CRITERIA-BASED REHABILITATION AND RETURN TO SPORT TESTING AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Aspetar recently published open access clinical guidelines for rehabilitation after ACL reconstruction in the British Journal of Sports Medicine. As part of our commitment to dissemination of this information, we are reproducing portions of that article here, and Roula Kotsifaki and Rod Whiteley are expanding on the return to sport testing process.

INTRODUCTION

Anterior cruciate ligament (ACL) injuries have a relatively low incidence but a high injury burden in terms of days lost from sports participation[1]. Individuals who wish to return to sport are often recommended to undergo anterior cruciate ligament reconstruction (ACLR) to restore knee stability[2-4]. After ACLR, the typical goal for the athlete is to return to sport as quickly as possible, preferably performing at the same level as preinjury, yet protected from re-injury[5]. The criteria to determine return to sport in clinical practice most often rely on a strength and hop test battery to evaluate functional symmetry between limbs[6,7]. Despite the advances in ACLR surgical techniques and the use of these criteria to return to sport, graft failure and contralateral ACL injury risk are reported as high as 22%, especially in young athletes[8,9]. In addition, more than a third of the individuals after ACLR are unable to return to pre-injury levels of activity[10], justifying the high burden of an ACL injury and the need for further investigation on the return to sports journey/pathway.

EVIDENCE-BASED REHABILITATION

Rehabilitation is a key component of the recovery process after an ACLR. Around 80% of ACL-reconstructed patients return to some kind of sporting activities, but only 65% return to their preinjury level and 55% to competitive level sports[11]. Aside from graft failure[9], short-term (e.g., muscle injuries)[12,13] and long-term (e.g. knee-related quality of life, meniscal or chondral injuries and osteoarthritis)[14-17] comorbidities of ACLR may also be negatively associated with an individual's rehabilitation.

There is evidence that inadequate rehabilitation combined with a premature and non-objectively evaluated return to sports may limit sporting performance and predispose to subsequent injury[6,7]. There is substantial heterogeneity in the available ACL rehabilitation protocols in the scientific literature[18-20]. There are also a variety of available tools to the physiotherapist (e.g. exercises, modalities, progression criteria, etc.) but no consensus regarding the content of the rehabilitation programme after ACLR nor the effectiveness of these rehabilitation

Figure 1: Summary of the clinical practice guidelines on rehabilitation after ACLR.

interventions[18-21]. Importantly, there is no agreement on the objective progression criteria, or the discharge criteria before return to sport[21-25].

A recent systematic review summarised the recommendations and appraised the quality of the available clinical practice guidelines for rehabilitation after ACLR[21]. Also, recent published work provided an overview of systematic reviews on the effectiveness of rehabilitation interventions after ACLR[26]. However, previous clinical practice guidelines[21] and the recent systematic review[26] failed to provide clinically relevant information required for daily practice in these reviews including advice regarding, for example: exercise initiation, eccentric training, plyometrics training, cross education. Our recent guideline document translated the available evidence into clinical recommendations based on expert consensus to inform the treating clinician[71].

Exercise interventions should be considered the foundation of ACLR rehabilitation. Yet, there is little information on the dose-response relationship between volume and/or intensity of exercise and outcomes and what constitutes the optimal rehabilitation strategy. Early accelerated rehabilitation characterised by joint mobilisation and weight-bearing within 3 days after surgery should be the mainstream approach in isolated ACL surgeries. When concomitant injuries (i.e., meniscal, cartilage) are present the early rehabilitation phase should be adapted according to the surgeon's instructions. Physical therapy modalities can be beneficial as an adjunct in the early phase of rehabilitation when pain and other post-operative issues are present. However, the evidence for some modalities are conflicting, and the adverse effects, as well as the cost and time required probably outweigh any benefits.

