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Optimization of the return to sport paradigm after anterior cruciate ligament reconstruction: a critical step back to move forward

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Running heading: Return to sport after anterior cruciate ligament reconstruction

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ABSTRACT

Athletes who have sustained an anterior cruciate ligament injury often opt for an anterior cruciate ligament reconstruction with the goal and expectation to resume sports. Unfortunately, the proportion of athletes successfully returning to sport is relatively low, while the rate of second anterior cruciate ligament injury has been reported to exceed 20% after clearance to return to sport, especially within younger athletic populations. Despite the development of return to sport guidelines over recent years, there are still more questions than answers on the most optimal return to sport criteria after anterior cruciate ligament reconstruction. The primary purpose of this review is to provide a critical appraisal of the current return to sport criteria and decision-making processes after anterior cruciate ligament reconstruction. Traditional return to sport criteria mainly focus on time after injury and impairments of the injured knee joint. The return to sport decision-making is only made at the hypothetical "end" of the rehabilitation. We propose an optimized criterion-based multifactorial return to sport approach based on shared decision-making within a broad biopsychosocial framework. A wide spectrum of sensorimotor and biomechanical outcomes should be assessed comprehensively, while the interactions of an individual athlete with the tasks being performed and the environment in which the tasks are executed are taken into account. A layered approach within a smooth continuum with repeated athletic evaluations throughout rehabilitation followed by a gradual periodized re-integration into sport with adequate follow-up may help to guide an individual athlete toward successful return to sport.

KEY POINTS

No gold standard exists for evaluating return to sport readiness after anterior cruciate ligament reconstruction.

Traditional return to sport criteria are mainly focused on time after anterior cruciate ligament reconstruction and knee impairments, while the return to sport decision-making process is only made at the hypothetical “end” of the rehabilitation.

We propose an optimized criterion-based continuous and multifactorial return to sport approach based on shared-decision making, with a focus on a broad spectrum of individual sensorimotor and biomechanical outcomes, within a biopsychosocial framework.

1 Introduction

Most athletes who wish to continue sports after an anterior cruciate (ACL) injury are advised to undergo ACL reconstruction (ACLR) [1]. Unfortunately, the overall secondary ACL injury risk after ACLR is around 15% [2]. For young athletes (< 25 years) returning to competitive sports involving jumping and cutting activities, secondary ACL injury rates of 23% have been reported, especially in the early return to sport (RTS) period [2]. Compared to their uninjured adolescent counterparts, this indicates a 30 to 40 times greater risk of sustaining an ACL injury after ACLR [2]. In addition, an ACL injury and ACLR are associated with an increased risk to develop tibiofemoral and patellofemoral joint osteoarthritis [3], which can affect knee symptoms, function and quality of life 10-20 years after ACLR [4, 5].

The decision when an athlete is allowed to RTS is multifactorial, difficult and challenging [6, 7]. Despite the development of RTS guidelines over recent years, there are still more questions than answers on the most optimal RTS criteria after ACLR. There is a lack of a scientific consensus on the RTS criteria used to release a patient to unrestricted sport activity after ACLR. Moreover, current RTS criteria may fail to identify residual biological, functional and psychological deficits. As a result of all these factors, the current clinical approach used to release athletes to RTS after ACLR may contribute to increased secondary ACL injury risk.

The primary purpose of this review is to provide a critical appraisal of current RTS criteria after ACLR. Recommendations for future optimizations are then presented based on current trends in the literature.

2 What is RTS?

One of the most fundamental questions in terms of RTS is the definition of RTS. Do we consider a RTS successful even when the athlete lowers the level of sports activity, returns to another less demanding sport, to the same sport with a lower performance level, or sustains a second ACL injury, another subsequent injury or knee osteoarthritis a few months or even years after RTS? A systematic review and meta-analysis by Ardern et al. [8] showed that on average 81% of athletes returned to some sort of sports, but only 65% returned to the pre-injury level of sport activity. Barely 55% returned to a competitive sports level.

The use of the term RTS must be accompanied by a detailed description of the individual characteristics of the athletes being studied (e.g. sex and age), the use of protective equipment (e.g. taping, bracing), the intensity, duration and frequency of each exposure, 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. It is unclear how long an athlete needs to maintain a specific level of sport activity before it can be claimed that the RTS was successful. The RTS rate in men professional soccer players was very high (> 90%) at 1 year after ACLR, but only 65% were still playing at the highest level 3 years after ACLR [9]. Similarly, decreased player performances and significantly shorter career durations were reported after ACLR in professional basketball players compared to uninjured controls [10]. Furthermore, it needs to be clarified whether the athlete perceives the RTS as successful [11]. Some athletes may not be satisfied with the outcome after ACLR even after returning to their previous performance level because of pain, instability, stiffness or swelling, or in some cases despite a lack of any abnormal findings during physical examination [12]. The clearance to RTS by clinicians does not necessarily mean that patients go back to sport at the same time, or resume sports at all [13]. This can be due to practical, social or contextual reasons, that may modify the final RTS decision (e.g. end of the season, individual goals, lifestyle changes, a shift in priorities or external pressures) [14], but also due to a mismatch between the clinician's and the patient's understanding of when a person is ready to RTS. Success can mean different things to different people (e.g. athlete, trainer or clinician) and is context- and outcome-dependent [15]. Unfortunately, no gold standard exists for identifying an individual successful outcome after ACLR [16]. However, if the athlete has the goal to RTS, all people involved in the RTS decision-making process should prioritize a safe RTS, i.e. a RTS with minimal risk of sustaining a re-injury and/or developing long-term complications such as degenerative joint disease [17].

