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The Relationship Between Disability and Hop Performance in Subjects Following Anterior Cruciate Ligament Reconstruction

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Abstract

Background and purpose: The purpose of this study was to determine the relationship between patient disability levels following anterior cruciate ligament reconstruction (ACLR) and closed kinetic chain performance as measured through a single leg hop for distance test, a 45-second sagittal plane hop test, and a 45-second frontal plane hop test.

Methods: Sixteen subjects, all cadets at the U.S. Air Force Academy who had undergone unilateral ACLR, participated in this study (10 males, 6 females, age=21.7±1.2 years, height=178.3±8.7 cm, weight=79.8±14.3 kg). The Knee Outcome Survey Sports Activity Scale (SAS) was used as our disability measure. The tests used to measure closed kinetic chain performance were the single leg hop test for distance and a 45-second sagittal and frontal plane hop test, which required subjects to hop back and forth over a strip of athletic tape in the required direction (front to back and side to side) as many times as possible during a 45-second period.

Results: The mean time from ACLR to testing for subjects in this study was 41.44±14.96 months (range =24 to 77 months). While no significant relationship existed between the SAS scores and the percent lower extremity differences for the single leg hop test or the 45-second frontal plane hop test, a significant relationship was noted between the SAS scores and the percent lower extremity differences for the 45-seccond sagittal plane hop test ($r=0.51$, $P<0.05$).

Conclusion: These findings indicate that the 45-second sagittal plane hop test could potentially be a useful clinical test in assessing a patient's disability level after ACLR, particularly if used in conjunction with other clinical assessment techniques

Keywords: Anterior cruciate ligament reconstruction, outcome, closed kinetic chain

Introduction

One of the most common knee injuries for active individuals and athletes is a rupture of the anterior cruciate ligament. Approximately 1 out of every 3,000 knee injuries results in a rupture of the anterior cruciate ligament in active people, which accounts for approximately 150,000 anterior cruciate ligament ruptures annually [1]. The most common mechanism for this type of injury is the result of high-velocity cutting, pivoting, landing, and jumping [2]. This type of injury conventionally requires surgery to re-establish knee stability and associated lower extremity strength on the surgical extremity, as well as requiring intensive rehabilitation for patients to return to sport or their prior level of function [1,3]. Well-established and accepted rehabilitation practices following anterior cruciate ligament reconstruction (ACLR) are focused on post-operative weight bearing, range of motion, strengthening, neuromuscular training, and return to sport/function [4].

Traditionally, testing for lower extremity strength after ACLR has been done in an open kinetic chain (i.e. distal segment of lower extremity not fixed). In the orthopaedic and sports medicine communities, isokinetic testing is a common open kinetic chain assessment method used to determine muscular strength in patients with a history of ACLR [5,6]. However, the ability of isokinetic testing to predict patient disability levels has been questioned [7,8], because isokinetic testing assesses muscle group torque production in a single plane at speeds under conditions that do not mimic functional activities. To overcome the limitations of open kinetic chain assessment, some clinicians have used closed kinetic chain assessment methods (i.e. testing with the distal segment of the lower extremity in a fixed position), such as hop tests, to assess disability levels in patients following ACLR. However, poor correlations have also been shown to exist between closed kinetic chain tests and patient disability levels following ACLR [3,6,9].

We believe there are two possible reasons that closed kinetic chain testing is poorly correlated with patient disability levels following ACLR. First, the tests have been limited to the sagittal plane. Second, the tests have not routinely assessed endurance capabilities of the surgically reconstructed knee and lower extremity. Because patients following ACLR often want to return to sports activities that are endurance-based with multiplanar movements, we hypothesize that closed kinetic chain tests that assess endurance performance with movements outside the sagittal plane may be more closely related to patient disability levels following ACLR than sagittal plane tests that are not endurance based. Therefore, the purpose of this study was to determine the relationship between patient disability levels following ACLR and closed kinetic chain performance as measured through a single leg hop for distance test, a 45-second sagittal plane hop test, and a 45-second frontal plane hop test.

