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ORIGINAL RESEARCH

THE RELIABILITY OF THE VAIL SPORT TEST™ AS A MEASURE OF PHYSICAL PERFORMANCE FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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ABSTRACT

Purpose/Background: The decision to return an athlete to sports following anterior cruciate ligament reconstruction can be controversial. The purposes of this study are 1) to describe a functional test (Vail Sport Test™) that includes the evaluation of muscle strength, endurance, power, and movement quality in those patients attempting to return to sports following ACL reconstruction and 2) to assess the reliability of the Vail Sport Test™.

Methods: A prospective cohort study design. A total of 30 (12 F, 18 M) subjects (18.1 ± 5.3 yrs) volunteered for the study. All subjects were post-operative ACL reconstruction (5.2 ± 1.9 months) and were in the process of returning to sports. Each subject completed the Vail Sport Test™ and was videotaped from the anterior and lateral view. The videotape was then viewed and graded at two different points in time (48 hours apart) by three licensed physical therapists. Intraclass correlations (ICCs) were calculated to determine intra- and inter-rater reliability.

Results: Intra-rater reliability was excellent with a range of .95 to 1.0. Reliability values between graders were .97 (ICC_{2},k) and 1.55 (SEM).

Conclusions: The results of this study suggest that the Vail Sport Test™ has excellent reliability when the same graders scored the test using video on repeated occasions. In addition, the test was reliable between different graders.

Level of Evidence: Level 2b

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INTRODUCTION

The timeline for return to sports after anterior cruciate ligament (ACL) reconstruction is often debated and can be difficult to determine. Factors such as range of motion (ROM), strength, pain, outcome scores, and functional performance tests may be considered when deciding if a patient is able to return to sports.[1] Because athletes are often returning to dynamic activities that involve large forces across the knee and may be at risk for re-injury, it is important that the measures used for evaluating a patient's readiness for return accurately assess the demands.

Hop tests have been used as a measure of functional performance in the lower extremity[2-5] and are believed to effectively test a patient's strength and neuromuscular control.[6] Additionally, they have been shown to be a reliable and valid outcome in patients who have undergone an ACL reconstruction.[3] When forty-two post-operative ACL-reconstructed (ACLR) patients were tested on four consecutive occasions, reliability scores ranged from .82 to .93 while demonstrating significant longitudinal validity. The patient's test performance on the hop test is described as the leg symmetry index (LSI) and is measured by comparing the involved limb to the uninvolved limb and is expressed as a percentage.[3] A score of 85% or less on the hop tests is considered to be abnormal.[7] While hop tests are often considered to be an objective measure that replicates the demands of high-level sport activities,[8] they may not be sensitive enough to identify some functional limitations due to their lack of multi-planar movements.[9]

Measurements of muscle strength are also considered to be important following ACL reconstruction.[10-14] If ACLR patients do not regain full quadriceps strength, gait abnormalities are evident.[13] When patients with quadriceps strength of greater than 90% of the uninvolved side (strong) were compared to a group of patients with quadriceps strength of less than 80% of the uninvolved side (weak) and ACL-deficient (ACLD) patients, the patients classified in the weak group demonstrated lower knee flexion angles during walking and jogging (similar to the ACLD group) than those classified in the strong group. However, strong group subjects were able to walk and jog with normal knee patterns, suggesting an ability to efficiently use the quadriceps.[13] As the ACLR patient progresses toward sport-specific activities, the need for quadriceps strength increases. Based upon the literature, an ACL-reconstructed patient should be able to achieve isokinetic quadriceps peak torque of up to 85% of the uninvolved lower extremity in order to progress to plyometric activities.[12] Similarly, a quadriceps strength index (percent strength of the opposite limb) of greater than or equal to 80% is believed to be important prior to these patients performing hop tests.[14] Failure to achieve these markers may demonstrate a patient's inability to adequately dissipate forces, and thus be at risk for injury.

