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Knee extensor strength and hop test performance following anterior cruciate ligament reconstruction

Kristoffer W. Barfod [a,b], Julian A. Feller [a], Taylor Hartwig [a], Brian M. Devitt [a], Kate E. Webster [c,*]

[a] OrthoSport Victoria Research Unit, Epworth HealthCare, Level 5, 89 Bridge Rd, Richmond 3121, Australia
[b] Afdelingslæge Artroskopisk Center, Hvidovre Hospital, Denmark
[c] School of Allied Health, College of Science, Health & Engineering, La Trobe University, Bundoora, Melbourne, VIC 3086, Australia

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ABSTRACT

Background: Knee extensor strength and single limb hop for distance have been suggested as useful measures to evaluate readiness to return to sport after anterior cruciate ligament (ACL) reconstruction.
The aim of the study was to examine the association between knee extensor strength and single leg hop for distance following ACL reconstruction and to determine the proportion of patients with knee extensor strength symmetry deficits at six and 12 months.
Methods: From December 2013 to December 2015 69 patients aged 14 to 45 undergoing primary ACL reconstruction were recruited. Isokinetic concentric knee extensor strength testing and single limb hop for distance were performed six and 12 months postoperatively. Satisfactory knee extensor strength was defined as a leg symmetry index (LSI) ≥85%.
Results: At six months 27.5% (19/69) of patients had recovered satisfactory knee extensor strength in the injured leg, improving to 46.4% (32/69) at 12 months. Recovery of satisfactory strength was associated with hopping distance. Hop symmetry was achieved considerably faster than knee extensor symmetry, with 66.7% (46/69) of patients demonstrating satisfactory hopping symmetry at six months, 89.9% (62/69) at 12 months. Recovery of hopping distance was not associated with knee extensor strength.
Conclusions: Single leg hop test cannot be used as a surrogate measure for knee extensor strength as no association was found between hop tests and knee extensor strength. Less than one in three patients at six months and one in two at 12 months had recovered satisfactory knee extensor strength.

1. Introduction

Weakness of the knee extensors is a common impairment following anterior cruciate ligament (ACL) reconstruction [1–9], and has been associated with an increased risk of rupture of the ACL graft [10]. However, re-injury rates vary considerably after ACL reconstruction. A systematic review by Wright et al. reported an overall rate of graft rupture of 5.8% and contralateral ACL rupture rate of 11.8% at a minimum five year follow-up [11]. The rates are higher in younger patients where evidence suggests that the

* Corresponding author at: School of Allied Health, College of Science, Health and Engineering, La Trobe University, Victoria 3086, Australia.
E-mail address: k.webster@latrobe.edu.au (K.E. Webster).

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risk of a second injury after ACL reconstruction is as high as 30% [12–14]. It is therefore important to be able to identify and address factors that might contribute to an increased risk of a second injury [12–14].

The timing of clearance to return to sport following ACL reconstruction varies widely between centres, as does the basis on which the decision is made [15]. In attempts to assess when a patient is able to make a safe return to sport, various strength tests, functional tests including hop tests, and patient reported outcomes have been used as assessment tools, typically somewhere between six and 12 months after surgery [10,16,17]. Strength testing, particularly of the knee extensors, is commonly included in test batteries. Isokinetic dynamometric strength testing is frequently reported but protocols vary widely with regard to mode of contraction, angular velocity, number of repetitions and range of motion. One such protocol proposed by Undheim et al. [18] in 2015 suggested concentric knee extension and flexion at an angular velocity of 60°/s, at a set range of motion of 0°–100°, using gravity correction, and measuring peak torque [18].

Most assessments use the non-operated leg for comparison, calculating a symmetry index to indicate the degree to which the operated leg has recovered [10,16,17]. Criterion thresholds for an acceptable recovery vary widely, with proposed levels of knee extensor strength ranging from 65% to 90% of the contralateral leg [10,4,7]. A commonly used criterion for return to sport is a leg symmetry index (LSI) of 85% or above for both strength and hop performance [20,21]. However, previous studies have shown that as few as 28% to 60% of patients have an LSI of 85% or greater for knee extensor strength at the time of return to sport, and that an LSI of less than 85% frequently persists for as long as two years after ACL reconstruction [3,9,22–24].

