Return to sport after an anterior cruciate ligament reconstruction

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DOI:
10.33612/diss.203441661

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GENERAL INTRODUCTION

A rupture of the anterior cruciate ligament (ACL) is a devastating injury that often occurs in pivoting sports such as soccer, handball and basketball [1]. The incidence of ACL injuries in pivoting sports is relatively high: 0.8-2.4% in male athletes and 2.0-3.2% in female athletes worldwide [2]. Patients who wish to return to sports (RTS) after an ACL rupture are advised to undergo an ACL reconstruction (ACLR) to restore knee function and stability [1]. The definition of RTS is as follows: returning to the pre-injury level of sport in both training and matches, but not yet at the desired performance level [3]. In the Netherlands, approximately 10000 ACLR's are performed every year [3]. An ACLR has significant consequences for patients [4, 5]. Patients after an ACLR have to deal with social consequences like the inability to participate in pivoting sports for a certain time, and injury in general is one of the main reasons for drop out in sports [4, 5]. The rate for a second ACL injury is high especially in patients aged <25 years [2]. Furthermore, patients with an ACLR have a 3-fold increased risk for osteoarthritis in the long term [5]. In addition to personal impact, an ACLR has financial and public health consequences since it is one of the most expensive knee arthroscopy procedures [4,5]. The rehabilitation program after ACLR and inability to work are high costs for public health care [6].

The most frequent question a patient asks after an ACLR is: "when can I play again?" [7]. However, the multifactorial decision whether and when a patient can RTS is one of the most challenging and complex decisions to make [8]. Before surgery, more than 90% of patients expect to RTS without any restrictions [9]. Unfortunately, only 65% of amateur athletes return to their pre-injury level of sports [6]. Rates for returning to competitive amateur sports are even lower, with only 55% of amateur athletes returning to play matches [6]. Furthermore, patients who RTS have a relatively high risk for a second ACL injury (up to 23%), especially for patients younger than 25 years [10]. There is need to improve current rehabilitation approaches.

Currently, RTS decisions are mostly based on subjective criteria such as "good stability" or "no side to side deficits" [11]. Specifically, national surveys between 2010 and 2015 reporting that only 30% of the clinicians considered objective testing before RTS [12, 13]. To illustrate, it was found that time postoperatively was often the only criteria for RTS [11]. To improve current RTS rates, objective measurements and criteria to support the RTS decision for patients after an ACLR are needed [14]. Unfortunately, there is a lack of objective measurements and criteria that can be used to guide the RTS decision after an ACLR. However, there are some promising physical and psychological factors described in literature and used in daily practice.

Symmetrical quadriceps and hamstring muscle strength are suggested to be essential for RTS [15]. More symmetrical hamstring strength was observed in patients who RTS as compared to patients who did not RTS [14]. Additionally, more symmetrical quadriceps strength in the injured leg compared to the non-injured leg prior to RTS is associated with a lower risk for second ACL injury [16]. These findings emphasize that symmetrical quadriceps and hamstring strength are important for patients to be able to RTS, including a decreased risk for second ACL injury. Currently, there is a lack of consensus for using muscle strength criteria in RTS decision-making. Commonly, limb symmetry indices (LSI) are computed for both quadriceps and hamstring strength with the non-injured leg used as a reference for the

injured leg [17]. However, the European Board of Sports Rehabilitation recommends that muscle strength should also be expressed in absolute values [17]. In addition, hamstring/quadriceps ratios are important since female athletes who demonstrated the combination of decreased hamstring strength and increased quadriceps strength have increased risk for ACL injury [18, 19]. It is advised to include LSI values, absolute values and hamstring/quadriceps ratio's as criteria for muscle strength [17, 18 ,19].

Jump-landing performance is important for RTS in patients after ACLR, and hop tests are frequently used test for measuring jump-landing performance [15, 20]. Patients with higher scores on hop tests are more likely to return to the pre-injury level of sport [15]. It is advised to use a hop test battery to support RTS decision-making [20]. Caution is warranted when using the non-injured leg as a reference value for the injured leg when analyzing hop test results since bilateral deficits can overestimate performance. Besides performance, analyzing jump-landing movement quality seems essential since research found that patients who showed less optimal movement quality (more knee valgus displacement) have an increased risk for second ACL injury [21]. Moreover, a stiffer landing with a decreased knee flexion angle in the injured leg was found in patients after ACLR, which potentially increase the risk for second ACL injury [22]. These findings emphasize the importance of jump-landing analysis for both performance and quality of movement in patients after ACLR.

In addition to the physical readiness, monitoring patient-reported outcome measures (PROMs) for self-reported knee function and psychological readiness are important for successful RTS. Significant lower scores on self-reported knee function questionnaires were found in patients who did not RTS compared to patients who RTS [23]. Additionally, previous studies found that psychological readiness is a predictor for returning to pre-injury levels of sport in patients after ACLR [23, 25]. In other words, patients with higher scores on questionnaires regarding psychological readiness for RTS had increased chances to successfully return to the pre-injury level of sport. Especially in the final phase of rehabilitation prior to RTS, the experience of fear for second ACL injury seems to play a significant role [26].