As we noted in a recent review *"Aspetar clinical practice guideline on rehabilitation after anterior cruciate ligament reconstruction"* (Kotsifaki R, Korakakis V, King E, et al)[71]: *The term "neuromuscular training" is often reported in the literature to describe sub-components of balance, proprioception, agility, and plyometric training. However, since every type of training (except visualisation) involves nerve and muscle action, we prefer to use the term "motor control" to better distinguish from strength/resistance training. Strength and motor control training should be combined in the rehabilitation protocol, and one cannot replace the other.* A summary of the recommendations can be viewed in Figure 1.

CRITERION-BASED REHABILITATION PROGRESSION

While a minimum time post operatively is required to allow biological recovery of the graft, there has been a progressive shift towards a criterion-based approach[27]. In a recent consensus statement[5] biological, psychological, and social factors were all considered to influence rehabilitation outcomes and successful RTS. A criterion-based rehabilitation and RTS progression should be based on appropriate evaluation of impairments, activities, participation and contextual factors, and combined with a minimum 9-month time after ACLR[28]. However, optimal criteria to guide rehabilitation and RTS remain unclear. In clinical practice, most common criteria include a strength test battery and a hop test battery to test functional symmetry between limbs[27].

Progress from one phase to the other should occur when the patient meets specific clinical milestones. This criterion-based approach ensures that progression in rehabilitation does not surpass the functional and biological capacity of the knee. The move from time-based to criterion-based protocols also means that progress is not delayed unnecessarily[29].

One of the greatest challenges during the rehabilitation after ACLR is patient compliance. Athlete expectations should be discussed, and the long rehabilitation journey should be explained, ideally before surgery. Setting realistic goals and achieving well-defined milestones along the way will keep the athlete motivated to continue and complete the rehabilitation protocol[30,31]. Periodic assessments during rehabilitation can help achieve this goal.

RETURN TO SPORT CRITERIA

Time as criterion to RTS

Until the early 90s, time was the only criterion used to clear athletes to RTS[27]. Since 1990, time has represented approximately 50% of the total RTS criteria reported in published research[27]. Time is still an important parameter to account for the decision for RTS as the graft needs time to heal. After surgical reconstruction, ACL grafts undergo a sequential remodeling process termed ligamentisation[32]. There are different stages of the ligamentisation process, but no agreement exists on their time course. Histologic maturation of the ACL graft occurs between 6 months to 3 years after surgery[33].

However, still today there are contradictory results whether time is a factor that influences re-injuries. The American Academy of Orthopaedic Surgeons (AAOS) guidelines reported limited evidence for the appropriate time to return to sport after ACLR[34]. Grindem et al[6], proposed a minimum time of 9 months before clearing a patient to RTS in order to decrease re-injury rates. Some studies propose to delay return to sport till 2 years after surgery, especially in young and female athletes[35-37]. Webster et al[38], investigated the injury rates in young athletes who were advised to delay return to sport until 12 months after ACLR and compared them with those who returned to sport earlier than 12 months. Subsequent ACL injury rates were high, even for patients who delayed their return 12 months after surgery[38].

Current return to sport criteria

Performance-based tests of muscle strength and single-legged hop ability have traditionally been the cornerstone of functional return to sport criteria[2,27]. A symmetry of >90% in functional and strength outcomes is recommended for athletes as a cut-off point indicating safe RTS[28].

There is some evidence that indicates passing a battery of tests, including strength and hop tests, reduces the risk of re-injury[6,7]. However, recently the validity of these protocols has been questioned[39,40]. Three recent reviews examined the association between passing return-to-sport criteria and risk of second ACL injury: two meta-analyses[39,40] and one systematic review[41]. The meta-analysis of Webster and Hewett[40] concluded that current return-to-sport criteria do not appear to decrease the risk of subsequent ACL injury in athletes. Though passing return-to-sport criteria reduced the risk of subsequent graft rupture by 60%, it increased the risk of a contralateral ACL rupture by 235%[40]. However, imprecision of pooled estimates and substantial levels of heterogeneity where noticed which could be explained by the low number of studies meeting selection criteria and differences in source populations, ages, and competition levels[42]. Losciale et al[39], did not find a statistically significant association between passing RTS criteria with risk of a second ACL injury and Ashigbi et al[41], concluded that passing a combination of functional tests and self-reported function with predetermined cutoff points used as RTS criteria is associated with reduced reinjury rates.