2.1 Summary and Recommendations for Future Research

RTS after ACLR is complex and multifactorial. There is no gold standard for identifying an individual successful outcome after ACLR. A clear definition of RTS and detailed descriptions of the individual characteristics and sport participation after ACLR is needed.

3 RTS criteria

In line with the definition of RTS, no consensus exists on the most appropriate criteria for releasing patients to unrestricted sports activities after ACLR [18]. Of the 264 studies included in a systematic review by Barber-Westin & Noyes (studies published between April 2001 and April 2011) [18], 40% provided no criteria for RTS after ACLR, 60% used time postoperatively at least as one of the RTS criteria and 32% used time as the only criterion. Only 13% used objective criteria.

The ability to decide whether an athlete is ready to safely RTS is further compromised by the paucity of prospective studies in literature validating current RTS criteria. Among a group of 46 males and 54 females with a pre-injury participation in level 1 and level 2 sports, delaying RTS until 9 months after surgery and a more symmetrical quadriceps strength prior to return to level 1 sport were associated with a reduced secondary knee injury risk [19]. However, of the

74 patients who returned to level 1 sports, the 51 patients who did not sustain a second knee injury had a mean quadriceps limb symmetry index (LSI) of 84.4%, which was below the recommended LSI of > 90% [19]. Another recent prospective study of 158 professional male soccer players who returned to sport after ACLR showed that those players failing to achieve the proposed RTS criteria were 4 times more likely to sustain a secondary ACL injury compared to those who met all 6 proposed criteria (including quadriceps and hamstrings muscle strength tests, 3 hop tests, an agility test, and the completion of on-field sport-specific rehabilitation) [20]. However, 12 of the 26 players with a second ACL injury met the RTS criteria, while 28 of the 132 players with no second ACL injury were not discharged by the RTS criteria, leading to a sensitivity of only 53% and a specificity of 79%.

The RTS tests and criteria used to evaluate RTS readiness are mostly based on subjective opinions. There is a lack of evidence supporting the relation between RTS and standard subjective and objective assessments [21]. This raises the question whether the current RTS tests address the appropriate issues and cut-off values [13], or whether they are sensitive or demanding enough to elucidate clinically relevant differences [11].

Shrier [14] recently proposed a Strategic Assessment of Risk and Risk Tolerance framework for RTS decisions, where factors affecting injury risk are grouped in the assessment of health risk, activity risk and risk tolerance. Within this overview, we mainly focus on the first two steps within this framework (the risk assessment process). In the following paragraphs, a structural summary of individual potentially modifiable RTS criteria within this risk assessment process is presented. However, we acknowledge that focusing only on very specific factors in isolation within a linear and unidirectional way is probably too simplistic. Several factors that are individually related to RTS may be interrelated to each other. The use of non-linear, multivariate and complex models in future studies, where the interactions between the different individual RTS criteria are taken into account, may provide a better framework for understanding the complex decision-making process of RTS after ACLR [14, 22, 23]. The relative importance of each of these criteria may depend on the individual. Therefore other researchers have proposed that individual patient-tailored RTS criteria should be used instead of the traditional "one-size-fits-all" RTS approach [6, 24].

3.1 Summary and Recommendations for Future Research

No consensus exists on the most appropriate criteria for releasing patients to unrestricted sports activities after ACLR. Only a paucity of prospective studies have validated RTS criteria after ACLR. Multivariate models should be used to unravel the complex RTS decision-making process. Prospective studies are needed to determine and evaluate evidence-based RTS criteria.

3.2 Time after ACLR

Time after ACLR is the most used criterion to assess RTS readiness [18]. Although this timing is highly variable (from 12 weeks to 12 months), the majority of studies traditionally allowed RTS after 6 months [18]. However, the risk of sustaining a second ACL injury is highest during the early period after RTS (6-12 months) [19, 20, 25-27]. Based on these data, and the persistence of biological and functional deficits until approximately 2 years after ACLR, other authors have proposed delaying high level unrestricted sport activity until 2 years after ACLR [28], which is in contrast with current RTS practices. However, time after ACLR is not necessarily related to functional outcome measures [29]. In a prospective study by Capin et al. [30], 14 young female athletes were only allowed to RTS after passing their RTS criteria (> 90% quadriceps strength LSI, > 90% LSI on hop tests, and > 90% on Knee Outcome Survey – Activities of Daily Living Scale (KOS-ADLS)). The 7 athletes who sustained a second ACL injury during a 2-year follow-up after ACLR had earlier normalization of gait biomechanics, met the RTS criteria more quickly and returned significantly earlier to sport compared to the 7 athletes who returned to sport without second ACL injury (mean ± SD 6.8 ± 1.9 months versus 9.5 ± 1.9 months) [30]. These findings are in line with the study by Grindem et al. [19] and imply that an earlier RTS (before 9 months) should be avoided, even in the absence of clinical and functional gait impairments. We propose combining time after ACLR with other objective RTS criteria to guide the RTS decision-making process. Furthermore, the re-orientation from a "wait-and-see-policy" to a goal-oriented rehabilitation and RTS criteria-based decision-making approach might promote the autonomous athlete's motivation and adherence to the rehabilitation program [31]. The implementation of more stringent objective RTS criteria across a broad spectrum of functional athletic capabilities will automatically delay the timing of RTS for the majority of athletes. Indeed, several studies have shown that most patients fail to achieve RTS criteria at 6 months after ACLR [19, 22, 32].

