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Strength Testing After Anterior Cruciate Ligament Reconstruction

A Prospective Cohort Study Investigating Overlap of Tests

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TITLE PAGE

Title: Strength testing following anterior cruciate ligament reconstruction. A prospective cohort study investigating overlap of tests

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ABSTRACT

The purpose of the present study was to determine whether overlap **(redundancy)** exists between individual tests in a comprehensive strength testing protocol used after anterior cruciate ligament (ACL) reconstruction surgery. If overlap is present, one or more components of the protocol could potentially be omitted to make the testing protocol more efficient, but without compromising the usefulness of the testing.

Sixty-nine patients (46M, 23F; mean age 28Y) were strength tested at 6 and 12 months after ACL reconstruction as part of a prospective cohort study. The following knee flexor and extensor strength tests were performed: isokinetic concentric strength at 60°/s and 180°/s, isokinetic eccentric strength at 60°/s, and isometric knee flexor strength at 60° flexion. Peak and average torque values were extracted and the ratio between the operated and non-operated limb calculated as a limb symmetry index. Overlap of strength tests was investigated by fitting a linear regression model to the data with an R^2 threshold of 0.56 used as an indication of overlap.

Overlap between peak and mean torque was present for extensor and flexor concentric and eccentric measurements at 12 months and for concentric measurements at 6 months. Peak torque measurements were therefore used for subsequent analysis. Concentric extensor peak torque at 60°/s and 180°/s showed overlap at 6 months (R^2 = 0.73) but not at 12 months (R^2 = 0.37). No other overlap was identified.

In conclusion, there is little room for omission of individual strength testing protocol components due to the lack of overlap between tests. Isometric, eccentric and concentric tests may all provide unique information and all therefore should be considered for inclusion.

Key words: Redundancy, overlap, ACL, test protocol

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INTRODUCTION

Despite the frequency with which anterior cruciate ligament (ACL) reconstruction is performed, much remains unknown about the factors that influence and predict a safe and successful return to sport, which is often the principal aim of the individual undergoing surgery (14,19). Restoration of muscle strength and function are considered important in order to safely return to physical activity and reduce the risk of further injury (3,20). For example, Grindem et al (10) reported that quadriceps strength deficits prior to return to sport were a significant predictor of future knee injury, with a 3% reduction in re-injury rate for every one percentage point increase in strength symmetry between limbs. In a group of professional male athletes, Kyritsis et al. also showed that for every 10% decrease in hamstrings to quadriceps ratio of the reconstructed limb the risk of graft tear increased 10-fold (13).

Although strength testing is generally considered a standard outcome measurement in clinical studies of knee function after ACL reconstruction, there are various methods of assessing strength. A variety of testing protocols have been developed, but most involve a number of types of tests and therefore require time and resources to complete(13,15,16,19). Three of the most common methods are isometric, isokinetic concentric and isokinetic eccentric strength tests (4). Isometric strength testing consists of pushing/pulling against an immovable object, and measures the strength of the muscle during a static contraction. Isokinetic testing can be done in two modes, namely eccentric and concentric. Isokinetic eccentric strength testing requires the person to push/pull against a resistance that opposes and exceeds the maximal voluntary contraction force in a way that lengthens the contracting muscle at a set velocity. Isokinetic concentric strength testing involves the person pushing/pulling against an object that moves in the direction of the force applied at a set velocity. For example, an eccentric quadriceps test results in movement toward greater knee flexion, whereas for quadriceps concentric contraction the movement is towards greater knee extension.

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These isokinetic tests can also be performed at different velocities, ranging from relatively slow (e.g. 60 °/s) through to velocities that more closely replicate the movement speeds of dynamic sports (e.g. 300 °/s). Slower velocities have been shown to have a low measurement error (18), but higher velocities may be more relevant due to their ecological validity.

While it may be feasible to implement all methods in a professional sports setting, in the majority of clinical environments this is not practicable. It may therefore be useful to identify whether each of the different methods of strength assessment provide both important and non-redundant information about a patient's recovery. With respect to the former, a number of studies have shown that isometric, concentric and eccentric strength are impaired after ACL reconstruction (9,16,20). This points to the importance of these measures of strength, but does not exclude redundancy between these assessments.

