A TEN TASK-BASED PROGRESSION IN REHABILITATION AFTER ACL RECONSTRUCTION: FROM POST-SURGERY TO RETURN TO PLAY – A CLINICAL COMMENTARY

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CLINICAL COMMENTRY

A TEN TASK-BASED PROGRESSION IN REHABILITATION AFTER ACL RECONSTRUCTION: FROM POST-SURGERY TO RETURN TO PLAY – A CLINICAL COMMENTARY

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ABSTRACT

There is a need to improve patient outcomes after anterior cruciate ligament reconstruction (ACLR). To do this likely involves a strong focus on optimizing rehabilitation processes and practices. Movement re-training is considered an important element of rehabilitation after ACLR, but there is a lack of knowledge on the 'how' and 'what' movement re-training should occur after ACLR. In its basic form, movement re-training after ACLR is about progressing a patient through gradually more demanding tasks from the point of being able to walk to being able to perform highly complex sports movements. However, there is a lack of guidance on when to implement certain tasks (e.g. when to begin running) and how to transition between tasks. This paper presents a 10 task progressions system which can form an important aspect of the movement-based re-training process, providing structure and patient autonomy. Monitoring knee function and movement and neuromuscular status to safely transition between these tasks is important. Although this task-based progression is designed for patients following a rehabilitation program after ACLR, it may have generalizability for all major lower limb injuries. The task-based progression was formed by combining theory, the best available evidence, and significant practice experience applied to movement re-training after ACLR. This approach supports patient autonomy, medical team communication and collaboration and can provide structure to the movement re-training process.

Keywords: Biomechanics, criterion-based progressions, movement system, performance rehabilitation, screening

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BACKGROUND AND PURPOSE

Outcomes following injuries such as anterior cruciate ligament (ACL) rupture are unsatisfactory, with lower than optimal return to sport (RTS) rates[1] and high re-injury risk.[2,3] To optimize patient outcomes after ACL reconstruction (ACLR) and limit long-term associated problems which can follow injury (e.g., knee osteoarthritis),[4] there is a need to optimize the rehabilitation and RTS approach. One area which is becoming increasingly important is movement re-training or 'functional' training. Movement dysfunction is thought to be a risk factor for both primary and secondary ACL injuries.[5-7] Disruption to the native ACL after injury, leads to mechanical instability of the knee, and can alter neuromuscular control due to disrupted mechanoreceptors within the ligament[8] and altered somatosensory input and joint proprioception. Multiple authors have identified altered movement quality in both the involved and uninvolved limbs after ACLR during various functional tasks.[9-14] It appears that an ACL injury results in altered movement bilaterally, when compared to pre-injury movement quality.[11] As such, it would appear that targeting the restoration of normal movement patterns is one of the priorities during rehabilitation and requires both single and bilateral limb activities.[15]

Although most clinicians and researchers understand that retraining movement after ACLR is important (e.g., the 'why'), there is often a disconnect with understanding the 'how' and 'what' of movement re-training post ACLR. There is a need to bridge the gap between theory and practice to provide practitioners who work with ACLR patients' clear guidelines on 'how' to train movement and 'what' exercises to do and when. Establishing clear task based goals have been suggested for athletes after ACLR to provide structure and clarity to the process.[16] One key task after ACLR is return to running, which is typically recommended based on time as opposed to function, with recommendations being around 12 weeks after surgery.[17] In terms of graft healing and maturation, the often cited reason for determining this time frame, this is an irrelevant date.[18,19] However this becomes a fixed point in the athlete, coaches, surgeons and rehabilitation specialists minds with the athlete feeling as though they are "failing" if they cannot run at that point and feeling "on track" if they are running at that time. The ability though, to perform specific tasks like running is not related to healing times, but more specifically to functional return. But, in the decision to return to running after ACLR, function is rarely assessed.[17] Conversely, there is a current practice-based trend regarding the implementation of functional tasks earlier than perhaps advisable. Such functional tasks are more exciting than traditional, simple, isolated tasks, which may become boring to the patient. However, after ACLR, patients are often ill-prepared for some functional tasks, which may increase athlete re-injury risk or result in joint overload, substitutions during performance, and/or complications in the rehabilitation process.

Therefore, the aim of this clinical commentary is to provide an easily implementable task-based progression, with specific criteria and monitoring suggestions as a guide during rehabilitation after ACLR. These task-based progression are expected to offer clarity to the process for all, autonomy to the patient, and provide clinicians with an evidenced informed approach to optimize their functional recovery approach.

LOAD MANAGEMENT CONSIDERATIONS

In terms of task-based progressions, it is important to initially establish the level of loading that a task may place on the body and have a clear understanding of the different total loading demands of each task. Loading can be considered as:

- peak loading (e.g., peak ground reaction forces),
- volume load (e.g., load times repetition) and
- rate of loading (e.g., time over which it is delivered/experienced)

It is important to plan and prepare for all types of loading and develop load tolerance to particular tasks. Load is dissipated via the neuromuscular system and absorbed passively via the tendons, ligaments and joints. Deficits in strength would mean insufficient neuromuscular capacity to eccentrically absorb forces during high load tasks, with greater reliance on joint complexes (tendon, ligament and joint structures) for passive force absorption.[20]