Power, or a patient's ability to produce a high force over a short period of time, is another return to sports factor that must be considered. Neeter et al.[11] used a battery of tests to assess overall leg muscle power in ACLR patients. When patients who were 6 months post-op ACL reconstruction were tested on the knee-extension, knee-flexion, and leg-press power tests 90% were identified as having abnormal or decreased leg power on the reconstructed side. This test battery was determined to be sensitive enough to identify strength performance deficits between the injured and uninjured sides and thus, could be used to determine if ACLR patients are ready to return to sports.[11]

The relationship between strength and function has been examined in regards to athletic performance;[4,15-18] however, there is some discrepancy in the literature when it comes to establishing this association. Isokinetic strength of hip abductors and adductors are not correlated with functional sideways hop tests in elite ice hockey players,[17] and isokinetic quadriceps strength is not strongly correlated with one-legged hop tests in healthy college students.[4] Conversely, the triple hop test has been shown to be a strong predictor of isokinetic quadriceps strength in Division I-AA college soccer players.[15] In the injured population, isokinetic quadriceps strength has been shown to be related to functional tests in patients following ACL reconstruction.[16,18] Petschnig et al[18] found a significant correlation between quadriceps peak torque and single and triple hop tests in 55 ACLR males. Likewise, 31 patients who had undergone ACL reconstruction demonstrated a significant relationship between quadriceps strength indices (ratio of injured to uninjured limb) and single and

triple hop indices.[16] In addition, the quadriceps strength of these patients was correlated with function as measured by a series of agility tests (shuttle run, side step test, and carioca tests) after surgery. Although these results suggest a relationship between strength and function as it relates to a patient's ability to return to sport, they do not involve an assessment on the overall quality of movement patterns during these tasks and did not identify those who could successfully return to sport .

A clinical tool for the identification of patients at high-risk for ACL injury has recently been established.[19] Padua et al[19] showed that individuals who demonstrate poor technique (more errors) during jump-landing tasks have different lower extremity kinematics and kinetics than those individuals who demonstrate excellent technique (fewer errors). As such, the Landing Error Scoring System (LESS) was developed and is considered to be a reliable and valid test for assessment of jump-landing techniques for sports that involve movements in multiple planes of motion. While this particular clinical tool has been used to screen those at risk for ACL injury, the same principles of identifying faulty movement patterns during dynamic tasks would seem to be useful in patients who are in the process of returning to sports.

While the assessment of strength, power, and function have all been identified as important factors in deciding when a patient is ready to return to sports-specific activities, each assessment alone has some limitations. Although a relationship between strength and function has been established, muscle endurance has not been accounted for. Likewise, if certain movement patterns predispose one to an ACL injury, similar measures of movement assessment during the return to sport phase after ACL reconstruction should be included. Therefore, the purposes of this study are as follows: 1) to describe a functional test (Vail Sport Test™) that includes the evaluation of muscle strength, endurance, power, and movement quality in those patients attempting to return to sports following ACL reconstruction; 2) to assess the reliability of the Vail Sport Test™. We hypothesized that the Vail Sport Test™ would prove to be a reliable tool when used in the assessment of a patient's readiness to return to sports following ACL reconstruction.

METHODS

Participants

Thirty ACLR patients (18 males, 12 females) who were in the process of rehabilitation volunteered and gave informed consent for this study. The surgical grafts used in the reconstructions included 11 hamstrings, 11 patellar tendons, and 8 allografts while additional procedures involved 7 meniscus repairs and 8 partial meniscal resections. Each subject was in the return-to-sports phase of the rehabilitation process when they completed the Vail Sport Test™. The mean age of the subjects was 18.1±5.3 years and the average time from surgery was 5.2±1.5 months. Subjects were active in organized sports at the high school, college, or recreational level and presented with a mean pre-surgery Tegner Activity score of 7 and a mean post-surgery Tegner Activity score of 5 at the time of testing. The Institutional Review Board of Greenville Hospital System (Greenville, SC) approved the research procedures.