Given that there is support for a variety of different methods of strength assessment after ACL reconstruction, and that studies in other populations have shown strong associations between these different strength assessment methods (18), it may be that overall strength is compromised and it is not actually necessary to perform a comprehensive strength assessment of each method of contraction. This might be indicated by strong associations between the individual's results on the different assessment methods, which might indicate that there is overlap between the strength testing methods. If overlap is present, one or more components of the protocol could potentially be omitted to make the testing protocol more efficient, but without compromising the usefulness of the testing. This has potentially important ramifications in clinical settings where time with the patient is limited, as it could allow for shorter assessment times. Conversely, additional important and non-redundant tests could be incorporated to gain a better insight into the patients overall functional status. Even in professional settings, where time constraints may not be as important, minimizing the number of tests would reduce the overall number of intense muscle contractions performed in a strength testing battery.

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This may be important in the early stages of rehabilitation as the patient is gradually progressed back to a full training load. Minimizing the intense strength assessments may also allow for more sports-specific field work to be implemented in a graduated program to achieve the same overall training workload.

The purpose of the present study was therefore to determine whether overlap exists between individual tests in a comprehensive strength testing protocol consisting of tests that are frequently used after anterior cruciate ligament (ACL) reconstruction surgery. **We expected the inherent properties of the hamstring and quadriceps muscles to equally affect the muscles ability to exert concentric, eccentric and isometric force.** We **therefore** hypothesized that for both knee extensors and flexors, there would be overlap between 1) concentric peak torque at different velocities and 2) concentric, eccentric and isometric peak torque.

METHODS

Experimental Procedure

Patients were positioned in a HUMAC NORM Dynamometer (Computer Sports Medicine Inc., 101 Tosca Drive, Stoughton, MA, USA) with the chair back at an 85° angle 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 rotation of the knee. The full range of motion of the knee and the weight of the leg in 60° of flexion was manually entered into the dynamometer. The non-operated limb was tested first, followed by the operated limb.

The test protocol consisted of the following four tests, which were chosen on the basis that they are four of the most commonly used methods of strength assessment reported in this population (4,6): Test 1 was an isokinetic concentric maximal contraction from full flexion to full extension and back at 60°/s. The tested range of motion was defined by the patient's range of motion.

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The quadriceps were tested first and then the hamstrings. Test 2 was performed in the same manner at 180°/s. Test 3 was a three-second isometric contraction of the hamstrings at 60° flexion. Test 4 was an isokinetic eccentric test from full extension to full flexion and back at 60°/s. For each of the four tests, two sub-maximal practice trials were completed, followed by three maximal contractions.

Subjects

All patients were aged between 16 and 45 years and were scheduled for primary ACL reconstruction by one of the two participating surgeons at a private clinic in Melbourne, Australia between 1st December 2013 and 31st January 2015 were invited to participate in a long term (10 year) prospective cohort study of outcomes following primary ACL reconstruction. The study was approved by the hospital Human Research Ethics Committee and informed consent was obtained and the rights of participants protected. As part of the study, strength testing was performed at six and twelve months after surgery.

Demographic data were collected through a web based questionnaire (https://www.limesurvey.org/). The study population consisted of 69 patients who completed 6 and 12 months follow-up. Demographics of the cohort are shown in Table 1. **This sample size was powered to define two-tailed correlations above R=0.24 (linear regression R^2 = 0.06) as statistically significant** (6)**.**

Table 1 should be placed here

Surgical Technique and Rehabilitation

ACL reconstruction was performed by one of two experienced knee surgeons using a single bundle technique with hamstring or patellar tendon graft. As the vast majority of patients (98%) had a hamstring graft, only patients with a hamstring graft were included in this study. Graft positioning was anatomic with the femoral tunnel drilled via 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 metallic interference screw inserted over a guide wire.

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All patients followed the same rehabilitation protocol, supervised by a local physiotherapist of the patient's choice, which emphasized early restoration of full knee extension and quadriceps function, particularly that of vastus medialis. Weight-bearing was allowed on an as-tolerated basis from the day of surgery and braces were not used. Progression through the protocol was guided by pain and swelling. In general, patients commenced body weight lower limb strengthening exercises at 2-3 weeks and riding a stationary bicycle at 3-4 weeks. Gymnasium-based strengthening commenced at around 6-8 weeks and light running at 3-4 months. Balance and landing exercises were introduced progressively from 4 weeks.

