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Return to sports after an ACL reconstruction in 2024 – A glass half full? A narrative review

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ABSTRACT

A successful return to sports (RTS) after an anterior cruciate ligament reconstruction (ACLR) is multifactorial, and therefore difficult and challenging. Unfortunately, low percentages of patients RTS, and for those who succeed, one-fifth of patients will sustain a second ACL injury. Over the past years, test batteries were developed to assess whether patients can RTS with a low risk for a second ACL injury risk. Low rates of patients who meet RTS criteria were found, coupled with the insufficiency of current RTS test batteries in predicting second ACL injuries suggesting poor sensitivity. The result of an RTS test is likely to reflect the content of a rehabilitation program, raising critical questions regarding what we are offering patients within the rehabilitation programme. Are we preparing our patients well enough for the high demands of complex situations within pivoting team sports? This narrative review offers insights from key lessons of the last 15 years on 1) RTS testing, 2) the content of rehabilitation, and 3) the RTS continuum, all from a "helicopter perspective".

1. Introduction

In pivoting team sports like football, handball, and basketball there is a relatively high incidence of a rupture of the anterior cruciate ligament (ACL), and patients who wish to return to sports (RTS) are advised to undergo a reconstruction of the ACL (ACLR) (Marx et al., 2003). The decisions involved in allowing an athlete to RTS are multifactorial, and therefore difficult and challenging (Zaffagnini et al., 2014). More than 90% of patients have an expectation to RTS without any restrictions (Feucht et al., 2016), but the reality is less promising. Research indicates that only 55% of the total population (elite and non-elite athletes) will succeed in returning to competitive sports (Ardern et al., 2014) and for those who have RTS, one-fifth of the total population will sustain a second ACL injury (Wiggins et al., 2016). These outcomes are far from optimal. The goal of this narrative review is to create an overview from a "helicopter perspective" of key lessons learned on the following three topics related to ACLR: 1) RTS testing, 2) the content of rehabilitation, and 3) the RTS continuum.

1.1. Part 1: RTS testing

1.1.1. Test batteries

Overall, the prevailing consensus is that the decision to RTS after an ACLR should be based on both criteria and time (Gokeler, Dingenen, & Hewett, 2022; Grindem et al., 2016; Ithurburn et al., 2019). Hence, RTS test batteries were developed, including physical parameters like muscle strength, jump-landing performance, and movement quality (Gokeler et al., 2017a; Herrington et al., 2021; Lynch et al., 2015; Paterno et al., 2010; Van Melick et al., 2016; Xergia et al., 2013). Additionally, psychological parameters were added to RTS test batteries (Ardern et al., 2015; Kvist et al., 2005; Nwachukwu et al., 2019; Truong et al., 2020). The current clinical RTS test battery often includes an isokinetic strength test (or handheld dynamometry as an alternative), a battery of hop tests, a jump-landing test for measuring movement quality (for example the Landing Error Scoring System test or the single leg hop-and-hold test), and patient-reported outcome measures (PROMs) for measuring self-reported knee function and psychological readiness for RTS (Gokeler et al., 2017a; Herrington et al., 2021; Lynch et al., 2015; Paterno et al., 2010; Van Melick et al., 2016; Xergia et al., 2013). Ideally, the true value of an RTS test battery is the potential ability to assess whether patients can have RTS with a low risk for a second ACL injury risk (Webster & Hewett, 2019a). A recent study showed that patients who pass RTS tests have an increased likelihood of RTS (Welling et al., 2020). This indicates that overall athleticism contributes to RTS (Maestroni et al., 2023). However, several studies found that passing RTS criteria did not result in a decreased risk of second ACL injury (Grindem et al.,