It is also important to understand how the load is distributed throughout the body and specifically the knee in particular. The extent of load will depend on the kinematics and the specific torques elicited at each joint. Typically, loading is distributed throughout the joints of the lower limbs, with acceptance/torque development occurring at the ankle, knee and hip depending upon the tasks and adopted movement strategy. Altered movement quality would result in differing joint torque loads being shared by the movement system, which could either increase knee joint loads (e.g., knee dominant pattern) or reduce the loads (e.g., knee avoidance strategy). A key element for task-based progressions is to understand the tensile load experienced via the ACL to provide 'optimal loading'.[21] This entails protecting the ACL-graft from excessive loads which could lead to graft attenuation or even failure, but sufficient enough load to encourage neuromuscular adaptations and graft remodeling/strengthening. An example of ACL loading during athletic activities was described by Laughlin et al.[22] using musculoskeletal modelling to provide an estimate of ACL tensile forces during single-leg landings (30 cm height) in a group of recreationally active females. Peak ACL load during the landing was ~0.7 × body mass, equating to 440 N for the female cohort in the study. While this value is clearly below the ~1300 N threshold which might be expected to rupture the female ACL,[23] sagittal plane motion is only one component influencing the resultant ACL load. The addition of altered tibial and/or femoral rotation due to poor biomechanics may exacerbate the load on the ACL[24] during landing, bringing it closer to the injury threshold. So, assessing and controlling for altered frontal and transverse plane control is an important aspect of movement re-training.

Finally, it is important to minimize excessive patellofemoral joint stress, given the high prevalence of patients who go on to develop patellofemoral pain syndrome after ACLR.[25-27] Understanding the extent of load which may be placed on the patellofemoral joint is important. In closed kinetic chain exercises (e.g., most functional tasks) such as lunges and the leg press, quadriceps muscle force and patellofemoral joint stress are highest near full flexion.[25,26] As such, it is recommended initially to restrict high load functional exercise to between flexion angles of 0-80°.

MONITORING OF THE ATHLETE

It is important to monitor the athlete to ensure that the response to the exercise is appropriate, but also that they are progressing optimally and have the appropriate function. The quality of movement and level of stress is important. The authors propose monitoring:

1. The response to the exercise
2. Movement quality during the task
3. Strength and
4. Muscle soreness

Monitoring the response to exercise

Any task-based progression must consider the biological healing and ability of the joint to withstand the loading demands. Pain and swelling can be used to determine task-based progressions, as these factors will relate to the loading stress experienced by the knee.[28] Optimal loading may be defined as the load applied to structures that maximizes physiological adaptation.[21] All exercises should typically be pain-free. If not specific adaptation to training or in regard to exercise quality has to be considered to continue to train function without affecting the knee joint homeostasis. Progression through tasks is allowed only when there is no pain (numeric rating scale) or swelling (stroke test) increase as a response to previous tasks, as these would indicate excessive previous loading levels to the knee joint and an adverse reactions, which may limit optimal adaptation.

Movement quality – Is the task too difficult?

The authors believe that rehabilitation needs to be geared at least in part to regaining symmetrical motion and appropriate movement strategies in order to reduce risk of re-injury and improve function. For this to be achieved, a means of monitoring limb alignment during functional tasks is required. Inability to maintain alignment may indicate the task is potentially too challenging. The assessment of movement quality is a matter of debate. 3-D camera motion tracking is considered the gold-standard method for motion analysis,[5] but is clinically not commonly available. In terms of optimal movement training, there is a need to have information on movement quality during the tasks at hand, and to be able to provide feedback to the patient, to create a continuous learning environment to solve the task and optimally progress. This should be easy to obtain, not require expensive equipment and also not require time consuming analysis. Clinically, it needs to be simple enough to be understood by the patient, to be effectively coached and adopted so the patient can learn to self-correct (a valuable stage of motor learning). Herrington et al.[16] suggests a qualitative movement assessment system based on a series of criteria including the ability to maintain control of the arms, trunk, pelvis and lower limbs in the sagittal plane. Here it is advised to adopt a similar approach, which focuses on teaching and monitoring the patient's ability to maintain control of the body utilizing teaching and training of optimal frontal plane (pelvis, trunk and lower limb, Figure 1a) and sagittal plane control (Figure 1b), depending upon the specific task. Task-based progression should be based on movement quality or technical proficiency during the tasks. If the task cannot be performed with sufficient quality, then it should be simplified, or the load is reduced (e.g., no or less weight, or add support).

Strength – Are they strong enough to do this task?

The ability to perform functional tasks is dependent on the neuromuscular systems ability to produce force (e.g., strength).[29] As discussed, various tasks will place differing loads on the movement system, both in terms of the whole system and as well as joint specific (e.g., knee dominant or hip dominant). Inability of the neuromuscular system to produce or accept force may result in either movement compensations and/or acceptance of passive loading via tendinous, joint, ligament, and potential joint overload. Additionally, muscle strength imbalances will result in altered movement quality, which may result in further movement compensations and reinforce inappropriate patterning.[30] As such, it is important to assess, monitor and use assessment of strength to guide task progressions. This also provides objective information to support shared decision making as a team on important functional milestones (e.g., initiating running, jumping and/or plyometric type tasks).

Knee extensor strength is a major barrier to functional progressions.[30] It is advised to assess knee extensor strength (respecting the time after surgery and possible ACL graft loading) and use this information to plan when to implement certain tasks or transition into different phases of rehabilitation. In addition, functional tasks require large force production for absorption from the whole kinetic chain. For example, bilateral landing, treadmill based running

Figure 1. *1a, an easy to utilise and teach model of movement analysis based on three lines in the frontal plane, with a line to assess trunk stability/ alignment, pelvis stability/alignment and limb stability/alignment. 1b, depicts the sagittal plane view which is dependent upon the task but a function of ankle to knee and knee to hip alignments.*

and single limb plyometric tasks typically involve ground reaction forces of 1-1.5,[31] 2-3[32] and 2-6[31,33,34] times body mass, respectively. So, understanding the ability of the lower limbs to produce and accept force can provide a measure by which the "when" a patient may be ready to begin practicing these potentially dangerous tasks after ACLR.