Data Analysis

Peak and average torque values were extracted and the ratio between the operated and non-operated limb calculated as a limb symmetry index (LSI: (OP-limb/non-OP-limb) x 100%). Before we investigated the overlap between the various strength tests, we initially investigated the overlap between two strength variables, peak torque and average torque, for each of the strength tests. If overlap were detected between these variables, only peak torque values would be used for assessing overlap between the various strength tests.

Statistical Analysis

Overlap was determined by fitting a linear regression model to the data and calculating the coefficient of determination, R^2, which is a statistical method of assessing how close the data are to the fitted regression line. Whilst there is no recognized R^2 threshold for overlap, a threshold of R^2=0.56 was chosen as it is equivalent to the threshold for an excellent correlation of R=0.75 in accordance with Portney and Watkins (19). All analyses were performed using IBM SPSS Statistics V22.0.0.0, and p-values less than 0.05 were considered statistically significant.

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RESULTS

A linear regression model of hamstring and quadriceps isokinetic strength at 6 and 12 months post ACL reconstruction revealed that all regressions were statistically significant (P<0.5), and that there were moderate to high correlations (R) between peak and mean torque values for both concentric and eccentric strength assessment (Table 2). At 6 months, the coefficient of determination (R^2) between peak and mean torque was high for concentric hamstring and quadriceps strength, indicating an overlap of these tests ($R^2 > 0.56$). At 12-months, further overlap was demonstrated between peak and mean torque for both hamstring and quadriceps, not only for concentric but also for eccentric strength assessment (Table 2). As a result, peak torque measurements were used for subsequent analysis.

Table 2 should be placed here

A linear regression model assessing hamstring and quadriceps strength using peak torque at varying velocities and modes of contraction revealed moderate correlation and minimal overlap (Table 3). Only concentric quadriceps peak torque at 60°/s and 180°/s showed overlap at 6 months ($R^2 = 0.73$) but not at 12 months ($R^2 = 0.37$). No other overlap was identified between varying velocities or modes of contraction. A graphical presentation of the correlations is found in figure 1.

Table 3 should be placed here

Figure 1 should be placed here

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DISCUSSION

This study aimed to identify potential overlap of isokinetic and isometric strength testing measurements commonly used in patients following ACLR. The main finding of this study was that there was very little overlap of test modes, suggesting that each test mode contributed independent information about a patient's functional capacity. On the other hand, it appears that either peak or mean torque values can be used with little impact on the outcome.

Isokinetic dynamometry is considered to be the gold standard of strength testing after ACL-reconstruction (9). It provides an objective measure of muscle strength, but has been criticized as lacking functional relevance to sporting and training situations (5,8). Testing at high angular velocity reflects movement velocities that occur in sporting situations, and therefore may be a more task-specific measure of strength (24). In contrast, evidence suggests that slow angular velocities better detect strength deficits as the maximum torque output is reached at angular velocities between 0 and 60°/s (22). Based on the latter observation, Undheim et al. have suggested concentric knee extension and flexion at an angular velocity of 60°/s as the most valid assessment for readiness to return to sport (22). However, overall these previous findings suggest that strength testing at both slow and fast angular velocities may provide different clinical information. This is supported by the present results showing that the two most commonly used angular velocities of 60°/s and 180°/s (22) do provide statistically different information. Testing was performed at the clinically relevant time points of both 6 and 12 months after ACL reconstruction, which is when people are often allowed to return to more challenging activities such as training and competition.

Only a relatively modest association was found between concentric and eccentric strength tests suggesting that they do provide relatively unique information. This is in contrast to an earlier study in young, healthy subjects showing a strong correlation between concentric and eccentric strength and therefore supporting the use of only concentric strength in the return to sport evaluation (23).

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Indeed, many strength testing protocols and return to play research have focused on concentric strength measurements (9,10,11,21,24), and in a systematic review from 2015 Undheim et al. suggested five repetitions of concentric knee extension and flexion at an angular velocity of 60°/sec as the most valid assessment for return to sport (22). However, the present results indicate that both concentric and eccentric strength tests may be important. Given the present results, and that many ACL tears happen in situations under eccentric quadriceps work (8), eccentric strength tests should perhaps play a larger role in return to play evaluations.

