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CLINICAL COMMENTARY

POST-OPERATIVE CRITERION BASED REHABILITATION OF ACL REPAIRS: A CLINICAL COMMENTARY

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ABSTRACT

The anterior cruciate ligament (ACL) is the most commonly reconstructed ligament of the knee. Most often, the goal of surgical reconstruction is to recreate stability within the knee and prevent joint degeneration. To date, clinical studies have not demonstrated the ability of various reconstruction techniques in establishing complete knee stability when comparing rates of osteoarthritis. Rates of osteoarthritis commonly resemble those of knees which have not be reconstructed and in this light, may not demonstrate a successful outcome. As modern medicine continues to develop and in the understanding of underlying biological processes grows, some surgeons have turned their attention back to an ACL repair technique. The purpose of this clinical commentary is to discuss the parameters associated with a phase progression for an isolated ACL repair. Physiological healing time frames, along with objective clinical assessment, following a criterion-based progression is described in accordance with post-operative healing parameters to serve as a reference for a rehabilitation specialist.

***Level of evidence*:** 5

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INTRODUCTION

Isolated anterior cruciate ligament (ACL) tears have been reported to occur at a rate of 68.8 per 100 000 people in the United States.[1] Prior to 1970, many ACL tears were managed using a ACL repair procedure in order to recreate stability in the knee.[2] These procedures were open surgical repairs and included all tear types, tear locations, patient ages and activity levels, and included various co-morbid knee injuries.[3,4] Moreover, following the open ACL repair procedure the post-operative management regime usually included long leg casting in slight flexion for as long as six weeks.[3,4] This management of ACL injuries resulted in poor patient reported outcomes and high failure rates,[3,4] ranging from 10% to as high as 100%,[3-5] and consequently lead to surgeons abandoning ACL repairs in favor of ACL reconstructions.[1,3,4]

The purpose of the ACL reconstruction is to create rotational and posterior/anterior knee stability, allowing the patient to resume their prior levels of activity while decreasing the chance of articular cartilage degeneration.[5-7] When measured against these goals, ACL reconstructions are not always successful.[5,7-9] Rates of degeneration and osteoarthritis do not appear to be slowed following ACL reconstruction with osteoarthritis development reported from 10% to as high as 100%;[5,7] a rate similar to patients managed conservatively.[7] Furthermore, despite efforts and intentions directed at returning patients to their prior level of activity participation, reconstruction of the ACL does not guarantee return to pre-injury status[5,10,11] with just 65% of athletes returning to their prior functional level.[12]

Given that positive outcomes after ACL reconstruction are not always certain, it seems appropriate to revisit ACL repairs. There are several potential benefits of repairing the ACL, including the avoidance of drilling tibial and femoral bone tunnels, which creates trauma to the knee joint. Tibial tunnel reaming during anatomic single bundle ACL reconstruction impacts the anterolateral meniscal root attachment, ultimately reducing failure strength.[13] Furthermore, preserving the native ACL results in more consistent anatomical tissue placement when compared to ACL reconstruction with an additional benefit of maintaining vascular and proprioceptive structures considered vital in knee and lower extremity for function and stability.[6,14] Lastly, donor site morbidity is eliminated.

Seemingly, most opponents to the ACL repair point to the decreased ability for the ACL to heal, however, recent research supports the concept that the ACL does have some intrinsic capacity to heal.[15,16] The proximal 1/3 of the ACL has been shown to have intrinsic healing properties that are similar to the medial collateral ligament (MCL) forming type III collagen fibers of similar histological make-up.[15] The ability of the ACL to spontaneously heal[15,16] would indicate that proximal ACL tears, when managed with an ACL repair may have the ability to restore joint stability.[17] Many of the same healing properties proposed by the ACL repair are realized in the healing response procedure.[18] Creating a healing stimulus by microfracturing around the anatomical footprint permits access to mesenchymal cells and a healing environment is established to support the ACL.[18] In an attempt to aid the healing response, the addition of a suture fixation and a biodegradeable screw could further secure the native ACL tissue to its origin. These factors, along with developments in surgical procedures and collagen-platelet-rich plasma scaffolding are allowing a second look at less invasive ACL surgeries.

