THE WHY, WHAT AND WHEN OF OBJECTIVE TESTING AFTER ACL RECONSTRUCTION

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WHY ARE WE TESTING?

The purpose of testing after ACL reconstruction is often questioned—is it to predict new injuries or assess an athlete's readiness to return to the game? Although certain sports medicine tests are associated with an increased risk of injury, accurately predicting injuries remains challenging[1]. Furthermore, conflicting findings exist in the literature regarding the effectiveness of passing a battery of tests in reducing the rates of new anterior cruciate ligament (ACL) injuries[2-5].

There are many ways to evaluate ACL surgery and rehabilitation outcomes. Much of the research has focused on the predictive validity of functional tests to predict a secondary ACL injury of the ipsilateral or the contralateral knee. Different stakeholders such as athletes, coaches, and clinicians, define success differently, ranging from a swift return to sport, regaining pre-injury performance, or preventing further associated injuries[6].

Second ACL injury affects 10 to 20%[7-9]. However, these results include all ACL injuries, contact and non-contact. One wonders if a direct kick to the knee resulting in a second ACL injury can be predicted by any discharge criteria or determine the success of surgery and rehabilitation? Presumably not. Consequently, the number of ACL new injuries that we might be able to prevent is much less.

Secondary prevention

Less than half of our ACL injured athletes are competing at the same level 3 years after their injury has been "fixed". What is stopping the rest? We've been overlooking a myriad of other injuries that about half of the athletes after ACL reconstruction (ACLR) suffer on attempting to return to sport. Subsequent injuries do not include only ACL injuries. Literature reports short-term (muscle injuries)[10,11] and long-term (meniscal or chondral injuries and osteoarthritis (OA))[12-14] consequences of ACL injury and reconstruction that require our attention. By focusing solely on the rates of second ACL injuries, we might overlook the real problems: other injuries preventing our athletes from resuming their sports activities.

Monitor progress during rehabilitation

When athletes are preparing to return to sport after an ACLR, it is essential to address any remaining deficiencies in their physical and psychological condition. These deficiencies can manifest in different areas such as strength, range of motion, joint laxity, performance, functional ability