Procedures

The Vail Sport Test™ is a return to sports assessment that incorporates a series of dynamic multiplanar functional activities against the resistance of a sportcord®.[20] There are a total of four components of the test that include a single-leg squat for 3 minutes (Video 1), lateral bounding for 90 seconds (Video 2), and forward/backward jogging for 2 minutes each (Videos 3 and 4). After each component, the patient is given 2.5 minutes to rest prior to proceeding to the next task. The patient is graded based upon the ability to demonstrate strength and muscular endurance, absorb and produce force, all while maintaining appropriate movement quality at the trunk and lower extremity. The potential scores for the individual components are as follows: the single leg squat and the lateral bounding both have a maximum award of 15 points, and the forward and backward jogging have a maximum award of 12 points each for a total composite score of 54 points.

The Vail Sport Test™ was videotaped from an anterior and lateral view and was graded at two different points in time (48 hours apart) by three licensed physical therapists with experience ranging between 3 and 18 years. Prior to grading, each grader completed a two-hour training session on how to correctly grade and

score the Vail Sport Test™. In addition, the graders were required to demonstrate proper understanding of the grading instructions by completing several practice tests as part of pilot testing.

Grading criteria for the Vail Sport Test™ includes assessment of technique for each component and is based on a binary scoring system (yes = 1, no = 0). One point is given for each standard completed with proper form during the time intervals of each of the four components. The total available points for the Vail Sport Test™ is 54 and a patient is required to score at least 46 out of 54 points (85%) in order to receive a passing score, although this has not been established in the research. The patient does not receive a point for the chosen standard if they continue to perform with an incorrect movement pattern (after they have received verbal feedback) on 3 consecutive repetitions within each time interval (**Appendix**). As an example, if, during the first minute of the single leg squat, the patient performs the movement with dynamic knee valgus 3 times in a row despite having been given feedback, then he or she would lose a point for that particular minute. These criteria are constant for each standard and component of the Vail Sport Test™. For the single leg squat the subject must perform each repetition at a cadence of 1 second up and 1 second down against resistance of a sportcord® with 1) the knee between 30° and 60° of flexion, 2) without dynamic knee valgus, 3) without the knee locking in full extension, 4) without the patella extending past the toe, or 5) the trunk excessively falling forward or to the side. The rationale for the single leg squat component is for the patient to demonstrate quadriceps and hip muscle endurance while maintaining appropriate movement strategies.

The lateral bounding component involves the patient performing a lateral hopping motion against the resistance of a sportcord® attached to the subject's waist via a belt and on the other end to an immoveable object that is level with the waist (wall, door, etc.). The injured leg is positioned as the inside leg or the leg closest to the wall. The patient is instructed to hop from one leg to the other (leg length distance), absorbing energy while they land by bending at the knee (primary) and hip (secondary). Landing boundaries (distance of the hop) are demarcated on the floor with two pieces of tape, one of which begins at the point of resistance of the sportcord® as it is stretched away from the wall and the other the measured distance of the subject's leg length from the first piece of tape. Grading of the task involves the patient performing each repetition as follows: 1) the knee flexes at least 30° upon the foot contacting the ground, 2) without dynamic knee valgus, 3) performs repetitions within landing boundaries, 4) the landing phase does not exceed 1 second in duration, and 5) without the trunk falling excessively forward or to the side. Because the duration of this component is 1.5 minutes, the scoring is broken into assessment of each of the criteria in 30 second intervals (1st 30 seconds, 2nd 30 seconds, 3rd 30 seconds). The subject receives one point for each criterion that is performed correctly during each 30 second interval for a maximum total of 15 points. For instance, if the subject demonstrates proper movement and technique on all of the criteria during the 1st 30 seconds and 2nd 30 seconds, but is unable to control their forward trunk lean on 3 consecutive repetitions in the last 30 seconds, then they would lose the point for that criterion and would consequently score 14 out of 15 points. The rationale for the lateral bounding is for the patient to demonstrate good absorption (knee excursion), power (landing phase time), and neuromuscular control (avoiding poor movement patterns) during lateral movements.