Currently, it is not clear if passing a battery of tests is associated with lower risk of second ACL injury. Relatively rare events (such as ACL reinjury) are statistically difficult, if not impossible, to predict with absolute confidence. Despite this caveat, we maintain that our clinical goals should be to restore all impairments and return the athlete back to their previous status, if not better.

In our recent studies we investigated the in-depth biomechanical status of athletes after ACLR[43-46]. We evaluated if clearance to return to sport ensures restoration of normal lower limb biomechanics not only in terms of kinematics and kinetics, as usually performed in the literature, but also in terms of symmetry in lower limb contribution (in terms of joint work and

> ***Hop distance is a poor metric of knee function however, landing of a horizontal hop can offer valuable information on the status of the knee joint.***

contribution to overall lower limb work) and musculoskeletal loading (in terms of muscle forces contribution, and knee joint contact forces). Our results indicate that achieving symmetry in current discharge criteria does not ensure symmetry in many of the specific biomechanical metrics investigated.

Hop distance is a poor metric of knee function

Hop for distance tests are the most frequently used functional tests after ACLR mostly because of the ease of use, since only a measuring tape is required. Athletes at the time to return to sport after ACLR might be symmetrical in terms of hop distance, but still exhibit moderate to large differences in biomechanical knee function as measured by generated or absorbed knee work[45,46].

Indeed, the distance hopped is a poor measure of knee joint function, and largely reflects hip and ankle function. During a single leg hop for distance the knee joint contributes little (about 12%) to the propulsive phase. Consequently, with 88% of the distance hopped being determined by the hip and ankle joint, deficits at the knee joint are almost entirely missed when relating knee function from the distance hopped[46]. Therefore, distance hopped may not be the appropriate metric for testing knee function in an athlete after ACLR and its relevance is therefore questionable.

Similarly, symmetry in triple hop distance can hide asymmetries in biomechanical knee function in ACLR athletes. Athletes after ACLR presented intra-limb compensations and between-limb asymmetries, which were not reflected in the symmetry of the distance hopped[45]. Asymmetries in the triple hop for distance are more prominent during the generation than the absorption phase. Interestingly, between-limb differences are not more pronounced in the triple hop compared to the single leg hop for distance.

There is a controversy on the sensitivity of hop for distance tests to screen for restoration of symmetry in lower limb function at the time to return to sport. Hop for distance tests are still being used as criteria to return to sport after ACLR, not because passing this test means you're safe to return to sport, but mainly because passing a battery of tests is associated with a lower risk of re-injury, as reported in the literature[6,7]. However, previous studies found that only strength measures are associated with re-injury rates, not performance during the hop tests[6,7]. The observed asymmetries in joint contribution and musculoskeletal loading underlying symmetrical hop distance performance, therefore further undermines the predictive validity of this metric (hop distance), and calls for careful re-evaluation of its use (Figure 2).

Status of the knee joint can be evaluated during landing following a horizontal hop

As hop distance is easy to measure it is often retained in testing batteries despite "hiding" many biomechanical deficits. However, the single leg hop for distance is one of the best tests to challenge knee function during landing, highlighted by deficits in knee work with compensations at both hip and ankle. The landing phase of a horizontal hop task can offer valuable information on the status of the knee joint. During landing of a forward hop knee work contribution is 65%[46,47]. It is therefore a sensitive test to evaluate energy absorption efficiency of the knee and check for interlimb compensations. For that reason, it should be key part in the rehabilitation protocol and testing after a knee injury. However, it requires laboratory

