



Clinical course and recommendations for patients after anterior cruciate ligament injury and subsequent reconstruction: a narrative review

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- Almost all athletes who have suffered an anterior cruciate ligament (ACL) injury expect a full return to sports at the same pre-injury level after ACL reconstruction (ACLR). Detailed patient information on the reasonable outcomes of the surgery may be essential to improve patient satisfaction.
- Pre-operative rehabilitation before ACLR should be considered as an addition to the standard of care to maximise functional outcomes after ACLR.
- We propose an optimised criterion-based rehabilitation programme within a biopsychosocial framework.
- No benchmark exists for evaluating return-to-sport (RTS) readiness after ACLR. Therefore, the authors propose a multi-factorial RTS test battery. A combination of both physical and psychological elements should be included in the RTS test battery.
- There is need for shared decision-making regarding RTS.

Keywords: anterior cruciate ligament injury; pre-operative rehabilitation; post-operative care; post-operative rehabilitation; psychological factors; return to sports; evaluation tools; time of return to sports

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Introduction

Athletes who wish to resume high-level activities after an injury to the anterior cruciate ligament (ACL) are often advised to undergo surgical reconstruction.^{1,2} Patients' general expectations after ACL reconstruction (ACLR) are high, with 94% expecting a return to sports (RTS) to the same level as before the injury.³ In addition, 98% of

patients expected no, or only a slight increased, risk of developing osteoarthritis (OA) either after primary ACLR or revision surgery.³ These expectations are in sharp contrast to the findings of a recent systematic review and meta-analysis, indicating that only 65% of athletes after ACLR returned to the pre-injury level of sport and 55% returned to a competitive sports level.⁴ Another area of great concern is the incidence of OA with degenerative changes reported as early as two years after the initial ACL injury.⁵ Moreover, second ACL injuries (re-tearing either the ACL graft or the contralateral ACL) have gained more attention, given the reported rates of 15%.⁶ For young athletes (< 25 years) returning to competitive sports involving jumping and cutting activities, second ACL injury rates of 23% have been reported, especially in the early RTS period.⁶

The demanding patient expectations and risk of developing OA and/or second injury after ACLR highlight the importance of detailed patient information pre-operatively about what a reasonable outcome could be. If the athlete has the goal to RTS, all stakeholders involved (e.g. surgeon, physical therapist, coach, patient, etc.) in the RTS decision-making process should prioritise a safe RTS, i.e. a RTS with minimal risk of sustaining a re-injury and/or developing long-term complications such as OA.⁷ Unfortunately, there is a paucity in the literature on the RTS criteria used to release a patient to unrestricted sport activity after ACLR.⁸ Hence, there is a need to improve our current practice in the treatment of patients who have sustained an ACL injury. We have much more to learn about the ACL-injured patient and the individual differences between patient injury patterns, treatment variation with respect to technique (single bundle/double bundle, graft selection), rehabilitation after ACLR and RTS decision-making. To make positive changes in our treatment algorithm for

each of these variables, we need better intervention methods and outcome measurement tools to help us understand how to improve on our overall results.

The importance of establishing registries on a national basis has been advocated by Scandinavian authors to analyse the outcome after ACLR.^{9,10} In many European countries, such registries are not available. Following these recommendations, clinical pathways may be established in individual hospitals or clinics to monitor patients after ACL injury, adapt the care to their individual needs and enhance successful RTS.¹¹ The work presented in this narrative review is the result of an international collaboration between orthopaedic surgeons, sport and human movement scientists as well as physical therapists with the objective of enhancing quality of life for patients after ACL injury and surgery, to reduce ACL re-injury rates and eventually to decrease the incidence of OA. The purpose of this manuscript is to present a narrative review of the current literature focusing on the clinical course of athletes after isolated ACLR. Important clinical milestones based on the framework of an evidence-based rehabilitation programme are presented. We advocate the use of a combined time- and criteria-based approach. For the decision-making of the RTS process, a novel multi-factorial test battery including shared decision will be presented.