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2016; Kyritsis et al., 2016; Losciale et al., 2019; Nawasreh et al., 2017; Sousa et al., 2017; Welling et al., 2020). On the other hand, a study by van Melick et al. discovered that patients who fail to meet RTS criteria were at greater risk of sustaining a second ACL injury (van Melick et al., 2022). Importantly, there is a discrepancy between these studies, as some researchers compared test results for all patients (Grindem et al., 2016; Kyritsis et al., 2016; Losciale et al., 2019; Nawasreh et al., 2017; Sousa et al., 2017; Welling et al., 2020), while others only discussed this for the patients who RTS (Kyritsis et al., 2016; van Melick et al., 2022). Obviously, patients who RTS have an increased risk for a second ACL injury compared to those who do not, and therefore, comparing all patients is methodologically flawed. Furthermore, it was observed that while meeting RTS criteria decreased the risk of second ACL injury in the ipsilateral leg, it paradoxically increased the risk in the contralateral leg (Webster & Hewett, 2019b). However, an editorial response article raised methodological concerns about the validity of the included studies and the risk of bias (Capin et al., 2019). In their reanalysis, it was concluded that patients who pass RTS test batteries have a lower risk for any second ACL injury, ipsilateral or contralateral. In conclusion, current RTS tests might lack appropriate sensitivity and specificity, and additional evidence is required to enhance RTS test batteries, ensuring greater certainty in their capacity to support successful RTS and risk for second ACL injury.

1.1.2. *If it happens on the field, test it on the field*

A plausible explanation for the failure to predict second ACL injuries is the discrepancy between clinical RTS testing and on-field performance in pivoting team sports (Gokeler, Dingenen, & Hewett, 2022). Current test batteries include constrained closed skill tests (like for example strength- or hop tests) in a predictable environment, whereas most ACL injuries occur in unconstrained open random environments. During pivoting team sports, athletes are exposed to multiple stimuli such as opponents, teammates, the ball, and potentially different surfaces (Buckthorpe et al., 2019a), which influences patients' decision-making and motor behavior. Moreover, physical performance in pivoting team sports depends on parameters such as repeated sprint ability, reactive agility performance, and sport-specific endurance (Bizzini et al., 2012), and because of detraining effects due to injury, these physical capacities are often reduced (De Almeida et al., 2018; Mendiguchia et al., 2014; Reilly & Mark Williams, 2003). This prompts a critical question if, for example, analyzing the jump-landing technique of a single leg hop test in a clinical, non-fatigued, pre-planned circumstance is the most optimal method to detect altered movement patterns in patients after ACLR (Gokeler, Dingenen, & Hewett, 2022). Current RTS test batteries do not reflect the sporting demands of pivoting sports. This is supported by recent findings showing kinematical differences in talented youth female football players between testing in a laboratory setting compared to on-field testing (Di Paolo et al., 2023). Achieving good movement quality with minimal risk factors for an ACL injury in a laboratory setting does not automatically translate into proper on-field movement quality. There is a mismatch between RTS testing and the demands of on-field performance in pivoting team sports. In other words, the ecological validity of current RTS tests is too low (Gokeler et al., 2020). A paradigm shift is needed, with more on-field testing instead of traditional clinical testing (Welling & Frik, 2022a). For on-field testing, the use of wearable sensor technology with an inertial measurement unit can be used to analyze movement patterns on the field since wearable sensor technology is portable and therefore useful for on-field testing outside a clinical or laboratory setting (Bolt et al., 2021; Camomilla et al., 2018; Iosa et al., 2016). However, the use of wearable sensor technology is still not widely available, and the analysis is time-consuming which makes it less practical for daily practice. An alternative for movement quality analysis is the Cutting Movements Assessment Scores (CMAS) test for the analysis of cutting movements in which trials are videotaped and scored retrospectively (Dos'Santos et al., 2019). Additionally, neurocognitive elements to stimulate reactive agility and on-field decision-making should be implemented in RTS testing. Neurocognitive elements refer to brain-stimulating exercises that involve being actively engaged in tasks that challenge the brain. Adding neurocognitive elements in RTS tests will increase the complexity of testing while maintaining the coupling of information and movement to stimulate reactive agility, aligning with the dynamic nature of pivoting team sports (King et al., 2021a). However, a recent review concluded that there are no valid reactive agility tests developed for patients after ACLR (Welling & Frik, 2022a). Future research should prioritize the development and validation of on-field testing protocols, leveraging emerging technologies (such as wearable sensor technology) and addressing neurocognitive dimensions (Grooms et al., 2023) to refine the assessment of patients after ACLR.

