

## Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction

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### Abstract

**Purpose** The purpose of this article is to present recommendations for new muscle strength and hop performance criteria prior to a return to sports after anterior cruciate ligament (ACL) reconstruction.

**Methods** A search was made of relevant literature relating to muscle function, self-reported questionnaires on symptoms, function and knee-related quality of life, as well as the rate of re-injury, the rate of return to sports and the development of osteoarthritis after ACL reconstruction. The literature was reviewed and discussed by the European Board of Sports Rehabilitation in order to reach consensus on criteria for muscle strength and hop performance prior to a return to sports.

**Results** The majority of athletes that sustain an (ACL) injury do not successfully return to their pre-injury sport,

even though most athletes achieve what is considered to be acceptable muscle function. On self-reported questionnaires, the athletes report high ratings for fear of re-injury, low ratings for their knee function during sports and low ratings for their knee-related quality of life.

**Conclusion** The conclusion is that the muscle function tests that are commonly used are not demanding enough or not sensitive enough to identify differences between injured and non-injured sides. Recommendations for new criteria are given for the sports medicine community to consider, before allowing an athlete to return to sports after an ACL reconstruction.

**Level of evidence** IV.

**Keywords** Return to sport · Strength · Hop performance · Patient's opinion · Knee function

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## Introduction

The majority of athletes that sustain an anterior cruciate ligament (ACL) injury do not successfully return to their pre-injury sport [8, 9]. One major reason for this could be that the athletes do not regain their pre-injury muscle function. A recent review concluded that, even though the vast majority (85–90%) obtained what were regarded as normal or near normal strength values, the return to sport rate was low [9]. Fear of re-injury was the most common reason for giving up sports participation or for returning to a lower level of sports [9]. Furthermore, recent studies report that patients who had undergone ACL reconstruction had  $\geq 90\%$  muscle function capacity in their injured leg compared with their non-injured leg and, at the same time, reported poor results when it came to rating their knee function during sports as well as their knee-related quality of life [2, 61, 66, 67, 91]. The results in muscle function tests do not harmonise well with the patients' own experiences and their scores for self-reported outcome measures. The interpretation of this discrepancy could be that the muscle function tests that are commonly used are not demanding enough or not sensitive enough to identify differences between injured and non-injured sides. Additionally, when tested during fatigued conditions 1 year after ACL reconstruction, only two-thirds of the athletes performed satisfactorily, despite the fact that they had  $\geq 90\%$  hop capacity when not fatigued [11]. Again, this indicates that the muscle function criteria that are commonly used are not sufficient.

The members of the European Board of Sports Rehabilitation (EBSR) searched, reviewed and discussed relevant literature in order to reach consensus on criteria for muscle strength and hop performance prior to a return to sports after an ACL reconstruction.

### A successful return to sports

There are many factors to consider when making the decision about when to allow a patient to return to sport. Creighton and et al. [21] have outlined a *decision-based return to play model* comprising three steps. Step 1 involves *medical factors* for evaluating the patient's health status, such as demographics, medical history, symptoms and signs. Step 2 involves *sport risk modifiers*, such as the type and level of sport, for evaluating risks if the patient returns to sport, while Step 3 involves *decision modifiers*, such as season, internal and external pressure and conflict of interest. The present article focuses on criteria for muscle function in Step 1, which is important for the risk evaluation process.

The definition of a *successful* return to sport is unclear in the literature. It needs to be clarified whether the return is to a pivoting or non-pivoting sport, contact or non-contact sport, the same pre-injury sport and same competitive level, the same sport but on a lower level, a different sport, or that the athlete merely perceives that the return to sport is successful [8, 47, 55, 76]. Furthermore, it is unclear how long the athlete needs to maintain that specific level of sporting ability, before it can be claimed that the return was successful. Can it be accepted as a successful return to sports if, after 1, 3 or 12 months, the athlete sustains a re-injury, contralateral injury or a subsequent injury to another structure? For this reason, the use of the term *return to sport* must be accompanied by a detailed description of the type and level of activity, as well as the time of return and duration of participation.