Pre-operative rehabilitation

Rehabilitation before surgery, termed ‘pre-operative rehabilitation’ is not only the physical preparation but also the psychological preparation for a lengthy period of reduced sports participation post-operatively. Besides the physical preparation, the time allocated for pre-operative rehabilitation needs to be used to prepare the patient mentally for the surgery and the long road to recovery afterwards. Self-efficacy and its implications on ACLR have been correlated. Thomée et al¹² developed a validated Knee Self-Efficacy Scale and demonstrated that high post-operative scores were positively associated with higher activity levels, younger age, male gender and Knee Injury and Osteoarthritis Outcome Score (KOOS)¹³ outcomes. Pre-operative self-efficacy significantly predicted RTS and knee-related quality of life following ACLR.¹⁴

After the ACL injury, it is imperative to reduce swelling, inflammation and pain, restore normal range of movement, normalise gait and prevent muscle atrophy pre-operatively. Several studies have explored the effects of pre-operative rehabilitation on outcomes after ACLR. Grindem et al¹⁵ found that pre-operative rehabilitation led to higher KOOS values two years after reconstruction compared with usual care. A cohort treated with pre-operative rehabilitation consisting of progressive strengthening and neuromuscular training had higher functional outcomes

and RTS rates compared with the benchmark cohort that also used a criterion-based post-operative rehabilitation programme two years after ACLR.¹⁶ Progressive pre-operative rehabilitation before ACLR should therefore be considered as an addition to the standard of care to maximise functional outcomes after ACLR.¹⁶

Goals of the pre-operative rehabilitation based on current literature are:¹⁷

- 1) education and mental preparation;
- 2) achieving full knee extension;
- 3) pre-operative strength deficit quadriceps < 20%;
- 4) a normal gait pattern;
- 5) minimal swelling.

Post-operative care

Using a criteria-based, evidence-based constructed approach to rehabilitation after ACL surgery is essential to systematically and successfully progress a patient through the rehabilitation process.¹⁸ It is imperative to control post-operative pain, inflammation and swelling during the first weeks of rehabilitation. Calming the knee down initially, starting slowly, will allow the rehabilitation to accelerate faster in the long run. Post-operative rehabilitation begins with a range of movement exercises, emphasising full passive knee extension and weight-bearing activities immediately post-operatively.¹⁸

Basic principles of rehabilitation

Post-operative rehabilitation is divided into three phases: phase 1, the early post-operative phase; phase 2, the intermediate phase; and phase 3, the sport-specific phase. Advancement of the patient to the next, more demanding phase is based on passing clinical criteria.^{17,19} In contrast to a recent review¹⁷ in which only a criteria-based approach was proposed, we consider that a combined time- and criteria-based approach is more appropriate. Adding a time line – with a certain margin – will allow clinicians to determine whether the patient is progressing as expected or if there are any factors that delay or obstruct recovery. Moreover, delaying RTS for at least nine months has been associated with reduced second knee injury risk.²⁰

Criteria to enter phase 2 (early post-operative rehabilitation):¹⁷

- 1) closed wound (by week 1);
- 2) no knee pain with phase 1 exercises (visual analogue scale);
- 3) minimal effusion;
- 4) normal mobility of the patello-femoral joint;
- 5) full passive knee extension (by week 1);
- 6) 120° to 130° of knee flexion;

