to 84 per 100,000 adults and a risk of up to 3.7% per year in professional athletes.[1,2] Untreated ACL ruptures can lead to joint instability, soft tissue injuries and joint degeneration.[3,4]

Early attempts at primary ACL repair were associated with poor outcomes, including a high failure rate in athletes, but these were open procedures with lengthy periods of immobilisation.[5,6] Consequently, ACL reconstruction became the preferred operative treatment of ACL rupture. However, this method has also been associated with a number of issues. Firstly, the graft does not restore the proprioceptive properties of a native ligament, with fewer than two thirds of patients returning to their pre-injury activity level.[7] Secondly, the procedure can be associated with clinically significant morbidity following graft harvest including hamstring muscle weakness (hamstring graft)[8] and anterior knee pain (patellar tendon graft).[9] The development of new arthroscopic techniques for ACL repair has resulted in a renewed interest in this procedure with good short term outcomes.[10-13]

The Internal Brace (IB) is an ultra-high strength 2mm wide polyethylene tape (FiberTape, Arthrex, Naples, FL) that bridges the repaired ACL, from tibia to femur.[13] This technique protects the ligament during the healing and remodelling phase, acting as a secondary stabilizer once the ligament is healed.[13] The femoral fixation of the IB uses a button, and a knotless bone anchor is utilized on the tibial

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end; in addition to anatomical repair of the ACL.[13] The ligament is encouraged to heal naturally, while not requiring any external braces. This allows accelerated rehabilitation with early mobilization and the IB will theoretically protect against injury recurrence.[13] As a result of this, the rehabilitation following surgery can be approached differently from that after standard ACL reconstruction. This clinical commentary outlines a new rehabilitation protocol that may be appropriate for patients undergoing ACL repair with internal bracing. Although the rehabilitation protocol itself is not necessarily accelerated, it is felt that the ACL repair with the IB facilitates a faster rate of progression through the required criterion (compared to a non-augmented repair) for the majority of patients.

## PROPOSED REHABILITATION PROTOCOL

Many protocols are based upon time frames for progression,[14] however in this criterion-based protocol, the emphasise that attainment of measurable milestones should form the criteria for progressing to the next phase. In addition, it is essential patients are completing all the exercises from the previous phase competently and without pain, before progression, as outlined in Figure 1.

### PRE-OPERATIVE REHABILITATION

The goals of this phase are to:

- Protect the unstable knee
- Reduce swelling
- Maintain quadriceps function
- Maximize knee extension

The patient should be assumed to have an unstable knee at this stage and flexion should be limited to 90 degrees (with an aim to maintain full extension).[15] The focus of the exercises should be modified based on the severity, irritability, and nature of the injury. Open-chain bodyweight quadriceps exercises are recommended with lower limb triple extension (with resistance limited to a TheraBand). Stretching should focus on areas of tightness identified during initial assessment. Hamstring and calf length should be assessed with maintenance of gluteal and core muscles as able.[16]

Precautions and restrictions need to be taken to protect the knee. A compression garment is advised with functional tasks during the day, with the leg being elevated and rested when exercises are not being performed. Ice should also be applied to the knee post exercise and when required to manage pain and swelling.

### IMMEDIATE POST-OPERATIVE REHABILITATION (PHASE I)

Progression through phases is entirely criteria led (Figure 1), however the expected duration of this phase spans post-operative days 1-10. The restoration of range of motion (ROM), especially active knee extension is a critical component of this phase.[17]

