Available online at www.sciencedirect.com
ScienceDirect
Clinical Biomechanics 23 (2008) 313–319
CLINICAL BIOMECHANICS
www.elsevier.com/locate/clinbiomech

Influence of trunk flexion on hip and knee joint kinematics during a controlled drop landing

J. Troy Blackburn [a,b,*], Darin A. Padua [a,c]

[a] Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, NC 27599-8605, USA
[b] Motor Control Laboratory, University of North Carolina, Chapel Hill, NC 27599-8605, USA
[c] Sports Medicine Research Laboratory, University of North Carolina, Chapel Hill, NC 27599-8605, USA

Received 13 April 2007; accepted 9 October 2007

Abstract

Background. An erect posture and greater knee valgus during landing have been implicated as anterior cruciate ligament injury risk factors. While previous research suggests coupling of knee and hip kinematics, the influence of trunk positioning on lower extremity kinematics has yet to be determined. We hypothesized that greater trunk flexion during landing would result in greater knee and hip flexion and lesser knee valgus. Identification of a modifiable factor (e.g. trunk flexion) which positively influences kinematics of multiple lower extremity joints would be invaluable for anterior cruciate ligament injury prevention efforts.

Methods. Forty healthy individuals completed two drop landing tasks while knee, hip, and trunk kinematics were sampled. The first task constituted the natural/preferred landing strategy (Preferred), while in the second task, subjects actively flexed the trunk upon landing (Flexed).

Findings. Peak trunk flexion angle was 47° greater for Flexed compared to Preferred ($P < 0.001$), and was associated with increases in peak hip flexion angle of 31° ($P < 0.001$) and peak knee flexion angle of 22° ($P < 0.001$).

Interpretation. Active trunk flexion during landing produces concomitant increases in knee and hip flexion angles. A more flexed/less erect posture during landing is associated with a reduced anterior cruciate ligament injury risk. As such, incorporating greater trunk flexion as an integral component of anterior cruciate ligament injury prevention programs may be warranted.

Keywords: ACL; Quadriceps; Hamstrings; Valgus; Flexion; Injury prevention

1. Introduction

Recent research on anterior cruciate ligament (ACL) injury mechanisms has begun to evaluate influences of kinematic factors proximal to the knee joint. Given the closed-kinematic-chain nature of the lower extremity following ground contact during landing and gait activities, it has been suggested that segmental motion of the mass superincumbent to the knee directly influences knee joint motion and loading. Specifically, it has been suggested that hip internal rotation and adduction contribute to knee valgus (McLean et al., 2004b; Zeller et al., 2003), a kinematic factor which has been linked to ACL injury risk (Hewett et al., 2005). This notion coincides with the "position of no return" during which non-contact ACL injury is hypothesized to occur, characterized by hip adduction and internal rotation, knee valgus and external tibial rotation, and subtalar pronation (Ireland, 1999). Additionally, females, a population which is at heightened risk for ACL injury (Arendt et al., 1999; Gwinn et al., 2000), simultaneously display lesser knee, hip, and trunk flexion during gait and landing tasks compared to males (McLean et al., 2004b; DiStefano et al., 2005; Salci et al., 2004; Yu et al., 2006; Decker et al., 2003), suggesting sagittal-plane

* Corresponding author. Address: Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, NC 27599-8605, USA.
E-mail address: troyb@email.unc.edu (J.T. Blackburn).

0268-0033/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2007.10.003

coupling of these joints. Furthermore, females also demonstrate greater knee valgus during these tasks compared to males (Russell et al., 2006; Ford et al., 2003), suggesting the coupling of lower extremity kinematics has a mulitplanar influence on ACL injury risk. As excessive knee valgus and a more erect landing posture (evidenced by a more extended knee, hip, and trunk) have been postulated as ACL injury risk factors (Griffin et al., 2000), continued research regarding the coupling of these joints is warranted.