1.1.3. *One-size-fits-all does not exist*

Undoubtedly, RTS after ACLR is more than muscle strength and hop tests. However, this does not diminish the utility of clinical RTS test batteries in guiding the individual rehabilitation process, based on RTS test results. Historically, the rehabilitation program for patients after ACLR applied a one-size-fits-all principle with a general rehabilitation program instead of an individual approach. However, recent studies found large individual differences in the percentages of passing RTS criteria, in which some patients passed the criteria, but others did not (Gokeler et al., 2017a; Herbst et al., 2015; Toole et al., 2017; Welling, Benjaminse, Seil, Lemmink, Zaffagnini, et al., 2018). Importantly, the RTS criteria vary between these studies and there is currently no consensus on RTS criteria (Mayer et al., 2024), which makes study outcomes hard to compare. Moreover, there is no consensus regarding the optimal quantity and criteria for RTS tests (Webster & Hewett, 2019a). As the number of tests and criteria increases, so does the challenge for patients to fulfill all requirements. If a patient fails to pass only one of the criteria, it means failure of the complete test battery, a phenomenon known as "the penalty of multiple tests" (Webster & Hewett, 2019a). Nevertheless, there is a need for a more individual approach to RTS after ACLR(Karlsson & Becker, 2015). So, instead of the traditional one-size-fits-all principle, it is advised to use an individual dynamic RTS profile for every patient after ACLR (Dingenen & Gokeler, 2017). As to monitor the rehabilitation progression, such an individual RTS profile should be created based on repeated measurements (e.g. every two to three months) assessing the strengths and weaknesses of each individual. For example, some patients might have restored muscle strength 6 months after ACLR, but still show suboptimal jump-landing movement quality at this time point with risk factors for a second ACL injury. Others might show good outcome scores on hop tests (achieving limb symmetry and norm values) but lack quadriceps strength at 9 months after ACLR (Welling, Benjaminse, Seil, Lemmink, Zaffagnini, et al., 2018). Currently, there is no consensus for the most optimal rehabilitation program for patients after ACLR(Mayer et al., 2024), which makes test results between studies hard to compare. For example, most rehabilitation protocols do not expose patients to quadriceps strength until 6–12 weeks after ACLR, which has significant consequences for strength scores on RTS tests (Welling et al., 2019). It is therefore advised that testing during rehabilitation after ACLR should begin far before RTS to monitor the rehabilitation progress and to adjust the content of rehabilitation if necessary. Additionally, testing parameters should align with rehabilitation stages to effectively monitor progress. For instance, inadequate quadriceps strength can potentially impact later stages, affecting cutting performance (Jones et al., 2022), change of direction movements (Jones et al., 2017), and braking strategies (Jones et al., 2016) during on-field rehabilitation (OFR). Asymmetrical quadriceps strength is associated with an increased risk for a second ACL injury (Kyritsis et al., 2016), and it is therefore advised that patients should pass quadriceps strength criteria before entering OFR. Thus, tailoring the test battery and criteria to different phases of rehabilitation is essential. For example, the criteria for return-to-run should be different compared to those for entering OFR. However, consensus is lacking on

criteria for various milestones in rehabilitation after ACLR. For example, a recent international survey revealed the need for more specific return-to-run criteria for patients after ACLR(Sayer et al., 2024). Based on the test results in the different phases of rehabilitation, the individual rehabilitation program should be optimized with increased attention to the relatively weak factors exposed with the test results. For clinicians, this requires clinical reasoning from the significance of test results to the content of the individual rehabilitation program. After every test session, patients get insight into the effects of the optimized individual rehabilitation program on RTS test battery scores, which might positively influence patients' motivation during rehabilitation. This emphasizes the value of repeated measurements during rehabilitation. By consistently monitoring the rehabilitation progress, RTS becomes a dynamic process with an individual approach (Dingenen & Gokeler, 2017).