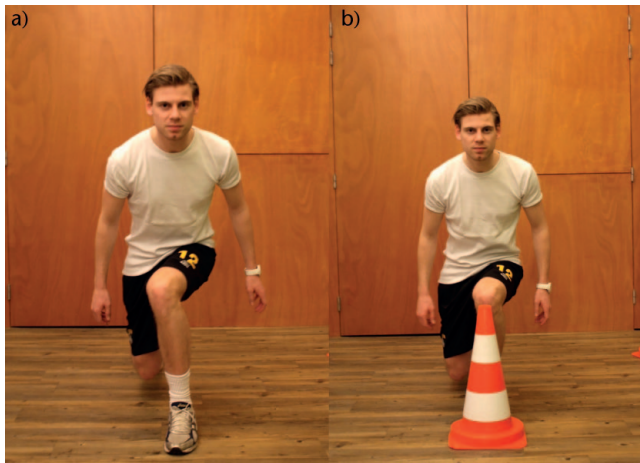


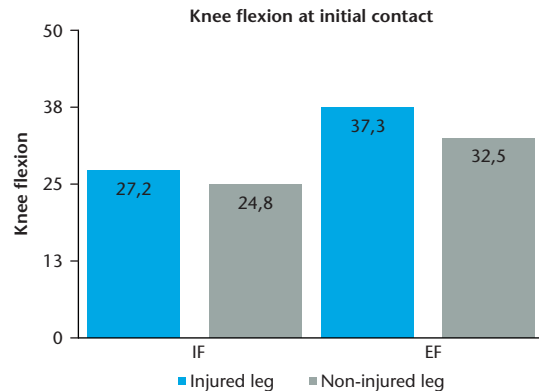
Fig. 1 Internal focus (a) versus external focus (b) instructions during a split squat. In (a) the patient was instructed to perform a split squat and keep knee over toes; in (b) the patient was instructed to touch the cone with his knee. Note the decreased hip adduction with the external focus instructions compared with the internal focus instructions.

- 7) voluntary control of the quadriceps;
- 8) active dynamic gait pattern without crutches;
- 9) satisfactory qualitative performance of phase 1 exercises.

The time needed to reach these goals should be within four weeks, except for passive knee extension, which should be achieved in the first post-operative week.¹⁸

In general, emphasis should be placed on movement quality of tasks during all phases. During rehabilitation, there is a window of opportunity to address altered movement patterns. It is imperative that patients re-learn all activities with normal movement patterns and the physical therapist should play close attention and intervene to target compensatory movements. We advise the use of concepts of motor learning to enhance the learning potential of the patient. Traditional current ACLR rehabilitation programmes may not be optimally effective in addressing deficits related to the initial injury and the subsequent surgical intervention.²¹ Gokeler et al²² conducted a systematic review and found that altered gait may persist for up to five years after ACLR. In light of the association between second ACL injury risk and altered movement patterns, it becomes clear that targeting normal movement patterns is one of the priorities during rehabilitation.

Work from our group recently emphasised the need to use objective tools that are sensitive to limb-to-limb deficits as well as the need to develop rehabilitation protocols that are targeted to eliminate limb asymmetries.²³ Novel training methods that are based on recent evidence (Fig. 1) should be incorporated during rehabilitation to target asymmetrical movement patterns that may pose a



IF internal focus; **EF** external focus instructions; for injured and non-injured leg

Fig. 2 Effect of internal and external focus instructions on knee flexion at initial contact for the injured leg and non-injured leg during the landing of a single leg hop for distance.

risk of a second injury.²⁴ Instructions provided by clinicians during rehabilitation sessions are 95% directed towards body movements.²⁵ The treating clinician may instruct a patient who has an altered gait pattern after ACLR to extend the knee more during the mid-stance phase. In the motor learning domain, this type of attentional focus is termed ‘internal focus’.²⁶ Conversely, an external focus of attention is induced when a patient’s attention is directed towards the outcome or effects of the movement (e.g. ‘imagine kicking a ball’, to facilitate extension of the knee). For example, instructions during landing from jumping are directed towards the execution of the movement itself, such as ‘keep the knees over the toes’, ‘land with a flexed knee’, ‘raise the knee to the level of the hip’ or ‘land with your feet shoulder-width apart’.^{27,28} A recent study demonstrated the effectiveness of external focus instructions.²⁹ Patients after ACLR received either an instruction with an internal focus or an external focus before performing a single-leg hop jump. The external focus group had significant larger knee flexion angles at initial contact, peak knee flexion, total range of movement and time to peak knee flexion compared with the internal focus group²⁹ (Fig. 2). Real-time feedback in terms of movement analysis to display real-time biomechanics has been effectively used in gait re-training³⁰ and may be a beneficial method to target persistent side-to-side asymmetries and specific movement abnormalities found in patients rehabilitating after ACLR.

