Journal of Biomechanics 48 (2015) 3724–3727

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

Unlocking the talus by eversion limits medial ankle injury risk during external rotation

Keith D. Button, Feng Wei, Roger C. Haut*

Orthopaedic Biomechanics Laboratories, Michigan State University, East Lansing, MI 48824, United States

ARTICLE INFO

Article history:
Accepted 6 August 2015

Keywords:
Subtalar
Talocrural
Eversion
Syndesmotic injury
High ankle sprain
Medial ankle sprain

ABSTRACT

Eversion prior to excessive external foot rotation has been shown to predispose the anterior tibiofibular ligament (ATiFL) to failure, yet protect the anterior deltoid ligament (ADL) from failure despite high levels of foot rotation. The purpose of the current study was to measure the rotations of both the subtalar and talocrural joints during foot external rotation at sub-failure levels in either a neutral or a pre-everted position as a first step towards understanding the mechanisms of injury in previous studies. Fourteen (seven pairs) cadaver lower extremities were externally rotated 20° in either a pre-everted or neutral configuration, without producing injury. Motion capture was performed to track the tibia, talus, and calcaneus motions, and a joint coordinate system was used to analyze motions of the two joints. While talocrural joint rotation was greater in the neutral ankle ($13.3 \pm 2.0°$ versus $10.5 \pm 2.7°$, $p=0.006$), subtalar joint rotation was greater in the pre-everted ankle ($2.4 \pm 1.9°$ versus $1.1 \pm 1.0°$, $p=0.014$). Overall, the talocrural joint rotated more than the subtalar joint ($11.9 \pm 2.8°$ versus $1.8 \pm 1.6°$, $p < 0.001$). It was proposed that the calcaneus and talus 'lock' in a neutral position, but 'unlock' when the ankle is everted prior to rotation. This locking/unlocking mechanism could be responsible for an increased subtalar rotation, but decreased talocrural rotation when the ankle is pre-everted, protecting the ADL from failure. This study may provide information valuable to the study of external rotation kinematics and injury risk.

1. Introduction

Positioning of the ankle prior to external rotation affects the behavior of the talus and therefore location of injury (Wei et al., 2012; Button et al., 2013b; Haraguchi and Armiger, 2009). A previous study in this laboratory has shown that the combination of ankle eversion and dorsiflexion followed by axial load and external rotation produces isolated anterior inferior tibiofibular ligament (ATiFL) (commonly called the syndesmotic ligament) injury, also known as high (or syndesmotic) ankle sprain. In a similar set of experiments, removing the eversion component mostly results in anterior deltoid ligament (ADL) injury, or a medial ankle sprain. Since the ATiFL restricts both fibular movement and external talus rotation (Sarsam and Hughes, 1988), the mechanism of high ankle sprain is attributed to a pre-tensioning of the ATiFL, as a result of the eversion and axial load, following by external rotation of the talus (Wei et al., 2012). Oriented approximately in the antero-posterior direction in the sagittal plane (Wei et al., 2012), the ADL is ruptured due to external rotation of the foot, supported by a clinical review which states that external rotation of the foot will "first rupture the deltoid ligament, with subsequent injury to the ATiFL" (Dattani et al., 2008; Wei et al., 2011b). Yet, despite no observation of ADL injury in the pre-everted ankles, the amount of foot rotation at failure was significantly higher than the failure rotation in neutral ankles (Wei et al., 2012), seemingly contradicting the notion that external foot rotation primarily strains the ADL. However, while there is more overall foot rotation in the pre-everted ankles, ligament strain is dependent on relative bone motion which was not documented at the point of failure in this previous study.