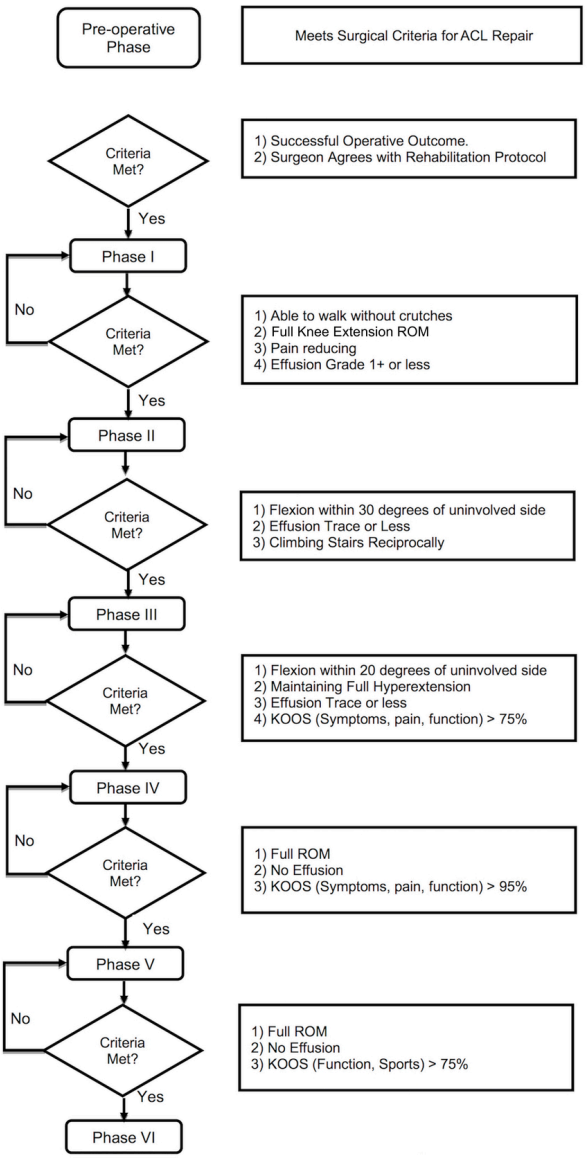


**Figure 1: Overview of progression through rehabilitation protocol**

The main goals in this phase to allow progression are: ability to walk without crutches, full active ROM in the knee, good pain management, and effusion Grade 1+ (Table 1) or less. It is also important to ensure that trunk/hip stability and quadriceps activation are maintained.[18] The restoration of a normal gait pattern is also an important component of this phase, ACL-deficient patients can ambulate with a characteristic flexed-knee gait, which can complicate tibiofemoral and patellofemoral mechanism restoration.[19,20]

The three domains that the exercises focus on in all phases are: ROM, strength and control, and proprioception and balance. The exercises reflect the importance of ROM in Phase 1.

Flexion and extension should be encouraged actively within limits, in this phase flexion is limited to 100 degrees with normal hyperextension (this can be practitioner administered passively as well) as active knee extension is crucial to this phase of recovery.[21] Other recommended ex-

**Table 1: Knee Effusion grading and clinical exam on stroke test**

| Grade | Clinical Exam |
|---|---|
| 0 | No wave produced on downstroke |
| Trace | Small wave on medial side on downstroke |
| 1+ | Large bulge on medial side with downstroke |
| 2+ | Effusion returns to medial side after upstroke |
| 3+ | Cannot move fluid out of medial side of knee |

Technique: the examiner strokes upwards from the medial joint line. A downward stroke on the distal lateral thigh is performed and a wave of fluid is observed at the medial knee

ercises to improve ROM in this phase include: patellar mobilizations, static quadriceps and gluteal contractions (isometrics), posterior chain soft tissue interventions, ankle pumps, and stretching of the calf and hamstrings. Low resistance work on an exercise bike is also permitted for up to 10 minutes, which encourages ROM and early introduction to cardiovascular fitness.

Strength and control is focused on the quadriceps muscle group as persistent weakness following ACL repair has been associated with increased morbidity.[22] Recommended exercises to focus on this muscle group in this phase are: quadriceps setting, short arc quadriceps (over a towel roll), active straight leg raises, and long arc quadriceps. Hamstring strengthening should be done with a resistance band. Wall slides (from 0 to 45 degrees) and calf raises are also recommended in this phase. In addition to the muscles of the thigh, hip control and strengthening is recommended, in non-weight bearing with particular focus on hip extension and abduction.[21] Core conditioning to improve lumbopelvic stability with emphasis on strengthening transversus abdominis is recommended;[23] however, this should be performed without any lower limb loading. Gait education and gait drills are also an important component to return the patient to full weight bearing status. In this phase, all open chain quadriceps exercises should be without load. Proprioception and balance are not the key focus of this phase and the only application of this domain is low grade knee proprioception exercises. Exercises should address deficit findings during objective assessment and be tailored to individual patients during each rehab phase.

At this early post-operative stage, restrictions are important to protect the knee. Ice, rest, and a compression garment are recommended as per the pre-operative instructions. In addition to this, leg crossing, running, jumping, twisting, and pivoting are all prohibited.