3.2.1 Summary and Recommendations for Future Research

Time after ACLR is the most used RTS criterion. No consensus exists on the ideal time frame to RTS after ACLR, but recent studies have shown that a RTS before 9 months after ACLR increases ACL re-injury risk. Time after ACLR is not associated with functional outcome measures. Integrated criterion-based RTS assessments should be developed.

3.3 Patient reported outcome measures

Patient-reported outcome measures (PROMs) are self-report questionnaires that measure an individual's perception of symptoms, function, activity and participation [16, 33]. 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: KOS-ADLS, Knee Outcome Survey - Sports Activities Scale (KOS-SAS), global rating of perceived function (GRS), Lysholm score, International Knee Documentation Committee 2000 Subjective Knee Form (IKDC2000), Cincinnati Knee Score, Knee Injury and Osteoarthritis Outcome Score (KOOS), the Tegner Activity Scale and Marx Activity Rating Scale [16].

Although items like reliability, responsiveness and validity have been reported, it is currently unknown what the optimal cut-off scores are in the context of RTS after ACLR [34-36]. The decision to allow RTS after ACLR solely based on PROMs has been questioned [37]. Low IKDC2000 scores were reasonably indicative of failing on a battery of functional performance RTS tests including quadriceps strength and single-legged hop indices, while good IKDC2000 scores were not predictive of successfully passing the functional performance test battery [37]. These data indicate that PROMs and functional performance tests evaluate different aspects of athletic function. It has been suggested that a combination of PROMs and objective performance-based measurements is needed to evaluate an athlete's RTS readiness more comprehensively [33].

3.3.1 Summary and Recommendations for Future Research

The most optimal combination and cut-off scores of PROMs are not known. RTS decision-making should not be based only on PROMs. Future studies should integrate PROMs with objective RTS measurements in the RTS decision-making process.

3.4 Clinical examination

Clinician-based assessment has traditionally focused on overall impairments of the knee (e.g. swelling, pain, strength, range of motion and joint laxity). Recent literature has called for increased attention to a more functional and whole-person health care approach in sports medicine within a biopsychosocial context [38]. Hence, RTS decision-making following ACLR requires consideration of not only physical but also psychosocial factors [15].

3.4.1 Muscle strength

Even though most athletes achieve an (what is currently considered) acceptable muscle function, the RTS rates after ACLR are disappointing [11]. The majority of studies measure the peak torque and/or total work of the hamstrings and quadriceps with isokinetic or isometric dynamometry to evaluate muscle strength after ACLR, even though debate exists on the most optimal outcome measures and the functional relevance of testing strength in an open chain situation [39]. Despite the fact that isokinetic knee strength evaluations after ACLR are commonly used to evaluate RTS readiness, these measures have not been sufficiently validated as useful predictors of successful RTS [39]. Kyritsis et al. [20] showed a 10.6 times greater ACL re-injury risk after ACLR for every 10% decrease in the hamstrings to quadriceps ratio of the involved leg. Greater asymmetric quadriceps muscle strength prior to level 1 RTS after ACLR was also a significant predictor of knee re-injury [19].

Most studies have exclusively focused on the evaluation of knee muscle strength after ACLR, although a systematic review of Petersen et al. [40] also revealed deficits in hip muscle strength after ACLR. A prospective study of

Khayambashi et al. [41] reported that a decreased hip external rotator and abductor strength increased primary non-contact ACL injury risk. Future studies should explore the value of including these parameters in the RTS decision-making process.

3.4.1.1 Summary and Recommendations for Future Research

A decreased hamstrings to quadriceps strength ratio and a greater asymmetric quadriceps strength can increase ACL re-injury risk, but the most optimal outcome measures and criteria to evaluate muscle strength in function of RTS after ACLR are not known. Most studies have exclusively focused on the evaluation of knee muscle strength. The validity of including muscle strength measurements of other joints, such as the hip, should be evaluated. The most optimal outcome measures and criteria to evaluate muscle strength should be determined in future research.

3.4.2 Hop tests

Noyes et al. [42] developed a set of 4 hop tests (single-leg hop for distance, triple hop for distance, cross-over hop for distance and 6m timed hop) with the purpose of representing an objective measure of the functional capabilities of an athlete related to the demands of high-level sport activities. These hop tests can provide a reliable performance-based outcome for ACLR patients and only require a minimal amount of equipment [43]. However, Hegedus et al. [44] found limited and conflicting evidence for the measurement properties of hop tests, making it difficult to decide whether an observed result is meaningful for an individual athlete.