Muscle weakness, specifically of the quadriceps, is common after ACLR, with reported side-to-side strength deficits of 23% at six months after ACLR and 14% after one year.³¹ The cause of quadriceps weakness in terms of the initial decline post-operatively and residual deficits after ACLR cannot only be solely explained by peripheral muscle adaptations. Palmieri-Smith et al³² postulated that quadriceps atrophy after ACL injury is at least in part

caused by the presence of arthrogenic muscle inhibition (AMI). AMI is a result of reflex activity after injury which leads to the inability to completely contract a muscle. Knee joint effusion results in AMI and altered knee joint mechanics that could potentially increase the risk of future knee joint trauma or degeneration.³³ Neuromuscular electrical stimulation appears to be a promising intervention to use after ACLR to reduce AMI.³⁴ Once the knee has calmed down, strengthening exercises can be initiated. Recently, cross-education has been proposed as a neurophysiological phenomenon where an increase in strength is achieved within the operated limb following strength training in the healthy contralateral limb. Papandreu et al³⁵ determined the effect of an eight-week cross-education training on quadriceps strength in 42 patients after ACLR. Cross-education training used as an adjunct to the ACL traditional rehabilitation programme at the early stage after ACLR significantly improved quadriceps strength compared with a group who performed standard strengthening. Incorporating eccentric quadriceps strengthening exercises has been advocated to optimise recovery of quadriceps strength.³⁶ Finally, high-intensity resistance training starting at eight to 20 weeks after ACLR contributed to a faster recovery of quadriceps power compared with low-intensity resistance training without introducing any adverse effect on knee joint stability.³⁷

Psychological factors

The road to RTS after ACLR is a very arduous journey and faces many potential setbacks such as pain, swelling or lack of progress in function to name a few. The injury and time out of sports can impair an athlete's sense of self-worth and identity, which is often based largely on his or her sports career and performance.³⁸ Unrealistic pre-operative patient expectations may have an impact on motivation during the course of rehabilitation. Therefore, detailed patient information on the reasonable outcomes of a specific operation seems to be essential to improve patient satisfaction. Sonesson et al³⁹ found that higher motivation during rehabilitation was associated with returning to pre-injury sport activity. Another study showed that patients who had returned to knee-strenuous sports after ACLR reported higher self-efficacy compared with those who had not returned.⁴⁰ A team approach that focuses not just on the physical recovery but also the psychological side might improve our ability to get athletes back to play.

Criteria to enter phase 3 (sport specific rehabilitation):^{17,41}

- 1) satisfactory qualitative performance of phase 2 exercises;
- 2) no feeling of giving way in previous phases or a negative pivot-shift;

- 3) limb symmetry index (LSI) > 80% for quadriceps and hamstring strength;
- 4) LSI > 80% for a hop test battery;
- 5) International Knee Documentation Committee Subjective Knee Form (IKDC)⁴² subjective evaluation > 70;

The time needed to reach these goals should be around four to five months;¹⁸ however, we want to reiterate that these timelines only serve as a guideline for the purpose of monitoring. Time needed to pass criteria is dependent on age, level of activity, goal setting, motivation, type of graft, rehabilitation, etc.

