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Clinically-relevant measures associated with altered contact forces in patients with anterior cruciate ligament deficiency

Emily S. Gardinier [a,*], Kurt Manal [b,c], Thomas S. Buchanan [b,c], Lynn Snyder-Mackler [b,d]

[a] School of Kinesiology, University of Michigan, Ann Arbor, MI, USA
[b] Delaware Rehabilitation Institute, University of Delaware, Newark, DE, USA
[c] Department of Mechanical Engineering, University of Delaware, Newark, DE, USA
[d] Department of Physical Therapy, University of Delaware, Newark, DE, USA

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ABSTRACT

Background: Knee joint contact forces are altered after anterior cruciate ligament injury during walking and may be related to clinically-relevant measures of impairments or self-reported function. The purpose of this study was to investigate the association of several clinically-relevant measures with altered knee contact forces in patients with anterior cruciate ligament injury.

Methods: Data for this study represent a cross-sectional observational analysis of thirty-seven (23 M, 14 F) patients with complete unilateral anterior cruciate ligament injury. Gait analysis with electromyography was used to obtain estimates of tibiofemoral joint contact force using an electromyography-driven musculoskeletal model. Multivariable linear regression was used to identify measures associated with tibiofemoral joint contact force.

Findings: Involved knee extensor muscle strength and patient-reported knee function on the Global Rating Scale of perceived function were significantly associated with peak tibiofemoral contact force for the involved limb. Patients who were stronger and who perceived higher knee function walked with greater contact forces on their involved knees. After controlling for walking speed, involved extensor strength explained 8.9% of the variance in involved peak tibiofemoral contact force and score on the Global Rating Scale explained an additional 9.4% of the variance.

Interpretation: Improvements in involved quadriceps strength and overall function as measured by patient self-report may be important for increasing involved limb contact forces, thereby restoring loading symmetry in these patients who demonstrate decreased involved limb loading after injury. These results highlight the potential value of studying the recovery of strength, self-reported function and joint loading symmetry in patients with anterior cruciate ligament injury.

1. Introduction

The risk for developing osteoarthritis is increased after anterior cruciate ligament (ACL) injury (Lohmander et al., 2007; Øiestad et al., 2009) and altered loading of the injured knee may contribute to the development of osteoarthritis in these patients (Griffin and Guilak, 2005). Individuals with ACL rupture walk with decreased contact forces on their involved knees (Gardinier et al., 2012a), and this altered loading is evident despite these patients having resolved effusion, range of motion, pain and obvious gait impairments at the time of testing. However, the utility of other clinically-relevant measures in explaining altered loading after injury has not been investigated.

Movement strategies adopted by patients after ACL injury are likely influenced by a constellation of factors including both physical impairments resulting from injury and behavioral adaptations resulting from the experience of functional instability. Clinically-relevant measures that have been shown to differentiate between ACL-injured patients with and without movement asymmetries include a multi-component functional classification exam (Chmielewski et al., 2001; Rudolph et al., 2001) and a functional return-to-sport assessment (Di Stasi et al., 2013). These assessments include performance-based as well as patient-reported test components. Other clinically-relevant measures that have been related to altered movement strategies include quadriceps strength (Lewek et al., 2002; Snyder-Mackler et al., 1991), knee effusion (Torry et al., 2000), time from injury (Wexler and Hurwitz, 1998), and self-reported function (Lewek et al., 2002). Identifying

* Corresponding author at: 0160 Observatory Lodge, 1402 Washington Heights, Ann Arbor, MI 48109, USA.
E-mail address: egardin@umich.edu (E.S. Gardinier).

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relationships between clinically-relevant measures and altered joint loading will highlight the rehabilitation constructs that are associated with normal and symmetrical loading, and will likewise promote the development of interventions that effectively target aberrant joint loading in these patients.

Identifying relationships between altered contact forces and clinically-relevant measures will also expand the impact and relevance of modeling estimates for clinical practice. Currently, estimates of muscle and joint contact forces in vivo require a musculoskeletal modeling approach and cannot be well-approximated using muscle activity (Meyer et al., 2013) or joint moments (Walter et al., 2010) alone. Musculoskeletal models used to estimate muscle and joint contact forces are necessarily complex and generating these model estimates requires gait analysis data, customized software and significant post-processing (Erdemir et al., 2007). Consequently, estimates of joint contact force are currently not widely available in the clinical setting. A better understanding of the patient-specific factors that relate to altered contact forces will help clinicians identify patients who likely demonstrate altered loading using clinically-available assessments.

The purpose of this study was to investigate the association of several clinically-relevant measures with altered knee contact forces in patients with ACL injury. We hypothesized that a combination of clinically-relevant measures including both performance-based and patient-reported measures would explain a significant portion of the variance in involved knee contact forces.

2. Methods

2.1. Subjects

Data for this study represent a cross-sectional observational analysis from thirty-seven (23 M, 14 F) participants with complete unilateral ACL injury who completed functional and biomechanical testing in our lab. Data were collected prospectively as part of either a randomized clinical trial (n = 25) (Hartigan et al., 2010) or subsequent case series (n = 12) and thirty of these patients were included in our primary analysis of knee joint contact forces after acute ACL injury (Gardinier et al., 2012a). All patients were recruited through the University of Delaware Physical Therapy Clinic. This work was approved by the Institutional Human Subjects Review Board and all participants provided informed consent prior to study enrollment.

