Clinical Biomechanics 29 (2014) 1125–1130

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Individuals with chronic ankle instability exhibit altered landing knee kinematics: Potential link with the mechanism of loading for the anterior cruciate ligament

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ARTICLE INFO

Article history:
Received 8 April 2014
Accepted 29 September 2014

Keywords:
Joint instability
Kinetic chain relationship
Ankle
Knee
Jump landing

ABSTRACT

Background: Alterations in sagittal plane landing biomechanics in the lower extremity have been observed within the chronic ankle instability (CAI) population. Interestingly, a potential link between the risk of anterior cruciate ligament (ACL) injury and ankle sprain history has been proposed. However, it is not known if the observed biomechanical changes associated with CAI could mimic factors related to the mechanism of ACL injury. We investigated the influence of CAI on anterior tibial shear force (ATSF), lower extremity sagittal plane kinematics, and posterior ground reaction force (GRF) in a jump landing task.
Methods: Nineteen participants with CAI and 19 healthy control participants performed a vertical stop jump. Peak ATSF was calculated during the first landing of the stop jump, with sagittal-plane kinematics and posterior GRF measured at peak ATSF. Independent t-tests, multiple linear regression, and Pearson bivariate correlation were used for statistical analysis.
Findings: Participants with CAI demonstrated less knee flexion at peak ATSF compared to the controls ($P = .026$). No group-differences were found for peak ATSF or the other biomechanical variables. Knee flexion was moderately correlated with peak ATSF ($r = -0.544$, $P = .008$); however, the contributing factor that most explained the variance in ATSF was posterior GRF ($R2 = 0.449$; $P = .002$) in the CAI group.
Interpretation: Our findings indicate that the CAI group may be exhibiting altered knee function during functional movement. Screening knee movement patterns in individuals with CAI may help develop preventative measures for future joint injury throughout the kinetic chain.

1. Introduction

Lateral ankle sprains are one of the most common lower extremity injuries in the physically active population (Doherty et al., 2014; Hootman et al., 2007; Waterman et al., 2010). Up to 73% of individuals with an initial lateral ankle sprain develop chronic ankle instability (CAI) (Konradsen et al., 2002; van Rijn et al., 2008), typically defined as recurrent ankle sprains with or without functional impairments and residual symptoms of giving-way (Delahunt et al., 2010; Gribble et al., 2013). Functional impairments associated with CAI could decrease an individual's activity level over the life span (Hiller et al., 2012; Konradsen et al., 2002), and the presence of CAI potentially leads to an early onset of degenerative pathology in the ankle, such as posttraumatic osteoarthritis (Valderrabano et al., 2006).

Previous literature has reported that the presence of CAI may be associated with neuromuscular and biomechanical alterations in the knee (Brown et al., 2012; Gribble and Robinson, 2009a, 2009b, 2010; Sedory et al., 2007) and hip (Beckman and Buchanan, 1995; Brown et al., 2011; Bullock-Saxton et al., 1994; Gribble et al., 2004). Specifically, a reduced knee flexion angle has been reported in individuals with CAI during a jump landing task (pre-landing: mean = 5.77°, SD = 3.63; at-landing: mean = 3.21°, SD = 5.03) compared to those without CAI (pre-landing: mean = 8.04°, SD = 5.14; at-landing: mean = 7.63°, SD = 6.11) (Gribble and Robinson, 2009a, 2010). Additionally, a decreased motoneuron pool excitability of the hamstrings and increased motoneuron pool excitability of the quadriceps have been observed in CAI population (Sedory et al., 2007). However, it is not known if the observed alterations in proximal lower extremity joint motion patterns and neuromuscular activity associated with CAI emulate factors that increase the risk of injuries to proximal lower extremity joints.

Anterior cruciate ligament (ACL) injury is one of the most debilitating injuries in sports (Uhorchak et al., 2003). It has previously been reported that 52% to 60% of patients that suffered an ACL injury had a previous history of ankle sprain (Kramer et al., 2007; Soderman et al.,

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http://dx.doi.org/10.1016/j.clinbiomech.2014.09.014
0268-0033/

2001). Kramer et al. (2007) examined a potential relationship between ACL injury risk and previous ankle sprain history and reported common factors that predicted inclusion in both the ACL injured and the ankle sprained groups. Patients with an ankle sprain history exhibited significantly increased general laxity and genu recurvatum as well as decreased iliotibial band flexibility (Kramer et al., 2007). Interestingly, both increased generalized laxity and decreased iliotibial band flexibility were also significantly related to a previous ACL injury (Kramer et al., 2007).