The final components of the Vail Sport Test™ are forward and backward jogging against resistance of the sportcord®. As with the lateral bounding, the sportcord® is attached to an immoveable object at waist height to provide resistance by pulling the patient toward its attachment point. This attachment is the same for both the forward and backward jogging. The patient is instructed to hop from one leg to the other in an up and down manner (similar to jogging in place) while using proper form and absorbing energy with each landing by bending at the knee (primary) and hip (secondary). The patient is expected to perform each repetition 1) with the knee excursion between 30° and 60° of flexion, 2) within landing boundaries, 3) without dynamic knee valgus, 4) without locking the knee during extension, 5) without the landing phase exceeding 1 second in duration, and 6) without the trunk excessively falling forward or to the side during landing. Similar to the lateral bounding component, rationale for forward and backward jog-

Table 1. *Demographics and descriptive results for Vail Sport Test™*		
	Males	**Females**
Age (years)	19.3±6.2	16.9±3.3
Months post-operative	5.4±1.6	5.6±1.4
Vail Sport Test™ Total Score	43.1±12.2	46.2±5.7
Individual Components		
Single Leg Squat	12.6±3.8	13.5±1.1
Lateral Bounding	11.3±3.3	12.8±2.2
Forward Jogging	9.7±3.2	10.8±1.7
Backward Jogging	9.4±4.4	10.8±1.8

ging includes the patient demonstrating good absorption (knee excursion), power (landing phase time), and neuromuscular control (avoiding poor movement patterns) during sagittal plane landing movements.

Data Analysis

The total score for each subject's Vail Sport Test™ was calculated after watching the video and a total score was given on both occasions the video was graded. Each grader was allowed to watch the video one time during the grading portion with the ability to pause and rewind as needed. The scores for each graded session were then compared across all three graders (inter-rater) and between each individual grader (intra-rater). Intra-class correlations (ICCs) were calculated to determine intra-(2,1) and inter-rater reliability (3,k). All analyses were calculated using SPSS version 19.0 (Chicago, IL 60606).

RESULTS

When the scores of the three graders were calculated for all 30 subjects, the average Vail Sport Test™ score was 45 (±10.2) out of a total of 54 possible points. Representative scores of the individual components of the test included single leg squat (13.0±3.0), lateral bounding (11.9±2.9), forward jogging (10.1±2.7), and backward jogging (10.0±3.6). Table 1 outlines specific scores for each gender.

Intra-rater reliability agreement was excellent with a range of .95 to 1.0 ($ICC_{2,1}$). Reliability testing between testers demonstrated excellent inter-tester agreement with an ICC value of .97 ($ICC_{2,k}$) and 1.55 (SEM). Reliability for the four individual components of the Vail Sport Test™ is as follows: single leg squat .92 ($ICC_{2,k}$) and .84 (SEM); lateral bounding .85 ($ICC_{2,k}$) 1.25 (SEM); forward jogging .92 ($ICC_{2,k}$) and .84 (SEM); backward jogging .99 ($ICC_{2,k}$) and .41 (SEM).

DISCUSSION

The results of this study suggest that the Vail Sport Test™ is a reliable measure of physical performance in ACL-reconstructed patients when the same graders scored the test on repeated occasions. Likewise, the test was also shown to be reliable between graders. While this test has previously been used as a measure of physical performance following ACL injury[20] and hamstring avulsion reconstruction,[21] until now there has been a lack of evidence with regard to the overall reliability of the test.