While strain in the ADL is strongly correlated with talocrural joint rotation, it has been suggested that the subtalar joint equally contributes to overall foot rotation (Siegler et al., 1988). Excessive subtalar joint rotation could also be problematic due to increased risk of subtalar ligament injury, which has been implicated in subtalar joint instability and calcaneal tilt (Kato, 1995; Heilman et al., 1990). Previous studies have measured subtalar and talocrural joint rotation during plantarflexion/dorsiflexion, inversion/eversion (Wong et al., 2005; Fassbind et al., 2011), and passive rotation (Siegler et al., 1988). While these studies noted that the contribution of both the subtalar and talocrural joints to foot rotation was dependent on the positioning of the ankle, they did

* Correspondence to: Orthopaedic Biomechanics Laboratories, Michigan State University, East Fee Hall, Room A-407, 965 Fee Road, East Lansing, MI 48824, United States. Tel.: +1 517 355 0320.
E-mail addresses: buttonke@msu.edu (K.D. Button), weifeng@msu.edu (F. Wei), haut@msu.edu (R.C. Haut).

http://dx.doi.org/10.1016/j.jbiomech.2015.08.007
0021-9290/

not document the effect of pre-eversion and axial load on joint motion during rotation. The objectives of the current study were (1) to measure the contributions from the talocrural and subtalar joints to the overall rotation of the foot-shank in an axially loaded foot and (2) to identify the effect of pre-eversion on these contributions. The hypothesis of the study was that pre-everting the ankle prior to rotation would lower the amount of talocrural rotation, but increase the amount of subtalar joint rotation for a given degree of foot rotation.

2. Methods

Fourteen (seven pairs) fresh-frozen human cadaver (age 58.5 ± 9.2 years) lower-extremities were used in this study. The limbs were stored at −20 °C and thawed to room temperature for 24 h prior to testing. The tibia and fibula were transected 15 cm distal to the center of the knee, and the proximal 10 cm of the bones was removed of tissue and cleaned with 70% alcohol. The cleaned portion of the bone was potted in an aluminum box with room-temperature curing epoxy (Fiber Strand, Martin Senior Corp., Cleveland, OH, US). Two screws were placed in the anterior and medial tibia before potting to help restrain the tibia in the potting material. Reflective marker arrays were screwed in the anterior medial aspect of the talus, posterior calcaneus, and on the tibia approximately 20 cm proximal to the articular surface. Computed Tomography (CT) scans with 0.6 mm slice thickness and in-plane spatial resolution of 0.508 mm (GE Discovery STE, Milwaukee, WI, US) verified the placement of the marker arrays.

Elastic athletic tape (Elastikon, J&J, New Brunswick, NJ, US) was used to constrain the foot onto a polycarbonate plate (32 cm × 8 cm). Experiments were performed with a customized hydraulic biaxial testing machine with a 244 Nm rotary actuator (Model SS-001-1C, Micromatic, Berne, IN, US) and a vertically oriented linear actuator (Model 204.52, MTS Corp., Eden Prairie, MN, US). The proximal (potted) end of the foot was attached to the rotary actuator through a biaxial load cell (Model 1216CEW-2K, Interface, Scottsdale, AZ, US) with a capacity of 8896 N of axial force and 113 Nm of torsion (Fig. 1). Right ankles were pre-everted 20° prior to rotation and left ankles were neutral in the coronal plane. A 1500 N compressive preload (approximately 2 × body weight) was applied to simulate dynamic weight bearing prior to rotation and 20° of internal tibia rotation (i.e. external foot rotation) was input in position control at 40 deg/s. This magnitude of axial load has been consistently used in previous studies from this laboratory, and the input rotation was selected to ensure that no ankle injury would occur during these tests (Wei et al., 2010).

A Vicon motion capture system (Oxford Metrics Ltd, Oxford, UK) was used to document the position of the marker arrays during motion. Coordinate transformations were performed on the tibia, talus, and calcaneus marker arrays in order to establish orthogonal coordinate systems in line with the three axes of the ankle (Fig. 2). Joint coordinate systems (JCS) were established between the tibia and talus (talocrural joint) and between the talus and calcaneus (subtalar joint), as defined by the International Society of Biomechanics (Soutas-Little et al., 1987; Wu et al., 2002).