Assessing knee extensor strength using concentric or isometric assessment via the isokinetic dynamometer or recording knee extension loads used in rehabilitation (hand held dynamometry), or using the leg press 8 or 10 repetition maximum (RM) can provide an indication of strength and be used to regularly monitor the patients to support task-based progressions.[16] In addition, although there is limited research attention, assessing unilateral and/or bilateral squat strength isometrically using force plate analysis could provide an useful objective measure of work/load distribution to support task-based progressions.[35,36]

Muscle soreness- was the loading too high?

After unaccustomed exercise, there may be muscle soreness referred to as delayed onset of muscle soreness, that occurs following exercise induced muscle reaction.[37] The degree of muscle reaction depends on many factors including exercise type, duration, intensity and habituation to the exercise.[38,39] Tasks that are too strenuous will result in significant muscle reaction, which may take substantial time to recover and may limit the ability to train in the subsequent days. Monitoring the muscle soreness can provide an indication of the muscle specific loading and required recovery time, which can then support subsequent training modifications.

SUGGESTED TASK-BASED MOVEMENT PROGRESSION FROM THE BEGINNING TO THE END – THE 10 TASKS

Below is presented the 10 tasks, from the beginning to the end of the functional recovery process after ACLR. These tasks are developed based on the load and movement skill requirements and in line with the progressive functional recovery process that is important after ACLR. Within each task, there are specific criteria to achieve prior to undertaking the task. Additionally, each task typically has sub-task progressions, which can be used to progress towards the task after attainment of the previous task. These can be used to support optimal progression between tasks.

1. Normal walking gait

The first milestone and task target (Figure 2) is typically to walk normally after surgery without aids (e.g., crutches). Following ACLR, a patient cannot not fully weight bear or walk without crutches for a period of time, often two to four weeks.[40] Abnormal gait patterns have been associated with muscle weakness,[41] decreased functional performance,[42] low patient satisfaction with outcome after surgery[43] and post-operative complications including osteoarthritis.[44] The abnormal gait patterns often become further exacerbated when the patient returns to running.[28] Thus, re-establishing normal gait early and safely after surgery is a key priority.

Normal or optimal gait biomechanics cannot occur without normal or optimal joint motion[45] and so the restoration of joint range of motion is essential to target the restoration of optimal gait. After ACLR, patients should achieve full extension (and control in extension) prior to 'leaving' the crutches. To be able to achieve full terminal extension, the ability to recruit the quadriceps and maintain active extension is essential. Quadriceps inhibition can prevent recovery of quadriceps muscle strength and the safe and expedient progression of rehabilitation.[46,47] Persistent quadriceps lag on single leg raise has been shown to indicate an inability to actively fully extend the knee. If this is not achieved by week five post ACLR, it would be considered a predisposing factor for significant quadriceps weakness at 6-months post-operation.[48] Prior to leaving the crutches, it is suggested to achieve full active knee extension, control of effusion and no 'joint overload' (e.g., clinical increase of swelling [> 1 cm, at the patella], or pain [+1 point]) and no quadriceps lag on active straight leg raise.

2. Bilateral squat

Neitzel et al.[49] found some patients after ACLR failed to symmetrically load their legs during squatting up to 12 months post-op and this was related to poor functional outcomes. A bilateral squat is a foundation exercise, involving triple flexion and extension