With the potential benefits and positive effects of an ACL repair, the clinician would benefit from a better understanding of the proposed steps necessary to return the patient to their prior level of function. The purpose of this clinical commentary is to discuss the parameters associated with a phase progression for an isolated ACL repair. Physiological healing time frames, along with objective clinical assessment, following a criterion-based progression is described in accordance with post-operative healing parameters to serve as a reference for a rehabilitation specialist.

POSTOPERATIVE REHABILITATION

The current literature relating to a criterion based rehabilitation protocol after an ACL reconstruction is inconsistent.[10,19] Despite the high prevalence of ACL reconstruction in the literature, consensus regarding weight bearing, range of motion, and initiation and progression of a periodized strength training program including running and return to sport does not exist.[10,19] The ACL repair, which is documented less frequently in the current literature compared to the reconstruction, has even less support in the literature. With this in mind, concepts proposed in this commentary aim to blend a criterion-based progression with patient presentation and the appropriate timelines associated with tissue healing and muscle adaptation.

Phase 1: Protection/ROM/Muscle Initiation (0-6 weeks)
The goals outlined in Phase I are important in directing the patients' overall return to function. The aim of the protection phase is not only to protect the repaired ACL, but to prepare the patient for the next phase of rehabilitation by restoring tibiofemoral and patellofemoral range of motion, initiating quadriceps activation, and resolving joint effusion.[20]

Post-operative restrictions are put in place to provide protection to the repaired ligament. The patient is placed in a standard postoperative hinged-knee which is set to allow for 0° – 90° of knee extension and flexion during gait activities for six weeks. Further, patients are allowed to ambulate in partial weight bearing (PWB) with a gradual increase to full weight bearing occurring at two weeks following surgery.[19] Crutches can be discontinued when the patient no longer demonstrates an antalgic gait or an extension lag during a straight leg raise.[21]

The role of early range of motion after surgery in reducing post-surgical complications and improving outcomes has been established in the literature.[19,22-24] Since passive tibiofemoral flexion and extension does not place undue stress on the surgically repaired ligament,[19,26,27] no restrictions are placed on passive range of motion post surgically. Passive tibiofemoral flexion is achieved with passive edge of table flexion and wall-slides. Progression of range of motion is guided by subjective patient reports, and limitations into progressing range of motion are directed by patient reports of pain. When >110° of passive flexion is present,[27] the patient is able to progress to stationary cycling without resistance as a way to assist with effusion.[28] Passive tibiofemoral extension can be achieved with posteriorly directed femoral glides in relation to a fixed tibia. In conjunction with a posterior femoral glide, a rotary mobilization of the femur directed externally in relation to the tibia can assist with tibiofemoral extension.

Establishing full passive patellofemoral motion is also important in the protective phase. Adhesions that form in the gutters of the anterior knee and in the anterior interval can limit tibiofemoral and patellofemoral range of motion and increase joint contact pressures.[26] As indicated by previous authors, patellar mobilizations in a superior/inferior and medial/lateral fashion should also be accompanied by medial/lateral mobilizations of both the patellar and quadriceps tendons to limit potential restrictions in both the tibiofemoral and patellofemoral joint.[25]

Effusion in the tibiofemoral and patellofemoral joints can result in increased pain, decreased quadriceps activation, limited range of motion, and prevent the patient from progressing forward with rehabilitation.[20] In accordance with physiological healing factors, joint effusion is expected to peak at day three and gradually resolve by the completion of Phase I at six weeks.[29] Treatment to aide in the resolution of joint effusion may include lymphedema massage, the use of pneumatic compressive devices, elevation, and an active muscle pump from the quadriceps and calves. In addition to techniques aimed to decrease joint effusion, the rehabilitative specialist is encouraged to progressively stress the tissue within its tolerance to avoid increased joint effusion.