## EARLY POST-OPERATIVE REHABILITATION (PHASE II)

This phase builds on the previous one and its expected duration is from weeks 1 to 3. From this phase onwards, the patient should have a full weight-bearing status. The focus is maintained on ROM of the knee and flexion is now permitted to 110-120 degrees with full knee hyperextension.

Restrictions for this phase are similar to Phase I. A compression garment is no longer required but the recommendations on ice, rest, and prohibited movements are unchanged.[15]

The major change in goals is the requirement to achieve stair reciprocal ascending and descending. ROM in flexion needs to be achieved within 30 degrees of unaffected side, along with full extension.

ROM exercises are maintained from the previous with minimal alterations. The time permitted on the exercise bike can be increased to 15 minutes, maintaining low resistance to encourage ROM and cardiovascular exercise. Active ROM exercises as described above can be carried out if the patient does not have access to an exercise bike.

Progression in strength exercises allows light loading (1-2kg) of open chain quadriceps exercises as pain and effusion allows within the ROM restrictions of this phase. Wall slides can be progressed to 90 degrees of flexion as pain allows. Closed chain exercises are introduced through light resistance-based knee extension (such as a Pilates Reformer Supine Leg Press). If the patient does not have access to a reformer or leg press, controlled wall squats can be used. Core conditioning to improve lumbopelvic stability with emphasis on strengthening transversus abdominis is recommended.[23] Core exercises added during this stage include supine hamstring bridges and supine gluteal bridges.[16]

On a stable base, static single leg stance is tested to ensure that the positioning of the hip and pelvis are adequate. On an unstable base (balance pad/cushion) double leg stance with arm movements is recommended for challenges to balance and proprioception.[24]

## INTERMEDIATE POST-OPERATIVE REHABILITATION (PHASE III)

The expected duration of this phase is from weeks 3-5. In addition to objective ROM testing for progression, the Knee Injury and Osteoarthritis Outcome Score (KOOS) is incorporated at the end of the phase to assess patient progress.[25] The tool is split into five domains: Pain, Symptoms, Activities of Daily Living (ADL), Sports/Recreation, and Quality of Life. As rehabilitation progresses, the focused domains and expected scores transition with it. During this phase, agility exercises are introduced and neuromuscular (NM) control is developed to ensure sufficient control for running as the program progresses.

ROM exercises are continued, with knee flexion up to 130 degrees and there is progression of resistance on the exercise bike, with an increase in duration of up to 30 minutes. Quadriceps strength is progressed with advancement of open chain quadriceps loading and inclusion of closed chain loading (body weight squats and lunges).[16] The introduction of shallow single squats (up to 45 degrees of knee flexion) will also contribute to quadricep strengthening. Step work is progressed through increased step height and the introduction of lateral movements and hamstring loading can be advanced. Early landing NM control can be commenced through Supine Pilates Reformer and jump board work, and 4-inch step downs are also an acceptable alternative at this stage. As in the previous phases, there is a continuation of core and trunk conditioning.[23] Once com-

**Table 2: "Soreness" Rules to guide rehabilitation[25]**

| Soreness Rules | |
|---|---|
| 1. Soreness during warm-up that continues | 2 days off, drop down one level |
| 2. Soreness during warm-up that goes away | Stay at level that led to soreness |
| 3. Soreness during warm-up that goes away but returns during the session | 2 days off, drop down one level |
| 4. Soreness the day after session (not muscle soreness) | 1 day off, do not advance program to next level |
| 5. No soreness | Advance 1 level per week or as instructed by physiotherapist |

fortable with single leg stance including arm movements on a stable base, patients can slowly progress to an unstable base. The introduction of side-stepping, carioca, and other agility level exercises focuses on balance improvement.

It is important to monitor pain and effusion as the patient is introduced to new activities and ensure that there is symmetrical patterning of the lower extremities on squat/lunge-based activities. The restriction on prohibited movements is lifted, however the patient should not yet be allowed to run at this stage. As the phase nears completion, the KOOS is used to determine eligibility for progression. The pain, symptoms and ADL domains are focused upon and scores >75% in each of these domains would deem the patient eligible to phase IV.

