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Recent advances following anterior cruciate ligament reconstruction: rehabilitation perspectives

Critical reviews in rehabilitation medicine

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Abstract Injuries to the anterior cruciate ligament are common. Surgical reconstruction is more prevalent than ever. This review article discusses treatment of the patient following surgical reconstruction of the anterior cruciate ligament. Various phases of rehabilitation are discussed with emphasis on early return of passive motion, early weight bearing, bracing, kinetic chain exercises, neuromuscular electrical stimulation and accelerated rehabilitation. Although evidence exists for the treatment of the surgically reconstructed cruciate ligament, more is needed to better define specific timeframes for advancement. Evidence exists that many of these young individuals are not fully returning to unlimited high level activities. This review article presents some of the latest evidence regarding anterior cruciate ligament rehabilitation in an attempt to help the busy clinician understand and relate basic and clinical research to rehabilitation of a patient following reconstruction.

Keywords Anterior cruciate ligament · Rehabilitation · Physical therapy · Knee rehabilitation · Musculoskeletal medicine

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Introduction

Reconstruction following injury to the anterior cruciate ligament (ACL) is a common surgical procedure with reports ranging from 100 000 to upwards up 300 000 reconstructions performed each year [1, 2]. These injuries are very common as they occur among both professional and recreational athletes. Since the ACL is the primary stabilizer for anterior tibial displacement and the secondary stabilizer for tibial rotation, an ACL-deficient knee can often lead to devastating consequences such as articular cartilage injuries, meniscus tears, functional instability and the potential for early-onset osteoarthritis [3, 4]. The role of physical rehabilitation of a patient following ACL rehabilitation is to return the athlete back to their premorbid functional level. This becomes especially important due to the fact that muscular deficits are seen following ACL reconstruction for up to 2 years post- surgery [5•, 6]. Additionally, the incidence of subsequent injury to either knee within 5 years following repair is 17% in those less than 18 years of age and 7% in those age 18–25 [7]. This is even further complicated with the fact that rehabilitation progression now is at an alarming rate due to advances in fixation methods. Compared to past rehabilitation protocols an athlete may now be released for sports activities as early as 8 weeks after surgery [8, 9]. Physical therapy post-operative protocols will prescribe the speed and safety with which an athlete returns to sports activity. Evidence for postoperative ACL rehabilitation will be discussed and includes modality use, return of motion, balance and proprioception, open and closed chain rehabilitation and return to sports criteria.

A plethora of literature has been written about rehabilitation following ACL reconstruction. Because autograft tissues (bone patellar-tendon bone (BPTB) and hamstring) are considered gold standards and most commonly used, this article will follow rehabilitation using autograft tissue. Recent evidence has shown only marginal clinical and functional differences in outcomes between bone patellar tendon bone and four-stranded semitendinosus/gracilis tendon autografts [3, 4, 10]. Certainly allograft tissue and synthetic grafts are sometimes used, but their use is less common in comparison to autograft tissue. This manuscript will be tailored for an isolated ACL reconstruction in a younger active patient. A slower progression may be needed for an older more normal patient [11]. Additional pathology such as concomitant ligament repair, meniscus, or articular cartilage injury will need to be taken into account and will more than likely create a delay in progression.

Following ACL reconstruction the graft goes through a process called ligamentization. Ligamentization occurs in several different stages including a) necrosis, b) revascularization, c) cellular proliferation, and d) collagen formation [12–15]. Very early following reconstruction the graft tissue will go through a process of necrosis. The graft will require a blood supply and early during the first several weeks will be nourished by bone blood and synovial fluid [15]. Following early necrosis the process of revascularization begins. This usually starts at approximately weeks 6–8 at which time animal studies have shown that the graft is at its weakest point in the post reconstruction process [16]. Some studies indicate that the graft may only reach failure loads of 11 to 50% at 1 year post-operative [17]. This process continues with cellular proliferation in which cells other than the native graft tissue may inhabit the graft. Usually by 30 weeks the post transplanted graft will have tissue characteristics that appear ligamentous. Collagen formation will continue for greater than 1 year [18].