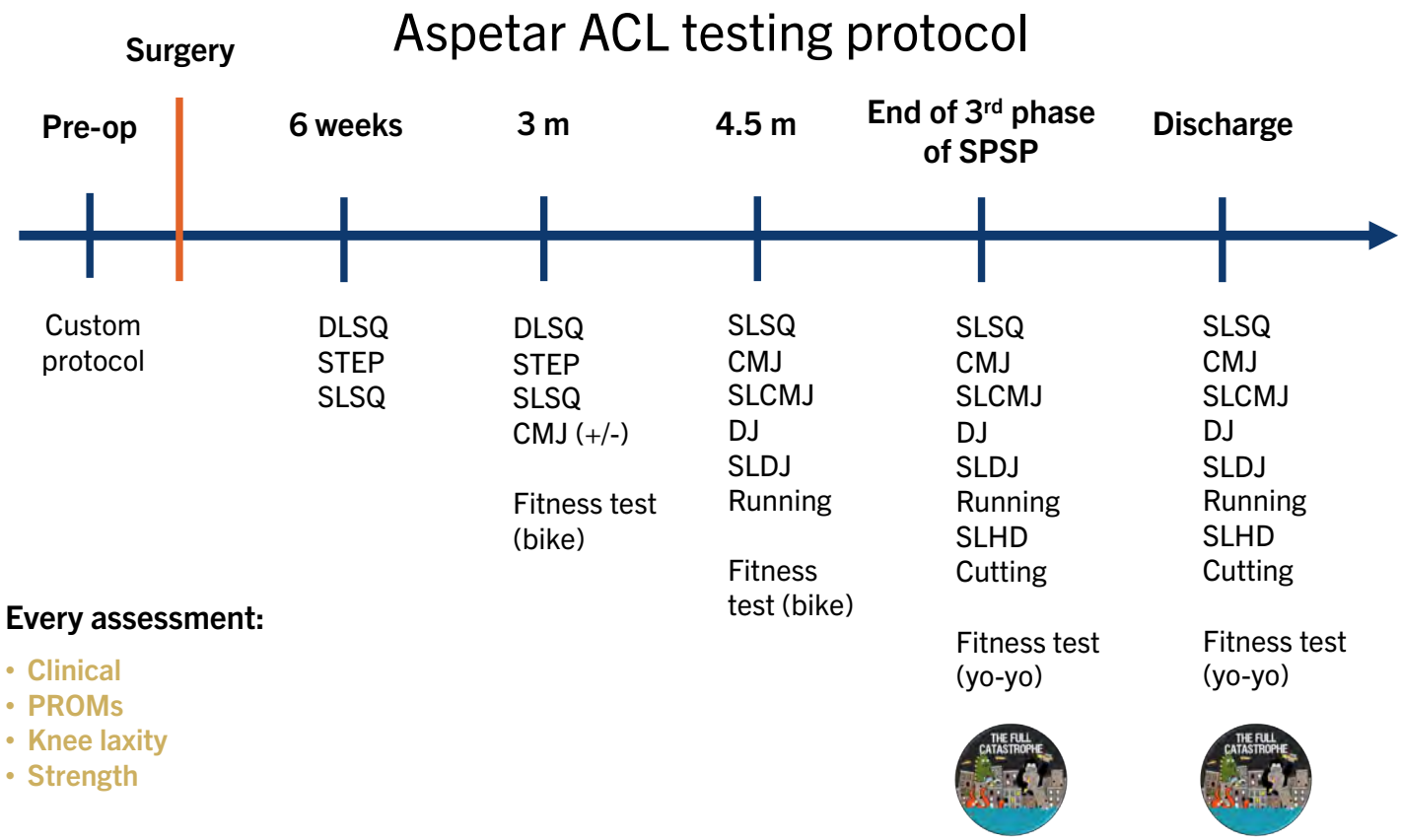

Figure 1: Summary of Aspetar ACLR testing battery. SPSP, sport-specific training; PROM, patient-reported outcome measures; DLSQ, double leg squat; SLSQ, single leg squat; STEP, step down; CMJ, countermovement jump; DJ, 2 leg drop jump; SLCMJ, single leg countermovement jump; SLDJ, single leg drop jump; SLHD, single leg hop for distance; CoD, change of direction.

and capacity, as well as psychological readiness. To accurately identify these areas of improvement, it is crucial to use tests and metrics with sufficient sensitivity. By continuously monitoring the progression of these metrics during the rehabilitation process, athletes can track their improvement and ensure a comprehensive recovery that addresses all aspects affected by the ACLR.

Performance

And if they eventually return, will they be the same? According to UEFA studies, although 87% of professional football players are still playing three years after an injury, only 65% of them have regained their pre-injury performance levels[15]. This disparity highlights the extent of the problem. If achieving a successful return to performance is the ultimate goal of surgery and rehabilitation, it appears that our current methods are falling short. Is there room for improvement in these return to performance rates? Unfortunately, the existing criteria mentioned in the literature offer limited assistance. Only a small proportion of studies have reported performance metrics at the time of return to sport[16]. Objective performance metrics at the time of return to sport are essential to enhance secondary prevention and accurately evaluate an athlete's readiness to perform at their full potential.

WHAT ARE WE TESTING?

Based on our extensive clinical experience and the deficits observed in athletes during their return to sport (RTS), we have developed a comprehensive testing battery. This battery, summarized in Figure 1, is designed to assess various aspects for a successful return to sport.

TESTING COMPONENTS

Clinical Assessment

All tests are initially conducted on the unaffected side and then compared to the affected side for assessment. Clinical testing is carried out at all stages of evaluation.

Range of motion measurements involve the use of a universal goniometer[17] to assess knee flexion, and an inclinometer is utilized to measure knee extension while the patient is in a supine position with their heels resting on a 10cm box. An unpublished reliability study has demonstrated that the inclinometer provides the most accurate results, and an excellent alternative is the use of a mobile application. To ensure accuracy, we avoid using the prone position and measuring the heel height difference due to the potential impact of quadriceps muscle mass atrophy on actual knee extension measurement post-surgery.

