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Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 5 (2016) 6−12
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Original article

Use of a portable motion analysis system for knee dynamic stability assessment in anterior cruciate ligament deficiency during single-legged hop landing

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Received 14 March 2016; revised 22 May 2016; accepted 7 June 2016
Available online 18 July 2016

Abstract

Background/objective: Anterior cruciate ligament (ACL) rupture results in knee instability, and patients are often unable to return to their previous level of activity. Current assessments rely on passive laxity tests, which do not correlate with function. Dynamic stability may be a better indicator for return to sport. However, equipment for measuring dynamic stability is ill suited for clinical use. The purpose of this study is to evaluate knee kinematics in ACL-deficient patients with a single-legged hop task using a portable motion analysis system. We hypothesize that the assessment task is able to differentiate ACL-deficient knees from healthy knees.

Methods: Ten ACL-deficient patients and 10 healthy controls were recruited. Participants were instructed to perform a single-legged hop, while kinematics was measured using a portable motion capture system (Opti-Knee; Shanghai Innomotion Inc., Shanghai, China). Kinematic changes after initial contact were examined. Repeatability of the results was examined by calculating the coefficient of variations of the pooled standard deviation of the tibiofemoral displacements. Side-to-side differences were calculated and compared between the two groups.

Results: One patient could not perform the task. Intraindividual variability was small after initial contact; the coefficient of variation in this region was 13−26%. ACL-deficient knees demonstrated lower flexion range of motion ($p = 0.008$) and increased internal/external rotation range of motion after landing ($p = 0.038$), while no significant differences were detected in the healthy group. Only the side-to-side difference in flexion was significantly different between the two groups ($p = 0.002$).

Conclusion: The altered knee kinematics in ACL-deficient patients can be revealed by a portable motion capture system, which may enable the clinical application of kinematic assessment in the evaluation of ACL deficiency.

Keywords: anterior cruciate ligament injury; biomechanics; kinematics; knee function; movement task

Introduction

Rupture of the anterior cruciate ligament (ACL) is one of the most common sport-related injuries in the lower extremities.[1] The ACL is one of the main stabilizers in the knee joint, and its disruption often results in deterioration in everyday function.[2] Joint stability influences knee function.[3] However, current assessment on knee stability relies on manual passive clinical tests that do not correlate well with functional outcomes.[4] A reason for this is that stabilization of the knee is dependent on two systems: static stabilizers, for which the ACL and the other knee ligaments are the main components, and dynamic stabilizers, which pertain to the

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http://dx.doi.org/10.1016/j.asmart.2016.06.002

muscular activity surrounding the knee joint.[5,6] In passive laxity tests, only the static stabilizers are engaged. Hence, the lack of a correlation between passive laxity tests and functional outcomes suggests that the integrity of the dynamic stabilizers may be a better indicator of knee function. In light of these, several studies have been conducted to assess and measure dynamic stability.[7,8]

Motion capture systems such as optical motion capture and biplanar fluoroscopy have allowed for objective and quantifiable assessment of dynamic knee stability. Results have shown that patients with knee joint laxity during the performance of motion tasks have worse functional outcomes.[9] This assessment may, therefore, prove to be clinically relevant in decision making. However, commonly used motion capture systems often require substantial resources that make it impractical for clinical use. Biplanar fluoroscopy is the gold standard for kinematic assessment, but the invasive nature makes this system unsuitable for regular clinical use to monitor treatment progress. Laboratory-based optical motion capture systems typically require sizable laboratories and intensive labour, which render it unfeasible for use in clinics. A portable motion capture system uses two infrared cameras attached to a portable workstation and has previously been used in a study to assess normal gait.[10] Several motion tasks may have been able to elicit an observable kinematic response; it has been shown that single-legged hop landing (SLHL) is sufficient to distinguish ACL-deficient (ACLD) knees from healthy knees.[11] Thus, development of SLHL assessment task using a portable motion capture system would enable the transition from research to clinic.

The purpose of this study is to evaluate tibiofemoral joint kinematics in ACLD patients with an SLHL assessment task using a portable motion capture system. Based on previous kinematic studies, we hypothesize that this system is able to differentiate ACLD knees from uninjured knees.

Materials and methods

Participants

Ten unilateral ACLD patients were recruited from the outpatient clinic of the department of Orthopaedics and Traumatology, Prince of Wales Hospital, Shatin, Hong Kong. Patients (age range, 18−50 years; no restriction on sex) were included if the injury was sustained at least 4 months prior to testing. Patients with pain or swelling at the knee joint and rerupture of a previous ACL reconstruction were excluded. All patients were scheduled for ACL reconstruction, and assessments were scheduled 3 months before ACL reconstruction. Ten personnel from the same department (age range, 18−50 years; no restriction on sex) with no previous history of injuries of the lower extremities were recruited as healthy controls.

Demographic data and medical history of the participants were collected. All the participants completed the International Knee Documentation Committee subjective knee evaluation form, Lysholm score, and postinjury Tegner activity level scale. For ACLD patients, concomitant injuries identified during the reconstruction surgery were documented. Prior to participation in the study, all the participants were provided with the study information and they signed a consent form. The study protocol was approved by The Joint Chinese University of Hong Kong—New Territories East Cluster Clinical Research Ethics Committee (Ref. No.: 2014.540). All experimental procedures were performed in accordance with the approved procedures.

Kinematic assessment

Tibiofemoral joint kinematics was acquired using a portable infrared optoelectronic motion capture system (Opti-Knee; Shanghai Innomotion Inc.). The system comprised two infrared cameras placed ~50 cm apart and a high-speed camera attached to a portable workstation. A set of eight reflective markers were used according to a standardized protocol provided by the developer. Two sets of markers were attached on the test limb according to premade grids, with each set consisting of four markers (Figure 1). A set of markers was attached 6−10 cm above the lateral epicondyle of the test leg, while a second set of markers was attached 1−5 cm below the fibular head. After fixing the markers, calibration was performed by marking specified body landmarks with the use of a pointer fixed with four reflective markers. With the participants in a level standing position and the lateral test side facing the cameras, the tip of the pointer was placed on the following points of the test leg: greater tuberosity, lateral epicondyle, medial epicondyle, lateral tibial plateau, medial tibial plateau, tibial tuberosity, fibular head, lateral malleolus, and medial malleolus. Three points on the ground were also captured. Data were collected at 60 Hz. Knee kinematics, including rotations and translations, were calculated for each frame using the geometric relationships between the reflective markers under the femur and tibia coordinate systems that were established during calibration.[10] The high-speed camera was also used to capture a video of the task and synchronized with the motion analysis data.

Participants were positioned within the capture area of the system, with all eight reflective markers being clearly detectable by the system throughout the task. They were asked to place both arms across the chest to prevent potential counterbalance attempts. A demonstration was given by the assessor on how to perform an SLHL task. A trial was considered successful if an individual was able to stand on the test leg, hop forward on the test leg over a distance of 1 m, land on the test leg, and maintain the single-legged stance until instructed by the assessor. Participants who were unable or unwilling to perform the task at the given distance of 1 m were allowed to perform it at their self-selected distance. Five successful trials were acquired for each participant on each limb.

Data analysis

For each successful trial, initial contact (IC) was identified using the captured video by manually identifying the instance