Phase I: post-operative week 1–4

On the first physical therapy visit clear instructions related to any information about the rehabilitation program will help increase self-efficacy and ease concerns. Education about postsurgical exercises, reasons for limited motion and crutch use and cryotherapy all will help stimulate early functional recover of knee function and help the patient create a realistic image about the rehabilitation process in general [11, 19, 20]. Immediately following surgery the initial focus of post-surgical rehabilitation is to minimize pain and swelling and to return knee extension symmetrical to the uninvolved side. Emphasis on early knee extension motion predominates, yet still achieving up to 90–120° of knee flexion is wanted also. With correct isometric graft placement full range of motion should be able to be achieved without damage to the newly placed graft.

Following surgery swelling and pain are both a part of the normal inflammatory response to begin the healing process. Because pain and swelling impede quadriceps motor firing patterns and gaining range of motion, cryotherapy and electrical stimulation are encouraged early. Intraarticular swelling can have detrimental effects on the articular cartilage and synovium when remaining in a joint for protracted time frames. A persistent hemarthrosis can occur in approximately 12% of post ACL patients [21]. Cryotherapy has potent beneficial effects of releasing endogenous opiates and decreasing nerve conduction velocity in those with painful joints following ACL reconstruction [22]. Clear evidence exists that cold therapy immediately following arthroscopic surgery to the knee creates a decrease in intra-articular temperatures resulting in a significant decrease in postoperative pain [23–29]. There is also evidence that cryotherapy is beneficial in the dis-inhibition effect on the quadriceps muscles [25, 30]. In addition to cold therapy the patient can be given treatment with interferential electrical stimulation to help relieve post -operative pain and edema [31]. Optimally these treatments should be done with the lower extremity elevated (higher than the heart) with intermittent compression [21, 32, 33]. To decrease the risk of frostbite, these treatments should be done for up to 20–30 min with a light cloth between the superficial skin and the cold source. If using a form of cryotherapy device, it is recommended to ensure using manufactured and physician recommended temperature settings.

Early randomized controlled trials on immobilization versus delayed range of motion demonstrated marked atrophy of the vastus lateralis and slow twitch muscle fibers with no adverse effect on graft laxity [34–39]. Since joint immobilization for extended time frames results in loss of ground substance and dehydration and approximation of fibers embedded in the extracellular matrix, range of motion of the knee is started early [37, 40]. Normal range of motion of the knee extension has been shown to be hyperextension of 5° in men and 6° in women [41]. Furthermore Shelboune and colleagues have shown that even small losses of 3–5° of extension can significantly affect outcomes following cruciate reconstruction [42•]. It is clear that extended immobilization of the knee is detrimental to structures that surround the knee including ligaments, cartilage, bone and muscles [37, 43–48]. If a patient has had additional procedures such as a meniscus repair, knee flexion will be limited to 90° for 4 weeks.

Because one of the most common complications following ACL reconstruction is post-operative motion loss, the immediate goal is for full knee terminal extension to be achieved as soon as possible. Immediate knee extension ensures that the intracondylar notch is not proliferated with scar tissue, resulting in a Cyclops lesion. A loss of extension can be particularly deleterious as it results in abnormal joint arthrokinetmatics at both the tibiofemoral and the patellofemoral joints leading to abnormal cartilage contact pressures, and inability to contract the quadriceps muscle due to fatigue and pain [49, 50]. Preoperative knee extension motion losses were studied in 102 patients within 2 weeks of having an ACL reconstruction with a 6 month follow-up [51]. Patients with a loss of knee extension motion prior to surgery (in comparison to the contralateral knee) were more likely to have limited knee extension after surgery. In some cases, a short stint in therapy prior to surgery to normalize knee motion may be beneficial. Although the goal to achieve extension is immediate (regardless of timing of first visit – day 2 versus week 2), range of motion into flexion is done as tolerated with an early goal of 90° flexion by the end of week one, and up to 120° by the end of phase I at the 4 week time frame. Following BPTB reconstruction active heel slides are performed as needed. Due to wanting to allow healing medial structures, those with a hamstring tendon ACL reconstruction, active heel slides are held for up to 3–4 weeks. During this time a wall slide (Fig. 1) or passive knee flexion by therapist or patient should be performed. Following the 4 week delay active heel slides should be able to be initiated. Unlike knee extension limitations, knee flexion limitations usually are resolved without complication. Intra-articular swelling and hemarthrosis may limit knee motion due to its space occupying effect or by pain created due to this swelling. Pain and swelling can be treated as described earlier in this manuscript with judicious use of cold therapy, compression, elevation and modalities.