While it has been suggested that a previous history of ankle sprain may increase the risk of ACL injury (Kramer et al., 2007; Soderman et al., 2001), the data in these studies are insufficient to support the potential biomechanical link. There has been no attention given to examine if biomechanical alterations demonstrated by CAI patients are associated with the mechanism of ACL injury during high risk and sport related tasks, such as a maximum vertical stop jump. Although the mechanism of ACL injury is multifactorial (Quatman et al., 2010), injury to the ACL most commonly results from excessive anterior tibial shear force (ATSF) while the knee is close to full extension and there is a greater posterior ground reaction force (GRF) (Chappell et al., 2005, 2007; Sell et al., 2007). Individuals with CAI present with decreased knee flexion and increased posterior GRF during jump-landing tasks (Delahunt et al., 2006; Gribble and Robinson, 2009a, 2010). These biomechanical variables have been shown to influence the amount of ATSF (Chappell et al., 2005, 2007; Sell et al., 2007), and increased ATSF has been implicated as a direct mechanism of excessive ACL loading (Sell et al., 2007). If these biomechanical alterations increase ATSF during dynamic tasks in participants with CAI, this would provide insight into a potential link between injury pathology at the ankle (CAI) and the knee (ACL). However, there are no previous investigations that have examined the amount of peak ATSF, sagittal plane kinematics in the lower extremity and posterior GRF at peak ATSF, and association between peak ATSF and these biomechanical variables in CAI population. Determination of biomechanical characteristics associated with CAI that can influence peak ATSF may provide important evidence for future studies to develop more preventative measures for knee joint injury in CAI populations. Therefore, the purposes of the present study were: 1) to investigate the influence of CAI on peak ATSF, lower extremity sagittal plane kinematics, and posterior GRF during a vertical stop jump; and 2) to examine the ability of the variances in pertinent biomechanical variables to predict the variances in peak ATSF in participants with CAI.

2. Methods

A case–control experiment design with a between-subjects factor (2 levels: CAI and healthy control) was used.

2.1. Participants

Thirty-eight physically active participants were recruited from the University community and volunteered for the study (Table 1). Physically active was defined as an individual engaging in at least 20 min of vigorous activity, three or more days per week (United States. Dept. Of Health and Human Services, 2000). All participants were free of any self-reported knee or hip injuries and balance or vestibular disorders, as well as had no history of low back pain in the previous six months and no previous history of fracture and surgery in the lower extremity. All participants read and signed the informed consent forms approved by the University of Toledo Institutional Review Board at the beginning of testing.

Nineteen participants with self-reported unilateral CAI were included. The inclusion of the CAI group was determined by: (1) having a previous history of at least one acute unilateral ankle sprain which caused swelling, pain, and temporary loss of function; (2) a history of at least two self-reported episodes of “giving way” without swelling and loss of function in the previous six months; (3) no previous history of ACL injury or reconstruction; (4) no previous history of any musculoskeletal and neurovascular injuries in the lower extremity other than the ankle; and (5) self-reported functional disability as a result of their ankle sprain history by scoring ≤90% on the Foot and Ankle Ability Measure (FAAM) activities of daily living subscale (FAAM–ADL) and ≤80% on the FAAM Sports Subscale (FAAM-S) as well as a score of at least four on Ankle Instability Instrument (AII) (Carcia et al., 2008; Docherty et al., 2006; Gribble et al., 2013, 2014a,b). The FAAM and AII have been shown as valid in assessing functional limitations and disability in those with CAI (Carcia et al., 2008; Docherty et al., 2006; Martin et al., 2005). No participant with CAI had acutely sprained his or her ankle in the 3 months before testing (Gribble et al., 2013, 2014a,b).

The control group included 19 participants with no history of any self-reported musculoskeletal and neurovascular injuries and disorders in the lower extremity. Participants in the control group were required to score 100% on both FAAM–ADL and FAAM-S and answer “no” to the question, “Do you have a history of ankle sprain?” on the AII. Participants in the control group were matched by sex, age, height, mass, and limb dominance to those in the CAI group. Limb dominance was defined as the limb used to kick a ball. After being matched to a CAI participant by demographic information and limb dominance, the control participant's test limb was set to match the CAI participant's involved limb. For example, if the CAI participant had a right involved ankle, then the right limb of the matched control participant was used for the statistical analysis.

2.2. Instrumentation

An electromagnetic tracking system (Ascension Technology Corp., Burlington, VT) synchronized with a non-conductive force plate (model 4060NC; Bertec Inc., Columbus, OH) via the MotionMonitor software (version 7.0; Innovative Sports Training, Inc., Chicago, IL) was used. Researchers have previously reported that electromagnetic tracking systems are valid and reliable to measure three dimensional movements of body segments and joints (An et al., 1988; Milne et al., 1996; Nakagawa et al., 2014). Electromagnetic sensors were placed over the

Table 1
Demographic information and Foot and Ankle Ability Measure (FAAM), FAAM Sports Subscale (FAAM-S), and Ankle Instability Instrument Scores for chronic ankle instability (CAI) and control groups [mean (SD)].

	CAI	Control	*P*-value
n	19 (10 males, 9 females)	19 (10 males, 9 females)	–
Age (year)	20.11 (1.63)	21.32 (4.04)	.30
Height (cm)	177.06 (9.38)	171.27 (9.02)	.19
Body mass (kg)	75.90 (17.04)	71.25 (14.92)	.14
FAAM (%)	82.77 (8.70)	100.00 (0.00)	<.001*
FAAM-S(%)	65.79 (10.90)	100.00 (0.00)	<.001*
Ankle Instability Instrument	5.58 (1.54)	0.00 (0.00)	<.001*
# of lateral ankle sprain	3.74 (2.81)	–	–
Time since last ankle sprain (month)	13.84 (14.41)	–	–

* Significant difference in FAAM, FAAM-S, and AII between groups ($P < .05$).