Comparison between isokinetic and isometric strength tests showed very little overlap, indicating that additional information can be obtained from the robotic isokinetic dynamometer measurements compared to simpler isometric tests. Isokinetic strength testing enables measurement of the muscular forces in dynamic conditions and provides optimal loading of the muscles during testing (2). This lack of association between dynamic and static strength measures in an ACL reconstruction cohort indicates that a simple isometric test may not be sufficient to determine post-surgical functional outcomes related to sports specific strength.

In summary, the strength measures of the investigated testing protocol showed little overlap indicating that they measure different aspects of quadriceps and hamstring strength. This is the opposite of what was hypothesized. It does not leave much room for streamlining the testing protocol, but does provide a rationale for performing the extensive test battery. The high angular velocities reflect the movements occurring in sporting situations whereas the slow angular velocities are better at detecting strength deficits (21,23). Concentric and eccentric contractions reflect different parts of the movement pattern.

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Isokinetic measurements allow for measurement of the muscular forces in dynamic conditions and isometric measurements are better at measuring peak torque considered a measure of force around a given point (2).

When reporting data, mean and peak torque do seem to overlap such that only one needs to be used. Peak torque is the most commonly reported in the literature, with 32 of 38 studies in a systematic review reporting it as one of the outcome measurements (22). In order to make reporting of data consistent, and to overcome issues inherent in mean torque scores such as variability in the range of motion impacting results, it might be helpful to consistently use peak torque as the unit of measurement.

Limitations

The study is limited by several factors. Firstly, the statistical method using a linear regression model to investigate overlap between the tests does not show the full picture as part of the variance is not accounted for. Secondly, though based on the available literature, the threshold for overlap was somewhat arbitrary. Generalizability of the study is limited by the size of the cohort and its characteristics as presented in Table 1. Additionally, we did not assess every possible permutation of isokinetic and isometric strength testing. Further research should consider including other testing modalities such as hand held dynamometry and isotonic strength testing to determine their overlap. Hand held dynamometry consists of a small load cell based force assessment tool which is held by the assessor while the patient exerts force against it, and is commonly used to assess strength in situations where a fixed dynamometer is not available(1). Finally, it was beyond the scope of this study to examine how the results of these different strength tests predict future injuries or return to sport capacity, which is the true measure of their usefulness in a patient assessment battery.

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PRACTICAL APPLICATIONS

There is little room for omission of individual strength testing protocol components based on overlap in this cohort, as the associations between tests were predominantly below the threshold set. Consequently, we cannot recommend that individual tests can be excluded from a testing battery. Future research should examine how these different strength measures predict return to sport outcomes and re-injury.

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Legend Figure 1: Scatter plots showing a graphical presentation of the correlations between strength tests.

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Table 1: Descriptive data of the study cohort	
Sex (male/female)	46/23
Age at operation (Y)	28 (8)
Height (cm)	177 (10)
Mass (kg)	83 (15)
Side (L/R)	30/39

Legend: Descriptive data of the study cohort. Values for continuous data are reported as mean (SD); all other values are presented as number of patients.

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Table 2: Overlap between 'peak' and 'mean' torque for isokinetic strength assessment					
Measure 1	Measure 2	6 months		12 months	
		R	R^2	R	R^2
Hamstring concentric PT	Hamstring concentric MT	0.89	**0.78**	0.91	**0.82**
Hamstring eccentric PT	Hamstring eccentric MT	0.72	0.53	0.85	**0.72**
Quadriceps concentric PT	Quadriceps concentric MT	0.93	**0.86**	0.90	**0.80**
Quadriceps eccentric PT	Quadriceps eccentric MT	0.73	0.53	0.87	**0.75**

Legend: Overlap of Limb Symmetry Index for peak and mean torque for isokinetic strength assessment at 60°/s was calculated using a linear regression model. R is the correlation coefficient. R^2 is the coefficient of determination (overlap). R^2 values > 0.56 indicate overlap and are shown in bold. PT = Peak torque. MT = Mean torque.