When assessing swelling, measuring knee girth at mid-patella may not be the most reliable option, considering possible bone deformities after surgery. Instead, we use the stroke test (or swipe test) as it offers greater accuracy in determining the actual level of swelling.

Stability assessments encompass the Lachman Test, Pivot Shift, subjective stability rated on a 0 to 10 scale, and instrumented knee laxity measurement.

Patient-reported outcome measures

Patient-reported outcome measures (PROMs) include evaluating pain levels using the Visual Analog Scale (VAS) during

> ***We should monitor our patients throughout rehabilitation and at the time to return to sport with whatever equipment and techonolgy we have availabel in our practice. What truly matters is to use the right tests, follow the right metrics and know why we measure them.***

rest and activity, as well as identifying the location of the pain. Subjective knee function is assessed using the International Knee Documentation Subjective Knee (IKDC) questionnaire[18], and psychological readiness to return to sport is measured using the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale[19] and the Tampa scale of kinesiophobia[20].

Strength

To evaluate the hip abductors and adductors, we assess them in a supine position with the knee extended (creating a long lever arm) using a break test (eccentric). For the assessment of hip external rotators, we employ an isometric test while the patient is seated[21].

Following ACLR both hip abductors and adductors tend to exhibit weakness, but their symmetry is typically restored within four months. However, it is worth noting that adductor muscles are generally weaker, more sensitive, and may take slightly longer to regain symmetry. Additionally we measure soleus isometric strength using force plates with a custom rig that has the patient seated, thigh horizontal, and ankle in dorsiflexion.

Quadriceps and hamstring strength are assessed using an isokinetic dynamometer. At six weeks post-surgery, strength testing is done isometrically at 60° of knee flexion for the quadriceps and 30° for the hamstrings. From three months post surgery, provided the patient has practiced and is prepared for this type of assessment, we transition to isokinetic testing. Our protocol includes 2 sets of 5 repetitions at 60°/s using a concentric mode. Professional athletes are subjected to additional testing for hamstring strength after 4.5 months, consisting of 1 set of 5 repetitions at 60°/s in an eccentric mode. We are comparing the peak torque between limbs but also aiming to restore the pre-surgical values, if available and also reach to the normative values for each sport. Range specific deficits are evaluated throughout rehabilitation especially inner range hamstring strength.

In the case of the quadriceps and hamstrings, the choice of graft can significantly impact the rehabilitation process. Athletes who receive a bone-patellar tendon-bone (BTB) or quadriceps tendon graft may experience a delay in restoring quadriceps strength compared to those with other graft choices. When athletes receive a hamstring graft, the restoration of hamstring strength can present particular challenges. Clinical experience has shown that achieving full hamstring strength restoration may be more difficult compared to other muscle groups, and there may be a "ceiling effect," limiting further improvements beyond a certain point. Considering the variations in graft choice and the potential challenges associated with certain graft types, personalized and targeted rehabilitation programs become even more critical.

Motor control

The movement assessment at 6 weeks includes double leg squats, step-up/down, and a single leg squat test. These activities are repeated at the three-month post-op mark to evaluate patients' progress.

At 3 months post-op some professional athletes may be capable of performing their first double leg counter-movement jump and drop jump test. However, the decision to proceed with these activities depends on their comfort level, readiness and current content of rehabilitation program. The results obtained from these early assessments serve as a baseline for evaluating progress in subsequent evaluations. Athletes in this phase typically exhibit reluctance to perform at maximum effort, display reduced speed in the countermovement, and attempt to avoid landing on the involved leg.

By the 4.5-month mark athletes should be able to perform double and single leg countermovement and drop jump tests. Additionally, they can undergo their first running test on the treadmill, at 16km/h for 10s. The use of an instrumental treadmill that can measure ground reaction forces (GRFs) provides valuable data for assessment. However, in the absence of such equipment, video analysis of running is also valuable.

Why all the fuss with vertical jumps?