Although there are several functional tests reported in the literature that are used to assess return to sports after ACL reconstruction,[3,16,22,23] they may not fully represent the high demands encountered in sports while also assessing the overall quality of movement. While hop tests are often used and have been shown to be reliable in patients undergoing rehabilitation following ACL reconstruction,[3] there may be limitations in the ability of these tests to assess muscle endurance and movement quality in multiple planes of motion. With the Vail Sport Test™, each component requires the patient to demonstrate not only muscle endurance, but also the qualitative ability to control the lower extremity during the task.

Even if return to sports tests contain components with stimuli high enough to simulate a patient's sport-specific activities, assessment of quality of movement and compensation can be difficult. Keays et al[16] examined knee strength and functional stability in post-operative ACL patients with the use of tests such

as the shuttle run, side step, carioca, and hop tests. Quadriceps strength was significantly correlated with both hop indices and agility tests in patients following ACL reconstruction. Similarly, when ACL reconstruction patients were compared to controls in bipedal functional tasks such as shuttle and agility runs, there were no significant differences between groups.[24] However, when these same patients were tested on single leg performance tasks, the patients who had undergone ACL reconstruction demonstrated deficits in the reconstructed limb. These results suggest that although bipedal functional measures of shuttle and agility tests may be more representative of a patient's required demands when returning to sports, they may be not sensitive enough to detect single limb performance deficits.[24]

A clinical tool (Landing Error Scoring System – LESS) used for screening athletes who may be at risk for ACL injury during landing has been developed and studied.[19] While this tool may often be used as a means of identifying those in need of an ACL prevention program, assessing overall movement quality in multiplanar movements may also be warranted in the return to sports phase of rehabilitation after ACL reconstruction. Grading of the Vail Sport Test™ was designed with constructs similar to the LESS in order to allow the clinician to observe movement quality and quickly determine whether or not the patient displays biomechanics that may predispose him or her to non-contact ACL injury.

The risk of suffering a knee injury has been reported to be higher in patients with a history of previous ACL injury than in those players without.[25-27] Of patients who were 2 years removed from ACL reconstruction, there was an increased risk of 3% for tearing either the intact contralateral ACL or the reconstructed ACL graft.[27] Likewise, poor biomechanics and neuromuscular control of the hip and knee during landing are considered to be predictors of second ACL injury in patients who have previously undergone ACL reconstruction.[26] Therefore, the ability of a test to indentify variables that place a patient at risk for ACL injury would appear to be an important factor when determining the appropriateness of returning to sports. Based upon the requirements of the Vail Sport Test™, a patient must demonstrate good control and power of the lower extremity during landing while overcoming the effects of fatigue. Therefore, it is the authors' belief that the Vail Sport Test™ is a reliable tool for assessing performance during the return to sport phase of rehabilitation.

Limitations

One of the limitations of this study is the fact that the subjects were taped and then graded at a later time rather than in a real-time manner. While this system allows the grader the ability to stop and start the videotape to score movement, which may enhance reliability, it also requires a greater time commitment on the part of the grader. However, this method has been used previously and with good results.[19]

Although the Vail Sport Test™ measures a patient's ability to control the lower extremity in the sagittal and frontal plane, it does not account for rotational movements which may be involved in an ACL mechanism of injury.[14,19,26,27] The inability of the Vail Sport Test™ to identify limitations during multiplanar movements is certainly a limitation, however, the test is believed to produce loads to the knee that are considered to be challenging to the joint and would thus give an indication of the functional abilities of the patient after ACL reconstruction.

In its present state a patient is required to score at least 46 out of 54 in order to pass the Vail Sport Test™. While this score (85%) has not been validated by research, the authors' experience and belief is that this number presents a significant challenge to those ACLR individuals when performing the test. However, continued research is required in order to provide a validated number for a passing score.