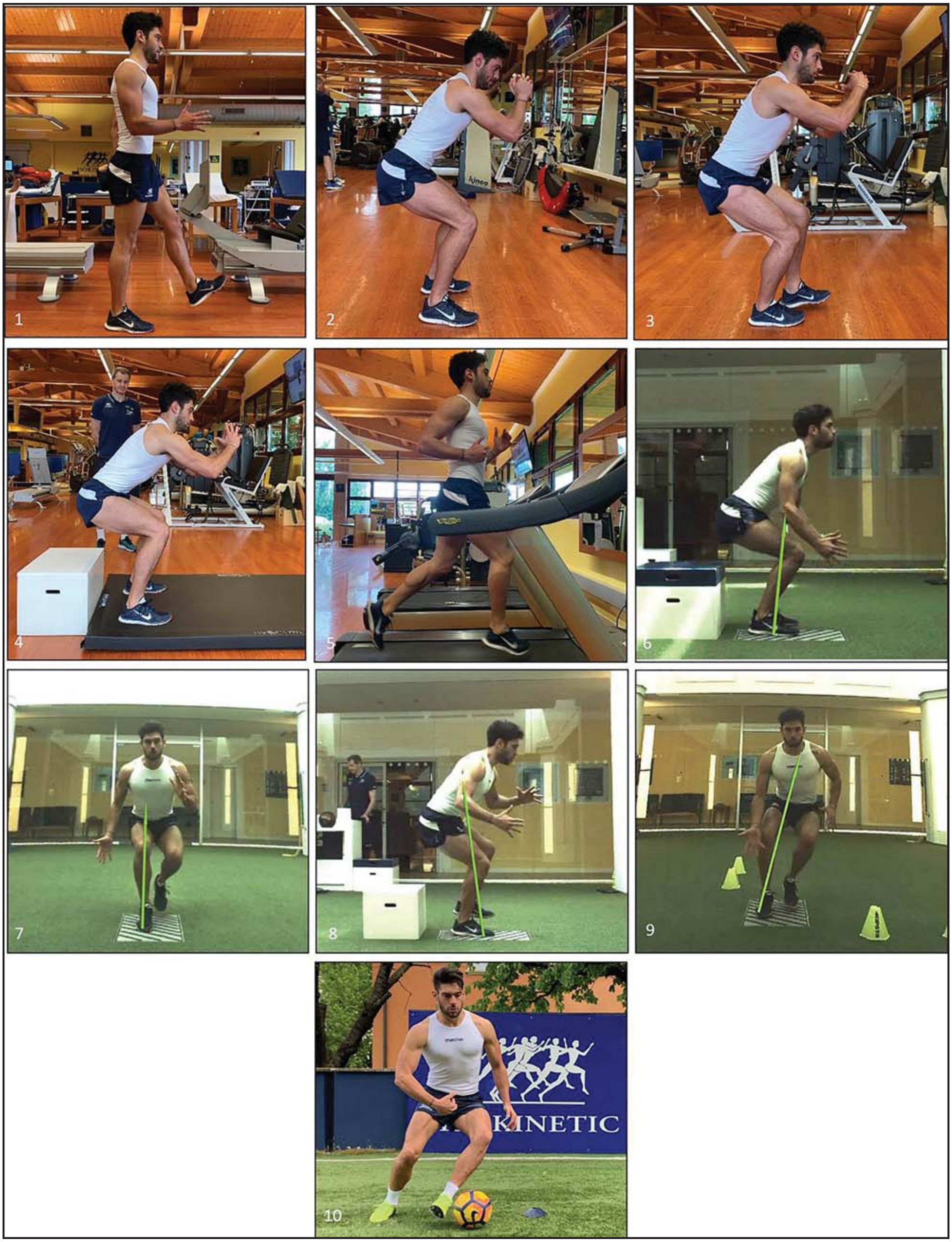

Figure 2. *The ten tasks progressions after ACLR, 1) walking, 2) bilateral squat, 3) single leg squat, 4) bilateral landing, 5) running on treadmill, 6) bilateral drop jump, 7) single leg deceleration, 8) single leg drop jump, 9) 90° cut maneuver, 10) sport-specific change of direction.*

of the lower limbs, while maintaining optimal trunk control. It provides a framework for developing compound strength (e.g., squat training) as well as serving as the motor patterning for other tasks (e.g., bilateral landing, jumping, plyometrics). So, its restoration early after surgery is a priority. Bilateral squat progressions can begin with squat, wall squat, goblet squat, back squat, front squat and overhead squat. These should all initially be performed without additional load and then with gradually increasing amounts of load, to aid functional strength development. Considering PFJ loading is important, an initially targeting lower knee flexion angles (< 90°), recommended. Optimal squat technique is a great precursor to single leg progressions (e.g., split squat). Importantly, there are times where squat activities are limited or when range of motion may be protected, such as after meniscal repair.

Unilateral foundation exercises – Single leg squat

The single leg squat represents probably the most functional foundation movement, involving triple flexion and extension with optimal control and minimal support on one leg. Single leg exercises are complex movements with lots of degrees of movement freedom. A single leg squat represents the foundation movement for progression to many tasks, which require acceleration, deceleration and landing on one leg, representing the fundamental movement pattern for all sports type activity. A single leg squat also requires supporting and moving full body weight. As the single leg squat requires balance and control, it is advised to be able to leg press nearly 100% body weight to have the necessary strength to tolerate body weight during the single leg squat. Progressing to single leg squats can be done through various tasks, with increasing complexity and load (e.g. body weight applied to the limb). For example, a split squat is more complex than a bilateral squat and requires the pelvis to stabilize in the frontal plane. The split squat will have roughly 60% body weight on the front limb and 40% of the back limb. Adding load to the tasks is advised prior to progressing to the more complex or higher load task (e.g., adding 20 kg of load, should add around 12 kg of additional load to the training limb, representing around 60 kg or around 75% body weight for an 80 kg athlete). The authors suggest the use of progressions to single leg squat to include: split squat, reverse lunge, walking lunge, step up and single leg squat.

Bilateral landing

Bilateral landing represents the first landing task, where the patient leaves the ground in the air and must accept the potentially high ground reactions forces with the neuromuscular system, which can result from acceleration to the ground due to gravity. Typical forces during bilateral landings can be around 1.5-2 times body mass[31] depending upon the height of the landing (which represents around one times body mass per limb delivered at high rates of loading). Prior to initiating landing tasks on the ground, it is also recommended that the athlete have attained at least one times body mass (single limb) and two-times body mass (double limb) for set of eight repetitions on the leg press. Bilateral landing allows for the training of eccentric control at the required speed, to prepare for single limb acceptance drills (e.g., single leg landing, running). Variations and progressions include landing from a box, landing from running on the spot, landing from a jump. These can also be vertical, horizontal or even rotational. Use of different surfaces can support the reduction in peak landing forces, such as use of the pool, sand or trampolines or a mat (e.g., synergy mat).

