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Using an accelerometer and the step-up-and-over test to evaluate the knee function of patients with anterior cruciate ligament reconstruction

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ABSTRACT

Background: Evaluating the dynamic knee function of patients after anterior cruciate ligament reconstruction is a challenge. A variety of objective tests have been developed but for various reasons few are regularly used in the clinic. It may be practical to perform the step-up-and-over test with an accelerometer.
Methods: A control group ($N = 26$) and an experimental group with a reconstructed anterior cruciate ligament ($N = 25$) completed questionnaires quantifying subjective knee function and fear of re-injury and then completed the step-up-and-over test.
Findings: Results showed that the experimental group performed differently than the control group for the step-up-and-over test's Lift Symmetry and Impact Symmetry ($P < 0.05$) and performance on these measures was related to the participant's subjective knee function ($\rho = -0.46$, $P < 0.01$; $\rho = -0.33$, $P < 0.05$, respectively). Supplemental results for individual leg performance and the patient's fear of re-injury are also reported and discussed.
Interpretation: Performance on the step-up-and-over test is different for participants with anterior cruciate ligament reconstruction than for those with intact anterior cruciate ligaments, and that performance is related to one's opinion of their knee's function.

1. Introduction

Rehabilitation following anterior cruciate ligament reconstruction (ACLR) is a challenging process to evaluate. The challenge begins with describing and understanding a patient's knee function, which is multi-factorial but can be characterized partly by the patient's post-surgical deficits. Patients with ACLR have deficits in their range of motion, gait, proprioception, cardiovascular fitness and muscular strength (Myer et al., 2006; Shelbourne and Nitz, 1990; van Grinsven et al., 2010; Werstine, 2009). Therefore, these parameters should be assessed to gauge improvement during rehabilitation and help decide when to return a patient to full physical activity. The current evaluation methods are, at least in part, unsuccessful since many patients are unable to return to their pre-injury physical activity level (Fithian, 2005; Kvist et al., 2005) and those that do return are at an increased risk of tearing their graft or tearing their contralateral anterior cruciate ligament (ACL) (Paterno et al., 2010; Pinczewski et al., 2007; Salmon et al., 2005; Wright et al., 2007).

Knee function is frequently evaluated using patient-completed questionnaires. Questionnaires, such as the widely used International Knee Documentation Committee's Subjective Knee Form (IKDC-SKF) (Irrgang et al., 2001), effectively measure a patient's symptoms, activity level and general knee function. A positive patient report, while subjective, is part of a complete ACLR evaluation and clinicians also require objective measures of knee function.

A common objective measure of knee function is time since surgery. Often, a time since surgery of six months is the only objective criterion for returning a patient to unrestricted activity (Barber-Westin and Noyes, 2011). In fact, Barber-Westin and Noyes (Barber-Westin and Noyes, 2011) report that time since surgery was a return-to-physical activity criterion in 60% of the ACLR rehabilitation studies and the only criterion used in 32% of the studies. These proportions are alarmingly high given the concern that time since surgery is a poor criterion (Barber-Westin and Noyes, 2011). More concerning is that objective measures, which could be used in conjunction with time since surgery, have been developed but are not frequently used. Tests that objectively assess knee function include single-leg hopping (Gustavsson et al., 2006), jumping and landing (Ford et al., 2003), knee extension and flexion (Keays et al., 2000; Lephart et al., 2002; Mattacola et al., 2002; Wilk et al., 1994), lunging (Alkjaer et al., 2002; Alkjaer et al., 2009; Mattacola et al., 2004) and stepping exercises (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004), but these tests were used in only 16% of studies (Barber-Westin and Noyes, 2011).

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The reasons why these valid, objective tests are not used more often for clinical evaluation are unclear; one reason may be their high physical demand. Activities that place high loads on the recovering knee can create the fear of re-injury and this fear can persist after completing rehabilitation (Ardern et al., 2011; Chmielewski et al., 2008; Kvist et al., 2005). If highly demanding evaluations like the single-leg hop (Gustavsson et al., 2006), drop vertical jump (Ford et al., 2003), and isokinetic knee strength tests (Keays et al., 2000; Lephart et al., 2002; Mattacola et al., 2002; Wilk et al., 1994) evoke the fear of re-injury then the performance may be altered to reduce the distress. In this case the fear of re-injury has altered the patient's performance and the resulting evaluation will not accurately reflect knee function.

Besides the physical demand of an evaluation, cost and complexity may be other reasons why objective testing is not more widely used. The high cost of motion capture systems and force plates required for some tests are unreasonable for many clinics. For example, several outcome measures from the forward lunge test require both a motion capture system and a force plate. In addition, there is the technical expertise to setup, run and maintain the equipment as well as process the data to produce the evaluative measures. Considering fear of re-injury, cost and complexity, a good knee function evaluation should have low physical demand, be inexpensive and simple to operate.