Quadriceps atrophy is common in an acute surgical knee and can lead to difficulty with active terminal knee extension during gait activities.[30] Quadriceps training is initiated immediately after surgery with isometric quadriceps sets in terminal extension. As tolerated, quadriceps strengthening is progressed to short-arc, open-kinetic-chain strengthening from 30° to physiological terminal extension to aid with normal restoration of gait mechanics.[30] The short-arc quadriceps exercise is shown to activate all quadriceps muscles at a greater EMG level as extension increases[31] and have similar strain on the ACL compared to a closed-kinetic-chain squatting exercise.[32]

Criteria for the progression from Phase I center around the goals outlined in Table 1. Initial passive range of motion into flexion and extension is performed by the therapist and should be maintained. Flexion is expected to be within 10° of the opposite limb, with efforts made to restore extension to values comparable to the contra-lateral limb. Finally, swelling is expected to be within 0.5 cm of the opposite

Table 1. *Protection Phase Guidelines and Goals 0-6 weeks post-operative.*

Precautions	Goals / Criteria to advance	Interventions
Full ROM	Active terminal knee extension >= 0 Active flexion to within 10º of opposite knee	Passive tibiofemoral mobilizations (posterior femoral glides, screw home mobilizations) Passive patellofemoral mobilizations (superior/inferior, medial/lateral) Patellar tendon and quadriceps tendon mobilizations (medial/lateral) Manual soft tissue massage (quadriceps, hamstrings, gluteus medius/minimus, gastrocnemius/soleus) Isometric quadriceps activation in terminal extension (building to 5 sets of 1 minute hold)
PWB	Gait without assistive device	Weight bearing progression (medial/lateral weight shifts, posterior/anterior weight shifts) Weaning off assistive device (gradual removal of crutches) Reciprocating stair ascension/descent
	Swelling within 0.5 cm of opposite knee (measured at superior pole of patella, 5 cm and 10 cm proximal to superior pole of patella)	Bike (115º flexion present) Lymphedema massage, distal to proximal Ankle pumps (3 sets of 20 reps, 2-3 times / day) Progression from mat muscle activation exercises to upright muscle activation exercises Balance progression (interventions include but are not limited to tandem stance, rhomberg stance, single leg stance, unstable surfaces, eyes opened/eyes closed))

ROM= range of motion. PWB= partial weight bearing

limb by the end of Phase I. Tables 2 and 3 provide examples of interventions commonly used at both weeks one and six.

Phase 2: Periodized Strength Development – Muscular Endurance (7-14 weeks)

After completion of the protection phase, the focus turns to progressive loading of the knee joint and soft tissues through a periodized program that focuses on the sequential development of muscular endurance, strength and power. Due to arthrogenic inhibition, the selective atrophy of type 1 muscle fibers following injury provides the physiological rationale for the development of a muscular endurance base.[20,33,34] Due to their decreased recruitment threshold requirements, type 1 muscle fibers are recruited and developed with light intensity and high repetitions.[35]

The strengthening of major muscle groups, especially the quadriceps, as outlined in Table 4 is recommended in Phase II. The rehabilitative specialist is encouraged to use this as a guide while working on an individualized treatment plan specific to the goals of each patient. An endurance based strength training program is recommended between two to

Table 2. *Example of first week post-operative interventions.*

Rehabilitation component	Intervention	Duration
Patellar mobility	Superior/inferior patella, quadriceps tendon, and patella tendon Medial/lateral patella mobilization	10 minutes
Tibiofemoral Extension	Posterior capsule stretch Screw home mobilization / posterior femoral glide	5-10 minutes
Tibiofemoral Flexion	Edge of table Supine on ball Wall slide	10-15 minutes
Knee, hip, and core strengthening	Quad sets-biofeedback (for 1 min) Glute sets – (3 sets of 10-20 sec isometric hold) TA sets – (3 sets of 10-20 sec isometric hold)	
Edema management/ Soft tissue massage	Quad/knee Hamstring Calf	10-20 minutes
	Stationary upright bike (no resistance)	5-10 minutes
Gait training PWB (two crutches)	Ascending/descending stairs TKE focus Heel strike	10 minutes

PWB= partial weight bearing. TA = transversus abdominus. TKE= terminal knee extension.

The above mentioned interventions are appropriate during Phase I of rehabilitation and can be used and should serve as a guideline for clinicians between the first and sixth weeks of rehabilitation if determined appropriate by the clinician.