Running –Run on treadmill

Running represents a functional task which all people should do and is often considered a milestone mark for the ACLR patient. It is perhaps the most prioritized task and is the foundation for all sporting type tasks (virtually all sports require you to be able to run). Running is a high load task and requires substantial strength and neuromuscular control. Each step taken during running represents weight acceptance of around 2-3 times body mass.[32] Effective implementation of running can serve as a useful training stimulus for developing strength and neuromuscular control. Ensuring optimal movement quality in the running gait is important before advancing to more high-risk complex sporting type movements. Assessing running gait training on a treadmill may allow the clinician to provide feedback (visual or immediate or delayed feedback with video recording) cues to support the improvement of the athletes running technique.[28] Key aspects entail normalization the range of motion of joints of the involved and uninvolved limbs which can be examined via video recording. Further analysis of stride length, contact times and force absorption by force plate embedded treadmills can facilitate more in-depth analysis and support optimal progressions. Pain free symmetrical gait at near maximal sprint speeds should be a key aim of gait retraining (this occurs towards end-stage rehabilitation). Optimal gait at slower running speed (8 km.h-^{1}) is requisite for progression to unilateral deceleration and landing training. It is essential that treadmill mechanics be restored prior to progression to outdoor running or agility drills. It is important to note that many measurable parameters of function do not normalize during the initial year following an ACL reconstruction.[50]

Bilateral plyometrics – Bilateral drop jump

Lower extremity plyometric exercises are commonly used by athletes to develop explosive speed, strength, and power. They involve a stretch-shortening cycle, where eccentric muscle contraction is quickly followed by concentric contraction of the same muscle (or muscles). During the eccentric phase (pre-stretch), the musculotendinous unit is stretched, which stores elastic energy, and the muscle spindles activate the stretch reflex. Plyometric training has been reported to be superior to more traditional resistance training for development of explosive lower limb performance[51,52] and can contribute to improvements in lower limb strength and power, increased joint awareness, and overall proprioception.[51,53-55] Performance of high-intensity plyometric exercise often produces muscle damage, due mainly to the eccentric component of the muscle action, and excessive joint loading (ligament, joint structures, tendon), which could result in injury.[56] Typical impact forces during plyometric exercise when performed on land is between 2-6 times body mass.[31,33,34] Performance in the bilateral drop vertical jump, specifically control of dynamic knee valgus has been shown to be associated with ACL injury/ re-injury risk.[5] High knee abduction moments seen in adolescents during drop jump[57] are not seen in more elite older/ established athletes.[58] This indicates the importance of optimal technique during the tasks and re-learning optimal technique prior to progressing to more challenging tasks. Again, it is vital to recognize many of the measurable parameters will not normalize during the first year following an ACLR.[50]

Unilateral landing/ deceleration –Single leg deceleration

ACL injuries typically occur during deceleration and landing tasks, and these movements represent a dangerous progression for the ACLR patient. They are also psychologically challenging for the patient due to their nature. The ability to absorb forces eccentrically and dissipate these via the neuromuscular system is an essential aspect of functional performance. Single leg landing and deceleration tasks represent a transition to loading of 2-3 times body mass on each limb.[59] As such, prior to initiating single leg landing tasks on the ground, it is recommended that the athlete restore knee extension strength to within 20% of the contralateral limb (e.g., 80% LSI, assessed via isokinetic or hand-held dynamometry) and have attained good single leg strength. It is advised the patient attain the ability to push 1.5 times body mass (or 2 times body mass for eccentric strength) in the single leg press exercise prior to progressing to single limb decelerations for optimal progression. Following the attainment/ practice of landing control drills it is important to practice these movements during more natural deceleration tasks from running. Initially, single leg landings/decelerations should be practiced on a surface which absorbs forces (e.g., mats, trampolines, sand) to reduce potentially high impact forces, with a progressive increase in height (e.g., 20, 30 and then 40 cm landings from step) or gradually progressive speeds prior to initiating deceleration actions. The focus task for progression to the subsequent task, should be optimal control and kinematics in a single limb deceleration from straight line run.

Unilateral plyometrics –Single leg drop jump

Sporting movements that include change of direction mimic the nature of unilateral plyometrics. Plyometric drills can improve neuromuscular control in athletes, which can become a learned skill that transfers to sporting competitive movements.[60] It is important to progress from uni-planar to multi-planar plyometrics as a progression and foundation for the practice of sport-specific tasks. It is recommended that satisfactory movement quality be achieved in the unilateral drop jump, with optimal force absorption prior to progression to rotational plyometrics or change of direction tasks. Unilateral plyometrics have typical landing forces between 2-6 times body mass.[31,34] Thus, representing a potentially dangerous activity for both possible injury and/ or joint overload. The eccentric nature can also result in high levels of muscle soreness, as such careful monitoring and implementation is needed.

Change of direction ability/coordination – 90º cut maneuver

Regaining symmetry in high load sporting tasks may be associated with lower re-injury risk.[6,7] Multidirectional movements and higher movement speeds place greater load on the knee, so it is important to gradually increase movement speeds[61] and complexity.[62,63] Knee abduction loads in side-step cutting are five times greater in handball elite players than the knee abduction loads in drop vertical jumps.[58] Beginning with simple movements and short angle changes is encouraged to limit the loading on the knee. Furthermore, learning the technique with a slow change of directions (e.g., two movements, with a slight pause in between movements) can allow safe introduction and training. Coaching the discrete movement (e.g., step-cut), training coordination and technique with a single or two steps into the movement (as such with lower approach speeds and body momentum to deceleration), prior to then gradually increasing the speed running speeds prior to cutting, once the optimal technique has been practiced and learnt is recommended. Optimal control in a 90º cut maneuver (Figure 2) is recommended before transitioning to sport-specific (reactive, contact, skills training) movement training.