If knee extension motion persists selected therapeutic exercises can be beneficial. Manual passive range of motion into hyperextension, supine hangs with a towel roll under the heel, prone hangs and knee thunks can all be used to create passive knee extension force [20, 52]. Allowing the knee to fall into extension for up to 20 min while the patient is in either prone or supine is a nice way to create low- load, long-duration prolonged stretch to induce a more plastic

Fig. 1 Patient performing wall slide exercise to increase passive knee flexion range of motion

deformation to the capsular structures on the posterior knee that could be limiting full extension. Patellofemoral complications are common, especially following the patient with the BPTB reconstruction [53]. Scarring intra-articular in the areas of the medial or lateral gutter, along the harvest incision site, or even around the smaller portal sites may create a loss of patellar mobility. These potential areas of limited mobility should be treated with immediate patellar mobilization in all directions. Emphasis should be placed on superior-inferior directed patellar mobilization to increase mobility for the extensor mechanism to function without restrictions of mobility. Superior patellar glide mobilizations will improve knee extension, while inferior patellar glides will assist with knee flexion. Patients can also be shown how to perform these mobilizations on themselves as part of their home exercise program.

Controversy exists on the restoration of full bilateral knee symmetrical range of motion. Although some suggest that a return of full symmetrical hyperextension does not affect ligament laxity, when significant genu recurvatum exists it is our belief that up to approximately 5° should be sufficient through manual mobilization or stretching techniques if the patient has normal to lax joints (>4/9 on Beighton Scale) [54, 55]. The remainder of hyperextension motion to become symmetrical will return through functional activities. If the patient is very hypomobile (0/9 on Beighton Scale) they may require additional stretching to bring them closer to symmetrical.

Due to the effects of asymmetrical limb loading early weight bearing is done with bilateral axillary crutches in a weight bearing as tolerated fashion progressing to full weight bearing over the first 1–2 weeks [56, 57]. Weight bearing may be delayed in those with concomitant articular cartilage repair or meniscus repair which may not tolerate the increased stress of full weight bearing. Tyler et al. followed 49 patients following BPTB reconstructions by placing subjects into an immediate weight bearing group and one that had 2 weeks delayed weight bearing [58]. At 2 weeks follow up range of motion was not significantly different between the two groups, however vastus medialis oblique electromyographic (EMG) activity was significantly increased in the weight bearing group. At the conclusion of the study muscle EMG activity was similar, but there were significantly different anterior knee pain levels with the early weight bearing group demonstrating less pain. Although early weight bearing has shown a decrease in pain with immediate weight bearing with no increase in graft laxity, immediate weight bearing's effects on articular cartilage is still unknown.

Motor control and function of the muscles around the knee are needed for all functional activities. Early emphasis day one should also include volitional contraction of the quadriceps muscle. With the BPTB reconstruction the extensor mechanism has undergone significant insult in the harvesting process. Early motor control will help to minimize surgical morbidity. An active quadriceps contraction pulls tension through the patellar tendon, minimizing the potential for entrapping scar tissue. It additionally squeezes the soft tissue of the anterior knee helping to decrease swelling [58]. Emphasis is placed on ability to produce a full sustained contraction of the quadriceps muscle. Several trials have demonstrated the benefits of high intensity electrical stimulation to improve quadriceps strength and gait parameters [3, 4, 59–64]. It is not uncommon for patients to have poor quadriceps tone during the first postoperative visit. If after 2–3 visits the quadriceps muscles are not firing effectively, use of neuromuscular electrical stimulation is warranted. Evidence appears to conclude that the most appropriate use of neuromuscular electrical simulation is with a volitional contraction of the quadriceps and hamstrings. Empirically, it seems that contractile activity is improved if this can be done during weight bearing. This can be done in an upright position once the patient can tolerate placing the limb in a dependent position with at minimum partial weight bearing. An additional benefit of the closed kinetic chain position is the decreased stress placed on the graft tissue as compressive forces at the tibiofemoral joint and con-contraction of muscles surrounding the knee help control excessive motion at all joints in the closed chain [65–68]. Additional positions for quadriceps exercises can include seated during isometric contractions with the knee in a position of a quadriceps set, straight leg raise, or within safe ranges of 90–45° of knee flexion. If the patient has difficulty performing supine terminal knee extension, they can perform this exercise in the prone position with hip extensors aiding achievement of full extension [69].