1.2. Part 2: the content of rehabilitation

1.2.1. Prevent underloading

The result of an RTS test is the outcome of the rehabilitation content. So, another perspective is a critical look at the content of the traditional rehabilitation program (Buckthorpe & Della Villa, 2020). Recently, the different stages of ACL rehabilitation are well described (Buckthorpe, 2019a; Buckthorpe & Della Villa, 2020; Buckthorpe et al., 2023; Van Melick et al., 2016), including essential aspects like restoring muscle strength, jump-landing performance, movement quality, plyometrics, change of direction movements, and agility (Taylor et al., 2017). Nevertheless, numerous studies published over the years have found low rates of patients passing RTS criteria (Gokeler et al., 2017b; Herbst et al., 2015; Toole et al., 2017; Webster & Hewett, 2019a; Welling, Benjaminse, Seil, Lemmink, Zaffagnini, et al., 2018). This raises the critical question if the traditional rehabilitation program is sufficient to prepare patients for a successful RTS. A follow-up study with a more progressive strength training program found that more patients pass RTS criteria if the quality of the rehabilitation program is improved (Welling et al., 2019). This indicates that patients can pass RTS criteria, as long as they train hard enough with sufficient training load. The progressive strength training program employed in this study featured a higher intensity and volume than the traditional training program for patients after ACLR. This was based on principles of the American College of Sports Medicine and other studies ("American College of Sports Medicine Position Stand. Progression Models in Resistance Training for Healthy Adults, 2009"; Garber et al., 2011; Myer et al., 2006, 2008; Schoenfeld, 2010) and the program was divided into different phases, characterized by a gradual increase in training intensity progressing from less than 50% of one-repetition maximal (1RM) in phase 2 to surpass 80% of 1RM in phase 4. It is a straightforward principle: by increasing the quality of the rehabilitation program, results on RTS tests will improve. This is in line with other studies (Della Villa et al., 2020a; Edwards et al., 2018; Franck et al., 2021). Ideally, this principle starts before surgery with preoperative rehabilitation to improve postoperative outcomes (Cunha & Solomon, 2022). It is advised that underloading during rehabilitation should be avoided to optimize preparation for the demands of pivoting team sports and improve outcomes.

1.2.2. Watch your language

Over the last few years, more knowledge was acquired in understanding the impact of instructions and feedback from clinicians to patients (Benjaminse et al., 2015; Bæktoft van Weert et al., 2023; Gokeler et al., 2015). Clinicians should be aware of the effects of their language choices. It is advised to implement the principles of implicit motor learning strategies in rehabilitation for patients after ACLR to improve movement quality and motor performance (Gokeler et al., 2019; Wulf & Lewthwaite, 2016). Abnormal landing patterns in the injured leg are common in ACLR patients (Kotsifaki et al., 2020; Miles et al., 2019; Read et al., 2020; Welling, Benjaminse, Seil, Lemmink, Zaffagnini, et al., 2018; Xergia et al., 2013), which might potentially increase the risk for a second ACL injury (King et al., 2021b). To improve movement quality, implicit motor learning strategies can be incorporated during rehabilitation. Implicit motor learning entails the acquisition of skills and knowledge without conscious awareness, the opposite of explicit motor learning, which involves the conscious body awareness of the patient during practice (Wulf, Shea, & Lewthwaite, 2010). During rehabilitation, the attentional focus of the patient can be guided either through an internal focus (IF) or an external focus (EF). IF instructions can facilitate explicit learning, while EF instructions can facilitate implicit motor learning. During an IF the patients' attentional focus is directed on how to perform body movements. On the other hand, during an EF the patients' attentional focus is directed towards the effects or outcome of the movements (Wulf & Dufek, 2009). The use of EF instructions enhances retention, transfer, and performance (jumping height or distance) and seems consequently a very powerful and effective method (Singh et al., 2021). However, there is currently limited evidence on the efficiency of EF instructions during rehabilitation. This emphasizes the need for ongoing research efforts to improve our understanding and implementation of implicit motor learning strategies with EF instructions for patients after ACLR.