Table 3. *Example of six week post operative interventions.*

Rehabilitation Component	Intervention	Duration
Patellar mobility	Superior/inferior patella, quadriceps tendon, and patella tendon Medial/lateral patella mobilization	10 minutes
Tibiofemoral Extension (as needed)	Posterior capsule stretch Screw home mobilization / posterior femoral glide	5-10 minutes
Tibiofemoral Flexion (as needed)	Edge of table with therapist assistance Supine on ball with therapist assistance Wall slide (supine on back	10-15 minutes
Hip, knee, and core strengthening	As previous	
	Standing heel raises	3 sets x 20 reps
	4 way hip (standing or on table; flexion/abduction/adduction/extension)	3 sets x 15 reps (resistance)
	Supine HS curl	3 sets x 15 reps (resistance)
	Balance (interventions include but are not limited to tandem stance, rhomberg stance, single leg stance, unstable surfaces, eyes opened/eyes closed)	
Edema management/Soft tissue mobilization (as needed)	Quad/knee Hamstring Calf	10-20 minutes
	Stationary upright bike (no resistance)	20 minutes
Gait training (as needed) Discharge assistive device	Level surface Reciprocating on stairs	5-10 minutes

HS= hamstring.

The above mentioned interventions are appropriate during Phase I of rehabilitation and can be used and should serve as a guideline for clinicians between the first and sixth weeks of rehabilitation if determined appropriate by the clinician.

Table 4. *Example of Muscular Endurance Phase Interventions weeks 7-14.*

Exercise (Focus on exercise)	**Repetitions / Sets**	**Work : Rest**
a. Wall squat holds (Quad)	30-120 sec / 2-4 sets	1:1, transition to none
a. TRX squats (Quad)	30-120 sec / 2-4 sets	1:1, transition to none
b. SL shuttle squats (Quad)	15-20 reps ea / 2-4 sets	1:1, transition to none
b. Supine bridge with HS curl (Hamstring)	15-20 reps / 2-4 sets	1:1, transition to none
c. Resisted lateral steps (Glutes)	15-20 reps ea / 2-4 sets	1:1, transition to none
c. Alternating lunge holds (Quad)	30 – 120 sec / 2-4 sets	1:1, transition to none

TRX= total body resistance exercise. SL= single leg.

The above mentioned interventions are appropriate during Phase II of rehabilitation and can be used and should serve as a guideline for clinicians between the seventh and 14th weeks of rehabilitation if determined appropriate by the clinician.

three times each week with at least 48 hours of rest in between.[35,36] Light to moderate loads of < 50% of the patients' 1-repetition maximum (1RM) are recommended for greater than 15 repetitions.[36] ACSM guidelines encourage between two and four sets with rest periods < 90 seconds.[35,36] The progression of double to single leg activities is also recommended throughout the progression of this phase.

Phase II progression criteria are outlined in Table 5. Single leg strength has been shown as an important predictor for control of frontal plain kinematics[37] and with return to sport decisions.[10,11,38,39] Therefore, the single leg squat and the Y-Balance Test are used as indicators of surgical limb strength and stability. A single leg squat from a 10-inch step over 15 repetitions will allow the rehabilitation expert the opportunities to assess frontal plain kinematics and strength at the trunk, hips, and knees visually. Anterior reach on the Y-Balance Test has been correlated with knee injuries and return to sport in the literature, and is being used as a progressive objective measure to show strength in the surgically repaired leg.[40-42]

Despite the focus on the development of muscular endurance, lower extremity muscular strength is still

Table 5. *Periodized Strength Development – Muscular Endurance Phase Guidelines 7-14 weeks post-operative.*	
Goals / Criteria to advance	**Stipulations**
Resistance cycling/TM walking x 20 minutes	Patient selected pace – Maintain
Full active range of motion	Equal to non-operative limb – Maintain
10 rep squat/10 rep leg press >70%	Refer to Appendix 1
Single leg squat from 10 inch for 15 reps	Avoidance of excessive trunk lean and knee/hip valgus
Anterior Reach within 8 cm	Compared to opposite leg
Quad Index >80%	Dynamometer compared to opposite leg
Inertial Measurement Unit (IMU)	Pass single leg squat
TM= treadmill.	