Paired *t*-tests were used to compare the amount of joint flexion, rotation, and inversion/eversion between neutral and everted ankles. Two-way repeated measures ANOVA (pre-positioning, joint) was used to compare the amount of flexion, rotation, and inversion/eversion between the two joints. *P*-values less than 0.05 were considered significant in all tests.

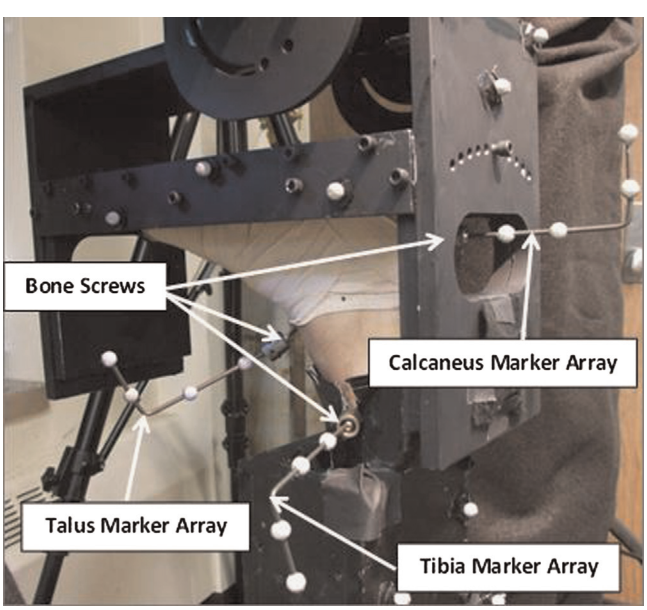

Fig. 1. Ankle with reflective marker arrays in the tibia, talus, and calcaneus in the testing fixture.

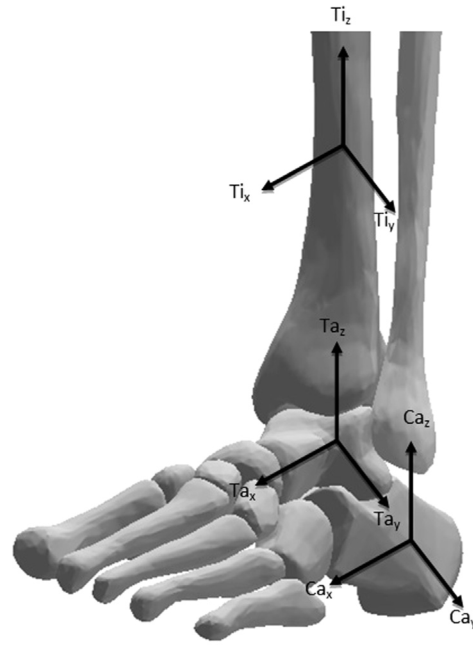

Fig. 2. Orthogonal coordinate axes on the tibia, talus, and calcaneus.

3. Results

Motions of the subtalar and talocrural joints during 20° of internal tibia rotation are shown in Table 1 (Note: talocrural motion refers to talus motion with respect to the tibia, while subtalar motion refers to calcaneus motion with respect to the talus). Both the neutral and everted joint rotation data were normally distributed. There was significantly more external rotation in the talocrural joint compared with the subtalar joint ($p < 0.001$). Additionally there was significantly more talocrural external rotation ($p = 0.006$), but significantly less subtalar external rotation ($p = 0.014$) in the neutral foot when compared with the pre-everted foot.

4. Discussion

While previous studies have investigated the effects of ankle pre-eversion on location of injury and strain generated in key ankle ligaments during external rotation of an axially-loaded foot (Button et al., 2013b; Wei et al., 2012), the current study examined the effects that pre-eversion had on talocrural and subtalar joint movement. Specifically, a key aim of the current study was to investigate why pre-everted ankles saw no ADL injury despite high levels of foot rotation at failure. Results of the study indicated that when the foot was axially loaded and externally rotated most of the foot-shank rotation comes from the talocrural joint. However, pre-eversion lowered the amount of talocrural joint rotation, supporting the hypothesis of the study and potentially lowering ADL injury risk.