Total leg strengthening is defined as exercise to joints proximal or distal to the joint in question are done to help decrease unwanted excessive frontal or transverse plane rotations that can occur due to either proximal or distal weaknesses. Lack of proximal trunk control can contribute to abnormal lower extremity alignment during functional exercises. Exercises for the hip and foot/ankle can be done in either open kinetic chain (OKC) or closed kinetic chain (CKC) positions.

Exercises in Phase I can include isometric exercises and a mixture of both OKC and CKC exercises. As the replaced graft is going through a process of necrosis at this time, the graft requires protection. Safe exercises at this time include isometric quadriceps sets, straight leg raises, CKC leg press, shuttle or squats (0–60°), and OKC extension (90–40°). In the early phases OKC knee extension should be done without additional weight distally.

Rehabilitation post- operative bracing during the early phases appears to result in fewer problems with swelling, and less pain compared to rehabilitation without a brace, however at longer-term follow-up there does not appear to have a substantial effect on clinical outcomes such as range of motion, laxity or function [70–72]. Although brace use is controversial, we utilize bracing more for relief of pain following surgery more than for pure stability purposes. Once the patient obtains good quadriceps control with ability to perform a straight leg raise without extensor lag they will be allowed to discontinue the use of their postoperative brace. If they continue to have an extensor lag >five degrees they will be asked to continue to use brace including sleeping with the brace locked in extension.

Phase II: postoperative weeks 4–6

This is the shortest phase in the rehabilitation process. During this time frame gait should be normalized. Any remaining lost extension motion should be treated with more aggressive means to decrease the risk of arthrofibrosis and the need for manipulation under anesthesia or arthroscopic debridement of scar tissue. Flexion range of motion may not be completely full, but should be progressing toward full. If there is a persistent effusion still after 4 weeks, judicious use of cryotherapy can be continued to decrease pain and swelling that may impair motion, decrease quadriceps control, and cause an altered gait pattern.

Sometimes gait may still be impaired due to compensatory strategies used when the knee was having more discomfort immediately following surgery. This altered gait at this time may be more unconscious in nature. Using a mirror to that the athlete can view themselves and their abnormal pattern during gait can be helpful. A useful drill for when the athlete is still walking with a stiff knee that lacks flexion following toe off is the high-stepping drill. The high-stepping drill can also be helpful to allow the patient to see that greater degrees of hip and knee flexion can occur during the gait cycle without pain (Fig. 2). Have the athlete perform a high stepping gait cycle where they pull the thigh higher into flexion to about waist level with each step. Performance of this bilaterally for approximately 10–15 steps can assist the athlete to see that normal degrees of knee flexion will not cause problems.

At this time frame graft necrosis should be ending and the process of revascularization should be beginning. Isometric exercises can be progressed to isotonic to slowly allow increased stress to the knee allowing greater graft strength during incorporation. Isotonic progressive resistive exercises can be performed in the ranges listed above for both open and closed chain strengthening. Contrary to popular belief there is some limited evidence that ranges of CKC 0–90, and OKC 90–0° may be safe without risk of graft laxity or elongation [73–77].

Fig. 2 High stepping over cones to increase normal heel toe gait cycle

Quadriceps strengthening can begin with wall slides progressing to mini-squats or progressive resistive leg press exercises. Heel raises can begin now unilaterally while balance and proprioceptive exercises can include weight shifting bilaterally with progressions to unilateral if tolerated. If a hamstring autograft was utilized initiation of gentle sub maximal isometrics can begin, while hamstring curls can be started if BPTB was the graft source. Historically hamstring activity was thought to be needed as these posterior knee muscles are synergistic to the ACL. Strengthening of the hamstring muscles may provide a primary dynamic restraint to anterior tibial translation [78]. The ACL- mechanoreceptor reflex arc to the hamstrings may cause a loss of proprioception, as a latency of the hamstrings is almost twice that of the normal contralateral uninjured knee [79]. At this time enough soft tissue healing of the hamstrings should allow tolerance to perform gentle hamstring and gastrocnemius and soleus flexibility exercises.