Given that few centres have access to routine isokinetic dynamometric strength testing or even hand held dynamometry testing, functional tests are commonly used as alternatives to or even as surrogates for strength testing. Although many functional tests have been used, one of the most frequently employed is the single leg hop for distance [19,20]. However, it is not clear whether the single leg hop for distance does in fact reflect knee extensor strength, as measured by dynamometric testing.

Therefore, the purpose of this study was to examine whether there is an association between knee extensor strength limb symmetry and single hop for distance limb symmetry at six and 12 months after ACL reconstruction.

2. Material and methods

2.1. Setting and participants

The study was performed as a prospective cohort study. Data were gathered at a private orthopaedic clinic in Melbourne, Australia over a two year period from December 2013. The study was approved by the hospital Human Research Ethics Committee and informed consent obtained from each participant.

Participants were recruited from a pool of patients aged 14 to 45 undergoing primary ACL reconstruction. Patients who were unable to attend follow-up were excluded, as were patients with a previous ACL reconstruction, significant ligamentous injury, and major chondral or meniscal damage in the contralateral knee.

2.2. Surgical technique and rehabilitation

ACL reconstruction was performed by one of two experienced knee surgeons using a single bundle technique with a hamstring tendon graft. Graft positioning was anatomic with the femoral tunnel drilled through the anteromedial portal. Proximal fixation was by means of an EndoButton CL Ultra (Smith & Nephew Endoscopy). The distal fixation was by means of a cannulated interference screw inserted over a guide wire.

All patients were provided with rehabilitation guidelines. Attendance at physiotherapy was at the patient's discretion, as many patients do not have ready access to regular physiotherapy in the Australian health system. The exact details of the patients' rehabilitation programs undoubtedly differed, but we believe this reflects the realities of orthopaedic practice in Australia. The rehabilitation guidelines provided were as follows.

In the first three weeks following surgery, patients were encouraged to reduce knee swelling with rest, ice, compression and elevation. They were allowed to weight bear as tolerated and knee range of motion exercises including active knee extension, active knee flexion, and prone leg hanging exercises were recommended at least three times per day. Patients were advised to use crutches for as long as they felt they required them; this ranged from a few days to as long as three weeks. From three weeks stationary bike, wall squats, straight leg raises, forward lunges and hamstring curls were introduced. It was recommended that patients commence a gym program at approximately five weeks which included the following exercises: leg press (both double and single leg–concentric and eccentric), half squats, stationary bike, rowing machine, cross-trainer and step-machine, hamstring curls, bridging (both double and single), calf raises, exercise ball drills for core stability, and leg extensions (after eight weeks). From 10 to 16 weeks, the rehabilitation progressed to hopping and landing drills and jogging, once there was no evidence of swelling. From 16 to 26 weeks, patients were typically allowed return to sports specific drills and activities, including kicking, dribbling, and controlled change of direction. From 26 to 52 weeks, patients were encouraged to increase the intensity of their training. A decision on return to sport was made by the treating surgeon based on the following criteria: no knee swelling, an essentially full range of knee motion, a stable knee on clinical examinations, good quadriceps strength, good control of a single leg step-down, and the patient's sense of confidence in his/her knee. The patient should have been participating in at least four weeks of unrestricted training prior to return to competitive sports.

2.3. Data collection procedures

Data were collected at six and 12 months postoperatively.

2.3.1. Strength test

Strengths tests were performed using a HUMAC NORM Dynamometer (Computer Sports Medicine Inc., 101 Tosca Drive, Stoughton, MA, USA) which has shown good to excellent reliability, with intraclass correlation coefficient (ICC) values ranging from 0.74 to 0.89 for knee tests [25]. The seat back was set at an angle of 85° and the seat adjusted to the length of the thigh. The thigh was strapped to the seat and the centre of rotation of the dynamometer was aligned with the centre of flexion of the knee. The full range of motion of the knee and the weight of the leg in 60° of flexion was entered in the dynamometer. The non-operated leg was tested first, followed by the operated leg. An isokinetic concentric maximal contraction from full flexion to full extension was performed at 60°/s. For each test, two warm up trials were performed followed by three maximal contractions. Three maximal contractions were used, as peak torque was our outcome of interest and further testing could have led to fatigue of the test subjects. Both legs were tested and the maximal value for each was used for further analysis.