expected to improve over this phase. The back squat/leg press and quadriceps symmetry index are used to assess the return of muscular strength. Values for the back squat and leg press are provided to better ensure that rehabilitation specialists will have the equipment necessary in order to measure strength values. Back squat values are based off of a male being able to back squat 1.25 times his body weight 10 times (10 repetition maximum) and a female being able to back squat 0.8 times her body weight 10 times (10 repetition maximum) (Appendix 1). A 10-repetition maximum is implemented to avoid over loading the joint and soft tissues. These values are also correlated with an equivalent load for measuring with a leg press machine in both single and double leg. A quadriceps symmetry index of 80% the non-surgical leg can also show strength progression.[45]

Phase 3: Periodized Strength Development – Muscular strength (15 – 21 weeks)

After a muscular endurance base has been established, the focus of rehabilitation becomes regaining muscular strength. A periodized model is used with the focus on muscle strengthening[46] of the quadriceps. When compared to the muscular endurance phase, muscular strength development is characterized by an increase in load and reduction in repetitions.[47,48] In addition to strength training, a running and agility progression are added with the goal of returning the athlete to practice by the completion of this phase.

Development of muscular strength targets type II A and B muscle fibers.[49] An example of possible exercise interventions is outlined in Table 6 with a continued focus directed towards quadriceps strengthening. Similar to a Phase II, patients are expected to perform strength training interventions two to three times each week with at least 48 hours of rest between sessions.[35,36] Moderate to heavy loads of at least 60-67% of a patients' 1-RM are recommended for muscular strength development.[36,49] Based off of a patients previous weightlifting experience, between 1 – 12 repetitions with two to six sets are used to help maximize

Table 6. *Example of Muscular Strength Phase Interventions Weeks 15-21.*		
Exercise (Focus of exercise)	**Repetitions / Sets**	**Work : Rest**
a. Single leg squat to target (Quads)	30-120 sec ea / 3-5 sets	1:2-3 after complete round
a. Front squats with DB/KB (Quads)	6-8 reps / 3-5 sets 70-80%	
b. Weighted reverse lunges (Quads)	6-8 reps ea / 3-5 sets 60-80%	1:2-3 after complete round
b. Nordic HS curl (Hamstrings)	8-15 reps / 3-5 sets	
c. SL Skaters 3 way (Glutes)	30-120 sec ea / 3-5 sets	1:2-3 after complete round
c. B shuttle jumps (Quads)	30 -120 sec / 3-5 sets	
Dynamic warm up (progress in intensity): High knees, butt kickers, A-skip, fwd/bwd lunge, Open/close gate, lateral shuffle, Over/under sideways, back pedal, sprint progression, ladders		
DB= dumbbell. KB= kettlebell. HS= hamstrings. SL= single leg. B= bilateral. The above mentioned interventions are appropriate during Phase III of rehabilitation and can be used and should serve as a guideline for clinicians between the 15th and 21st weeks of rehabilitation if determined appropriate by the clinician.		

strength gains.[36,49] Depending on the complexity of movement, rest times between two to five minutes are encouraged.[36,49] It is also recommended that every four weeks, the patient goes through a de-loading week to allow for appropriate recovery of muscles and soft tissue structures with a resistance of 50-60% utilized.[49]

To this point, a running progression has not been implemented and should only be included if the patients desired activities include running. A criterion based model that addresses strength[50] in a dynamic and fatigued state[51] is appropriate in determining a progression to running.[52] A quadriceps index of 90% in ACL reconstructed knees has been correlated with near normal jogging mechanics and is considered an appropriate marker for assessing strength.[53] Despite not being a validated criterion for the knee, these authors believe that a passing score during the Vail Sports Test allows a rehabilitation specialist to observe how a patient would accept load while in a fatigued state and provides insight to how they would perform during a running activity. With these criteria met and a satisfactory muscular strength base established, a staged running progression starting with 70% weight bearing is implemented in an Alter-G treadmill. A similar reduced load running progression can be completed in a pool initially at chest depth with progression to shallower water depths. Over the course of two to three weeks, weight bearing is progressed during each running session by 5% until able to tolerate 100% weight bearing. Table 7 gives an example of this progression, but clinical judgment should be used in the progression to minimizing swelling and pain. If significant swelling and pain present, the patient is to regress back to the previous day. When the patient is able to successfully run pain free for 20 consecutive minutes, and strength and endurance criterion are still met, a graded agility progression is started. Agility drills are added in a single plane and progressed from 25% of maximal speed. Despite a lack of concise evidence in the literature, these authors believe that after two successful consecutive sessions without swelling and pain, it is appropriate to increase the intensity of the agility drills by 25% of an athlete's subjective perception of intensity via rate of perceived exertion. In addition to increased intensity, the athlete and rehabilitation specialist begins to introduce planes of motion to the agility drills to prepare for return to sport.