A successful return to sport in the short term means a low risk of re-injury [5, 56, 68, 83, 89]. ACL re-injury occurs in 6–13% of ACL-reconstructed knees [57, 83, 95] and 2–6% sustain a contralateral ACL injury [83, 89, 102]. It has been reported that, in elite Alpine skiing, as many as 30% of the ACL-injured skiers sustain an ACL injury in the contralateral knee [77].

In the long term, a successful return to sport means that there is a low risk of developing knee osteoarthritis (OA) [5, 50, 60, 64–66, 101]. Several risk factors for the development of knee OA after ACL injury are reported in the literature [24, 41, 75, 84, 85]. A systematic review discussed whether the risk of developing knee OA might be somewhat exaggerated in the literature [64]. It has been stated that 50% of patients with an ACL injury [49] and 70% of the patients that also have a meniscal injury will develop knee OA [27]. The systematic review concluded that there was a 0–13% knee OA prevalence 10–15 years after an isolated ACL injury and that patients with combined ACL and meniscal injuries had a prevalence of 21–48% [64]. Strong evidence identifying meniscal injury and meniscectomy as risk factors for the development of knee OA after ACL injury was found [64]. However, the results in a single-leg hop test 1 year after the ACL injury have been stated as a predictor of future development of knee OA [75], and muscle weakness is commonly suggested to be a risk factor [24]. It has further been suggested that neuromuscular function may be of importance in preventing knee OA [40, 71, 81, 100] and that poor muscle function might be a predictor of OA development [75, 92, 93]. It is possible that early neuromuscular rehabilitation resulting in good knee function, and a modification of physical activity could reduce the risk of developing knee OA in the long run after ACL injury [42].

It seems clear that within the first year after surgery, far from all athletes with an ACL injury return to their

pre-injury level of sport. Ardern et al. [8] found that as many as two-thirds of the athletes who had undergone ACL reconstruction had not returned to the same competitive level of sport 12 months after surgery. Their analysis of return to sport outcomes in six other studies [20, 32, 45, 58, 87, 96] showed that 75% of the athletes returned to some form of sports activity. Sixty-four per cent returned to competitive sports, but not necessarily at the same level as pre-injury. It also seems clear that women (26%) have a much lower rate of successful return to the same pre-injury level of sport compared with men (37%), even though women and men appear to have the same intentions to return to sport [8].

Despite the seemingly low rate of athletes that actually do return to the same pre-injury level of sport within the first year after surgery, the recommendations that are given to the ACL-injured athlete on when to return to sport usually range between 3 and 9 months [8, 43, 86].

### Factors affecting the ability to return to sports

Many factors that affect an injured athlete's ability to return successfully to sports after an ACL injury have been suggested. The most common factors discussed in the literature are the pre-injury status of the athlete, associated knee injuries, time to treatment, time to surgery, surgical technique, knee kinematics after injury/surgery, rehabilitation protocol, compliance, functional knee stability, knee symptomatology and the level/intensity of the sport [3, 8, 9, 13–16, 19, 21–23, 29, 88]. The achieved level of muscle function [2, 12, 23, 34, 46, 53, 59, 72, 79, 97], psychological factors, such as fear of re-injury and low self-efficacy beliefs, the patients' 'desired' physical activity level and social factors, such as family or work career, are also frequently discussed [8, 18, 28, 29, 37, 38, 44, 45, 47, 54, 63, 64, 90, 94].

Furthermore, it has been noted that patients' compliance decreases over time during the rehabilitation process [13]. ACL-reconstructed athletes express frustration that the progress during rehabilitation is much slower than they had expected. As a result, the compliance of some patients decreases, some will even give up, while others increase their efforts and continue with their rehabilitation [32].