RTS

A recent consensus statement was released on the RTS continuum:⁴³

- 1) return to participation: the athlete may be participating in rehabilitation, training (modified or unrestricted), or in sport, but at a level lower than the RTS goal. The athlete is physically active, but not yet 'ready' (medically, physically and/or psychologically) to RTS. It is possible to train, but this does not automatically mean RTS;
- 2) RTS: the athlete has returned to his or her defined sport, but is not performing at his or her desired performance level. Some athletes may be satisfied with reaching this stage and this can represent successful RTS for that individual;
- 3) return to performance (RTP): this extends the RTS element. The athlete has gradually returned to his or her defined sport and is performing at or above his or her pre-injury level. For some athletes, this stage may be characterised by personal best performance or expected personal growth as it relates to performance.

RTS should include a detailed description of the type of activity (e.g. pivoting or non-pivoting, contact or non-contact sports), level of activity (e.g. elite, competitive or recreational), performance level (e.g. match statistics) as well as the timing and duration of sport participation after ACLR.²³

Tools to determine RTS

We want to emphasise that the RTS decision-making process should be viewed as a continuum, which is too large to perform in only one step. Each rehabilitation exercise or phase can be considered a small step in the direction of RTS. The decision-making should take multiple factors into account which will be discussed in the following section.



Fig. 3 Anterior and rotational knee laxity measurement devices: a) the GNRB: the ankle and patella of the tested leg are fixed and a motorised platform applies the anterior force behind the shank. The sensor placed on the tibial tuberosity measures the anterior displacement; b) the Rotameter: the individual is lying prone while wearing ski boots attached to the frame of the device. The handle bar allows the examiner to apply the torque both in internal and external rotation.

Knee laxity and graft healing

ACLR aims to restore knee laxity in all directions. Knee laxity measurements can be performed post-operatively to follow the graft evolution and detect a potential anomaly (graft elongation, iterative rupture, contralateral rupture, etc.) (Fig. 3).

Graft maturation is a slow process that is individually different from person to person and can take more than two years. It consists of four phases: the initial avascular necrosis; the re-vascularisation; cellular proliferation; and finally remodelling.⁴⁴

It has been shown that the side-to-side difference in anterior knee laxity can vary from -2.1 mm to +2.3 mm one year after ACL reconstruction. However, little is known about the evolution of knee laxity over the months/years. Various studies reported knee laxity measurements at a specific time point after ACLR. Their conclusions are still difficult to generalise, due to the diversity of surgical techniques, graft types, fixations, associated injuries and measurement techniques. Four to 36 months after the ACLR, 45% to 100% of patients were reported to have a side-to-side difference < 3 mm.⁴⁵⁻⁴⁷

Non-invasive devices for pivot-shift assessment have been developed in the last ten years⁴⁸ both to diagnose ACL injury and to detect residual rotatory laxity after ACLR. Zaffagnini et al⁴⁹ proposed a tri-axial accelerometer for pivot-shift quantification, which showed a good inter- and intra-rater reliability and correlation with clinical grading. Therefore, such technologies could represent a potential aid in the follow-up evaluation of patients undergoing ACLR and in the RTS decision algorithm, since both anteroposterior and rotatory stability is required to safely RTS. This issue is relevant since Mouton et al⁵⁰ determined that both anterior and rotational knee laxity appear to be greater in the contralateral, non-injured knees of ACL-injured patients than in healthy controls, suggesting that increased physiological laxity could be a risk factor for (second) ACL injuries.⁵¹ Increased laxity is associated with more hip adduction and knee valgus during drop landings

in female patients.⁵² Baumgart et al⁵³ demonstrated that playing football and stretching led to significant increases in anterior translation of 1 mm and 2 mm, respectively, measured with the KT-1000 (MEDmetric, San Diego, California). The increase in anterior translation may result in higher ACL injury risk.⁵³ Summarising, the recent development of rotational laxity measurement devices has added significant knowledge to the field. The high variability between individuals as well as the ability to identify knees with increased physiological knee laxity may improve screening and prevention programmes for athletes.⁵¹

Possible indirect monitoring through MRI is currently under investigation as incomplete graft maturation is related to a hyper-intense graft signal on MRI. However, the MRI evaluation of graft signal still represents a controversial issue, since Biercevic et al⁵⁴ reported a correlation between signal intensity and hop test and KOOS at three and five years, respectively, while Li et al⁵⁵ did not find any correlations with IKDC or Lysholm and Tegner score⁵⁶ at three, six and 12 months. Therefore, a routine MRI assessment of graft maturity does not provide solid insights for RTS.