Materials and methods

Subjects

Sixteen subjects, all cadets at the U.S. Air Force Academy, participated in this study (10 males, 6 females, age=21.7±1.2 years, height =178.3±8.7 cm, weight =79.8±14.3 kg). Selection criteria included: 1) a history of unilateral ACLR performed greater than 24 months prior to the time of participation in this study; 2) no posterior cruciate ligament injury or history of knee surgery prior to ACLR; 3) 100% recovery from previous injuries to the low back and lower extremity (not including involved knee); 4) completion of a rehabilitation program that focused on an early return of full range of motion, early full weightbearing, lower extremity strengthening, and a full return to military and athletic activities; 5) clearance from an orthopaedic surgeon to return to preinjury activity levels based upon the following criteria for ACLR: a minimum of 6 months for noncontact activities, a minimum of 9 months for contact activities; 6) full return to all required military and sport activities, and; 7) a satisfactory clinical examination indicating no effusion and a negative Lachman's test. All subjects had undergone ACLR using a bone-patellar tendon-bone autograft. Prior to participation, all subjects read and signed an informed consent document approved by the Institutional Review Board at the U.S. Air Force Academy.

Design

This was a descriptive study in which the relationship between patient disability and closed kinetic chain performance was assessed. Disability was measured by the scores on the Knee Outcome Survey (KOS) Sports Activity Scale (SAS) [10-12]. Closed kinetic chain performance was assessed through a single leg hop for distance test, a 45-second sagittal plane hop test, and a 45-second frontal plane hop test. The single leg hop for distance test has demonstrated good test-retest reliability in healthy, young adults [intraclass correlation coefficient (ICC)=0.92; standard error of measurement (SEM)=4.61 cm] and in patients following ACLR (ICC=0.92; SEM=3.49). However, we are not aware of studies that have assessed reliability of the 45-second sagittal plane hop test or the 45-second frontal plane hop test as we describe in this study [13,14].

Patient Disability Measure

The scores on the KOS SAS [10-12] were used to measure disability. Subjects completed the KOS SAS prior to functional testing. Items on the KOS SAS assessed symptoms (pain, crepitus, stiffness, swelling, instability) and functional limitations that individuals experienced while playing sports (running, stopping, starting, jumping, landing, cutting, pivoting). The subject's responses regarding symptoms were graduated in terms of the amount of disability that individuals experience during activities of daily living or sports. Responses regarding functional limitations ranged from no limitation to the inability to perform the specific activity.

The KOS SAS was numerically graded on a scale of 0 to 100, with higher scores indicating lower levels of disability. The scores on the KOS SAS indicated the degree of disability experienced by the patient following ACLR. The KOS has been shown to be a reliable and valid measure of disability in patients with knee impairments [10-12].

Functional Tests

Single Leg Hop for Distance Test

The first test patients performed was the single leg hop for distance. A tape measure was secured to the floor. Subjects began the single leg hop test by standing unilaterally with the anterior aspect of their athletic shoe at the zero mark of the tape measure. They were instructed to hop as far as possible forward and land on the tape measure. The distance from the zero mark of the tape measure to the point where the subject's heel hit the ground was measured. Following two practice trials, subjects performed two test trials for each lower extremity in an alternating fashion, beginning with the noninvolved lower extremity. A 30-second rest period separated each trial. Each subject was required to report the sense of full recovery following this rest period before proceeding on to another test.

45-sec Hop Tests

A single strip of athletic tape (3.8 cm width, 61.0 cm long) was placed on the floor. Subjects performed two functional tests, which involved jumping over the strip of tape in an anterior/posterior (sagittal plane hop test) and medial/lateral (frontal plane hop test) direction. The test started after the researcher said, "1-2-3-Go." Subjects were required to hop back and forth over the tape line in the required direction as many times as possible during a 45-second period, beginning with the noninvolved lower extremity. In order for repetitions to count, subjects were required to completely clear the tape. Thirty seconds of rest was allowed between the practice repetitions and test repetitions. Following the 45-second sagittal plane hop test, a 3-minute rest period was allowed. Each subject was required to report the sense of full recovery following this rest period before proceeding on to the 45-second frontal plane hop test, which also began with the noninvolved lower extremity.

Procedure

A warm-up was performed by each subject, consisting of 5 minutes of self-paced stationary cycling, followed by quadriceps, hamstring, and calf muscle stretching of both lower extremities for 3 repetitions of 30 seconds duration. After the warm-up was completed, single leg hop testing took place. For all of the single leg hop tests, the noninvolved lower extremity was tested prior to the involved lower extremity. This sequence was used because it evaluates the patient's willingness to be tested and also serves to decrease apprehension by allowing exposure to the particular test with the noninvolved lower extremity [15].