### Muscle function

Restored lower extremity muscle function, such as knee extensor and flexor muscle strength and one-legged jumping ability, is considered to be important after an ACL reconstruction in order successfully to return to sports or physical activity [2, 10, 23, 35, 47–49, 57, 75]. It remains

unclear whether patients with an ACL reconstruction sufficiently restore their muscle function, since most studies only report results at group level, which are between 70 and 90% of the non-injured leg [4, 6, 7, 17, 36, 39, 51, 52, 58, 70, 73, 74, 80, 82, 99, 104]. It is furthermore unclear whether the graft choice influences the recovery of muscle function. A recent meta-analysis indicated that patients with bone-patellar tendon-bone autograft have greater deficits in extensor muscle strength and a lower deficit in flexor muscle strength compared with hamstring autograft [103]. In a 2- to 5-year follow-up, Ageberg et al. [2] did not find any differences between patients who, in a randomised clinical trial (RCT) [25], had undergone surgical reconstruction and rehabilitation and those patients who had been treated solely with rehabilitation. This indicates that reconstructive surgery may not be a prerequisite for restoring muscle function.

The limb symmetry index (LSI) has been the most frequently reported criterion for assessing whether muscle strength and hop performance are normal or abnormal, i.e. that the capacity of the injured leg is, or is not, as good as that of the non-injured leg. The rationale is to ensure that the injured leg reaches an acceptable LSI level in order to minimise overuse and/or acute injury when returning to sport or strenuous work [10]. An LSI of <90%, i.e. more than 10% difference between limbs following ACL injury and reconstruction, has been regarded as unsatisfactory for both strength and hop performance. One major problem with the LSI in research is that it conceals individual results, which can be revealed if, for example, the results are presented as success rates, i.e. the proportion of patients that reach an acceptable LSI. Long-term follow-ups of patients with an ACL injury indicate that muscle function, presented as the LSI, improves somewhat over time from 1 year up to 2–5 years after surgery [1, 56, 83, 84]. This can be partly explained by the fact that a reduction in muscle strength in the non-injured leg over time is not unusual [33, 91]. In conclusion, it seems clear that the validity of the LSI for evaluating the effects of rehabilitation interventions requires further study.

### Battery of muscle function tests

When it comes to the assessment of strength and functional performance after ACL reconstruction, the concept of a 'battery of tests' has been suggested in order to measure strength and hop performance [19, 21, 22, 30, 59]. A battery of tests, including three different tests for lower extremity muscle strength (leg extension, leg flexion and leg press) and three different hop tests (vertical jump, hop for distance and side hop), has been shown to be reliable and to have a greater ability, compared with any single test,

when it comes to discriminating between the injured and non-injured sides in patients after an ACL injury and those who have undergone ACL reconstruction [30, 59]. When evaluating each test in the battery of tests separately, the patients had, at group level, reached  $\geq 90\%$  of the capacity in their injured leg at both the 1- and 2-year follow-ups [91]. When using the more demanding criteria for a successful outcome in terms of muscle function, i.e. that the patients should reach  $\geq 90\%$  on all the tests in the battery, the results were considered poor. Fewer than 50% of the patients were successful when using the more demanding criteria of  $\geq 90\%$  in *all three tests* in the strength test battery or  $\geq 90\%$  in *all three tests* in the hop test battery. Similarly, by increasing the acceptable LSI level from  $\geq 90\%$  to  $\geq 95\%$  or  $\geq 100\%$ , the results were naturally poorer for each of the individual tests in the battery of tests. Finally, when using the criteria of reaching an LSI of  $\geq 100\%$  in all three strength tests, *as well as* in all three hop tests, none of the patients had normal muscle function [91].

As previously stated, there appears to be a discrepancy between the patients' self-reported results for knee symptoms/function and the results of muscle function tests [8]. At a mean follow-up time of more than 3 years after ACL reconstruction, a recent review and meta-analysis by Ardern et al. [9] of 48 studies, evaluating 5,770 athletes with an ACL reconstruction, showed that 82% of the athletes had returned to some kind of sport, 63% to their pre-injury level and 44% to their pre-injury level of competitive sport. Patients with good hop performance were more likely to return to sport than patients with poor hop performance. Fear of re-injury was the most common reason for giving up sports participation or for returning to a lower level of sport [9]. This could indicate that the patients are not satisfied with their knee function and that the criteria for muscle strength and hop performance are insufficient.