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Table 3: Overlap between hamstring and quadriceps strength at different velocities and modes of contraction					
Measure 1	Measure 2	6 months		12 months	
		R	R^2	R	R^2
Hamstring concentric PT 60°/s	Hamstring concentric PT 180°/s	0.63	0.40	0.64	0.41
Quadriceps concentric PT 60°/s	Quadriceps concentric PT 180°/s	0.86	**0.73**	0.61	0.37
Hamstring concentric PT 60°/s	Hamstring eccentric PT 60°/s	0.53	0.29	0.47	0.22
Quadriceps concentric PT 60°/s	Quadriceps eccentric PT 60°/s	0.52	0.27	0.56	0.31
Hamstring Isometric PT	Hamstring eccentric PT 60°/s	0.52	0.27	0.32	0.10
Hamstring Isometric PT	Hamstring concentric PT 60°/s	0.60	0.36	0.60	0.36
Hamstring Isometric PT	Hamstring concentric PT 180°/s	0.27	0.07	0.46	0.21
Legend: Overlap of Limb Symmetry Index for isometric and isokinetic strength assessment **was calculated using a linear regression model**. R is the coefficient of correlation. R^2 is the coefficient of determination (overlap). R^2 values >0.56 indicate overlap and are shown in bold. PT = Peak torque.					

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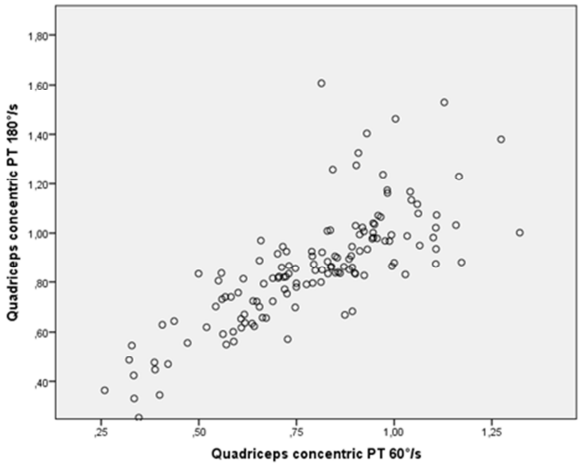

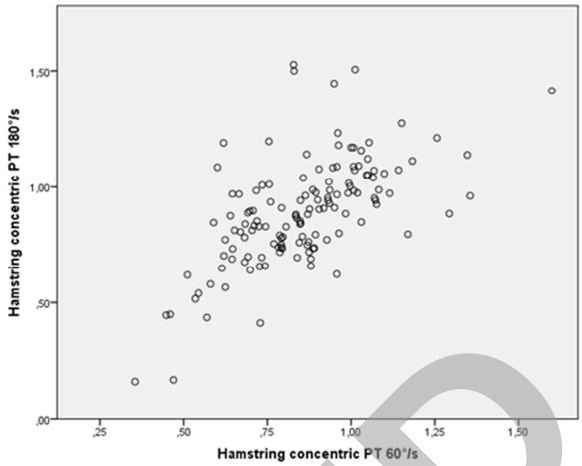

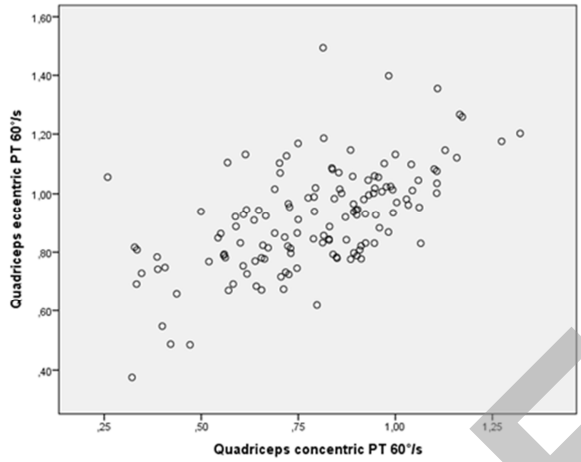

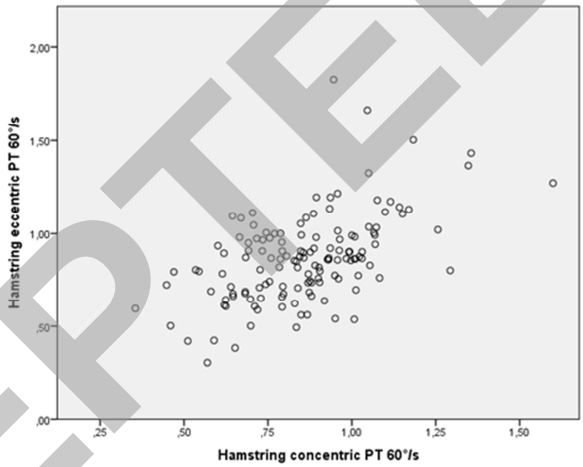

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