Sport-specific movements – Movement control under sport specific change of direction

Training neuromuscular control in sport-specific movements and during skill-based training sessions helps the athlete prepare for safe participation in sports like soccer. To do this, a program of progressive sport-specific movements must be created, supporting transfer of movement patterns into sport-specific scenarios. This includes a gradual progression to more challenging tasks at higher speeds, to high speed reactive multi-directional tasks and then sport-specific tasks with more challenging visual-motor requirements (e.g., greater number of choices).[61,63] Reactive movements can challenge movement quality and increase knee loads more than planned movements.[62] Thus, delaying reactive movement training until the athlete has achieved safe movement quality in pre-planned tasks, and restoring and confirming safe movement quality in reactive movements prior to RTS, are crucial aspects of movement based re-training process. Injuries to the ACL typically occur in sporting activity, involving complex stimuli and an external focus of attention.[64] It is important to transition from the conscious controlled movements with limited external distraction and pre-planned nature to the highly chaotic and reactive nature of movement requirements in

Figure 3. *Perturbation training on the field to prepare an athlete for contact upon return to play. The athlete must aim to maintain optimal control and kinematics as well as ball contact with contact using swiss ball or another devise, such as player-to-player contact.*

sporting activity.[65] Evidence suggests that an external focus of attention with movement training results in superior retention of tasks.[66] Ecological dynamics states that skilled performance arises from performer-environment interaction. It is essential to appreciate the role and importance of perception/cognition in movement and ensure this process is trained in the movement specific drills. The program entails gradually exposing newly acquired movement patterns to sport-specific situations

Table 1. *Ten task progressions after ACL reconstruction, with the specific tasks, exercise group and the required strength and knee range of motion to allow unrestricted practice of the tasks. Strength is measured with isometric or isokinetic knee extension and leg press and/or squat strength testing. Squat strength reported is the force expressed as a percentage of body mass measured isometrically with force plate and isometric testing rig and not the additional load lifted during free weight squat.*

Task No	Task group	Exercise Name/ target movement	Required strength to allow unrestricted practice of task	Required knee range of motion
1	Walking	Walking with no limp unaided (e.g., without crutches)	Good quad recruitment	Full knee extension
2	Bilateral foundation movements	Bilateral squat to 90° with less than 20% asymmetry in limb loading	50% BM single limb leg press	Full knee extension/ flexion >90°
3	Unilateral foundation movements	Single leg squat to 90°	80% BM single limb leg press	> 120° flexion
4	Bilateral landing	Bilateral landing control from sub-maximal jump	100% BM single limb leg press and/or 150% BM double limb leg press/squat	> 130° flexion
5	Running	Treadmill running at 8 km.h^{-1}	125% BM single limb leg press/squat and/ or Isometric knee extension > 70% LSI	> 130° flexion
6	Bilateral plyometrics	30 cm bilateral drop jump	>80% LSI knee extension and 125% BM single limb leg press/squat or 200% BM single limb leg press/squat	Full
7	Unilateral jumping/ landing	Single leg deceleration from forward and lateral running	>80% LSI isokinetic knee extension and/or 150% BM single limb leg press/squat	Full
8	Unilateral plyometrics	Single leg drop jump	As above	Full
9	Pre-planned multi-directional movements	90° cut maneuver	As above	Full
10	Sport-specific movements	45° re-active change of direction	>90% LSI isokinetic knee extension and/or 200% BM single limb leg press/squat	Full

BM= body mass; LSI= Limb symmetry index

with increasing complexity, decision making (e.g., choices) and environmental stimuli to support the transfer and preparation for application of their motor skills in their sport-environment. In addition, incorporating perturbation/ contact training (Figure 3) is important to prepare for team sports such as soccer which involve player to player contact.

SUMMARY

Establishing clear task-based progressions can provide structure to a rehabilitation approach and give autonomy and motivation to a patient after ACLR. This clinical commentary presents 10 task-based progression which can be used by clinicians for their patients who intend to return to sporting activity after ACLR. Progression through a task and between tasks is based on respecting the joint, strength, movement quality and muscle soreness. Many aspects of function do not typically normalize within the first year after ACLR and stronger attention to achieving optimal and symmetrical movement quality is needed. The presented task-based framework is evidence informed and based on applying theory into practice.