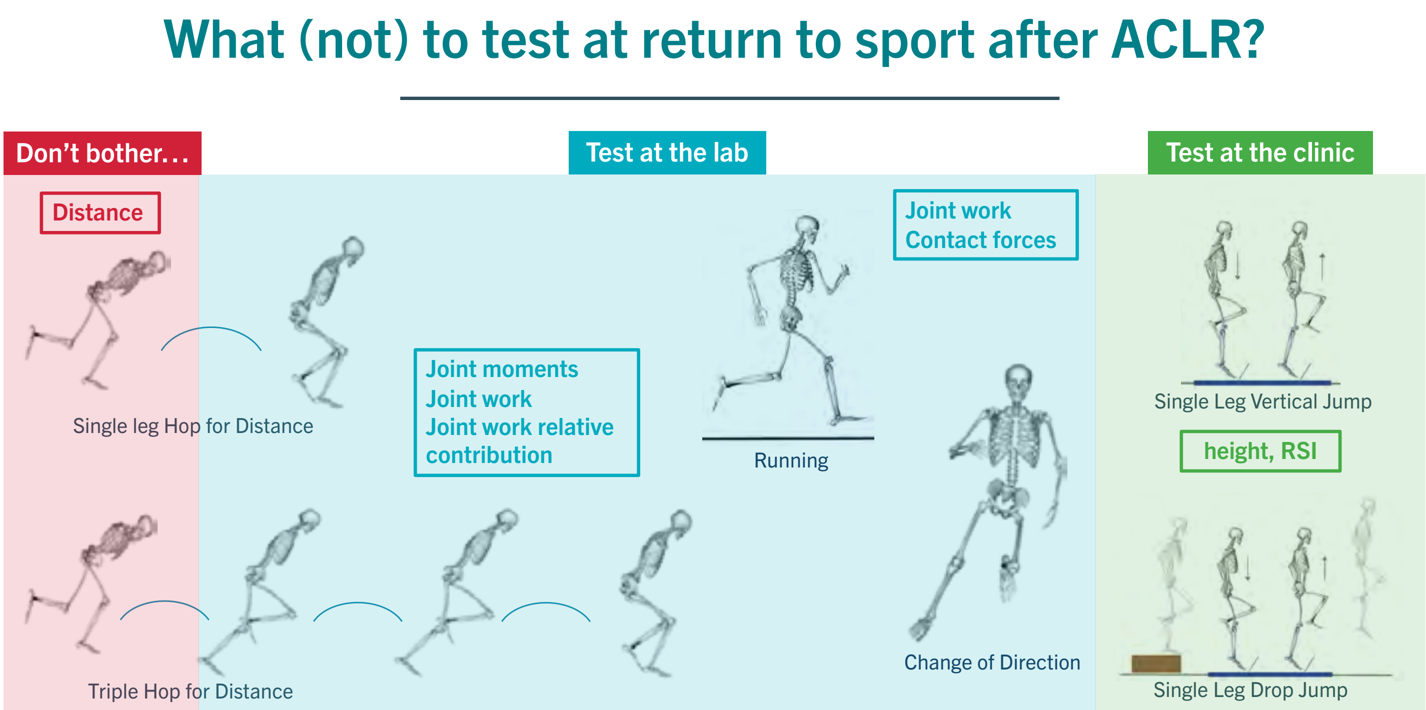

Figure 2: Visualisation of the tests and metrics to evaluate at the time to RTS after ACLR. Measuring distance doesn't give any additional information at the time to RTS. However, landing of a horizontal hop is important and should be included in the battery of tests. Examine metrics like knee moments, joint work or work contribution to look for interlimb compensations. At the lab, we also need to measure running and change of direction. If there is no access to a biomechanical lab, better use vertical tests. Use reactive tests like the single leg drop jump and metrics like the reactive strength index to assess explosiveness and reactivity.

Illustration

equipment allowing 3D biomechanical analysis. Consequently, future research should focus on identifying proxy variables of these loading characteristics, perhaps from using wearable technology or other approaches, which would allow monitoring these parameters in a clinical setting.