1.2.3. Psychological challenges

Numerous studies conclude that an ACL injury is not only a physical injury but also a psychological injury (Ardern et al., 2013, 2015; Kvist et al., 2005; Nwachukwu et al., 2019; Truong et al., 2020; Welling et al., 2022). Especially, fear of a second injury often plays a significant role before RTS (Clement et al., 2015; Kvist et al., 2005). A recent study found that better physical qualities result in higher psychological scores (measured with the Anterior Cruciate Ligament–Return to Sport After Injury Scale (ACL-RSI) questionnaire) (Aizawa et al., 2022). In other words, if patients are physically better, they feel more psychologically ready for RTS. However, some patients might require specific interventions to improve psychological readiness, even when they are physically ready for RTS (Clement et al., 2015; Te Wierike et al., 2013). Clinicians must be attuned to identifying patients grappling with psychological challenges during rehabilitation. Furthermore, clinicians should be aware of the profound impact of their behavior on patients' experiences throughout rehabilitation, particularly in shaping a positive rehabilitation environment. Embracing and implementing the principles of the self-determination theory during rehabilitation is essential to create a more positive rehabilitation environment (Chan et al., 2017; Welling et al., 2022) with increased motivation and satisfaction. The self-determination theory postulates that a patient's autonomous motivation can be supported by facilitating the satisfaction of three psychological needs: 1) autonomy, 2) competence, and 3) relatedness (Chan et al., 2017). Hence, it is encouraged to involve patients when organizing the training sessions, including supportive feedback instead of controlling feedback while using principles such as self-controlled and positive feedback to enhance autonomy and competence (Hooyman et al., 2014; Lewthwaite et al., 2015; Truong et al., 2022; Wulf & Lewthwaite, 2016). Relatedness can be achieved by improving social support aspects by creating groups where patients can train together and feel supported in sharing their experiences and feelings with others (Disanti et al., 2018; Langford et al., 2009; Truong et al., 2020; Welling et al., 2022; Werner et al., 2018). Moreover, improvement of patient communication is necessary since there is a gap between patient expectations for RTS before the ACLR and outcomes after ACLR. Unrealistic expectations could result in a vicious circle of reduced confidence, poor performance and therefore frustrations, decreased motivation, and decreased patient satisfaction (Chan et al., 2017; Feucht et al., 2016; Logerstedt et al., 2014; Meierbachtol et al., 2018). This can influence the psychological readiness for RTS dramatically. Improvement of patient communication will potentially increase patient satisfaction, and patient motivation and fulfill realistic patient expectations regarding rehabilitation and RTS. Potentially, this will create a more positive rehabilitation environment with motivated patients with less frustrations and

higher psychological readiness for RTS. It is crucial to note that there is limited evidence supporting this statement, emphasizing the need for further research into the psychology of readiness for RTS among patients following ACLR. Additionally, there is a call for more investigation into the impact of implementing the principles of the self-determination theory during rehabilitation.

1.2.4. Train the brain

It is suggested that an ACL injury is not only a musculoskeletal injury but also a small neural lesion (Piskin et al., 2022). After an ACL injury, proprioceptive information flow from neurons in the ACL to the central nervous system is disrupted (Xu et al., 2022). Furthermore, the ligament (ACL) is often replaced by an autograft tendon (hamstring, patellar, or quadriceps). This indicates that the body needs to be reprogrammed, which is known as cortical reorganization (Neto et al., 2019; Piskin et al., 2022). During pivoting team sports, the neurocognitive load is relatively high since players need to be able to process different stimuli and make decisions based on this input. It is consequently advised to train the brain during rehabilitation by creating an environment with a high neurocognitive load, providing patients with a wide variety of motor tasks, as an addition to the high-quality training program. A recent study revealed deficits in neurocognitive function in ACLR patients, which emphasizes the implementation of neurocognitive load in rehabilitation (Lang et al., 2023). Important to mention, it is advised to gradually build up neurocognitive load during rehabilitation to prevent neurocognitive overload. In other words, it is advised to start with a period of relatively low neurocognitive load and to extend this gradually to a rich environment that includes more brain dynamics (Grooms & Myer, 2017). Exercises with neurocognitive load include activities like dual tasks, attention, perception, memory, decision-making, and planning (Piskin et al., 2022). More in detail, examples of relatively simple exercises with neurocognitive load are dyad training (both observation and stimulation) and working memory challenges like simple math tasks in which patients need to call out the correct answer on a math problem while performing a skill (Walker et al., 2021). Traditional rehabilitation programs often lack this neurocognitive approach. The implementation of neurocognitive load in rehabilitation is currently a missing link in the traditional rehabilitation content and more research is needed on the effects of neurocognitive load during rehabilitation for patients after ACLR.