Another potential limitation of the original set of hop tests is that this test battery mainly consists of straight movements in the sagittal plane, thereby potentially hindering elicitation of clinically relevant functional performance deficits. During pivoting sport activities, an athlete has to move in multiple directions. The inclusion of a combination of hop tests whereby an athlete is forced to move as quickly as possible in multiple directions might better represent the challenges encountered during functional movements and increase the sensitivity for detecting deficits [45]. Examples here are the figure-of-8 hop [45], side hop [45, 46] or square hop test [46]. A systematic review by Abrams [47] indicated that discrepancies between the operated and non-operated leg became more apparent when using more challenging tests such as the fatigue single-leg hop and side hop tests. However, only the traditional hop tests have been related with RTS after ACLR [19, 20]. Another disadvantage of the traditional outcomes of hop tests is the strict focus on quantitative outcomes (distance, time and limb symmetry), while outcomes related to the quality of movement are not captured [48].

3.4.2.1 Summary and Recommendations for Future Research

There is conflicting evidence regarding the measurement properties of hop tests. The most optimal hop test RTS criteria after ACLR are not known. Hop tests have mainly been performed in the sagittal plane for the purpose of RTS decision-making. The measurement properties and most optimal criteria of hop tests, including multidirectional hop tests, should be determined to assess RTS readiness.

3.4.3 Limb symmetry index (LSI)

From a clinical point of view, using the LSI by comparing the operated and non-operated leg after ACLR is the most obvious way to evaluate RTS readiness. For quantitative outcomes of isokinetic muscle strength evaluations and hop tests, LSI > 85-90% were traditionally considered as safe cut-off values to RTS [49-51]. However, one may question the acceptance of 10-15% difference between legs. It is possible that these so called "small" differences in physical function may have a high impact on the ability to return to high-level sport activities. More stringent recommendations which were categorized based on type of activity (pivoting, contact or competitive versus non-pivoting, non-contact or recreational) have been presented [11]. For the pivoting/contact/competitive group, these authors recommended a 100% LSI for knee extensor and knee flexor muscle strength and a single-leg hop LSI > 90% on 2 maximum hop tests (e.g. single hop for distance, vertical hop, etc.) and 1 endurance hop test (e.g. triple hop, stair hop, side hop, etc.). 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 and at least 90% LSI for the involved limb hop performance on 1 maximum or 1 endurance hop tests [11]. At 6 months after ACLR, with success defined as those patients who scored LSI of > 90% in a set of 3 hop tests and 3 strength tests, none of the patients met the criteria [32]. In fact, only 23% of all patients were successful at 2 years in meeting the criteria [32].

Even though a more symmetrical hopping performance has been related to returning to pre-injury sport level [8], this symmetry-based approach is debatable and may lead to underestimations of clinical relevant deficits, as bilateral neuromuscular, biomechanical and functional performance deficits have been demonstrated after unilateral ACLR [52-57]. This implies that a clinician is forced to refer to "normal" performances on certain tasks or pre-injury data of the athlete. However, only very limited scientific data are available in the literature on normative absolute values for strength and hop tests. Caution is therefore warranted when generalizing data from a specific population to other study groups or individuals.

3.4.3.1 Summary and Recommendations for Future Research

The most optimal LSI is unknown and might differ between individuals with varying type and level of sport activity. Caution is warranted when using LSI as bilateral deficits can be present. The validity of LSI during the RTS decision-making process should be further explored.

3.4.4 Assessment of movement quality

An increased knee valgus movement, a decreased internal hip external rotation moment, a greater asymmetrical internal knee extensor moment at initial contact during a drop vertical jump, and postural stability deficits during single-leg stance significantly increased second ACL injury in a group of 35 female and 21 male athletes who returned to sport after ACLR [58]. Another prospective study by Paterno et al. [59], including 61 female athletes with an ACLR, showed an altered hip-ankle coordination during a dynamic single-leg postural coordination task compared to similar athletes who did not suffer a second ACL injury during follow-up. Although no other prospective biomechanical studies after ACLR exist, these preliminary findings are in line with the trend in the current literature to emphasize the importance of movement quality during rehabilitation of ACLR patients [51, 60-62].

It is increasingly recognized that a knee does not function as an isolated joint, but rather as an intermediate joint within a linked system of segments which need to interact with each other within different planes of movement during dynamic sport activities [63, 64]. However, multi-dimensional time-varying biomechanical data are often reduced to zero-dimensional data (e.g. peak single-joint and single-planar joint angles or moments), which might compromise our understanding of multi-joint and multi-dimensional athletic movement behavior. From this perspective, the use of vector field statistical analysis approaches might provide additional insights in future studies [65].

In addition to this fundamental research, it is imperative that efforts are made to translate these complex laboratory-based procedures to more clinical-friendly methodologies. Most currently available biomechanical studies after ACLR used sophisticated equipment in laboratory environments. The use of two-dimensional video analysis and visual observational scales to evaluate multi-segmental movement quality in clinical settings shows promising results [56, 66-69]. Future studies should assess the value of these measures in relation to RTS readiness.