2.3.2. Hop test

A single hop for distance was performed as previously described [20,26]. The test has shown excellent reliability (ICC 0.96, standard error of the measurement (SEM) 4.56 cm) [27]. The patient stood on one foot, hopped as far as possible, and landed on the same foot. Patients were required to control the landing and any double hops or hops in which the contralateral foot touched the ground, were excluded. The hop distance was measured from the starting line (toe touching the line), to the toe of the foot on landing and recorded with a tape measure. Each leg was tested twice, the non-operated leg first, and the maximal jumping distance per leg was used for further analysis.

For both strength and hop distance, a LSI was calculated as the operated leg / the non-operated leg × 100%.

2.4. Statistical analyses

For both strength and hop distance, patients were grouped at both time points according to whether their LSI score was 85% or above (satisfactory) or below 85% (unsatisfactory). Outliers were identified manually and excluded on a case-wise basis.

To examine the association between knee extensor strength and single leg hop for distance, contingency tables (2 × 2) were constructed and the McNemar test was used to test for significance. Comparison of group means was performed using an independent sample t-test. All analyses were done using IBM SPSS Statistics V22.0.0.0, and p-values less than 0.05 were considered statistically significant.

3. Results

There were 69 consecutive patients who completed both six and 12 month assessments and were included in the study. Six months of follow-up was performed at mean 201 (Standard deviation (SD): 52) days after the operation and 12 months of follow-up at 379 (SD: 30) days after the operation. Demographics of the cohort are shown in Table 1.

At six months only 27.5% (19/69) had recovered satisfactory knee extensor strength in the operated leg, improving to 46.4% (32/69) at 12 months (Table 2).

Recovery of satisfactory knee extensor strength was associated with hopping symmetry ($p < 0.01$). Of the patients who had an LSI ≥85% for knee extensor strength, 94.7% (18/19) also had LSI ≥85% for single leg hop for distance at six months. This percentage rose to 100% (32/32) at 12 months.

Satisfactory hopping distance was recovered considerably faster than knee extensor strength, with 66.7% (46/69) demonstrating satisfactory hopping symmetry at six months, and 89.9% (62/69) at 12 months (Table 2). Recovery of hopping distance was *not* associated with knee extensor strength as only 39.1% (18/46) of patients, who recovered satisfactory hopping distance, had recovered satisfactory knee extensor strength at six months, rising to 51.6% (32/62) at 12 months.

4. Discussion

The main finding of this study was that satisfactory performance of a single hop for distance test (LSI 85% or above) did not imply satisfactory recovery of knee extensor strength (LSI 85% or above). As such, the single leg hop test should not be assumed

Table 1
Descriptive data of the study cohort.

Sex (male/female)	47 (68%)/22 (32%)
Age at operation (Y)	27.7 (8.1)
Height (cm)	176.7 (9.8)
Weight (kg)	82.4 (15.4)
Side (L/R)	31 (45%)/38 (55%)

Values for continuous data are reported as mean (SD). All other values are presented as number of patients (percentage).

Table 2
The relationship between patients with recovered knee extensor strength and hopping distance.

	LSI	Single leg hop test							
		6 months				12 months			
		<85%	≥85	Sum	p	<85%	≥85%	Sum	p
Knee extensor strength	<85%	22	28	50	<**0.01**	7	30	37	<**0.01**
	≥85%	1	18	19		0	32	32	
	Sum	23	46	69		7	62	69	

A 2 × 2 crosstab showing the relationship between the number of patients having recovered satisfactory knee extensor strength and satisfactory single hop distance. Analysis for significance was performed using the McNemar test. LSI = leg symmetry index. Significance level was set at p = 0.05, with significant values shown in bold.

to be a surrogate measure for knee extensor strength in the operated leg following ACL reconstruction. Another important finding was that less than one third of the patients had regained satisfactory knee extensor strength in the operated leg compared to the non-operated leg at six months after ACL reconstruction, and the proportion was still less than half at one year.