Previous research supports a link between landing forces and knee injury (Dufek and Bates, 1991), and numerous investigations have demonstrated relationships between landing forces and frontal and sagittal plane kinetics and kinematics. In a prospective study, Hewett et al. (2005) reported a significant correlation between peak knee valgus angle and peak vertical ground reaction force in individuals who sustained ACL injury, and that the vertical ground reaction force was 20% greater in individuals who sustained ACL injury compared to those who did not. Furthermore, those who sustained ACL injury displayed lesser knee flexion compared to those who did not, and knee flexion angle was correlated with the vertical ground reaction force in these individuals. McLean et al. (2005) demonstrated the dependency of peak knee valgus moments during cutting tasks on hip and knee joint kinematics. Yu et al. (2006) demonstrated that hip and knee joint angular velocities were correlated with posterior and vertical ground reaction forces. Lastly, videotape feedback has been demonstrated to increase knee flexion displacement and decrease vertical ground reaction forces simultaneously (Onate et al., 2005), supporting the link between landing kinematics and kinetics. These data suggest that lower extremity landing kinetics and kinematics and the subsequent load placed on the ACL are highly interlinked in a multiplanar manner, a notion which is supported by investigations of the effects of various knee joint kinematic configurations on ACL stress and strain in cadaveric specimens (Durselen et al., 1995; Fukuda et al., 2003; Kanamori et al., 2002).

The aforementioned relationships between frontal and sagittal plane kinematics and landing forces suggest that greater hip and knee flexion and a smaller knee valgus angle are associated with lesser ground reaction forces, potentially shielding the ACL from excessive loading. While the coupling of hip and knee kinematics and the link between lower extremity kinematics, landing forces, and ACL injury are supported in the literature, it is unclear how trunk motion influences these factors. Specifically, it is unclear how the sagittal-plane positioning of the trunk influences hip and knee joint kinematics. Identification of a single modifiable factor (e.g. trunk flexion angle) which has the potential to alter lower extremity kinematics in a multiplanar manner that is associated with a lesser ACL injury risk would be invaluable to injury prevention efforts. Therefore, the purpose of this investigation was to evaluate the influence of trunk motion in the sagittal plane on hip and knee joint kinematics. It was hypothesized that trunk flexion during landing would result in greater knee and hip flexion, lesser knee valgus, and lesser hip adduction and internal rotation.

2. Methods

2.1. Subjects

Forty healthy volunteers (20 males, 20 females: age = 21.5 (SD 1.9) years, height = 1.73 m (SD 0.10), mass = 74.6 kg (SD 17.47) constituted the sample for this investigation. All subjects were physically active, participating in physical activity a minimum of 20 min 3 times per week, and had no history of (1) ACL injury, (2) lower extremity surgery, (3) neurological disorder, (4) chronic lower extremity injury, or (5) lower extremity injury within the six months prior to data collection. Subjects read and signed an approved informed consent document prior to data collection. All data were sampled from the subject's right lower extremity, which corresponded with the dominant leg in 37 of the 40 subjects (93%).

2.2. Instrumentation

Electromagnetic tracking sensors (Flock of Birds, Ascension Technology Corp., Burlington, VT, USA) were positioned on the thorax, sacrum, thigh, and shank using doubled-sided tape. Global and segment axis systems were established with the X-axis designated as positive forward/anteriorly, the Y-axis positive leftward/medially, and the Z-axis positive upward/superiorly. The trunk and right lower extremity were modeled by digitizing the C7/T1, T12/L1, hip, knee, and ankle joint centers. The hip joint center was estimated using a least squares method (Leardini et al., 1999), while knee and ankle joint centers were defined as the midpoints between the digitized medial and lateral femoral condyles and medial lateral malleoli, respectively. Vertebral joints were defined as the digitized space between the corresponding spinous processes. The Motion Monitor motion capture system (Innovative Sports Training, Chicago, IL, USA) was used for model generation/calibration and data acquisition.

2.3. Experimental procedures

Subjects performed two controlled vertical drop landing tasks utilizing a repeated-measures design during which trunk, hip, and knee kinematics were assessed. For the first task, subjects stepped off a platform 60 cm in height with the right knee extended (McNitt-Gray, 1993) and performed a double-leg landing onto a non-conductive force plate (Bertec Corp., Columbus, OH, USA), with only the right foot making contact with the force plate. This task represented the subject's natural/preferred landing strategy (Preferred). For the second task, subjects stepped off the platform in a manner identical to the first, but were