REFERENCES

1. Ardern CL, Webster KE, Taylor NF, et al. Return to pre-injury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med.* 2011;39:538-43.
2. Webster KE, Santamaria LJ, McClelland JA, Fellar JA. Effect of fatigue on landing biomechanics after anterior cruciate ligament reconstruction surgery. *Med Sci Sports Exerc.* 2012;44(5):910-6.
3. Wiggins AJ, Granhi RK, Schneider DK, et al. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med.* 2016;44(7):1861-76.
4. Culvenor AG, Patterson BE, Guermazi A, et al. Accelerated return to sport after anterior cruciate ligament reconstruction and early knee osteoarthritis features at 1 year: an exploratory study. *PM R.* 2018;10(4):349-56.
5. Hewett T, Myer G, Ford K, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes a prospective study. *Am J Sports Med.* 2005;33: 492-501.
6. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med.* 2010;38(10):1968-78.
7. Paterno MV, Rauh MJ, Schmitt LC, Ford KR, Hewett TE. Incidence of second ACL injuries 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med.* 2014;42(7):1567-73.
8. Dhillon MS, Kamal B, Sharad P. Differences among mechanoreceptors in healthy anterior cruciate ligaments and their clinical importance. *Muscles Ligaments Tendons J.* 2012;2(1):38-43.
9. Decker MJ, Torry MR, Noonan TJ, Riviere A, Sterett WI. Landing adaptations after ACL reconstruction. *Med Sci Sports Exerc.* 2002;34(9):1408-13.
10. de Fontenay BP, Argaud S, Blache Y, Monteil K. Motion alterations after anterior cruciate ligament reconstruction: comparison of the injured and uninjured lower limbs during a single-legged jump. *J Athl Train.* 2014;49(3):311-6.
11. Goerger BM, Marshall SW, Beutler AI. Anterior cruciate ligament injury alters preinjury lower extremity biomechanics in the injured and uninjured leg: the JUMP-ACL study. *Br J Sports Med.* 2015;49:188-95.
12. Lee SP, Chow JW, Tillman MD. Persons with reconstructed ACL exhibit altered knee mechanics during high speed maneuvers. *Int J Sports Med.* 2014;35(6):528-33.
13. Paterno MV, Ford KR, Myer GD, Heyl R, Hewett TE. Limb asymmetries in landing and jumping 2 years following anterior cruciate ligament reconstruction. *Clin J Sports Med.* 2007;17(4):258-62.
14. Sterns KM, Pollard CD. Abnormal frontal plane knee mechanics during sidestep cutting in female soccer athletes after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med.* 2013;41(4):918-23.
15. Dingenen B, Gokeler A. Optimization of the return-to-sport paradigm after anterior cruciate ligament reconstruction: a critical step back to move forward. *Sports Med.* 2017;47:1487-1500.
16. Herrington L, Myer G, Horsley I. Task-based rehabilitation protocol for elite athletes following anterior cruciate ligament reconstruction: a clinical commentary. *Phys Ther Sport.* 2013;14(4):188-98.
17. Rambaud AJM, Ardern CL, Thoreux P, et al. Criteria for return to running after anterior cruciate ligament reconstruction: a scoping review. *Br J Sports Med.* 2018;52(22):1437-44.

18. Claes S, Verdonk P, Forsyth R, Bellemans, J. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *Am J Sports Med.* 2011;39:2476-83.

19. Woo S, Abramowitch S, Kilger R, Liang R. Biomechanics of knee ligaments: injury, healing and repair. *J Biomech.* 2006;39:1-20.

20. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing ACL injuries: Current biomechanical and epidemiologic considerations – Update 2010. *N Am J Sports Phys Ther.* 2010;5:234-51.

21. Glasgow P, Phillips N, Bleakley C. Optimal loading: key variables and mechanisms. *Br J Sports Med.* 2015;49:278-9.

22. Laughlin WA, Weinhandl JT, Kernozek TW, et al. The effects of single-leg landing technique on ACL loading. *J Biomech.* 2011;44(10):1845-51.

23. Chandrashekar N, Mansouri H, Slauterbeck J, Hashemi J. Sex-based differences in the tensile properties of the human anterior cruciate ligament. *J Biomech.* 2006;39(16):2943-50.

24. Mokhtarzadeh H, Ng A, Teow CH, et al. Restrained tibial rotation may prevent ACL injury during landing at different flexion angles. *Knee.* 2015;22(1):24-29.

25. Culvenor AG, Collins NJ, Vicenzino B, et al. Predictors and effects of patellofemoral pain following hamstring-tendon ACL reconstruction. *J Sci Med Sport*. 2016;19:518-23.

26. Culvenor AG, Øiestad BE, Holm I, et al. Anterior knee pain following anterior cruciate ligament reconstruction does not increase the risk of patellofemoral osteoarthritis at 15- and 20-year follow-ups. *Osteoarthritis Cartilage.* 2017;25:30-3.

27. Feller JA, Webster KE. A randomized comparison of patellar tendon and hamstring 300 tendon anterior cruciate ligament reconstruction. *Am J Sports Med.* 2003;31:564-73.

28. Myer G, Brent J, Ford K, Hewett T. A pilot study to determine the effect of trunk and hip focused neuromuscular training on hip and knee isokinetic strength *Br J Sports Med.* 2008;42:614-9.

29. Siff M. Biomechanical foundations of strength and power training. In Zatsiorsky V (Ed) *Biomechanics in Sports;* Blackwell Sci Ltd. 2001:103-39.

30. Palmieri-Smith RM, Lepley LK. Quadriceps strength asymmetry following ACL reconstruction alters knee joint biomechanics and functional performance at time of return to activity. *Am J Sports Med.* 2015;43:1662-9.

31. Cleather D, Goodwin J, Bull A. Hip and knee joint loading during vertical jumping and push jerking. *Clin Biomech.* 2013;28:98-103.

32. Cavanagh PR, Lafortune MA. Ground reaction forces in distance running. *J Biomech.* 1980;13:397-406.

33. Colado JC, Garcia-Masso X, Gonzalez L-M, et al. Two-leg squat jumps in water: an effective alternative to dry land jumps. *Int J Sports Med.* 2010;31:118-22.

34. Donoghue OA, Shimojo H, Takagi H. Impact forces of plyometric exercises performed on land and in water. *Sports Health.* 2011;3:303-9.

35. Nuzzo J, McBride J, Cormie P, McCauley G. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. *J Strength Cond Res.* 2008; 22(3): 669-707.

36. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci.* 2013;13(6):646-52.