The tests were terminated if the subject could no longer continue or if they reported pain in their involved knee. Subjects completed the single leg hop for distance test first, then the 45-sec hop tests in random order.

Reliability Study

In order to estimate test-retest reliability of our testing methods, 18 subjects, all cadets at the U.S. Air Force Academy (12 males, 6 females, age=20.2±1.6 years, height =174.2±6.8 cm, weight =77.6±12.2 kg) with no history of lower extremity injury or pain within the past 12 months were assessed as previously described prior to collecting data for the descriptive study. The testing sessions were separated by 24 to 48 hours. For the second test session, subjects were required to report that the status of their lower extremities had not changed since the time of the initial test.

Data Analysis

Reliability Study

The Kolmogorov-Smirnov test was used to evaluate assumptions of normality. Since the data were normally distributed, a dependent t-test was used to assess differences between dominant and nondominant lower extremities for the single leg hop for distance test, the 45-second sagittal plane hop test, and the 45-second frontal plane hop test. Test-retest reliability was determined through ICCs [16]. The ICC (2,k) formula was selected to assess the reliability of the single leg hop test because the values representing each single leg hop test were a mean of two measures. The ICC (2,1) formula was selected to assess the reliability of the 45-sec sagittal and frontal plane hop tests because the values representing each test were comprised of a single measure. The ICC was based upon the results of a repeated measures analysis of variance, which compared the test-retest trials for each of the single leg hop tests. The ICC were classified in the following manner: 0.90 to 0.99, high reliability; 0.80 to 0.89, good reliability; 0.70 to 0.79, fair reliability, and less than 0.69, poor reliability [17]. The standard error of measurement (SEM) ($SD\sqrt{1-ICC}$) was calculated to assess the amount of error associated with repeated measurements for each single leg hop test.

Descriptive Study

The Kolmogorov-Smirnov test was used to evaluate assumptions of normality. Since the data were normally distributed, a dependent t-test was used to assess differences between involved and noninvolved lower extremities for the three hop tests. Pearson product moment correlation coefficients were then used to assess the relationship between the KOS SAS and the percent lower extremity differences for the single leg hop test, the 45-second sagittal plane hop test, and the 45-second frontal plane hop test. The percent lower extremity differences for the three hop tests were calculated as follows: noninvolved lower extremity scores - involved lower extremity scores/noninvolved lower extremity scores x 100. The probability level was set at $P \leq 0.05$.

Results

Reliability Study

No significant differences were noted between dominant and nondominant lower extremities of healthy subjects for the single leg hop test, the 45-sec sagittal plane hop test, and the 45-sec frontal plane hop test ($P>0.05$). The ICC for the single leg hop test, the 45-sec sagittal plane hop test, and the 45-sec frontal plane hop test were 0.91, 0.91, and 0.81, respectively. The SEM for the single leg hop test, the 45-sec sagittal plane hop test, and the 45-sec frontal plane hop test were 4.42 cm, 4.69 repetitions, and 4.63 repetitions, respectively.

Descriptive Study

The mean time from ACLR to testing for subjects in this study was 41.44±14.96 months (range=24 to 77 months). The KOS SAS score for subjects with a history of ACLR was 89.25±9.12 (range=68 to 98). Means, standard deviations, and ranges for noninvolved and involved lower extremities for the single leg hop test, the 45-second sagittal plane hop test, and the

45-second frontal plane hop test are presented in **Table 1**. No significant differences were noted between the involved and noninvolved lower extremities of subjects with a history of ACLR for the single leg hop test or the 45-seccond frontal plane hop test (*P*>0.05). However, the involved lower extremity of subjects with a history of ACLR performed significantly fewer repetitions on the 45-second sagittal plane hop test when compared to the noninvolved lower extremity.

Table 1. Means, standard deviations, and ranges for noninvolved and involved lower extremities for the single leg hop test and 45-second sagittal and frontal plane hop tests.