Functional performance tests are often recommended to evaluate a patient's physical readiness to return to sport after ACLR anterior cruciate ligament reconstruction (ACLR) [17]. The objective of these tests is to assess the symmetry of lower extremity performance, e.g. by using single-leg hop tests, designed to simulate sport related demands and neuromuscular control [28–30]. Furthermore, it has been proposed in recent ACL reconstruction studies that there is an increased reinjury risk in patients not meeting a minimum 90% LSI on functional performance tests and strength tests [10,31]. However, not one specific deficit in postoperative functional testing has been attributed to an increased risk of re-injury.

There appears to be a widely held assumption that poor quadriceps strength corresponds to poor single-leg hop test performance. The relationship between poor quadriceps strength and abnormal limb symmetry on the hop tests was reported by Noyes et al. in 1991 in a study of 67 patients with ACL deficiency; the authors reported a statistical trend between low velocity quadriceps isokinetic test results and hop tests [20].

A recent study by Herrington et al. who evaluated the association between quadriceps strength and functional performance after ACL reconstruction in 15 professional soccer players at the time of return to sport found that over 80% of the players failed to exceed the limb symmetry of ≥90% for strength tests, although 75% of the cohort passed the ≥90% criteria for hop tests [32]. The authors concluded that there were significant deficits in quadriceps strength at the time of return to sport, whereas hop testing, a commonly used outcome measure, failed to show the same levels of deficit. These findings are in keeping with the results of the current study, in which the deficits reported were even more profound, possibly explained by the fact that the cohort was not professional athletes. Presumably, patients are able to compensate for the weak knee extensors with strong hip and trunk muscles and a good neuromuscular control of the lower extremity, as these have been shown to be important for hopping [33,34]. Based on the results of the current study, the single leg hop test should not be used as a surrogate for standardized knee extensor strength.

At six months, most patients expect to start training and gradually resume sporting activities. In many, if not most, centres, patients are typically allowed to resume full sports participation by nine to 12 months. However, the current data show that half of the patients have not regained satisfactory knee extensor strength in the operated leg within 12 months of ACL reconstruction and may be at an increased risk of a further injury due to their impaired strength if they are allowed back to play. This data reflects the results of a recent study by Beischer et al. who found that only 20% of the adolescents and 28% of adults who had returned to sport had recovered their muscle function 12 months after ACL reconstruction. Similar results were also reported by Toole et al. who found only 28% of patients had regained satisfactory strength at time of return to sport [9], and Fink et al. who found large deficits in both strength and functional tests 5½ and eight months after ACL reconstruction [35,24].

To put the results of this study into context, the participating patients were recreational to sub-elite athletes aged 14–45 years, rather than elite athletes who may recover strength faster due to better rehabilitation [36]. The patients may have also gained strength in the non-operated leg during the rehabilitation period, thus making the operated leg seem relatively weaker. That being said, there are studies indicating the opposite, in that ACL reconstruction has been shown to result in lower peak and explosive strength of the contralateral leg, as well as impaired dynamic balance when performing a single-leg squat [37,38]. The reason for this crossover effect is unknown but it is presumably centrally mediated. It has been hypothesized that this effect might partly explain why patients undergoing ACL reconstruction are at significantly increased risk for injuring the contralateral ACL [13,38,39]. Recent literature suggests that the use of LSI values can mask these bilateral deficits and should be used with caution. Absolute values normalized to body weight are suggested to be more specific and relevant methods of analyzing data [40]. This was not done in the present study as this method does not account for the inherent variability in strength and hopping distance among people with the same weight.

5. Conclusions

Single leg hop test cannot be used as a surrogate measure for knee extensor strength as satisfactory hop test performance can be achieved in the absence of satisfactory knee extensor strength. Furthermore, less than one in three patients had recovered satisfactory knee extensor strength six months after ACL reconstruction, at the time when they are often expecting to resume sporting activity. This had only improved to one in two at 12 months.

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