3.4.4.1 What is the reference?

From a movement quality point of view, a recent systematic review attempted to determine “normal” ranges of hip and knee kinematics based on studies using three-dimensional motion analysis of females during athletic tasks commonly used to assess ACL injury risk [70]. However, normal ranges of kinematic outcomes can be influenced by numerous variables including sex, age, sport specificity, sports or activity level, injury history, individual anatomical characteristics, the methodology used to measure kinematics, the tasks being performed and the natural variability of human movement behavior [70]. It is therefore not surprising that wide ranges of normal values were reported [70]. Based on the current scientific literature, the “norm-based” approach is therefore not yet supported when evaluating an individual athlete from a primary or secondary injury prevention perspective. Furthermore, only pursuing the “normalization” of biomechanical and/or neuromuscular outcomes during interventions to decrease (re-)injury risk, and neglecting the individual characteristics of an athlete, may again lead to suboptimal outcomes. When pre-injury data for an individual athlete were available, one would be able to refer to these outcomes, but in most cases these data are lacking. Furthermore, the pre-injury individual characteristics may have been less optimal, thereby contributing to the multifactorial reason why the initial injury would have occurred. A return to the same level after injury as before injury therefore cannot be a good enough outcome. The advanced clinical reasoning skills of a clinician remain essential when assessing an individual athlete.

3.4.4.2 Task and environmental constraints

Movement quality, objectively evaluated with biomechanical measurements, may vary according to the task being selected after ACLR [71]. During athletic activities, an athlete has to visually perceive the constantly and quickly changing, unpredictable environment (e.g. movement of another player, opponent or a ball), quickly process these situational-specific visual-spatial cues within the central nervous system and develop an appropriate physical response while maintaining dynamic stability of the body. Several studies have shown that experimentally visually cued temporal constraints can affect whole body kinematics and knee loading during athletic activities such as cutting [72, 73]. Therefore, one could argue that environments should be as realistic and context-specific as possible when evaluating the ability to RTS. However, most currently used dynamic RTS tests are performed within a predictable, fixed or “closed” environment. Training or testing in closed environments may decrease the ability to transfer the learned patterns towards highly unpredictable three-dimensional open environments encountered during athletic activities. In addition, most athletes are familiar with the tests, as the same movement tasks are often performed and learned during rehabilitation. As a consequence, an athlete may be aware of the criteria to perform these tests with an “optimal” movement quality. This may lead to situations whereby clinicians rather evaluate a conscious, internally focused and learned movement behavior of the athlete instead of the dynamic capabilities of an athlete which are related to real game situations.

Athletes recovering from injury typically have an increased internal focus of attention [74]. This can be a result of the fear to sustain a re-injury, lack of confidence in the injured body part or the predominantly internally focused instructions provided by the clinician during a prolonged time of rehabilitation. Nevertheless, during athletic activities it is highly important to be able to redirect attention to the most relevant environmental cues. Several studies have shown that the performance on postural control tasks decreases significantly more in ACL injured and ACLR patients compared to healthy controls when the neurocognitive loading increases [52, 53, 75-79]. This can be established by including temporal constraints, distracting or occluding the visual system, increasing the level of task uncertainty, performing dual tasks or including fatigue, psychological stressors, decision-making or combinations of those factors in RTS tests.

3.4.4.3 Sensorimotor system

The cascade of neurophysiological alterations after ACL injury, in combination with the reported deficits across the whole spectrum of the sensorimotor system after ACL injury and ACLR, support the theory that an ACL injury should be considered as a neurophysiological injury, and not as a “simple” musculoskeletal pathology with only local mechanical or motor dysfunctions [80, 81]. These alterations may contribute to the increased need to rely on visual feedback and conscious movement planning with an internal focus of attention after ACLR. The central nervous system may become overloaded in these particular situations where task and environmental constraints are altered. This neurocognitive overload may lead to a momentary loss of visual-spatial disorientation and decreased dynamic joint stability, potentially increasing secondary ACL injury risk [82, 83]. However, the ability of an individual to handle neurocognitive overloading may be missed with the traditional RTS test batteries. Most RTS batteries mainly focus on the motor end of the sensorimotor system, and fail to comprehensively address the interaction of an individual with the task and environmental constraints. This is in contrast with the current injury prevention and rehabilitation literature, where for example the inclusion of an external focus of attention and visual-motor interaction training is increasingly supported to enhance motor learning and stimulate the transfer of a learned motor behavior towards a variety of functional athletic tasks and dynamic environments [81, 84, 85]. The recognition and application of this framework might allow developing more efficient RTS criteria in the future.

3.4.4.4 Fatigue

RTS tests are mostly performed in a non-fatigued state. However, fatigue can have detrimental effects on multiple biomechanical and neuromuscular variables during tests that are currently used to assess RTS readiness in ACLR athletes [86-90]. In a study by Augustsson et al. [86], all ACLR patients met the RTS criteria (defined as a LSI > 90% on the single-leg hop test) in a non-fatigued state, while 68% showed an abnormal LSI when fatigued. Similarly, Gokeler et al. [89] found an increase in the Landing Error Scoring System score during a bilateral drop vertical jump when fatigued in an ACLR and non-injured control group. Moreover, the influence of fatigue on lower extremity biomechanics is even more pronounced during unanticipated landings, further emphasizing the interactive role of fatigue and decision-making after ACLR [91]. Based on the current literature, it can be argued that testing athletes in a fatigued state may enhance the ability to detect clinical relevant deficits after ACLR [92].