1.2.5. Incorporate on-field rehabilitation

OFR in the late phase of ACL rehabilitation, is essential to prepare our athletes for the demands of the sport. Recent reviews, and expert opinions emphasize the importance of OFR as the bridge between clinical rehabilitation and RTS in pivoting team sports (Buckthorpe et al., 2019a; Buckthorpe et al., 2019b; Della Villa et al., 2020b; Gokeler et al., 2020; Villa Della et al., 2012). OFR includes physical and psychological challenges that reflect the patients' movement behavior when performing their sport (Bizzini et al., 2012; Sheppard & Young, 2006). As mentioned before, physical sport-specific parameters for pivoting team sports are often reduced by detraining effects caused by injury (De Almeida et al., 2018; Mendiguchia et al., 2014; Reilly & Mark Williams, 2003) and during OFR these physical parameters are trained gradually to build up chronic training load. As a result, patients' psychological readiness for RTS of patients improves (Meierbachtol et al., 2018). Important to mention, that patients experience OFR as the most fun part of rehabilitation (Welling et al., 2022). In restoring movement quality during OFR, it's essential to progressively retrain patients' motor control to ensure proper movement technique with minimal risk factors for a second ACL injury (Buckthorpe et al., 2019a). This progression should involve increasing complexity in sport-specific movements, beginning with preplanned actions such as basic curved running drills and advancing to reactive agility movements with high neurocognitive load, potentially involving pressure from an opponent player. Additionally, to facilitate understanding and application of appropriate cutting mechanisms, practitioners can refer to the technical framework proposed by Donelon et al. (Donelon et al., 2020), which offers guidance on developing and refining technical movement skills. Furthermore, for a gradual increase of chronic training load including the progressive incorporation of neurocognitive elements, the control-chaos continuum can be used which is adapted to football (Taberner et al., 2019) and basketball (Taberner et al., 2023). Within this five-phase framework, patients start in the high control phase which includes a linear running protocol with low musculoskeletal impact forces, followed by the moderate control phase with change-of-direction movements, control to chaos with more sport-specific exercises (for example football- or basketball-specific technical exercises), moderate chaos with agility exercises, and high chaos including "worst-case scenarios" (high speeds/high chaos). Especially the high chaos phase includes highly variable, spontaneous, and unanticipated movements reflecting the unpredictable nature of pivoting team sports (Taberner et al., 2019). However, there is currently no evidence that supports the implementation of the control-chaos continuum in rehabilitation for patients after ACLR. Further research in this area is necessary to investigate its efficacy and potential benefits.

1.2.6. Secondary prevention

A primary role of rehabilitation after ACLR is reducing the risk for a second ACL injury. However, current rehabilitation programs seem to fail to reduce the risk for a second ACL injury and therefore, ACL rehabilitation does not stop after achieving RTS. It is therefore crucial to counsel patients on the impact of their behavior post-rehabilitation in the context of secondary ACL injury risk (Wong et al., 2023). While some patients might continue with their training program after rehabilitation, others do not. This is in line with a recent study that found decreased scores on hop tests in patients 5 years after ACLR, compared to their performance during rehabilitation (Patterson et al., 2020). This indicates a decrease in physical parameters and a possible increase in secondary ACL injury risk. Clinicians and patients should be aware of the effects of their behavior after rehabilitation, in relation to secondary ACL injury risk.

1.3. Part 3: the RTS continuum

Crucially, RTS is not a static moment in time but rather a dynamic and holistic process with an individual approach. This makes RTS for patients a complex journey. Recently, a new framework (the RTS continuum) was proposed by Buckthorpe et al. with more focus on performance (including sport-specific OFR) instead of prevention (Buckthorpe, 2019a). This progressive framework includes four stages starting from OFR, to return to training (RTT), to return to competition (RTC), and return to performance (RTP). According to this framework, successful RTP is achieved when patients return to competitive matches with optimal performance, including a minimal risk for a second ACL injury (Buckthorpe, 2019a). Before entering the first phase of the continuum (OFR), patients need a basic physical and psychological level of readiness, which is measured with the current clinical RTS test battery. Thus, a paradigm shift is needed in which current clinical RTS criteria like muscle strength, hop tests, movement quality, and psychological parameters should be used as minimal requirements for patients to start OFR, instead of strict criteria for RTS, as visually presented in Fig. 1. The transitions between the different stages are dynamic and Global Positioning System (GPS) monitoring can be used to monitor the external load progression between the stages of the RTS continuum, to build up chronic training load, and to avoid spikes in external training load (Blanch & Gabbett, 2016; Reid et al., 2013). However, it is yet unknown which parameters are associated with the different transitions in the RTS continuum, and more research is needed in this domain.