Ideally, the information gained through MRI assessment should be combined with laxity measurement with MRI.⁵⁷ Espregueira-Mendes et al⁵⁷ presented the Porto-knee testing device which was shown to be a reliable tool as the difference of anterior translation between the lateral and medial plateau (as obtained from MRI) was highly correlated to the pivot shift. Moreover, with regards to its diagnostic capacity, the summed translation of both tibial plateaux led to a highly specific test (specificity 93.8%) and the total rotation of the lateral plateau led to a highly sensitive test (sensitivity 92.9%). These promising results, if confirmed, may help us to have a more complete overview of knee laxity after ACLR in the future. Whether a delay in RTS following ACLR to nearly two years to allow for complete healing of the ACL graft will prevent failure of the graft should be investigated in future studies.

Strength

Although there is a lack of scientific consensus on the criteria to clear an athlete for RTS, achieving 'appropriate' levels of strength is often mentioned by clinicians.⁸

More stringent recommendations, which were categorised based on type of sports activity, have been presented.⁵⁸ A combination of strength and hop test assessment was used. For the purpose of this section, a 100% LSI for knee extensor and knee flexor muscle strength was proposed for the pivoting/contact/competitive group. For the non-pivoting/non-contact/recreational group, they recommended at least 90% LSI for the involved limb knee extensor and knee flexor muscle strength.⁵⁸ There are a few major issues when using these criteria:

- 1) only 23% of all patients achieved the above mentioned 56 test battery at two years after ACLR. In line with these findings, some authors however have proposed to delay RTS for two years after ACLR.⁵⁹ However, this may pose a significant challenge as to whether such an approach is feasible in daily practice;
- 2) the LSI is based on the assumption that the uninjured leg can be used as a reference for strength;
- 3) is it acceptable to have a 10% deficit between limbs?

Larsen et al⁶⁰ proposed that deficits are underestimated when using the uninjured limb as reference. Their results show that not only do patients experience side-to-side deficits after ACLR, but the uninjured limb of ACLR is also significantly weaker compared with a matched limb of a control group. This implies that the uninjured limb is significantly affected by the ACL injury, thereby questioning the use of the LSI as a criterion for RTS.⁶⁰ A successful outcome for a strength or power test should be a symmetrical level of performance between limbs, which also matches the level of performance within their peer group.⁶¹ A systematic review by Undheim et al⁶² revealed that isokinetic knee strength has not been sufficiently validated as a useful criterion measure for RTS. Most studies have exclusively focused on the evaluation of knee muscle strength, but deficits in hip muscle strength have been found after ACLR.⁶³ Clinicians should pay more attention to the hip muscles as decreased hip external rotator and abductor strength have been associated with increased primary non-contact ACL injury risk.⁶⁴ In addition, second ACL injury risk has also been linked to a decreased hip external rotation moment.⁶⁵

Functional tests: adding movement quality assessment

With regards to ACLR, objective outcome measures include clinical and functional performance tests (FPTs)

and are popular due to their ability to quantify knee function.