Cutting and running should be included in test batteries that evaluate readiness to return to sport

Our recent study in athletes after ACLR using musculoskeletal modelling to estimate ACL and tibiofemoral contact forces concluded that restoring performance symmetry in RTS criteria was not associated with symmetry in ACL or knee joint loading patterns[43]. These differences were most pronounced for the higher loading tasks like cutting and running. Running and change of direction are the main dynamic maneuvers of elite male soccer players[48,49] as well as in other multi-directional team sports, like basketball, handball and volleyball, which are also characterized by a high frequency of lateral movements and jumps[49]. Given that asymmetric ACL loading was only apparent during cutting and running, it seems important to include and biomechanically evaluate sport-specific activities, such as running and cutting in return to sport testing procedures. Cutting was the most sensitive task to reveal asymmetries after ACLR and should be included in the testing battery at the time of RTS. Currently, discharge criteria are based on performance (eg, height, distance) during functional tests; however, these are unable to detect tibiofemoral loading asymmetries. The restoration of symmetrical joint loading might protect against a second ACL injury or future knee degeneration changes. Further work is needed to evaluate the longitudinal changes in loading symmetry, not only during gait but also during sport-specific dynamic tasks, and their relationships with early postoperative cartilage changes in patients undergoing ACLR. Because monitoring knee loading requires advanced biomechanical equipment and skills, it is important to find proxies to measure knee loading in a clinical setting (Figure 2).

Jump height is a better indicator of knee function than distance hopped

Cutting and running are important tasks to test at return to sport, but there are no easily-measured outcomes to show the impairments or the differences between limbs[43,50]. Unfortunately, most clinicians do not have access to a biomechanical lab or the expertise to analyze these kind of data.

In a clinical setting, jump height is a more sensitive metric than hop distance to evaluate an athlete's status during rehabilitation and at the time to return to sport after ACLR. Vertical performance metrics like jump height and reactive strength index can better identify interlimb asymmetries than horizontal jumps. Athletes at the time to RTS had 97% symmetry in hop distance but only 83% and 77% symmetry in jump height during a single leg countermovement jump and a single leg drop jump, respectively[51]. These findings are explained in part by the different demands on knee function between horizontal and vertical jumps. In healthy individuals, the relative knee work contribution in the concentric phase was three times greater during the vertical hop than during the horizontal hop[47]. The greater knee work contribution during vertical hops likely explains why performance deficits are more readily apparent than during horizontal hops in those with knee impairments.

During both vertical and horizontal jump tests, biomechanical differences in knee work were more pronounced during the concentric than the eccentric phase. These differences were not captured by the horizontal performance metric (hop distance) but were captured by the vertical performance metrics (jump height). Interestingly, despite athletes after ACLR, presenting symmetry in strength >90% (tested in concentric mode), symmetry for other outcome measures (e.g., joint moment, power or contact forces) during functional activities was far less.

Rehabilitation should therefore include not only concentric training, but more dynamic (e.g.: jump, hop, eccentric, stretchshortening) components. From a testing perspective, in a clinical setting or in the field, without access to advanced equipment we would recommend the use the vertical jump height symmetry as a discharge criterion instead of the currently used hop for distance symmetry to better evaluate the knee status of an athlete. Additionally, to assess additional aspects of physical and performance underlying readiness to return to sport like explosiveness and reactivity, we would recommend the use of reactive tests like the single leg drop jump and metrics like the reactive symmetry index. Recent technological developments can provide valid and reliable methods to measure vertical jump performance, such as low-cost force plates, contact mats, photoelectric cells, or even mobile applications[52-57].

Drop jumps place a greater demand on the ankle and less on the hip than countermovement or horizontal jumps yet are still very demanding on the knee joint[46]. Single leg drop jump height is frequently the last jump performance measure to recover post ACLR with an asymmetry of 20-30% for both jump height and reactive strength index at 9 months after surgery despite > 90% symmetry in single leg hop[50,58]. Again deficits in knee work are highly prevalent and greatly influence performance. Not only has ongoing biomechanical asymmetry been reported at 9 months post ACLR[58], but those asymmetries are greater than in healthy athletes[50]. In addition, both single and double leg drop jump performance and biomechanics have been shown to be diminished in athletes who go on to injure their contralateral previously healthy ACL after return to play highlighting the importance of including drop jump testing post ACLR[59].