Closed kinetic chain squats can be done beginning on a stable surface with progressions to unstable or labile surface. The athlete is asked to flex the knees to approximately 25–30° and maintain that position as it will produce a co-contraction of the hamstrings and quadriceps [80]. Squats on tilt board can be done with a board tilting in either medial/lateral or anterior/posterior directions (Fig. 3). A proprioceptive component can be added to this exercise by having the therapist provide a perturbation force by taping on the board in different locations. Fitzgerald et al. examined perturbation training in ACL deficient patients and found that those undergoing this form of training had more satisfactory outcomes and decreased frequency of giving way episodes following their ACL injury [81].

As proprioceptive control is increased the athlete should be asked to perform advanced drills that work on preparatory agonist-antagonist co-contraction. These would include dynamic stabilization drills such as cone stepping, and lunges in multiple directions including anterior/posterior, medial/lateral and diagonal drills. Performance of lunges should be done by landing on a slightly flexed knee and holding this position briefly so that co-contraction can occur. Lunge progression should occur by performing lunges in classical movement patterns such as anterior/posterior and lateral prior to diagonal and multi-plane lunges last. Higher level lunges can occur by lunging with a rotation, onto a labile surface or with a perturbation. When these lunges are tolerated, the patient concentration can be altered by having them throw or catch a ball indicative of their respective sport (basketball, soccer, football, etc.).

Phase III: postoperative 6 weeks–3 months

The hallmark of this phase is moving the patient to basic functional activities to tolerance of those more advanced activities that allow them to progress to full recreational or sporting activities at much higher levels. An overall concern during this phase is evidence that the autograft itself is reaching its weakest point structurally during the 6 to 8 week time frame postoperatively [16]. Additional evidence states that the actual graft may only reach between 11 and 50%

Fig. 3 Squats done on a tilt board to increase proprioceptive effect

failure loads of the native ACL at the 1-year point [17]. It is theorized that controlled loading will enhance ligament and tendon healing, while excessive stress loading to an ACL graft may cause graft elongation leading to excessive unwanted anterior-posterior laxity [44, 82, 83]. The patient should have full range of motion of both knee extension and flexion. There should be no pain or discomfort with basic functional activities. By the end of 12 weeks they should have enough strength and balance to allow progression of controlled individual sports and recreational activities. This does not mean that they will be independent with a full return of sports, but that they can begin controlled individual functional sports activities.

Exercises can progress to knee progressive resistive isotonic knee extension exercises in the range of 90–45°. This range can be done both concentrically and eccentrically at this time. Single leg squats and unilateral leg press in the range of 0–45° can be done safely. At 12 weeks as long as a satisfactory exam is performed the patient is progressed to higher functional activities.

Phase IV: postoperative 3 months–6 months

It is during this phase that the patient readies themselves for a gradual progression of return to full sports participation. If the patient has a successful clinical examination with no swelling or pain with normal activities, if they have full motion, and no instability they are allowed to begin straight in-line jogging. This is usually progressed on an every other day basis to give a full day rest between jogging sessions. Bilateral plyometric exercises requiring the stretch shortening cycle can also begin progression to unilateral as tolerated. Exercises that stress single-limb postural control are given first on level ground and then progressed to an unstable labile surface.