Hop distance may not be the most effective measure of an athlete's knee status[22,23] and is no longer part of our discharge criteria.

In contrast to the horizontal hop test, the vertical jump test provides a more comprehensive evaluation of an athlete's biomechanical restoration. These tests measure the athlete's jump height and reactive strength index (RSI), which are more sensitive performance metrics in capturing underlying differences in biomechanics[24]. During a vertical jump, the contribution of the hip, knee, and ankle joints is almost equal both in propulsion and

landing[25]. Consequently, any deficiencies or compensations in these joints will be more apparent during the vertical jump, making it a valuable test for assessing an athlete's readiness to return to sport.

Drop jumps place a greater demand on the ankle and less on the hip than countermovement or horizontal jumps but they are still very demanding on the knee joint[26]. Single leg drop jump asymmetries in height and reactive strength index are likely to be the last jump performance metrics to recover post ACLR with an asymmetry in 20-30% for jump height and reactive strength index at 9 months after surgery[27,28] and at the time to return to sport[29]. 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[30]. We aim to restore vertical jumps metrics which can serve as a valuable indicator of an athlete's overall lower limb strength, power, and functional ability. Once we do that, we are almost 95% in our rehabilitation progress.

The advantage of vertical jumps is that we can monitor progression without the need for advanced equipment. Calculating knee work is typically not possible in clinical situations where biomechanical analyses are not available, however estimating jump height, contact time, and reactive strength index is more feasible for clinicians (contact mats, phone-based apps, photoelectronic cells, etc.).

Horizontal hop landing

Assessing the horizontal hop landing phase can provide valuable information on the status of the knee joint. During landing of a forward hop the knee contributes up to 65% of the work[25,26] making it a highly sensitive test for evaluating the knee's energy absorption efficiency and detecting any interlimb compensations. Athletes with BTB or quadriceps tendon graft face particular challenges to adequately absorb energy at their knee during landing of a horizontal hop. For that reason, it should be a key part in the rehabilitation protocol and testing after a knee injury.

Change of direction mechanics

While restoring vertical and horizontal jump mechanics is crucial, it is not sufficient to clear an athlete for a return to sport after ACLR. For athletes involved in pivoting sports, it is important to also restore mechanics during change of direction tasks. Even at 9 months post-ACLR, there are still differences in sagittal and frontal plane biomechanics during change of direction tasks, despite no statistical differences in performance time[28,31]. Targeting these variables during ACL rehabilitation may help reduce the risk of reinjury[32]. Furthermore, at the time to return to sport there are still differences in symmetry in ACL forces and tibiofemoral joint contact forces, particularly during higher loading tasks like cutting and sprinting[33]. Our protocol includes testing planned and unplanned change of direction of 90°.

While these tasks can provide valuable information on the knee joint's status, they require 3D biomechanical analysis, which may not be available in all clinical settings. However, these tests and metrics are important for professional athletes to ensure that their knee joint's status is fully restored before clearance to return to unrestricted training. At a minimum, we would recommend analysing movement from a 2D perspective, which may be easily and cost-effectively performed with hand-held devices/tablets.

Biomechanical analysis

During the Sports-Specific (SPSP) phase, and typically at a midpoint within this phase, we conduct the first marker-based motion analysis capture. This assessment takes