3.4.4.5 Summary and Recommendations for Future Research

Less optimal movement quality during functional movements can increase re-injury risk. Most RTS tests have mainly focused on single-joint (the knee) and single-planar biomechanical outcomes, and on the motor end of the sensorimotor system. The validity of RTS tests focusing on multi-segmental and multidirectional movement quality should be evaluated. Athletes should be evaluated across a broad sensorimotor spectrum, including the interactions between an individual and the task and environmental constraints. It is recommended to develop RTS tests that employ the effect of fatigue.

3.4.5 Psychological factors

Traditional rehabilitation after ACLR and subsequent RTS criteria has predominantly focused on the recovery of the physical capacity to cope with the physical demands of a specific sport, maximize performance and decrease re-injury risk [17]. During recent years, it has become clear that physical recovery alone is not sufficient to ensure successful RTS [7]. Many athletes with good physical function do not RTS after ACLR [93]. The importance of psychological factors after ACLR is increasingly recognized in the literature [7, 94]. A recent review on contextual factors affecting RTS after ACLR identified that lower fear of re-injury, greater psychological readiness and a more positive subjective assessment of knee function favored a return to pre-injury level of sport after ACLR [7]. Sonesson et al. [95] 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, evaluated with the Knee Self-Efficacy Scale (K-SES) [96], compared with those who had not returned [97]. The ACL-Return to Sport after Injury (ACL-RSI) scale has been developed to assess the athlete's psychological readiness to RTS [98]. This 12-item questionnaire assesses emotions, confidence and risk appraisals associated with RTS after ACLR and has been proved to discriminate between athletes who returned to sports after ACLR and those who did not [99]. At 4 months after ACLR, an ACL-RSI cut-off score of 56 points predicted RTS at 12 months with a sensitivity of 58% and specificity of 83% [99]. Nevertheless, psychological factors are typically not systematically evaluated during rehabilitation and RTS decision-making after ACLR [100]. A paradigm shift from the traditional physical-focused RTS evaluation towards a more holistic approach where psychological factors are comprehensively assessed as well has been proposed [100]. Early evaluation and recognition of maladaptive or dysfunctional psychological responses during rehabilitation may allow the clinician to address these modifiable deficits with targeted interventions before RTS [100, 101].

3.4.5.1 Summary and Recommendations for Future Research

Psychological factors play a significant role in RTS outcomes but are typically not evaluated during the RTS decision-making process. It is advised to integrate psychological factors within a holistic biopsychosocial RTS decision-making approach.

4 How to organize a RTS decision process?

Nyland [102] considers the RTS decision-making process as a continuum, which is too large to perform in only 1 step. Each rehabilitation exercise or phase can be considered as a small step in the direction of RTS [102, 103]. Pre-operative, operative as well as post-operative factors during rehabilitation can affect RTS [103, 104]. This more layered approach within a smooth continuum of recovery throughout the whole rehabilitation is in line with the contemporary criteria-based rehabilitation approaches [103, 105, 106], but in contrast with the traditional “yes” or “no” question at the hypothetical “end” of rehabilitation [102, 103, 107]. Repeated athletic evaluations during the rehabilitation should be considered as small steps on the road to RTS. The decision to allow full return to unrestricted athletic activities should not be considered as the endpoint of this continuum [15]. Even though we currently do not know how RTS criteria develop over time after RTS, maintenance programs and longer follow-ups are advised to further improve or at least maintain functional levels following an intense rehabilitation period [107]. Secondary prevention programs have been proposed [108, 109], but their effectiveness for reducing re-injury risk and increasing RTS rates have yet to be investigated. A graphical overview of the proposed continuum is presented in Figure 1.

Gradual planning and periodization 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, physiologically, neurocognitive as well as psychological perspective. The failure to fully recover after ACLR, while allowing a RTS based on non-specific criteria without a progressive re-integration into sport, may lead to a lack of confidence in the athlete, fear of re-injury and the persistence of risk factors that ultimately increase the re-injury risk. To finally integrate an athlete into a team sport, progressions can be made from (1) return to reduced team training without contact, (2) return to full (normal) team training with contact, (3) return to friendly games (initially not over the full duration) and (4) return to competitive matches (initially not over the full duration) [60]. This may reflect a more comprehensive phasic periodization of RTS, in line with the recently proposed continuum of RTS [15].

In addition, exclusively focusing on the performance on the aforementioned RTS tests may fall short in terms of effectively monitoring how an athlete can handle the increasing training and competition workloads [110, 111]. An athlete may be able to successfully perform functional RTS tests, but when performing greater workloads than they are prepared for, the risk for an unsuccessful RTS and re-injury is still increased [110]. For that reason, Blanch & Gabbett [110] 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 4 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. For a clinician, it is therefore important to know the physical demands of the specific sport and to gradually expose an athlete to the sport-specific workloads in order to successfully integrate a player back into sport. This concept highlights again the dynamic interaction between rehabilitation and the RTS decision-making process.