IS RESTORED SYMMETRY THE HOLY GRAIL OF REHABILITATION AND DOES ASYMMETRY IMPLY RISK OF CHRONIC MUSCULOSKELETAL INJURY?

Limb symmetry index (LSI) is typically used to monitor and control the internal (between-limbs) loading symmetry during rehabilitation. Recently, the use of LSI for evaluating outcomes has been questioned, mainly because the uninvolved healthy limb, which is used as a reference, is also deteriorating during the long rehabilitation period after ACLR[60,61].

However, this might not always be true if strengthening the uninvolved leg is part of the rehabilitation protocol. Monitoring the progress of both legs throughout rehabilitation allows clinicians not only to address a potential poor progression post-ACLR, but also to control the excessive development of the uninvolved limb strength that could become a ‘moving target’ impossible to attain. Given that healthy athletes, are mostly symmetric in strength, functional, and biomechanical outcomes[46,62], we suggest that restoring symmetry should be part of the goals of the rehabilitation after ACLR.

Nevertheless, it is important to note that symmetry in functional outcomes that are commonly used to clear an athlete to return to sport does not mean the athletes will have symmetry in tibiofemoral joint contact forces during dynamic tasks[43]. These asymmetries may however predispose athletes for subsequent injury. So far, it is unknown if and how long the observed loading asymmetries during dynamic tasks persist after they RTS. This finding of asymmetry is highly relevant as it is unknown if these asymmetries can be related to future injuries or more chronic pathological knee conditions like meniscus or chondral damage, or early OA. How OA is initiated and what factors trigger the disease process remain unclear, although the mechanical environment is accepted to be an important contributor[63]. Lower knee loading has been linked to risk of a second ACL injury[64], knee joint cartilage degeneration[65], and the development of tibiofemoral OA within 5 years after ACLR[66]. On the other hand, researchers have also associated overloading of the articular tissues with cartilage damage[67] and consequently with OA development[68,69]. Whereas moderate mechanical loading is crucial for maintaining healthy cartilage, abnormal joint loading (either insufficient loading or adversely high-intensity joint loading) probably increases the risk of OA[70]. As discussed below, future work is however needed to further elucidate the causal relationship between the observed loading asymmetries and incidence of chronic musculoskeletal degenerative disorders following ACLR.

CONCLUSION

Inadequate rehabilitation combined with a premature and non-objectively evaluated return to sports may limit sporting performance and predispose to subsequent injury. Exercise interventions should be considered the mainstay of ACLR rehabilitation. Physical therapy modalities can be helpful as an adjunct in the early phase of rehabilitation and may allow earlier pain-free commencement of exercise rehabilitation. Progress from one phase to the next should only occur when the patient meets specific clinical milestones. This criterion-based approach ensures that progression in rehabilitation does not surpass the functional and biological capacity of the knee. Setting realistic goals and achieving well-defined measurable milestones along the way will keep the athlete motivated to continue and complete the rehabilitation protocol. Biomechanical metrics are not restored at the time to return to sport after ACLR, despite passing current discharge criteria. Hop distance, currently used as discharge criterion after ACLR, is a poor metric of knee function however, assessing landing of a horizontal hop can offer valuable information on the status of the knee joint. Cutting and running should be included in the battery of tests to evaluate readiness of an athlete to return to sport. In the clinic, where no advanced technology is available, jump height is a better indicator of knee function than distance hopped. Lower limb symmetry should not be the only outcome used to monitor patient’s progression during rehabilitation after ACLR however, residual loading asymmetries at the time to return to sport might predispose to future injuries.

References
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