The step-up-and-over (SUAO) test simulates stair climbing and is less demanding than many proposed knee function tests. It involves navigating a single step and requires concentric knee control to step-up and eccentric control to step-down (Bailey and Costigan, 2015; Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). Most studies of the SUAO test use a force plate (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004), but there is recent evidence that a 3-axis accelerometer is a valid alternative to a force plate (Bailey and Costigan, 2015). A single force plate with its amplifier and cables can cost >10,000 USD while accelerometers can be purchased for <400 USD. With a simple accelerometer the SUAO test could be an evaluation that is objective, of low physical demand, inexpensive and simple to operate.

The SUAO test using an accelerometer has not yet been used to evaluate the knee function of patients with ACLR. The performance of patients and individuals with intact ACLs was different on the SUAO test when measured with a force plate (Chmielewski et al., 2002; Mattacola et al., 2004), but it is unknown if the same will be true when measured with an accelerometer. Therefore, this study had two main objectives: first, to establish whether or not participants with ACLR performed differently on the SUAO test than participants with ACL-intact knees, and second, to determine if a participant's performance on the SUAO test is related to their subjective knee function.

2. Methods

2.1. Participants

A control group and an ACLR group were recruited. The control group was required to have a current activity level ≥ 5 on the Tegner Activity-Level Scale and the ACLR group was required to have a pre-injury Tegner activity score ≥ 5, indicating a high level of physical activity (Tegner and Lysholm, 1985). In addition, all participants had to be free from current injuries of the lower limbs and back, aside from the repaired ACL for participants in the ACLR group. According to an a priori sample size computation 26 participants were needed in each group. In total 26 participants with intact ACLs were recruited to the control group and 26 participants with ACLR were recruited to the experimental group, with 1 person dropping out for personal reasons not related to testing. Of the 25 ACLR participants remaining, 17 received a hamstrings (semitendinosus and gracilis) graft while 8 received a quadriceps (bone-patella-bone) graft. The median time since surgery of all ACLR participants was 5.6 months (SD: 2.6; range: 1.3–9.2), therefore, some experimental participants had completed their required physical therapy sessions and had been cleared to return to unrestricted activity. All participants gave informed consent to participate in the study.

2.2. Procedure

2.2.1. Questionnaires

Following informed consent, the participants completed the IKDC-SKF. This questionnaire contains 18 items that quantify knee symptoms, sports activities and general knee function, and together, is a valid and reliable measure of subjective knee function (Irrgang et al., 2001). Scores for this test range from 0 to 100, with 100 representing optimal knee function. In addition to the IKDC-SKF, the ACLR group also completed the Tampa Scale of Kinesiophobia-11 (TSK-11), a questionnaire containing 11 items scored on a 1–4 scale, with a score of 11 representing no fear. The TSK-11 total score is a valid and reliable measure of the fear of re-injury (George et al., 2012). Five ACLR participants did not complete the questionnaires, reducing the sample sizes for the IKDC-SKF (N = 46) and the TSK-11 (N = 20).

2.2.2. Instrumentation

After completing the questionnaires, participants had a 3-axis, wireless accelerometer (3-Space Wireless Sensor, YEI Technology, Portsmouth, OH, USA) strapped over the spinous process of their L3 vertebra, which approximates the location of the participant's center of mass (Moe-Nilssen, 1998). From this position the accelerometer returns criterion-valid measures for the SUAO test (Bailey and Costigan, 2015). Accelerometer data was collected at 200 Hz by the 3 Space Suite software program (V3.0r9, YEI Technology, Portsmouth, OH, USA).

2.2.3. SUAO test

The SUAO test was performed on a level floor with a 305 mm high box. Participants stood behind the box and then stepped up on the box with the lead leg, carried the body and trail leg over the box, and landed with the trail leg contacting the floor on the other side of the box (Bailey and Costigan, 2015; Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). Five trials were completed by each leg and the order of all 10 trials was randomized. For the control group the lead leg was either the dominant or non-dominant leg and for ACLR group the lead leg was either the involved or uninvolved leg. Participants were instructed to complete the SUAO test at a self-selected, comfortable pace. Previously the SUAO test was performed at maximum speed (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004) but a slower pace requires less effort and may be safer.

2.3. Analysis

The SUAO test measures refer to the performance of the participant's lead leg – the one that steps onto the box. The acceleration profiles, measured in *g*s, were filtered using a second-order, dual-pass, low-pass Butterworth filter with a 20 Hz cutoff frequency. The net acceleration profile was computed by combining the accelerations from all three independent axes. The body weight index, commonly used to report SUAO test results, was then computed by subtracting one *g* from the net accelerometer profile and then multiplying by 100. Using a custom Matlab program (R2011B, The MathWorks Inc., Natick, MA, USA) the Lift Index, Impact Index and Movement Time measures were extracted from the body weight index (Bailey and Costigan, 2015). The Lift Index was the peak value during the up-phase of the step while the Impact Index was the peak value during the down phase. Movement Time was the time from the initial weight shift to the Impact Index, where the initial weight shift was the first instance that the absolute value of the body weight index exceeded 5% of static standing. Therefore, the Lift and Impact Indices characterized the concentric and eccentric control of the lead leg's knee at the lift and impact phases, respectively, and Movement Time characterized both the concentric and eccentric