	Mean±SD	Range
Single Leg HopTest (cm)		
Noninvolved LE	178.57±26.94	125.85-217.95
Involved LE	177.84±27.13	126.25-216.2
Sagittal Plane Hop Test (reps)		
Noninvolved LE	97.69±9.97	85-119
Involved LE	91.55±13.60	70-114
Frontal Plane Hop Test (reps)		
Noninvolved LE	111.19±10.75	92-124
Involved LE	109.69±15.80	77-131

While no significant relationship existed between the SAS scores and the percent lower extremity differences for the single leg hop test (r=0.07, *P*>0.05) or the 45-second frontal plane hop test (r=0.26, *P*>0.05), a significant relationship was noted between the SAS scores and the percent lower extremity differences for the 45-seccond sagittal plane hop test (r=0.51, *P*<0.05).

Discussion

Single-leg hop tests are closed kinetic chain performance measures that are commonly used to assess return to sport capabilities after ACLR. Unfortunately, the relationship between patient disability levels following ACLR and single leg hop test performance, especially for endurance based tests or those outside of the sagittal plane, has not yet been adequately established. The purpose of this study was to determine the relationship between patient disability levels following ACLR and closed kinetic chain performance as measured through a single leg hop for distance test, a 45-second sagittal plane hop test, and a 45-second frontal plane hop test.

Reliability study

Test-retest reliability coefficients for each of the single leg hop tests assessed in this study were classified as good to high. Furthermore, we feel that the SEM values were acceptable in relation to the mean values calculated for each of the single leg hop tests. Based upon these ICC and the small SEM, we deemed the three single leg hop tests acceptable for use in the descriptive part of our study. With regard to the single leg hop for distance test, our reliability results are consistent with prior authors that have determined good test-retest reliability and acceptable SEMs in healthy, young adults and in patients following ACLR [13,14]. However, we are not aware of prior studies that have assessed reliability of the 45-second sagittal plane hop test or the 45-second frontal plane hop test as performed in this study; thus, we are unable to compare our reliability results for these tests to prior studies.

While the ICC provides information about the consistency between two or more sets of measures, the SEM can be used to calculate the range in which a subject's "true score" may be expected to lie when the amount of error associated with repeated measurements is considered. For example, the SEM for the single hop for distance test was 4.42 cm. If an individual hops 200 cm on the single hop for distance test, we can be 95% confident that the "true score" for this individual lies within ±2 SEM, or between 191.16 and 208.84 cm. Furthermore, a change in this individual's score on the single hop for distance test of greater than 8.84 cm most likely represents a real change in their performance that may not be due to measurement error.

Descriptive study

A maximum score of 100 on the KOS SAS would indicate that the subject had no functional limitations. The subjects in our study scored a mean of 89 on the SAS, indicating that our subjects generally experienced minimal levels of disability after their ACLR. For example, this mean disability score on the SAS suggests that subjects can likely cope with their required military and sport activities, although they likely have not achieved full 100% recovery from their knee injury as of yet. The results of our study regarding SAS scores following ACLR correspond to the results reported by Ross et al. [9], who studied Air Force Academy cadets with a history of ACLR. The subjects in the Ross et al. [9] study had a mean score of 86 on the SAS. The slightly higher scores in our study could be due to the fact that the time from ACLR to testing for subjects in our study was a minimum of 2 years, while patients in the Ross et al. [9] study had a minimum of 1 year from ACLR to testing. We speculate that increased time between ACLR and testing allows the patient to be more confident in all aspects regarding the involved knee. Compared to the patients in the Ross et al. [9] study, the patient's in our study had one more year of exposure to military and sports activities.

When using tests that assess physical performance, it is often assumed that the tests correlate to the patient's level of disability. For example, if two very similar gymnasts two years following ACLR are examined with a series of hopping tests, we might expect the gymnast who reports a higher level of disability to not score as well on the hopping tests. In order for the tests examined in our study to be useful, they should be at least moderately correlated to patient disability and be sensitive enough to detect lower extremity performance deficits. The subjects in our study scored a mean of 89 on the SAS, indicating they experienced some level of disability after their ACLR. However, only the 45-sec sagittal plane hop test results were moderately correlated to patient disability levels and sensitive enough to detect lower extremity deficits. Specifically, the involved lower extremity of subjects with a history of ACLR in our study performed significantly fewer repetitions on the 45-second sagittal plane hop test when compared to the noninvolved lower extremity.