Taken together, these findings strongly argue for a close cooperation between all members within a multidisciplinary team, facilitating a shared decision-making process [17, 112]. A graphical overview of the aforementioned traditional and optimized RTS approach is presented in Figure 2.

4.1 Summary and Recommendations for Future Research

The RTS decision is typically made at the hypothetical "end" of rehabilitation, without adequate follow-up. Researchers should focus on the development of test batteries across the whole continuum of criterion-based rehabilitation, and not only at the hypothetical "end". RTS decision should be based on shared decision-making. Workload should be objectively measured during the rehabilitation to enable a gradual periodized RTS after ACLR.

5 What RTS criteria can clinicians use now?

Numerous limitations in the literature have been presented in this manuscript, followed by suggestions for future research. Nevertheless, clinicians cannot wait for years of research to make daily clinical decisions. Until more evidence-based RTS criteria are available, shared decisions can be made based on the integration of the best available evidence, clinical experience and patient preferences [17]. While acknowledging the current limitations, we propose a combination of different existing parameters at the hypothetical "end" of rehabilitation in Table 1, which need optimization and validation across the whole continuum in the future, based on the suggestions proposed in the current manuscript. The definition of successful RTS outcomes should be discussed before and throughout the rehabilitation process to tailor an individual RTS decision-making process.

6 Conclusion

The critical appraisal of the current literature provided in this article has shown that no gold standard exists when evaluating RTS readiness after ACLR. The identification of the current limitations in the literature and the proposed optimizations within this review may serve as a solid baseline from which to improve the RTS decision-making process after ACLR in the future.

Compliance with Ethical Standards

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Conflicts of interest

Bart Dingenen and Alli Gokeler declare that they have no conflicts of interest relevant to the content of this review.

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FIGURE LEGENDS

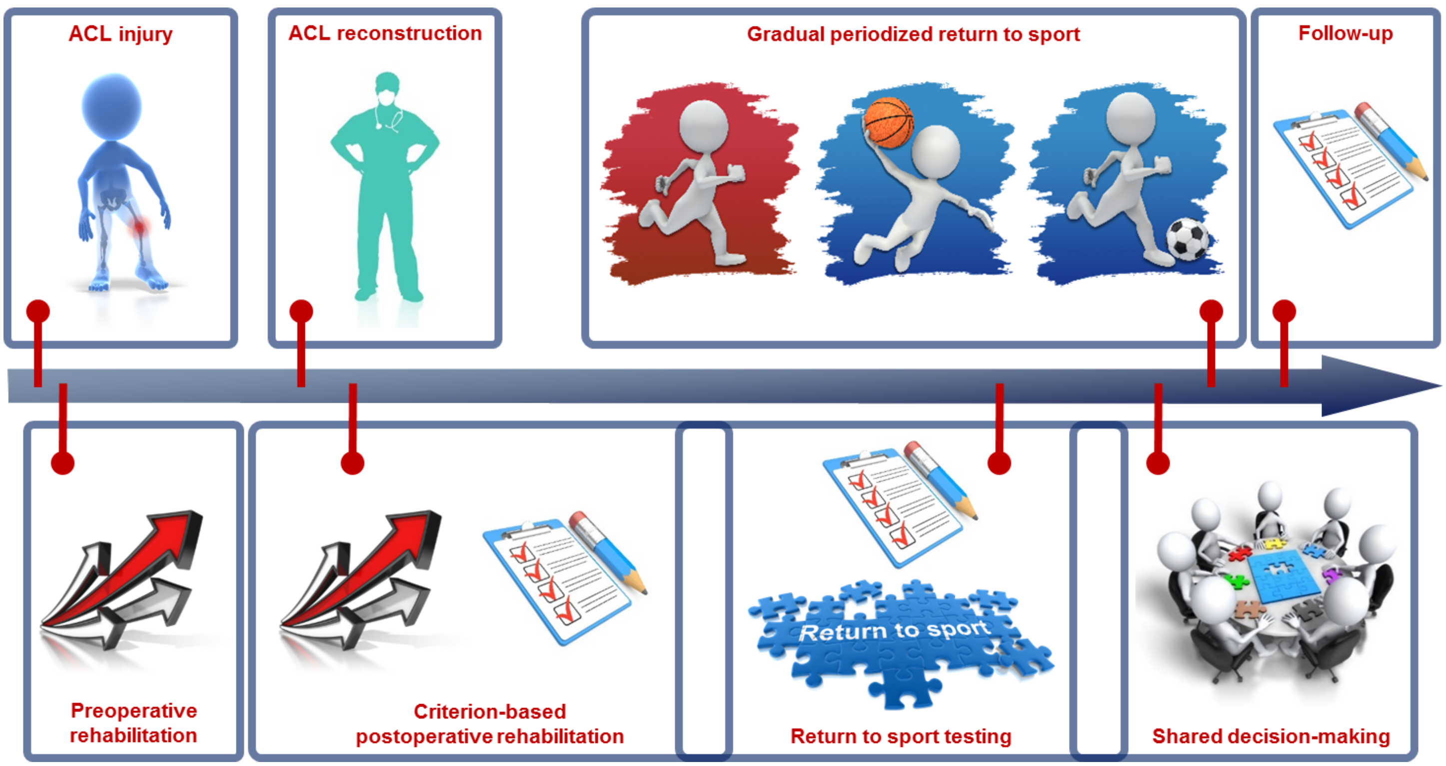
Fig. 1 A graphical overview of the proposed return to sport (RTS) continuum after anterior cruciate ligament (ACL) injury and ACL reconstruction. A layered individual continuous approach starting with the ACL injury, followed by preoperative rehabilitation, the ACL reconstruction, a criterion-based postoperative rehabilitation, RTS testing, a careful shared decision-making process and gradual periodized re-integration into sport-specific activities with adequate follow-up is presented.