## LATE POST-OPERATIVE REHABILITATION (PHASE IV)

This phase is the final controlled rehabilitation phase before the patient begins the transition to sport-specific rehabilitation and is expected to last from weeks 5-8. The restrictions on ROM are lifted and full flexion and hyperextension are encouraged. From this phase onwards, restrictions are based on the "soreness" rules (Table 2) to guide the intensity and frequency of rehabilitation.[26] The patient is still prohibited from running and it is important to monitor kinetic chain ROM and control (e.g. ankle dorsiflexion and hip control) to prevent overload of the anterior knee.

ROM exercises should continue unmodified if there is a perception of tightness or a tendency to stiffen. There is graded progression of open chain quadriceps loading, with an aim to achieve >80% strength when compared to the unaffected side via dynamometry (isokinetic or hand-held). Closed chain loading is also increased, limiting range to 50% to ensure good eccentric control.[16] Single leg squat depths are increased to 90 degrees of flexion and lunge activities are altered to incorporate multi-directional movements. NM landing control exercises are also commenced using landing from step or mini jumps. There is continuation of hamstring, trunk and bridge conditioning. Single leg balance is progressed and sport-specific components (catch/throw) are introduced. Agility work is advanced into tight space movement drills and 'cutting' movements (e.g. figures of 8) are introduced.

The symptom, pain and ADL domains of the KOOS are still the focus of this phase with >95% score a criterion for progression.

## TRANSITIONAL PHASE (PHASE V)

The emphasis during this phase (weeks 8-12) is the continued progression of activity level and the transition to sport-specific rehabilitation (Phase VI). The focus of the KOOS changes to the function and sports/recreation domain and dictates progress.[24] The "soreness" rule (Table 2) will dictate progress and anterior knee overload continues to be avoided.[26] The restriction on running is lifted and the running program (Table 3) is commenced. This program should not be performed more than four times/week and no more than every second day. A maximum of two levels can be progressed in a seven-day period.[14]

There is progression of closed chain quadriceps loading, with regards to both weight and depth of movement. Landing exercises are advanced with an increase in step height, single leg landing control and the introduction of rotational components. Sport specific work can also be added at this stage if indicated (e.g. Olympic lifts or slide board work). Multi-component agility circuits are used allowing a mix of static and dynamic stability.

The goals by the end of this phase are to achieve limb symmetry index of: quadriceps strength >90%, hop testing >85%, KOOS (Function, Sports/Recreation) >75% and Y-balance test composite score >85%.[27]

## SPORT-SPECIFIC REHABILITATION (PHASE VI)

This phase is expected to begin after 12 weeks. The "soreness" rules continue to be followed to monitor frequency and intensity of rehabilitation.[26] The running program is continued and once it is completed, the relevant sport-specific components are developed and advanced.

The depth and weight of closed chain loading of the quadriceps continues to be progressed, plyometric components can be added to landing component exercises and conditioning of hamstring, bridge and trunk work should be continued. Advanced cutting, twisting and turning movements can be added with progressive exposure to training drills, finally working towards open play.

The goal domains mirror phase V with expected advancement of limb symmetry index to achieve Quadriceps strength >95%, hop testing >95%, KOOS (Function, Sports/Recreation) >95% and Y-balance test composite score >95%.

**Table 3: Rehabilitation Running Program**

| Running Progression | |
|---|---|
| **Treadmill or Outdoors** | **Track** |
| **0.2 km walk; 0.2 km jog x 10 (4 km)** | Jog straights /walk bend (4 km) |
| **0.2 km walk; 0.4 km jog x 7 (4.2 km)** | Jog straights / jog 1 bend every 2nd lap (4km) |
| **0.2 km walk; 0.6 km jog x 5 (4 km)** | Jog straights / jog 1 bend every lap (4 km) |
| **0.2 km walk; 0.8 km jog x 4 (4 km)** | Jog 1.75 laps / walk 1 curve (2 km) |
| **Jog full 4 km** | Jog all laps (2km) |
| **Jog 5 km** | Jog 5km |
| **Jog 6 km** | Jog 6 km |
| **Alternate between running and jogging every 0.5 km x 6** | Alternate between running on the straights and jogging on the bends (6km) |

In addition to the Phase VI goals, the patient must adequately demonstrate sport-specific readiness. Consequently, additional sport-specific testing may be required to determine the readiness of return to play.