Table 7. *Jogging progression example starting at week 19.*

Week	Run (minutes)	Walk (minutes)	Alter G percentage	Cycles
19	1	4	70%	2 - 4
20	3	2	85%	4
21	1	4	95-100%	2 - 4
22	2	3	-	3 - 4
23	3	2	-	4
24	4	0.5 - 1	-	3 - 4
25	20	-	-	-

Criteria for the advancement from Phase III are outlined in Table 8. As the patient progresses towards a return to activity, the use of objective measures defined by the literature are used to assess function. The progression of muscular strength continues to build on strength gained from the previous phase. Single limb strength is again assessed with the Y-Balance Test, however, the 4 cm difference from non-surgical leg now reflects data supported in the literature pertaining to decreased rates of injury.[40-42] Back squat/leg press strength is expected to be at 80% of predicted 10 RM by the completion of phase III. The quadriceps symmetry index and girth measurements have been used in the past to assess return to sport and are expected to be at 90% and within 1 cm of non-surgical leg, respectfully.[10] Another measure supported by the literature for return to sport is the hamstring/quadriceps ratio which has been established at 60% and measured using hand-held dynomometry.[54] Finally patients must pass the single leg drop test as measured by

Table 8. *Periodized Strength Development – Muscular Strength/Power Phase Guidelines 15 – 21 weeks post-operative.*

Able to run x 20 minute (<12 min/mile)	Maintain
10 rep squat / 10 rep leg press >80%	Refer to appendix 1
Anterior Y Balance within 4 cm	Compared to opposite leg – Maintain
Quad girth within 1 cm	Compared to opposite leg - Maintain
Quad index within 90%	Dynamometer compared to opposite leg at 30° - Maintain
Hamstring/Quad ratio 60%	Dynamometer compared to opposite leg - Maintain
Inertial measurement unit (IMU)	Pass single leg hop/box drop

an inertial measurement unit (IMU), further assessing neuromuscular control by way of tibial angular motion and indicating a patients' ability to control dynamic movements at their limb.[51] Neuromuscular is believed to be an important factor in a successful return to sport.[10] Rehabilitation facilities will likely not possess a three-dimensional motion analysis system able to capture tibial motion and therefore can rely on an accurate but more portable IMU system.[51] Once these criteria are met, the patient is able to return to practice and progress to Phase IV.

Phase 4: Periodized Strength Development – Muscular Power/Speed/Agility phase (22+ weeks)

Historically, clearance for complete return to sport followed a time based model and was subject to clinical examination performed by the intervening surgeon occurring at six months.[10] However with the primary factor for return to sport being time[10] and with re-tear rates occurring at similar rates before and after six months from surgery,[55] a stronger focus on a criterion based model, especially during this return to sport phase, should be used.[10]

The fourth phase of rehabilitation is directed towards the development of muscular power, speed, and agility with the end goal being the complete return to sport. Continuing with a linear periodization model, appropriate strengthening, conditioning, power, speed, and agility drills that best replicate the demands of the sport or activity are incorporated.