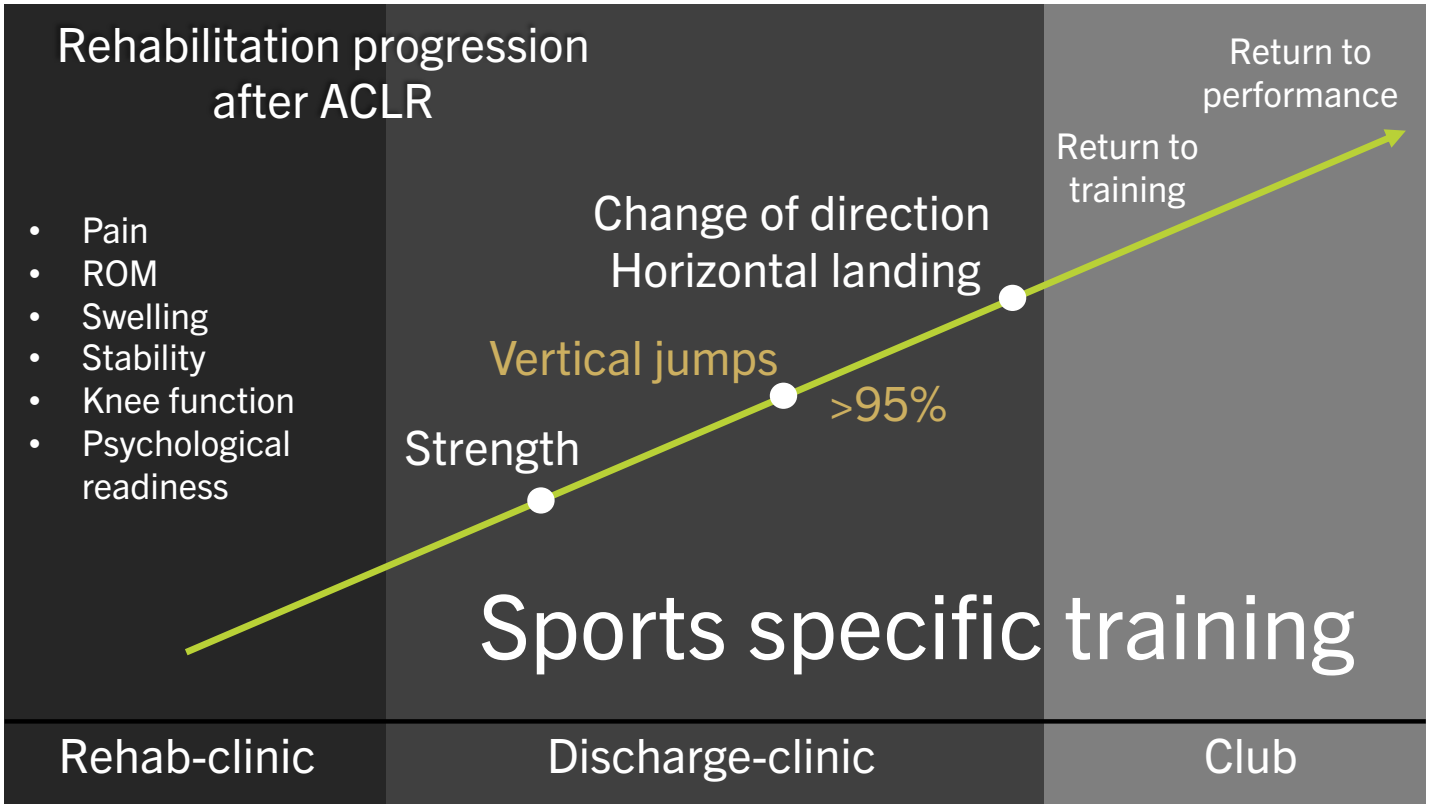

Figure 2: Overview of the components of rehabilitation that we need to restore before clearing an athlete to resume training with their club.

place after the athlete has been introduced to acceleration, deceleration, and change of direction drills. The purpose of this analysis is to gain detailed biomechanical insights into the athlete's movement patterns and performance.

The tasks performed during the motion analysis capture include vertical jumps, a hop for distance, change of direction drills, running, and a cardiovascular endurance test (yoyo test). These tasks cover a range of movements relevant to the athlete's sport and provide valuable data for evaluation.

The biomechanical report generated from the motion analysis includes information in all three planes of motion. It examines joint angles, joint torques, and joint powers, providing a comprehensive understanding of the athlete's movement mechanics. Additionally, relative joint contributions and key performance metrics are analysed to assess specific areas of focus.

The clinician utilizes the findings from the biomechanical report to make informed decisions and adjustments to the rehabilitation plan. This individualized approach ensures that the rehabilitation plan addresses the unique needs of each athlete, taking into account their biomechanical characteristics and performance indicators.