As most advanced activities require core stability to maintain center of mass, balance and postural control, exercises for the trunk and hips are desired. Core trunk training and stability are related to the body's ability to actively control the body's center of mass in response to the forces generated from distal body parts during athletic competition [84]. Consensus is that by restoring core strength and stability a reduction of injury risk my occur due to the more effective control of athletes center of mass during higher level activities [85–87]. Core training can consist of multiple exercises for the core such as sit-ups, bridging exercises, single leg bridges, straight leg deadlifts and planks (Fig. 4) just to name a few. All exercise progression for the lower extremities should begin bilaterally and progress to unilateral loading. Improvement in single limb balance can begin by maintenance of single limb stance on a flat level surface while moving the contralateral extremity through classic

Fig. 4 Plank exercises to strengthen core

movement patterns such as flexion/extension, abduction/adduction. Once this has been proven successful movements of the contralateral extremity through the transverse plane is added. Single limb balance can be progressed by time or numbers of repetitions of the contralateral extremity movements. These balance exercises can be progressed by having the athlete perform balance techniques in increasing degrees of knee flexion which may also have a protective effect as activities in knee flexion may limit exposure to excessive anterior tibial shear loads that may overload graft tissue while performance of dynamic tasks [88–90]. Increased progression of single limb balance can include balance with eyes closed, progressing to the entire balance sequence being done on a labile surface. Although these types of exercises are thought to be beneficial for increasing balance and proprioception, their use for objective assessment may be difficult to assess by a clinician as they may not be sensitive enough to determine deficits following ACL reconstruction [91].

A more conservative approach is utilized with plyometric activity beginning after 12 weeks. Plyometric exercises use the muscles stretch shortening cycle to allow maximum production of concentric contraction following a rapid eccentric loading of the muscles [92, 93]. Hewett has shown that a 6-week plyometric training program was able to alter the strength and landing mechanics of female athletes as a result of increased strength and function [94]. The authors found a 22% decrease in peak ground reaction forces and 50% decrease in abduction/adduction moments at the knee during landing. These improvements in function are extremely important for those following ACL reconstruction as increased loading and valgus collapse are common mechanism of cruciate ligament injury. As the patient progresses through this phase they can begin to perform entry-level double-limb plyometric jumps with a progression to low-intensity single- limb plyometrics. These activities will allow a gradual progression of the addition of ground reaction force attenuation during more functional activities. Inability to attenuate ground reaction forces are considered to put athletes at an increased risk for ACL injury [95]. Examples of bilateral entry level plyometrics would include simple bilateral ankle jumps, bilateral jumping in place, and bilateral ricochets. Entry level single-leg plyometrics would include low-level lateral bounding, step and stick, and jogging in place. As the patients strength increases and they demonstrate tolerance to these exercises they can progress to higher level plyometric exercises described in Phase IV.

Phase IV: 6 months +

It is during this final stage of rehabilitation that the patient may be released for full return to functional individual and team recreational or sports activities. This could not occur at a more perfect time as the physical therapist is lifting activity restrictions as the athlete is becoming more confident in their knee. It must clearly be remembered that this is the same time frame that athletes will start to expose their knee to forces and motions that may load the reconstructed graft to near it limits [89, 96]. This phase is usually a little more vague in regards to appropriate exercise progressions with less detail in regard to clinical guidelines as to when it is safe to introduce more high-risk or high-load activities [11, 97]. Presently there is little agreement as to when it is safe to return to sports participation [98–100]. Determining return to play is often dictated by several forms of assessment. Isokinetic strength tests are often used as criteria to return to full unrestricted sports activity. Others utilize functional testing methods such as jumping, hoping, and agility tests. As no single test (strength or function) has been proven to be superior, return to sports participation is oftentimes based on physician and therapist preference for testing method rather than evidence-based science. Most of these standard objective measures such as these are temporal based measures and therefore are quit variable and may have limitations if used in isolation to determine return to full activity. This is concerning since as many as one in four patients undergoing an ACL reconstruction will suffer a second tear within 10 years of their first [101]. Furthermore recent biomechanical data has shown that altered neuromuscular control of the hip and knee during a dynamic landing task as well as postural stability deficits after ACL reconstruction are predictors of a second ACL injury after an athlete has returned to sports [102•]. This data would seem to indicate that even after rehabilitation, there may be ongoing neuromuscular deficits that continue**.** Indeed several studies have demonstrated decreased muscular strength, joint position sense, postural stability, and various parameters of force attenuation for 6 months to 2 years following reconstruction [5•, 56, 102•, 103–105, 106•].