Furthermore, three recent studies report high LSI values for single muscle function tests 2 years after surgery, with scores of between 70 and 90 on the KOOS<sub>Sports&Recreation</sub> and between 65 and 75 on the KOOS<sub>Quality-of-life</sub> [2, 61, 91]. The same pattern has recently been reported at 2 years and 10–15 years after ACL surgery [66, 67]. This could mean that the muscle function tests that are commonly used are not demanding enough or not sensitive enough to identify differences between the injured and non-injured sides and muscle function results do not correlate with patients' experience and reported outcome measures.

Athletes who had returned to sports were classified as having unsatisfactory hop capacity when they were tested during fatigued conditions 1 year after ACL surgery [11]. All the subjects had  $\geq 90\%$  hop capacity in their ACL-reconstructed leg compared with the non-injured leg during non-fatigued conditions. However, when the quadriceps

muscle was fatigued, the ACL-reconstructed leg was unable to perform satisfactory in two-thirds of the subjects. Again, it is likely that the muscle function tests that are commonly used are not sensitive enough to identify differences between injured and non-injured sides.

Muscle function deficits following ACL reconstruction can be due to insufficient rehabilitation protocols [74]. It is possible to speculate that ACL rehabilitation protocols focus too heavily on functional low-loading and sport-specific exercises. As a result, weight training intensity might be too low to increase muscle strength and muscle volume to satisfactory levels. A 12-week eccentric resistance training programme, implemented as early as 3 weeks after ACL reconstruction, resulted in greater increases in muscle volume and muscle function of the quadriceps and gluteus maximus muscles compared with a standard rehabilitation protocol [26]. As increases in muscle strength and volume take a considerable length of time [98], it may be possible that the time that the patients spend on weight training during rehabilitation is in fact, in most cases, insufficient.

In order to obtain good muscle function after ACL reconstruction, three factors have been found to be predictors of outcome: good pre-operative quadriceps strength [23], little or no pre-operative anterior knee pain [31] and high self-efficacy of knee function [90].

In order to match the patients' low rate of return to sports and their low scores for sports ability and knee-related quality of life, as well as to minimise the negative short- and long-term consequences for those that do return to sports, the criteria that are commonly used for muscle function should be revised. This means that more precise, demanding criteria for muscle function are needed. Rehabilitation protocols should therefore be further developed to be more effective and/or more time needs to be spent on muscle function rehabilitation.

The recommendations of the EBSR relating to muscle function in individuals who have undergone ACL reconstruction are based on what is published in the scientific literature, as well as clinical and research experience among the members of the EBSR.

Please observe that the recommendations (Table 1) are based on comparisons with the non-injured leg. No data are as yet available in the literature in terms of absolute muscle strength and hop value levels for different sports. Furthermore, we do not make any recommendations for eccentric strength criteria, as not enough data are available in the literature. Muscle function is naturally far more complex than knee extensor strength, knee flexor strength and one-legged hop capacity. Aspects of muscle function, such as lower extremity strength performance in other situations or the importance of motor control, have not been considered in the present article.

**Table 1** Recommended criteria for strength and hop performance prior to a return to sport after ACL reconstruction

Type of sport	LSI strength	LSI hop performance
Pivoting		
Contact	100% on knee extensor <i>as well as</i> knee flexor strength	90% on two maximum <sup>a</sup> <i>as well as</i> one endurable <sup>b</sup>
Competitive		
Non-pivoting		
Non-contact	90% on knee extensor <i>as well as</i> knee flexor strength	90% on one maximum <sup>a</sup> <i>or</i> one endurable <sup>b</sup>
Recreational		

<sup>a</sup> For example, a vertical jump and a hop for distance [30, 62, 69, 78]

<sup>b</sup> For example, the triple jump [78], stair hop [78] or side hop test [30]

### EBSR recommendations

1. Reports on a return to sport must be accompanied by a detailed description of the type and level of sport, as well as the time of return and duration of participation.
2. Muscle strength and hop performance must be presented as both absolute values and the LSI.
3. LSI values must be presented at group level, together with success rates, i.e. the proportion of patients who achieve an acceptable LSI.

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