The single leg hop for distance test results showed little correlation (r=0.07) with patient disability as measured by the SAS scores. This finding is in general agreement with those of previous authors [3,6,9]. Wilk et al. [6] and Ross et al. [9] reported low correlation coefficients (r=0.39 and r=0.36, respectively) between the single leg hop test and patient disability following ACLR. These results also correspond with the results of the findings of a systematic review conducted by Losciale et al. [3], who found that there was low predictive validity between hop testing and patient disability following ACLR due to the majority of hop testing being performed in a single plane. As stated in our study, single leg hop for distance test does not correlate to functionality for patients following ACLR.

The single leg hop for distance test may not provide an accurate assessment of the patient's ability to function during military and sports activities for several reasons [3]. Since these tests are single plane premeditated tasks, they do not emulate the multiplanar and endurance-based activities that military and sports activities involve. Furthermore, the slight deficits seen in the subjects in our study (**Table 1**) with the single leg hop test may not have been great enough to influence function during military and sports activities.

The limitations with the single leg hop test encouraged us to examine tests outside the sagittal plane with an endurance component, like the 45-sec frontal plane hop test. However, this test exhibited a low correlation (r=0.26) with patient disability scores as measured by the SAS. The frontal plane hop test required the patient to hop side-to-side in the frontal plane over a single strip of athletic tape as many times as possible in 45 seconds. To better use the frontal plane hop test in evaluating patient disability levels following ACLR, perhaps the distance hopped should be increased by using 2 parallel strips of athletic tape placed 30 or 40 cm apart, thus increasing the degree of difficulty of the test [18,19]. However, this is speculation and further study is indicated to support or refute this recommendation.

While the 45-sec frontal plane hop test exhibited a low correlation with patient disability scores as measured by the SAS, a significant relationship was noted between the SAS scores and the percent lower extremity differences for the 45-second sagittal plane hop test (r=0.51). One potential reason that the 45-sec sagittal plane hop test was more correlated with patient disability than the 45-sec frontal plane hop test may have been because the distance of the hop was greater than in the frontal plane hop test, which placed greater stress on the knee. We speculate that perhaps the sagittal plane musculature, such as the quadriceps, was less developed in our subjects than the frontal plane musculature, making the frontal plane test easier to manage than the sagittal plane test. Additionally, Nyland et al [20] suggested that after ACLR, a long-term protective mechanism may be present to minimize knee loads that tend to increase anterior tibial translatory knee forces during intense repetitive single-leg activities in the sagittal plane. Intense repetitive single-leg activities in the frontal plane could also place stress on the knee, particularly with valgus loads.

While a significant relationship was noted between the SAS scores and the percent lower extremity differences for the 45-second sagittal plane hop test (r=0.51), further evaluation of the data reveals that the 45-second sagittal plane hop test only explained 26% of the variance in SAS scores (r^2=0.26). Thus, other factors not examined in this study accounted for the remaining 74% of the variance in patient disability as measured by SAS scores. Further study is needed to determine what measures provide the most effective estimate of patient disability following ACLR.

A limitation of this study is that we used a small sample size. Repeating this study with a larger sample size would be useful and those findings would increase the confidence in the results of our study. All of the subjects in this study were young adults currently enrolled at the United States Air Force Academy. We recommend caution in generalizing the results of this study to other populations.

Conclusion

The purpose of this study was to determine the relationship between patient disability levels following ACLR and closed kinetic chain performance. While no significant relationship existed between the SAS scores and the percent lower extremity differences for the single leg hop test, or the 45-second frontal plane hop test, a significant relationship was noted between the SAS scores and the percent lower extremity differences for the 45-second sagittal plane hop test. From these findings, we believe the sagittal plane hop test could be a useful clinical test in assessing a patient's disability level after ACLR, especially if used in conjunction with other clinical assessment techniques (e.g., range of motion, graft integrity, thigh strength, proprioception, patient subjective report of knee function). However, the single leg hop test and the 45-sec frontal plane hop test, as described in this study, should be used with caution when assessing a patient's disability level following ACLR.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions

Authors' contributions	JP	MR
Research concept and design	✓	✓
Collection and/or assembly of data		✓
Data analysis and interpretation	--	✓
Writing the article	✓	--
Critical revision of the article	✓	✓
Final approval of article	✓	✓
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