Finally, a gold standard for assessing readiness to return to sports following ACL reconstruction is lacking in the literature and makes it difficult to compare to the Vail Sport Test™. Even though this test battery is believed to have validity, the lack of gold standard precludes validity. In addition, the finding of reliability is not indicative of validity and thus the results should not be interpreted as the Vail Sport Test™ being able to assess a patient's readiness to return to sports. While hop tests are a reliable and valid measure of performance based outcome following ACL reconstruction,[3] the authors of the current study believe that the constructs of the Vail Sport Test™ represent significantly different variables and assess additional

components of muscle endurance and quality of movement. However, future research involving measurements of performance constructs after a patient has returned to sports in relation to a Vail Sport Test™ score is needed in order to validate these beliefs.

CONCLUSION

The Vail Sport Test™ is a functional tool that is reliable in assessing performance in ACLR patients during the return to sports phase of rehabilitation. When used as a component in a battery of outcome measures, this test may allow the clinician to effectively evaluate a patient's power, neuromuscular control, muscle endurance, and movement quality.

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APPENDIX

VAIL SPORT TEST™

Name: _____ **Date:** _____

MD: _____ **DX:** _____ **Mo. S/P:** _____

Total Points: _____**/54** * Patient must score 46/54 on the test in order to pass

Single Leg Squat (goal: 3 minutes)

1. Knee flexion angle between 30 and 60˚

   Yes (1) No (0)

2. Patient performs repetitions without dynamic knee valgus
   *knee valgus = patella falls medial to the great toe

   Yes (1) No (0)

3. Patient avoids locking knee during extension

   Yes (1) No (0)

4. Patient avoids patella extending past the toe during knee flexion

   Yes (1) No (0)

5. Patient maintains upright trunk during knee flexion

   Yes (1) No (0)

Minute 1 _____ Minute 2 _____ Minute 3 _____

Single Leg Squat Total Points: _____/15

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).

Lateral Bounding (goal: 90 seconds)

1. Knee flexion angle is 30˚ or greater during landing

   Yes (1) No (0)

2. Patient performs repetitions without dynamic knee valgus
   *knee valgus = patella falls medial to the great toe

   Yes (1) No (0)

3. Patient performs repetitions within landing boundaries

   Yes (1) No (0)

4. Landing phase does not exceed 1 second in duration

   Yes (1) No (0)

5. Patient maintains upright trunk during knee flexion

Yes (1) No (0)

1st 30 sec _____ 2nd 30 sec _____ 3rd 30 sec _____

Lateral Bounding Total Points _____/15

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 30 second timeframe).

Forward Jogging (goal: 2 minutes)

1. Knee flexion angle between 30 and 60˚

Yes (1) No (0)

2. Patient performs repetitions within landing boundaries

Yes (1) No (0)

3. Patient performs repetitions without dynamic knee valgus
* knee valgus = patella falls medial to the great toe

Yes (1) No (0)

4. Patient avoids locking knee during extension

Yes (1) No (0)

5. Landing phase does not exceed 1 second in duration

Yes (1) No (0)

6. Patient maintains upright trunk during knee flexion

Yes (1) No (0)

Minute 1 _____ Minute 2 _____

Forward Jogging Total Points _____/12

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).

Backward Jogging (goal: 2 minutes)

1. Knee flexion angle between 30 and 60˚

Yes (1) No (0)

2. Patient performs repetitions within landing boundaries

Yes (1) No (0)

3. Patient performs repetitions without dynamic knee valgus
    * knee valgus = patella falls medial to great toe

    Yes (1) No (0)

4. Patient avoids locking knee during extension

    Yes (1) No (0)

5. Landing phase does not exceed 1 second in duration

    Yes (1) No (0)

6. Patient maintains upright trunk during knee flexion

    Yes (1) No (0)

Minute 1 _____ Minute 2 _____

Backward Jogging Total Points _____/12

- If patient repeats error on 3 consecutive repetitions after correction, they are not eligible to receive a point for that particular standard (within each 1 minute timeframe).

VIDEO LEGEND - VAIL SPORT TEST™

Video 1. Single Leg Squats

Video 2. Lateral Bounding

Video 3. Forward Jogging

Video 4. Backward Jogging