Fig. 2 A graphical overview of the most important differences between components of the traditional and proposed optimized return to sport (RTS) approach after anterior cruciate ligament reconstruction (ACLR). Traditionally, the RTS decision-making process is mainly based on time after ACLR (1) and impairments of the knee (2). The RTS decision is only made at the hypothetical "end" of the rehabilitation without adequate follow-up (3), which may lead to a narrow view of RTS readiness after ACLR (4). The optimized criterion-based (1) and multifactorial (2) approach presented in this paper focuses on a wider spectrum of individual sensorimotor (3) and biomechanical outcomes, including for example the evaluation of multi-segmental movement quality (4), but also takes into account the interactions of an individual with the task and environmental constraints (5) (e.g. multi-directional single-legged RTS tests, inclusion of task uncertainty, decision-making, external focus of attention and open environments). The RTS decision is not simply made at the hypothetical "end" of the rehabilitation, but is considered as a step-by-step continuous process (6) (Figure 1). The whole RTS decision-making process is made within a broad multifactorial biopsychosocial framework, and based on shared decision-making (7). This optimized RTS approach may allow a "big picture view" of the RTS readiness of an individual athlete (8).

Table 1. Return to sport criteria that clinicians can use today

- Time after anterior cruciate ligament reconstruction > 9 months [19, 30]
- Patient reported outcomes measures:
  - Symptoms, function, activity, participation:
    - IKDC2000: 18-24 years (> 89.7 males; > 83.9 females), 25-34 years (> 86.2 males; > 82.8 females), 35-50 years (> 85.1 males; > 78.5 females), 51-65 years (> 74.7 males; > 69.0 females) [37]
    - Tegner Activity Scale: according to the desired activity level
  - Psychological factors:
    - Anterior cruciate ligament return to sport after injury (ACL-RSI) scale > 56 [99]
    - Knee self-efficacy scale (K-SES): males > 7.2; females > 6.8 [97]
- Objective measures:
  - Clinical evaluation of knee impairments [49, 51]:
    - Full range of motion
    - No pain
    - No swelling
    - No abnormal laxity: KT-1000 arthrometer < 3 mm increased anterior laxity compared to contralateral side, < 3 mm Lachman test, grade 0 pivot-shift test
  - Quantitative outcomes [11, 19, 20, 22]:
    - Muscle strength:
      - Pivoting, contact, competitive sports: > 100 % LSI on knee extensor and knee flexor strength evaluated with concentric isokinetic dynamometry at 60°/s, 180°/s and 300°/s.
      - Non-pivoting, non-contact, recreational sports: > 90 % LSI on knee extensor and knee flexor strength evaluated with concentric isokinetic dynamometry at 60°/s, 180°/s and 300°/s.
      - Hamstrings/quadriceps strength ratio > 58% evaluated with concentric isokinetic dynamometry at 60°/s [20]
    - Hop tests: multidirectional: LSI > 90%
  - Movement quality:
    - Evaluation of multi-segmental movement quality during double- and single-leg dynamic activities: individual assessment with advanced clinical reasoning
    - Inclusion of sport-specific fatigue
- Sport re-integration:
  - Gradual training towards real game situations
  - Gradual increase workloads (avoid rapid spikes) [110]
  - Assess tolerance of sport-specific training: no pain, swelling, stiffness, giving way
- Medical and sport risk modifiers [14]:
  - Age, sex, personal medical history, type of sport, level of sport, position played, ability to protect (e.g. taping / bracing).
- Decision modifiers [14]:
  - Timing of the season, external pressure from club, trainers, parents, conflict of interest (e.g. financial), lifestyle changes, priorities, individual goals.
- Shared decision-making [112]

IKDC2000: International Knee Documentation Committee 2000 Subjective Knee Form; LSI: limb symmetry index


ACL injury
ACL reconstruction
Gradual periodized return to sport
Follow-up
Preoperative rehabilitation
Criterion-based postoperative rehabilitation
Return to sport
Return to sport testing
Shared decision-making

(1) Time-based
(2) Knee-focused
YES
NO
(3) A yes or no RTS decision only at the hypothetical “end” of the rehabilitation
(4) Narrow view of RTS readiness after ACL reconstruction
Traditional return to sport approach
Biopsychosocial framework
Return to sport
(1) Criterion-based
(2) Multifactorial
(3) Sensorimotor spectrum
(4) Multi-segmental
(5) Interaction individual - task - environment
(6) RTS continuum
(7) Shared decision
(8) Big picture view
Optimized return to sport approach