Besides test methods, another perspective is to look critically at the content of the strength training program. Delaying RTS to at least 9 months after ACLR allows more time, however, this is only effective if this time is filled with high-quality rehabilitation [27]. One of the main components in early rehabilitation after ACLR is restoring quadriceps and hamstring strength [28]. However, rehabilitation programs without a gradual increase in intensity and volume of the strength training program result in muscle strength deficits [17]. The intensity and volume of the standardized traditional strength training program might not be sufficient enough for patients to RTS since RTS rates are relatively low. Furthermore, there is a lack of published recommendations for the content the strength training program after ACLR [27, 29]. Therefore, the standardized traditional strength training program should be critically reviewed. More progressive strength training should be included in the rehabilitation program for restoring muscle strength deficits in patients after ACLR.

Muscle strength, jump-landing performance and movement quality, PROMs for self-reported knee function and psychological readiness for RTS should be objectively monitored

during rehabilitation to support the RTS decision-making process (Figure 1). However, the optimal objective test methods and cut-off criteria to evaluate the readiness to RTS and to decrease the risk for a second ACL injury remain yet unknown.

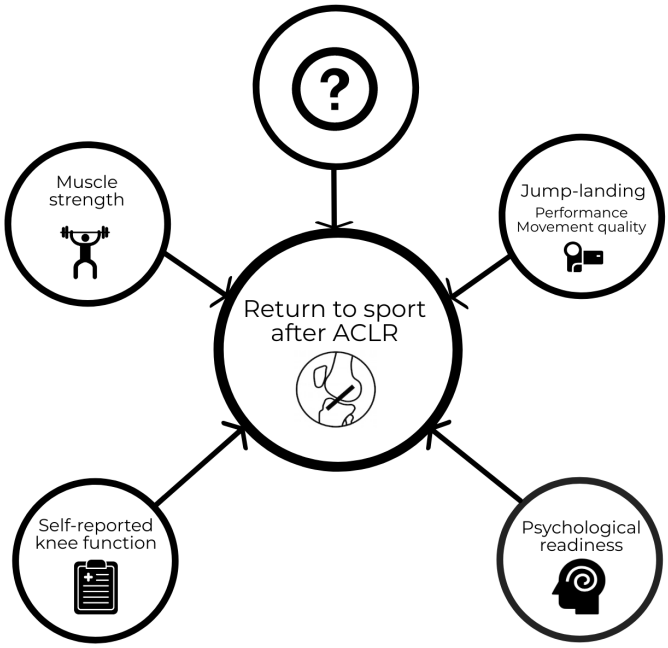

Figure 1. *Model that describes important factors for RTS in patients after ACLR, including a question mark.*

The aims of this dissertation are: 1) to investigate which criteria should be used for determining RTS readiness of patients after ACLR, 2) to investigate the effects of a progressive strength training program on test results and passing rates of RTS criteria and 3) to investigate the relationship between passing criteria, RTS rates and potential risk for second ACL injury.

OUTLINE OF THE DISSERTATION

Several factors are important for successful RTS in patients after ACLR. Therefore, a multifactorial test battery was developed in **Chapter 2**. The test battery included an isokinetic muscle strength test for quadriceps and hamstring strength, three different hop tests to measure jump-landing performance and a jump-landing test to assess the jump-landing movement quality. Moreover, two questionnaires were added related to PROMs for self-reported knee function and psychological readiness for RTS. The test battery was performed in patients around 6 months after ACLR. Several criteria were defined for the test battery and the goal of this study was to investigate how many patients pass RTS criteria. A follow-up study was performed in **Chapter 3** including the same RTS test battery in a larger sample of patients after ACLR. It was investigated how many patients pass the RTS criteria at both 6 and 9 months after ACLR.

For hop tests, the non-injured leg is often used as a reference value for the injured leg. It is therefore common to calculate a LSI value. However, bilateral deficits can result in high LSI values which could overestimate the patients' performance. Therefore, in **Chapter 4** the use of LSI values in hop tests was investigated by comparing the scores of the injured leg and non-injured leg of patients after ACLR with age and gender matched normative data.

Altered movement patterns in patients after ACLR could potentially increase the risk for second ACL injury. However, jump-landing patterns are often analyzed in a quantitative manner only (for example jumping distance), while outcomes related to the quality of movement are often not captured. Therefore, jump-landing patterns were analyzed quantitatively and qualitatively during a single leg hop test in **Chapter 5**. We used a simple, clinically friendly 2D movement analysis method in both the injured leg and non-injured leg in patients after ACLR.

In **Chapter 6** the standardized rehabilitation program was adapted and more progressive strength training was added to the ACLR rehabilitation and patients were followed during their rehabilitation and tested around 4, 7 and 10 months after ACLR. In this study we investigated the effects of the adjusted rehabilitation program on isokinetic quadriceps and hamstring strength and PROMs for self-reported knee function. Furthermore, the results of patients after ACLR were compared with healthy age and sex matched controls.

Many studies regarding RTS after ACLR are focused on quantitative analysis. However, there is a lack of studies that are focused on patients' experiences during rehabilitation after ACLR. Therefore, an open-ended survey was conducted in **Chapter 7** to understand the positive and negative experiences of patients during the rehabilitation.

Currently, it is unknown if patients who pass RTS criteria have greater likelihood for RTS. Therefore, in **Chapter 8** patients were followed up to two years after ACLR, to investigate the relation between the RTS test battery and RTS rates. In addition, we investigated the relation between the RTS test battery and second ACL injuries.

In **Chapter 9**, the findings of the research projects are discussed with an outline for future research.

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