Rehabilitation exercises as this time frame should utilize the concept of overload to develop strength and power in the athlete yet at the same time are within a level of acceptance to create minimal exposure to potential injury risk of re-rupture of the still maturing graft. In this final phase of rehabilitation activities that require unique aspects of their respective sport can be used in treatments. Those that require power generation, cutting, and change of direction may be important. In addition to the previous exercises described these athletes can now perform in a controlled environment exercises such as higher level plyometric exercises including bilateral box jumps (jumping to the box) performed in both anterior and lateral directions, single-leg box jumps (hopping to the box) (Fig. 5) performed both anterior and lateral, higher level lateral bounding, power skipping, and zigzag bounding, and scissor-jumps just to name a few. Myer et al. suggest ensuring adequate knee and hip flexion angles and a decrease in knee abduction or

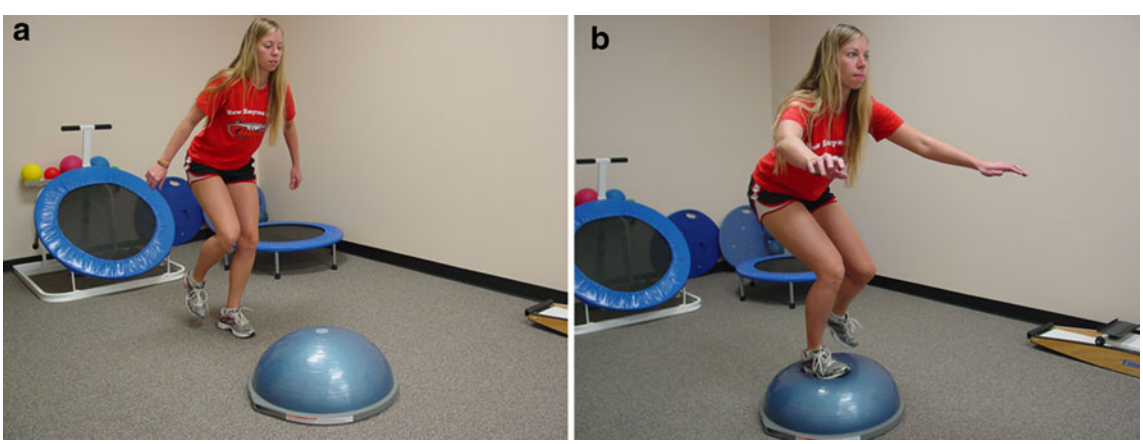

Fig. 5 Plyometric power strengthening via single leg hoping to surface (a = starting position, b = ending position)

Table 1 Postoperative anterior cruciate ligament reconstruction protocol

Phase/Criteria for advancement	Goals	Brace/WB status	Therapeutic exercises
Phase I: PO Weeks 1–4	Protect graft fixation	**Brace**	Heel slides as tolerated BPTB
Criteria for Advancement II	Minimize effects of immobilization	Week 0–1	Wall slides 0–45° (hamstring repairs)
Good quad set	Control inflammation	Locked full extension	Quadriceps sets(NMES if poor control)
Approximately 120° flexion	Full extension ROM	Week 1–2	Patellar mobilizations
Full knee extension	Education	Unlocked for ambulation when full extension with no lag	Non-weight bearing gastrocnemius and hamstring stretches (hold 3 weeks if hamstring repair)
		Week 2–4	SLR in all planes – with brace if extensor lag
		DC brace when full extension with no lag	Multi-hip
		If lag in extension >5 sleep in brace	Quadriceps isometrics at 60° and 90°
		WB Status	Toe raises bilaterally
		WB as tolerated	Terminal knee extension (T-band)
		Bilateral axillary crutches	Balance – bilateral weight shifts
			Stationary bike (high seat, low tension)
Phase II: PO Weeks 4–6	Restore normal gait	**WB Status**	Exercise as previous
Criteria for Advancement III	Maintain full extension	No assistive device when gait with no antalgia	Wall slides 0–90°
Excellent quadriceps set	Progress flexion ROM		Multi-hip
SLR without extensor lag	Protect graft fixation		Toe raises unilaterally
Full knee extension			Leg press - bilaterally
No signs of inflammation			Balance – bilateral weight shifts – unilateral
			Hamstring isometrics (hamstring repairs) – curls (BPTB)
			Hamstring and gastrocnemius & soleus stretch
Phase III: PO 6 Weeks–3 Months	Full ROM	Functional brace may be recommended by physician for use during sports for first 1–2 years after surgery	Flexibility as appropriate
Criteria for Advancement to IV	Improve strength		Stairmaster/Nordic Track (avoid knee hyperextension)
Full pain-free ROM	Improve endurance		Isolated knee extension 90°–45° progress to eccentrics
85% quadriceps and hamstring strength	Improve proprioception		Advanced CKC – Single leg squats; leg press – unilaterally (0°–45°)
Good static proprioception and balance Physician clearance for advanced activities	Prepare for functional activities Avoid overstressing graft		Step-ups (begin 2″ progressing to 8″)
	Protect PF joint		
Phase IV: PO 3 months–6 months	Progress strength	Functional brace may be recommended by physician for use during sports for first 1–2 years after surgery	Begin in-line jogging
Criteria for Advancement to V	Progress power		Initiate bilateral plyometric exercises
Full pain-free ROM – flexion and extension	Progress proprioception		Progress proprioception - Slide board, ball toss, racquets
No patellofemoral irritation 90% quadriceps and hamstring strength	Prepare for return to *controlled* individual functional activities/sports		Walk/jog progressions
Sufficient proprioception			
Physician clearance for advanced activities			