As different sporting activities require various combinations of power, speed, and agility, it is up to the rehabilitative specialist to implement their knowledge of strength and conditioning to adequately prepare each athlete. An example of possible exercise interventions is outlined in Table 9 with the focus switching from strictly strength, to power and strength maintenance. Optimal power development uses a resistance of 30% of the patients 1-RM and is suggested to enhance athletic performance and thought to best simulate most athletic events.[56] However, increasing both movement speeds and rate of force development, is best trained with 75-90% of the patients' 1-RM for 1-5 repetitions.[46] This is completed over three to five sets with two to five minutes of rest.[46] The development of optimal power, speed, and agility can be targeted with intense, brief activities avoiding fatigue, and should be performed early in the session.[46]

Table 10 outlines the goals for Phase IV. Strengthening should continue throughout this phase with a 10-repetition squat or leg press of 90% or greater being expected by the completion of the phase. Also, in accordance with strength, the patient must maintain

Table 9. *Example of Muscular Power Phase Interventions at Weeks 22+.*

Dynamic warm up (full intensity) **:** High knees, butt kickers, A-skip, fwd/bwd lunge, Open/close gate, lateral shuffle, Over/under sideways, back pedal, sprint progression, ladders

Exercise (focus of exercise)	**Repetitions / Sets**	**Work : Rest**
a. Power Clean (Power)	1-5 reps / 3-5 sets 70-90%	2-5 minutes
b. Front Squat (Strength)	6-10 reps / 3-5 sets 50-65%	1:3
c. Nordic Hamstring Curls (Strength)	12-20 reps / 3-5 sets	1:2
d. Conditioning (Endurance) - Burpees - Box jumps	21 – 15 – 9 (repetitions performed of each movement per round)	None
Core Strengthening		
Abdominal crunch Isometric hold	45 sec / 4 sets	
Prone back extension Isometric hold	45 sec / 4 sets	

Table 10. *Periodized Strength Development – Muscular Power/Speed/Agility Phase Guidelines 22+ weeks.*

Goals / Criteria to advance	**Stipulations**
Modified T-test within norms of sports	Refer to normative values based on sports/position if appropriate
Single leg hop series	>90% non-involved leg
10 rep squat / 10 rep leg press >90%	Refer to appendix 1

previously outlined values pertaining to anterior reach on the Y-Balance Test, quadriceps girth, quadriceps index, the Vail Sports Test, single leg hop/box drop with an IMU and hamstring / quadriceps ratio in order to return to unrestricted sport activity. Finally, the addition of the modified T-test and single leg hop series adds in the patients' ability to tolerate the rigors of the sport or activity and indicate they are able to return to unrestricted sports participation.[46,52,57] Ultimately, the patient, doctor, and therapist should agree on the patients' ability to return to activity based on subjective and objective measures.

Limitations with this criterion driven progression include the lack of data supporting improved functional outcomes. Furthermore, because long-term studies utilizing current ACL repair techniques are lacking, clinicians must rely on data from reconstruction procedures along with physiological healing timelines to support our approach for the design of the optimal post-operative physical therapy program for patients following ACL preservation and repair. The concepts presented should continue to be challenged and progressed as new information is presented, but these concepts serve as a starting point for how best to approach the rehabilitation of the knee following repair of the ACL.

CONCLUSIONS

While there is limited research pertaining to postoperative rehabilitation for the ACL repair, this clinical commentary offers suggested interventions based on evidence from anatomical, biomechanical, tissue-healing studies, and current literature of ACL reconstruction in establishing a safe and structured postoperative protocol. With the possibility of more ACL repair procedures being performed, therapists may benefit from the suggested structured progression of rehabilitative criteria that are supported by literature to help improve patient outcomes. This commentary aims to serve as a framework for which future research in clinical and laboratory settings can build off of to further support the data presented.

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Appendix 1. *Strength calculations*[43,44].

Athletes Male

Body Weight	80% 10 RM leg press (lbs) [Single leg]	90% 10 RM leg press (lbs) [Single leg]	10 RM leg press (lbs) [Single leg]	10 RM squat (lbs)
100	250[138]	282[155]	313[172]	113
110	276[152]	310[171]	345[190]	124
120	301[166]	339[187]	376[207]	135
130	327[180]	367[202]	408[225]	146
140	352[194]	396[218]	440[242]	158
150	377[207]	425[234]	472[260]	169
160	403[222]	453[249]	504[277]	180
170	428[235]	482[265]	535[294]	191
180	454[250]	510[281]	567[312]	203
190	479[264]	539[296]	599[330]	214
200	505[278]	568[312]	631[347]	225
210	530[292]	596[328]	663[365]	236
220	555[305]	625[344]	694[382]	248
230	581[320]	653[359]	726[399]	259
240	606[333]	682[375]	578[318]	270
250	632[348]	711[391]	790[435]	281