DISCHARGE CRITERIA

Completion of the rehabilitation protocol and clearance to return to sport is not the same as return to competition. We propose minimum criteria required for a professional athlete to be cleared from the clinic/hospital setting and start training with their club, whereupon they should then gradually return to full participation (Figure 2). These criteria should be adjusted and individualised according to their previous activity level. Our proposed discharge criteria are based on our clinical experience, research findings and our normative data[34,35].

It's important to acknowledge that the decision to return to training is not always straightforward and may be influenced by various factors outside the realm of pure medical considerations. By embracing informed and shared decision-making, athletes can navigate these complex choices, ensuring their well-being, while also considering the demands and pressures of the competitive environment they operate in.

IS SYMMETRY IMPORTANT?

The goal of rehabilitation is to return the athlete back to normal. It is difficult to define normal, as this is different for each patient.

Loading asymmetries may predispose athletes for subsequent injury. So far, it is unknown if and how long the observed loading asymmetries during rehabilitation and at the time to return to sport persist after they return to sport. This 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 failure signs, or early OA. Whereas moderate mechanical loading is crucial for maintaining healthy cartilage, abnormal joint loading (either insufficient loading or high-intensity joint loading) increases the risk of OA[36]. Our goal during the rehabilitation is to restore those asymmetries.

Clinicians should use asymmetry metrics on an individual level and by comparing to the noise of each test and each metric[37]. Normally, the clinician does not have preoperative test values to set the end goals for each patient[38]. Achieving symmetry is an important goal during rehabilitation, but equally important is to return the athlete to their previous level of performance. We suggest that the uninvolved limb should be monitored during rehabilitation, and both limbs should reach matched-control normative values in the absence of pre-operative data.

TESTING TIPS

While manual muscle testing is commonly used, it is not the optimal option for precise and accurate measurements. Hand-held dynamometer is a must-have tool in every physical therapy clinic. Furthermore, for ACL and other lower and upper limb injuries, the use of force plates becomes necessary to gather more comprehensive data.

We are currently witnessing a shift in the way we approach testing and data collection, with the increasing accessibility of portable labs such as smartphones. This advancement in technology allows us to gather and analyse data with ease, reducing the need for specialized biomechanists or engineers. It presents us with an opportunity to expand our testing capabilities beyond basic measurements like girth and range of motion. As healthcare professionals, it is crucial for us to embrace this new era and leverage these opportunities to benefit our athletes.

To ensure effective testing, it is important to establish a regular testing schedule, such as every six weeks or two months. It is vital not to skip testing days, even if there are limitations due to insurance or other reasons. Testing should be integrated into the rehabilitation session, as it not only benefits the patient but also provides the clinician with a roadmap for guiding the rehabilitation process.

Standardization is key in testing. It is advisable to standardize the tests themselves, the tester performing the assessments, and the order in which the tests are conducted. Testing requires practice to minimize variability. Therefore, it is important to test only the tasks that the patient has trained before, as testing unfamiliar tasks may yield inaccurate results. It is also beneficial to create a database of normative data. If working within a club, aim to establish a normative database specific to your athletes, including measures of strength, jump metrics, and other performance indicators. If pre-injury data is not available, consider referencing normative data from the literature. However, keep in mind that each athlete is unique, and certain metrics can vary significantly depending on factors such as sex, sport, position, age, and more.

KEEP CALM AND KEEP ON TESTING!

Objective testing plays a vital role in the rehabilitation process after an ACLR. By providing measurable data it becomes a valuable tool in tracking treatment progress, ultimately leading to improved patient outcomes. The objective nature of such testing eliminates subjectivity and bias, ensuring reliable and consistent evaluations. It enables us to assess athletes' performance, identify strengths and weaknesses, and design targeted training programs. At the time to return to sport, objective testing is a cornerstone of evidence-based decision-making.

Objective testing is and should be dynamic. With new research and results continually emerging, tests and metrics must adapt to stay up-to-date and relevant. By embracing the ever-evolving nature of objective testing, we can ensure that it continues to be a powerful and effective tool in guiding rehabilitation and athletic performance enhancement.

References
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