Hop tests are the preferred type of FPT due to usage of the uninjured limb as a control for between-limb comparisons and as a reference against which discharge from rehabilitation and RTS is often determined.⁶⁶ Commonly used hop tests are the single hop for distance, triple hop for distance, triple cross-over hop and the 6-metre timed hop.⁶⁷ Researchers have recommended that FPT should also include an endurance hop test such as the side hop.⁵⁸ LSI criteria > 90% are often used as cut-off scores for RTS.^{58,68} As with the LSI for strength, there are some concerns regarding the use of the uninjured limb as a reference for the involved limb. Abnormal movement patterns have been reported not only for the involved limb but also the uninjured limb after ACL injury.⁶⁹ Hence, a bilateral deficit may lead to a falsely high LSI, since LSI is calculated as a ratio between the values of the limbs. Aberrant movement pattern may affect performance. This was confirmed in a recent study.⁷⁰ When compared with normative data, patients after ACLR had significant and clinically relevant shorter jump distances for the triple-leg hop for distance (involved limb: male patients 125.7 cm, female patients 43.5 cm; uninjured limb: male patients 104.1 cm, female patients 30.8 cm).⁷⁰ This study highlights that athletes who have undergone an ACLR demonstrate bilateral deficits on hop tests in comparison with age-, gender- and sports-matched normative data for healthy controls. Using the LSI may underestimate performance deficits and should therefore be used with caution as a criterion for RTS after ACLR.

Findings from a newly developed test battery performed six months after ACLR revealed that, in general, 78% to 85% of patients passed the LSI > 90% for the single leg for distance and triple-leg hop, but only 50% passed the side hop test.⁷¹ Gokeler et al⁷² found an increase in the Landing Error Scoring System (LESS)⁷³ score during a bilateral drop vertical jump when fatigued in an ACLR group. These findings indicate that fatigue has a profound effect on performance and movement quality in patients after ACLR. The outcome measure of hop tests is strictly quantitative in nature (distance, time and limb symmetry), while outcomes related to the quality of movement are not captured.⁷⁴ We propose that a RTS test battery should include assessment of movement quality and we have used the LESS score to determine asymmetry during a jump-landing task.⁷¹ This study revealed that, six months after ACLR, 30% of patients demonstrated a score (LESS > 5) that may predispose them to increased second ACL injury risk.⁷¹ In a previous study, we further emphasised that RTS should include multi-segmental movement quality (not only knee) assessments during double- and single-leg dynamic activities.²⁴

Complex biomechanical testing

Complex biomechanical testing includes gait analysis,^{23,75,76} biomechanical analysis using force-plates,⁷⁷ electromyography^{77,78} and movement analysis.⁷⁹ Many studies have been published using this technology after ACLR. Although they have been successful in documenting persisting functional deficits after ACLR, none of them has succeeded in being implemented on a routine basis in daily clinical practice so far. Future work should include standardisation and simplification efforts of this technology as well as large-scale reference data acquisition to improve the follow-up of ACLR patients.

Patient-reported outcome measures (PROMs)

PROMs are self-report questionnaires that measure an individual's perception of symptoms, function, activity and participation.⁴² Various PROMs have been developed that are specific for ACL injuries or more generic for knee injuries. In a survey, the following PROMs were proposed: the Knee Outcome Survey Activities of Daily Living Scale and a Sports Activity Scale; global rating of perceived function; Lysholm score; IKDC; Cincinnati knee score; KOOS; the Tegner activity scale; and Marx activity rating scale.⁴² The decision to allow RTS after ACLR solely based on PROMs, however, has been questioned.⁶⁸ These researchers found that patients who scored poorly on the IKDC were over four times more likely to fail the RTS tests. However, for the athletes who scored well on the IKDC, nearly 50% overestimated their recovery.⁶⁸

Time after ACLR

Time after ACLR is the most used criterion to assess RTS readiness with the allowed RTS after six months.⁸ Unfortunately, the risk of sustaining a second ACL injury is highest during the early period after RTS (six to 12 months).⁸⁰⁻⁸³ Grindem et al²⁰ recommend that RTS should be delayed until nine months after ACLR. For every month's delay to RTS, the re-injury was reduced by 51%. Patients who participated in level I earlier than nine months after ACLR sustained 39.5% re-injuries compared with 19.4% knee re-injuries in those who returned to level I later than nine months after ACLR. Others have even advocated the delay of RTS for up to two years to allow for biological recovery of the knee (e.g. graft healing) and functional recovery (e.g. strength) to reduce the high incidence of second ACL injuries.⁵⁹