Study inclusion criteria were: (1) regular pre-injury participation in IKDC level I/II (jumping, cutting or pivoting) sports (Hefti et al., 1993), (2) age between 13 and 55 years, (3) complete unilateral ACL rupture confirmed through clinical examination and MRI and (4) functional classification as a noncoper (i.e. demonstrating characteristic dynamic knee instability after injury) according to the criteria described by Fitzgerald and colleagues (Fitzgerald et al., 2000). Knee range of motion, effusion, pain, and obvious gait impairments were treated and resolved before testing in accordance with the impairment treatment protocol described by Hurd and colleagues (Hurd et al., 2008). Prior to entering the study, patients underwent physical examination by a licensed physical therapist. Before participating in study testing, patients were required to demonstrate full knee extension (0°), exhibit minimal knee effusion (grade of 1+ or less using the modified stroke test (Adams et al., 2012)), report no knee pain with hopping up and down on the involved limb and demonstrate no visually obvious gait impairments when assessed by the therapist. Study exclusion criteria were presence of a full-thickness chondral defect ≥1 cm^2, symptomatic meniscus tear or concomitant grade III rupture to other knee ligaments.

2.2. Clinical testing

Patients were asked to report the number of times they had experienced their knee giving way (e.g. sensation of buckling or shifting) since their injury. Time since injury was also recorded. Isometric knee extensor strength was then tested using the burst superimposition technique (Snyder-Mackler et al., 1995). Patients were seated in a KIN-COM dynamometer (Chattanooga Corp., Chattanooga, TN, USA) A supramaximal burst of electrical current was delivered via two 3″ × 5″ self-adhesive electrodes applied to the testing limb while the patient performed a maximal effort kick to elicit maximal force. Maximum volitional force was the maximal force output prior to the burst, and activation ratio was the maximum volitional force divided by the maximum force output resulting from the supramaximal burst. If activation ratio was less than 95% (operationally defined as normal (Chmielewski et al., 2004)), the test was repeated up to two more times in order to achieve a true maximal volitional effort. The highest maximum volitional force measurement was normalized to body mass and tibia length for analysis.

After strength testing, patients completed 3 self-report outcomes: the Knee Outcome Survey Activities of Daily Living Scale (KOS-ADLS) (Irrgang et al., 1998) and the Global Rating Scale of perceived function (GRS) and the International Knee Documentation Committee 2000 subjective form (IKDC 2000) (Irrgang et al., 2001). The KOS-ADLS contains 14 items that assess patients' perceived limitations related to various impairments and daily activities (Irrgang et al., 1998) and gives a score expressed as a percentage of the 70-point maximum score. The KOS-ADLS is a reliable, valid, and responsive instrument for the assessment of functional limitations that result from a wide range of knee pathologies (Irrgang et al., 1998). The GRS consists of a single item in which patients are asked to score their perceived overall knee function on a scale of 0 to 100, with zero representing an inability to perform any activity and 100 representing their knee function prior to injury, including sports participation. The IKDC 2000 (Irrgang et al., 2001) contains 20 items and gives a score expressed as a percentage of the 87-point maximum score. The IKDC 2000 is a valid and reliable instrument for assessing patients' symptoms, function, and sports activity in patients with a variety of knee problems (Higgins et al., 2007; Irrgang et al., 2001). All scores were calculated after clinical testing was completed.

All patients included in this study reported no pain with hopping immediately prior to clinical testing. Nonetheless, we assessed the potential association of knee pain and joint loading by categorizing each patient's response to the first item on the KOS-ADLS (which asks to what degree the experience of knee pain affects their usual daily activities). If patients reported that they did not have pain with daily activities (item score = 5), they were categorized as having no pain. If patients reported having any pain (item score ≤4), they were categorized as having knee pain for the purposes of this study.

2.3. Biomechanical testing

Patients were asked to walk at their self-selected, intentional speed down a 20-m walkway. An 8-camera video system (sampling rate 120 Hz) (VICON, Oxford Metrics Ltd., London, UK) with embedded force platform (sampling rate 1080 Hz) (Bertec Corporation, Worthington, OH, USA) was used to record marker trajectories and ground reactions. Passive retro-reflective markers (Gardinier et al., 2012b) were used to define anatomical coordinate systems and track limb motion during gait. Surface electromyography (EMG) was recorded using an MA-300 EMG System (sampling rate 1080 Hz) (Motion Lab Systems, Baton Rouge, LA, USA) and was used as input to the musculoskeletal model for estimation of muscle forces.

Muscle forces were estimated using an EMG-driven musculoskeletal model of the knee (Buchanan et al., 2004; Gardinier et al., 2012b) that has demonstrated good repeatability (Gardinier et al., 2013) and high accuracy when validated using in vivo contact force data recorded from an instrumented knee prosthesis (Manal and Buchanan, 2013). The lower extremity anatomical model (SIMM 4.0.2, Musculographics, Chicago, IL, USA (Delp et al., 1990)) contained 10 musculotendon actuators for the knee and was scaled according to anatomical dimensions