37. Cleak MJ, Eston RG. Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. *Br J Sport Med.* 1992;26:267–71.

38. Connolly DAJ, Sayers SP, McHugh MP. Treatment and prevention of delayed onset muscle soreness. *J Strength Cond Res.* 2003;17:197–208.

39. Tee JC, Bosch AN, Lambert MI. Metabolic consequences of exercise-induced muscle damage. *Sports Med.* 2007;37:827–36.

40. Della Villa S, Boldrini L, Ricci M, et al. Clinical outcomes and return-to-sports participation of 50 soccer players after anterior cruciate ligament reconstruction through a sport-specific rehabilitation protocol. *Sports Health.* 2012;4:17-24.

41. Bush-Joseph C, Hurwitz D, Patel R, et al. Dynamic function after anterior cruciate ligament reconstruction with autologous patella tendon. *Am J Sports Med.* 2001;29:36-41.

42. Decker M, Torry M, Noonan T, Sterett W, Steadman J. Gait re-training after anterior cruciate ligament reconstruction. *Arch Phys Med Rehabil.* 2004;85: 848-56.

43. Kocher M, Steadman J, Briggs K, Sterett W, Hawkins R. Relationship between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2004;32:629-34.

44. Dye S, Staubli H, Biedert R, Vaupel G. The mosaic of pathophysiology causing patellofemoral pain: therapeutic implications. *Oper Tech Sports Med.* 1999;7:46-54.

45. Clark NC. The role of physiotherapy in rehabilitation of soft tissue injuries of the knee. *Orthop Trauma.* 2015;29:48–56.

46. Hopkins JT, Ingersoll CD, Edwards JE, et al. Cryotherapy and TENS decrease arthrogenic muscle inhibition of the vastus medialis following knee joint effusion. J *Athl Train*. 2002;37:25-32.

47. Lynch A, Logerstedt D, Axe M, Snyder-Mackler L. Quadriceps activation failure after anterior cruciate ligament rupture is not mediated by knee joint effusion. *J Orthop Sports Phys Ther*. 2012;42:502–10.

48. Potter H, Foo L, Magnetic reasonance imaging of joint arthroplasty. *Orthop Clin North Am.* 2006; 37:361-73.

49. Neitzel J, Kernozek T, Davies G. Loading response following anterior cruciate ligament reconstruction during the parallel squat exercise. *Clin Biomech*. 2002;17:551-4.

50. Agarwalla A, Puzzitiello RN, Liu JN, et al. Timeline for maximal subjective outcome improvement after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2019;47(10):2501-9.

51. Miller M, Berry C, Bullard S, Gilders R. Comparison of land-based and aquatic-based plyometric programmes during 8-week training period. *J Sport Rehabil.* 2002;11:268-83.

52. Potteiger JA, Lockwood RH, Haub MD, et al. Muscle power and fiber characteristics following 8 weeks of plyometric training. *J Strength Cond Res.* 1999;13: 275–9.

53. Fatouros IG, Jamurtas AZ, Aggelousis N, et al. Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J Strength Cond Res.* 2000;14:470–6.

54. Martel GF, HarmerML, Logan JM Parker CB. Aquatic plyometric training increases vertical jump in female volleyball players. *Med Sci Sport Exerc*. 2005;37:1814-9.

55. Robinson LE, Devor ST, Merrick MA, et al. The effects of land vs aquatic plyometrics on power, torque, velocity, and muscle soreness in women. *J Strength Cond Res.* 2004;18:84-91.

56. LaStayo PC, Woolf JM, Lewek MD, et al. Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. *J Orthop Sports Phys Ther*. 2003;33:557-71.

57. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492-501.

58. Kristianslund E, Krosshaug T. Comparison of drop jumps and sport-specific sidestep cutting: implications for anterior cruciate ligament injury risk screening. *Am J Sports Med*. 2013;41(3):684-8. doi: 10.1177/0363546512472043.

59. Norcross MF, Lewek MD, Padua DA, et al. Lower extremity energy absorption and biomechanics during landing, part I: sagittal-plane energy absorption analyses. *J Athl Train*. 2013;48(6):748-56. doi: 10.4085/1062-6050-48.4.09.

60. Myer G, Ford K, McLean SG, et al. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med*. 2006;34:445-55.

61. Vanrenterghem J, Venables E, Pataky T, Robinson MA. The effect of running speed on knee mechanical loading in females during side cutting. *J Biomech*. 2012; 45(14):2444-9.

62. Besier TF, Lloyd DG, Ackland TR, et al. Anticipatory effects on knee joint loading during running and cutting maneuvers. *Med Sci Sports Exerc.* 2001;33(7):1176–81.

63. Wolpert DM, Diedrichsen J, Flanagan JR. Principles of sensorimotor learning. *Nat Rev Neurosci.* 2011;12:739–51. doi: 10.1038/nrn3112.

64. Waldén M, Krosshaug T, Bjorneboe J, et al. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. *Br J Sports Med.* 2015;49:1452-60

65. Buckthorpe M, Della Villa F, Della Villa S, Roi GS. On-field rehabilitation – Part 2: A 5-stage program for the soccer player focused on: linear movements, multidirectional movements, soccer-specific skills, soccer-specific movements, and modified practice. *J Orthop Sports Phys Ther.* 2019; 49(8):570-5.

66. Gokeler A, Benjaminse A, Welling W, et al. The effects of attentional focus on jump performance and knee joint kinematics in patients after ACL reconstruction. *Phys Ther Sport.* 2015;16:114-120.