On-field rehabilitation as a key component of the RTP continuum

Gradual planning and periodisation to progress from training in a controlled environment in clinical practice to athletic activities in highly uncontrolled environments is needed during rehabilitation. Too often, the end phase of

the rehabilitation is not extensive or specific enough, thereby exposing athletes to specific training loads and training characteristics that they cannot handle from a physical, physiological, neuro-cognitive and psychological perspective. For that reason, Blanch and Gabbett⁸⁴ proposed the inclusion of the acute/chronic workload ratio in the RTS decision-making process. This ratio describes the relation between the workload of the last week (acute workload) in relation to the rolling average workload of the last four weeks (chronic workload). This concept can be applied to a wide range of individually functional relevant training variables representing external workload (e.g. number of jumps or high speed running covered) or internal workload (e.g. rating of perceived exertion). Rapid spikes in acute/chronic workload ratios during the RTS process should be avoided. To allow a safe RTS, we propose to train in RTS groups after the end of the rehabilitation to perform functional and sport-specific exercises. The idea is to accompany the athlete on the field to train his skills in increasingly sports-like situations and conditions.

For the RTP phase, we propose the following:²³

- 1) time after ACLR more than nine months;
- 2) satisfactory clinical examination (negative pivot-shift, anterior laxity < 3 mm, no swelling, full range of movement);
- 3) satisfactory on-field programme completion without adverse reactions (pain, swelling) and no feeling of instability;
- 4) muscle strength for pivoting, contact, competitive sports: 100% LSI for knee extensor and knee flexor strength;
- 5) multi-directional hop tests LSI > 90% and within normative values of healthy athletes;
- 6) IKDC scores 18 to 24 years (89.7 male patients, 83.9 female patients); 25 to 34 years (86.2 male patients, 82.8 female patients); 35 to 50 years (85.1 male patients, 78.5 female patients); 51 to 65 years (74.7 male patients, 69.0 female patients);
- 7) ACL-return to sports after injury⁸⁵ score > 56;
- 8) Knee Self-Efficacy Scale⁸⁶ score of 7.2 male patients, 6.8 female patients.

The authors feel that the focus has been on standard and controlled RTP tests whereas most injuries occur when patients return to competitive sports which includes anticipation and reaction to opponents with quick changes in directions. More emphasis should be given to motor control factors such as reaction time, visual-motor control and complex task environmental interaction. In addition, exercise physiological tests should be integrated in the RTP test battery. Below, we present various tests that could be adopted in future RTP decision-making for a football player.

- 1) Yo-Yo intermittent recovery test performance can be used for players of different within- and between-league competitive levels;¹²
- 2) reaction time and accuracy to intercept an incoming ball;⁸⁷
- 3) visual motor response time under different fatigue conditions;⁸⁸
- 4) all the information throughout the entire rehabilitation should be critically evaluated in a shared decision-making process that include the health professionals (surgeon, physical therapist, exercise physiologist, etc.), the coach and the athlete.⁸⁹ The overall goal is to protect the health of the athlete.

This narrative review presented the clinical course and recommendations based on recent research for patients who have sustained an ACL injury and underwent subsequent ACLR. It exposed many of the persisting knowledge gaps after ACLR, in particular the difficulty to standardise rehabilitation and RTS in the daily clinical practice.

The key points of this paper are:

- 1) the proposal of an optimised time- and criterion-based rehabilitation programme within a biopsychosocial framework that starts before ACLR;
- 2) using a multi-factorial RTS test battery in the absence of a benchmark for evaluating RTS readiness after ACLR. A combination of both physical and psychological elements should be included in the RTS test battery;
- 3) the demonstration of a need for shared decision-making regarding RTS;
- 4) the need to validate this criteria- and evidence-based rehabilitation programme.

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ICMJE CONFLICT OF INTEREST STATEMENT

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LICENCE

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