Table 1 (continued)

Phase/Criteria for advancement	Goals	Brace/WB status	Therapeutic exercises
Phase V: 6 months +	Progress strength Progress power Progress proprioception Prepare for *full return* to functional activities Safe return to athletics including individual/team sports Education on possible limitations	Functional brace may be recommended by physician for use during sports for first 1–2 years after surgery	Continue to progress flexibility and strength Progress plyometrics – unilateral Walk/jog progression Forward/backward running progressing from ½, ¼, full speed Cutting, cross-over drills, carioca Initiate sports specific drills as appropriate Gradual return to sports participation Maintenance of strength and endurance

Revision surgery please delay protocol by 2 weeks. BPTB = bone patellar – tendon bone; DC = discontinue; NMES = neuromuscular electrical stimulation; PO = post-operative; PWB = partial weight bearing; ROM = range of motion; SLR = straight leg raise; WB = weight bearing;

valgus collapse are performed during these higher level activities to ensure safety and to decrease faulty motor patterns that could have been part of the injury mechanism to begin with [107, 108]. These higher level exercises require more careful scrutiny of biomechanics and require verbal and visual feedback commonly to develop safe exercise progression.

Home – versus supervised therapy

Despite the fact that Howe et al. reported improved outcomes with formal supervised rehabilitation as compared to those who did not receive supervision, there appear to be several recent studies that compare home-based rehabilitation to that of supervised therapy by physical therapist [109]. Most of these studies appear to support that home based therapy may produce similar outcomes as clinic-based programs [110, 111, 112•, 113]. It must be stressed that each of these studies included some form of formalized physical therapy in a supervised fashion and none of these protocols were completely unsupervised. These reports would suggest that ACL rehabilitation may not need continuous monitoring on a daily or weekly basis, but attending physical therapy for the purpose of education, assessment, monitoring function and progression of treatment plan remain a critical aspect of a safe and effective rehabilitation program [4]. Future randomized controlled trials without any formal therapy will be needed to determine if a simple home exercise program is truly comparative to formal therapy.

Conclusions

Immediate rehabilitation following ACL reconstruction begins by reducing swelling and post-surgical inflammation, improving range of motion (including full terminal knee extension), and optimizing quadriceps motor control. The ability to return an athlete to unrestricted return to competition requires a full return of neuromuscular control, strength and endurance of the post-surgical extremity. A gradual progression of increased stress is applied to the knee and lower extremity through a four phased program described (Table 1). Rehabilitation following ACL reconstruction should be based on clinical science and the best available evidence.

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analyzed during a bilateral drop vertical jump. A significant side-by-group interaction for peak vertical ground reaction force (VGRF) was observed during the landing phase of drop vertical jump in all of the reconstructed group. The involved limb displayed significantly lower VGRF than the involved limb and both the preferred limb and non preferred limb in the control group. No effect of sex was noted.

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