Over the past 15 years, it became evident that there are significant relations between physical and psychological parameters and RTS outcomes. The concern here is that the relationships between these isolated

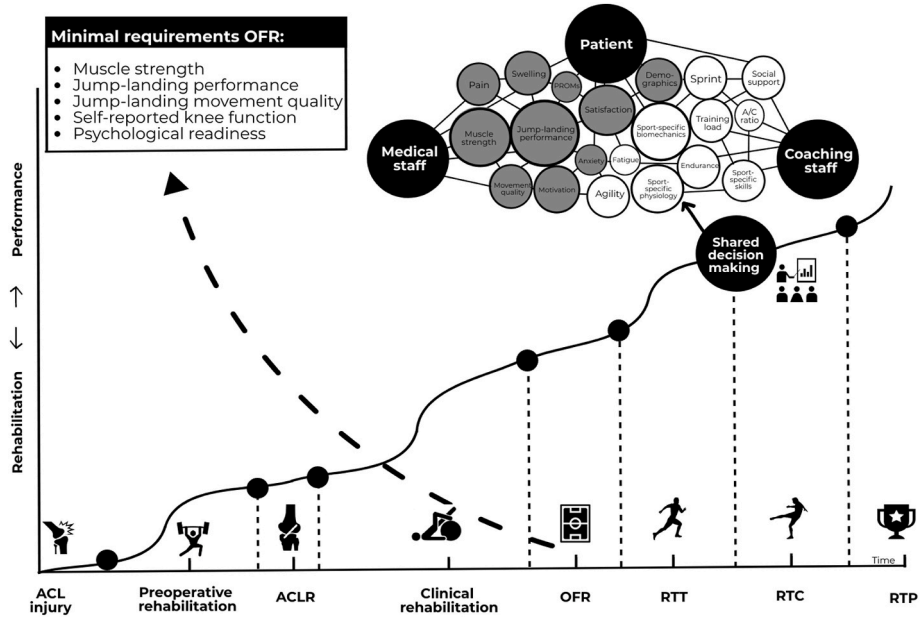

Fig. 1. Example of an individual dynamic RTS profile as a non-linear process in the transition phase between RTT and RTC within the road to recovery along the RTS continuum. In this example, in the "web of determinants", the grey circles were objectified, and the white circles were not. The size of the circles represents different parameters and is different in every phase and transition for every individual patient. OFR = on-field rehabilitation, RTT = return to training, RTC = return to competition, RTP = return to performance.

parameters and RTS outcomes are non-linear (Karlsson & Becker, 2015) and represent only a part of the full picture (Feller & Webster, 2013). Hence, a more comprehensive and holistic approach is needed and consequently, the complex systems theory has been proposed as a pathway (Bittencourt et al., 2016; Tassignon et al., 2019). According to this theory, delving into quantitative parameters alone does not automatically unveil the understanding of behaviors, experiences, and ultimate outcomes. Rather than focusing solely on isolated parameters, patients should be perceived as complex and holistic biological systems wherein numerous factors and relationships collectively influence the outcomes, in a so-called 'web of determinants' (Bittencourt et al., 2016; Tassignon et al., 2019). Unfortunately, complexity includes accepting some level of uncertainty (Doll & Trueit, 2010). As mentioned before, one-size-fits-all does not exist, so an individual approach is needed for every patient. As a result, the transitions between phases of the RTS continuum are inherently complex and it is therefore important that all members of a multidisciplinary team (patient, medical staff, coaching staff) should participate in managing the balance between rehabilitation, training, and competition (shared decision-making) (Bittencourt et al., 2016; J. King et al., 2019; Tassignon et al., 2019).

2. Conclusion

There are still more questions than answers regarding RTS after ACLR. The findings of the last 15 years are only a part of the puzzle and future research is needed. Unfortunately, RTS after ACLR is a dynamic and individual process and therefore complex. However, if we manage to do the relatively simple things the right way, the glass is half full and outcomes will improve.

Data availability statement

All data used to support the findings of this study are available upon request wouter.welling@pro-f.nl.

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Ethical statement

This study was approved by the institutional review board (IRB) of PRO-F physical therapy approved this study (IRB nr: 2023001).

CRediT authorship contribution statement

Wouter Welling: Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

None.

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LIST OF ABBREVIATIONS

ACL = anterior cruciate ligament
ACLR = anterior cruciate ligament reconstruction
RTS = return to sports
IF = internal focus of attention
EF = external focus of attention
OFR = on-field rehabilitation
RTT = return to training
RTC = return to competition
RTP = return to performance
GPS = Global Positioning System

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