## ADDITIONAL KNEE LIGAMENT INJURY

ACL injuries commonly present with associated ligamentous or meniscal injuries. These need to be considered alongside the ACL repair both surgically and in planning the patient's rehabilitation.[28] It is important to identify the most limiting factor requiring protection, this will guide the decision making for any multi-injury situation.[18]

### MEDIAL COLLATERAL LIGAMENT (MCL)

The MCL is commonly injured in an ACL rupture. Non-operative management of this injury can delay progression of rehabilitation proportional to the degree of injury, however deviation from the guidelines is not required. Concurrent traditional repair of the MCL may require a flexion minimizing brace for six weeks.[29] However, the IB method can be utilized for operative repair of MCL injuries, which may allow these post-operative limitations to be avoided and rehabilitation expedited as per the protocol.

### ANTEROLATERAL LIGAMENT (ALL)

The ALL is not reinforced routinely during ACL reconstruction or repair surgery, however, the IB technique has been applied to it to improve tibio-femoral rotatory stability in the presence of ACL injury. In high risk groups, such as young female patients, those with hypermobility, gross instability or desire to return to high demand pivoting sports, this technique can be beneficial to reduce re-rupture rates. This may also allow greater confidence in progressing the patients' rehabilitation and should not affect advancement through the protocol.[30]

### MULTI-LIGAMENT INSTABILITY

The rehabilitation of these patients is inevitably prolonged and due to the increased complexity and potential for multiple, staged surgeries. Rehabilitation in these cases should be guided by the surgeon/post-operative protocols. Early surgical intervention has shown better outcomes than delayed surgical repair.[31] There is a potential for utilization of the IB in some of the injuries which may expedite recovery when compared to a traditional repair/reconstruction, where six to eight weeks of immobilization is often recommended.[32] However, there are presently no reported case series of IB use and recovery in these multi-ligament injuries.

## DISCUSSION

As the understanding of post-operative ACL rehabilitation has progressed, there has been an increased focus on early ROM and early weight-bearing. Initial ACL repair studies without IB had the extremity immobilized in a long leg cast at 30 degrees of flexion following the operation.[5,33-40] Dependant on the protocol, this cast was kept on for two weeks,[27,36] six weeks,[32,34,35,37,38] or eight weeks[31] before transitioning to rehabilitation exercises. More recently, patients were not immobilized in a cast but instead used knee bracing, which was locked in extension.[41-45] Some rehabilitation protocols locked this for a fixed time frame: two days,[46] four days,[47] or two,[40] three,[5] and four[43] weeks. Other protocols were patient dependant and the brace was locked in extension until volitional quadriceps control had returned.[41,42] This overall conservative approach to rehabilitation may have contributed to muscle atrophy, joint stiffness and ultimately poorer outcomes as a result.

There is limited focus on specific rehabilitation exercises following ACL repair in the literature. Multiple authors make references to quadriceps strengthening,[32,34,37,38] though in all of these papers it occurs following the removal of external immobilization. ACL repair with augmentation using the IB means there is no requirement for any fixed external brace immobilization post-operatively and rehabilitation can be commenced in a timely fashion.

There has been greater focus on rehabilitation following ACL reconstruction, with focus shifting from protocol driven recovery to progression-based programs.[48] While detailed, criterion-based rehabilitation protocols exist for

ACL reconstruction,[13,17] this is not the case for ACL repair. Therefore, a criterion-based rehabilitation protocol for ACL repair with IB augmentation is proposed in this paper. This regimen has been used in a cohort of ACL repair patients, where good patient reported outcomes have been reported at two years post-operatively.[49] However, as this is a novel technique and the data currently only exist during case series. As IB usage increases in ACL repairs, more robust and detailed data will be available regarding its long term uses, advantages, and pitfalls in a patient population.

## CONCLUSION

This is the first evidence-informed rehabilitation protocol specifically designed for patients who have undergone an isolated primary ACL repair using an IB. The effects of concomitant injuries and their effects on rehabilitation have been discussed. Critical clinical milestones have been presented to guide rehabilitation progression and guidelines for activity frequency/intensity modification and return to running suggestions have also been offered.

## CONFLICT OF INTEREST

GM is a consultant for teaching for Arthrex and has a patent for the InternalBrace, outside the submitted work.

No other author has any conflict of interest to declare.

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