Athletes Female [43,44]

Body Weight	80% 10 RM leg press (lbs) [Single leg]	90% 10 RM leg press (lbs) [Single leg]	10 RM leg press (lbs) [Single leg]	10 RM squat (lbs)
80	132[73]	148[81]	165[91]	60
90	149[82]	167[92]	186[102]	68
100	166[91]	186[102]	207[114]	75
110	183[101]	205[113]	228[125]	83
120	199[110]	224[123]	249[137]	90
130	216[119]	244[134]	271[149]	98
140	233[129]	263[145]	292[161]	105
150	250[138]	282[155]	313[172]	113
160	267[147]	301[166]	334[184]	120
170	284[156]	320[176]	355[195]	128
180	301[166]	339[187]	376[207]	135
190	318[175]	358[197]	398[219]	143
200	335[184]	377[207]	419[231]	150
210	352[194]	396[218]	440[242]	158
220	369[203]	415[228]	461[254]	165
230	386[212]	434[239]	482[265]	173

General Population Male [43,44]

Body Weight	80% 10 RM leg press (lbs) [Single leg]	90% 10 RM leg press (lbs) [Single leg]	10 RM leg press (lbs) [Single leg]	10 RM squat (lbs)
100	208[114]	234[129]	260[143]	94
110	229[126]	258[142]	287[158]	103
120	250[138]	282[155]	313[172]	113
130	272[150]	305[168]	339[187]	122
140	293[161]	329[181]	366[201]	131
150	314[173]	353[194]	392[216]	141
160	335[184]	377[207]	419[231]	150
170	356[196]	401[221]	445[245]	159
180	377[207]	425[234]	472[260]	169
190	399[220]	448[246]	498[274]	178
200	420[231]	472[260]	525[289]	188
210	441[243]	496[273]	551[303]	197
220	462[254]	520[286]	578[318]	206
230	483[266]	544[299]	604[332]	216
240	505[278]	568[312]	631[347]	225
250	526[298]	591[325]	657[361]	234

Appendix 1. *(continued)Strength calculations*[43,44].

General Population Female [43,44]

Body Weight	80% 10 RM leg press (lbs) [Single leg]	90% 10 RM leg press (lbs) [Single leg]	10 RM leg press (lbs) [Single leg]	10 RM squat (lbs)
80	111[61]	125[69]	139[77]	51
90	125[69]	141[78]	157[86]	57
100	140[77]	158[87]	175[96]	64
110	155[85]	174[96]	193[106]	70
120	169[93]	190[105]	211[116]	77
130	183[101]	206[113]	229[126]	83
140	198[109]	223[128]	247[136]	89
150	212[117]	239[132]	265[146]	96
160	227[125]	255[140]	283[156]	102
170	241[133]	271[149]	301[166]	108
180	255[140]	287[158]	319[176]	115
190	270[149]	304[167]	337[185]	121
200	284[156]	320[176]	355[195]	128
210	299[165]	336[185]	373[205]	134
220	313[172]	352[194]	391[215]	140
230	327[180]	368[202]	409[225]	147

*** Squat / Leg press calculation notes and equations** [43,44]

- **Athletes**
  - Males are based off of 1.5 x body weight for 1 RM
  - Females are based off of 1.0 x body weight for 1 RM
- **General population**
  - Males are based off of 1.25 x body weight for 1 RM
  - Females are based off of 0.85 x body weight for 1 RM
- **1 RM back squat equation (based on weight and number or reps)**
  - 1 RM = rep weight x $(\text{reps})^{0.1}$
- **10 RM from 1 RM**
  - Squat 1 RM = 10 RM x 100 / 75
  - Squat 10 RM = 1 RM x 75 / 100
- **Squat to leg press 10 RM conversion (convert to KGs)**
  - Leg press 10 RM = (Squat 10 RM/0.354) – 2.235
  - Squat 10 RM = (Leg press 10 RM x 0.354) + 2.235