Foot Position Shifts Injury Initiation among Ankle Ligaments during External Rotation

B. Nie, JL. Forman, AR. Mait, J-P. Donlon, R.W. Kent

I. INTRODUCTION

Syndesmosis sprains among athletes lead to significantly higher time lost from play than the more common lateral or medial ankle sprains [1-2]. The mechanics of syndesmosis sprains primarily involve external rotation of the foot within the ankle joint, associated with concomitant particular patterns of ligament trauma due to an initial foot position in flexion and/or eversion [3-4]. A precise description of ankle sprains across a variety of foot positions generated *in situ* by athletes is absent in the literature. The objective of this study was to determine the relationship between foot position prior to external rotation and the associated injury initiation and propagation among ankle ligaments.

II. METHODS

A finite element (FE) model of a mid-size adult male foot and ankle was used to represent mechanical characteristics of the ankle and subtalar joints [5]. The model consisted of bony structures, articular cartilage layers and ligaments. Each major ligament was modelled as a group of collagen fibers to functionally consider the non-uniform loads across the microstructures [6]. The model was validated previously using a parallel post-mortem human subject (PMHS) study and proved capable of predicting the ligamentous injury patterns and sequence under well-defined external foot rotation [7].

Different initial positions of the foot were achieved by combining physiological flexion (θ_F) (plantar flexion or dorsiflexion) and eversion (θ_V) rotations from a neutral posture (Fig. 1a). θ_F was investigated degree by degree ranging from -15° to 15° (-: plantar flexion, +: dorsiflexion) and θ_V from 0° to 15°. The foot remained in a neutral posture when both θ_F and θ_V equaled 0°. A subsequent external rotation (θ_R) of 60° was applied to generate ligamentous injuries (Fig. 1b). A total of 496 simulation cases were performed. All rotations were applied to the calcaneus quasi-statically, with the proximal end of the tibia fixed and the other bones free in all six degrees-of-freedom. The magnitude of the external rotation at which a failure occurred to any fiber element ($\theta_{R,\,Inj}$) was used to indicate the initiation of injury to ankle ligaments. Specifically, the magnitude of θ_R at which fiber failure occurred to the syndesmotic ligament in tension, i.e., the anterior tibiofibular ligament, ATiFL, ($\theta_{R,\,ATiFL}$) was used to indicate the initiation of syndesmosis sprains.

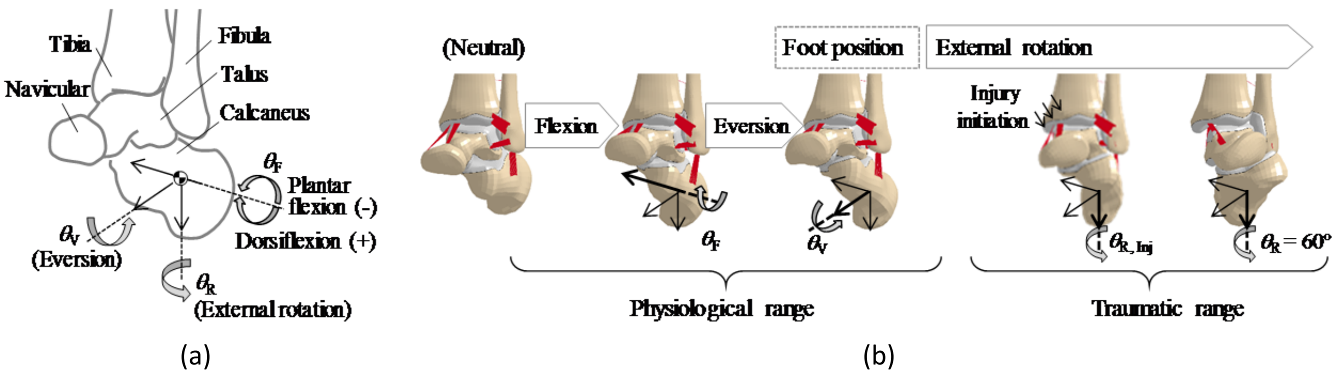

Fig. 1. (a) Rotation angles of the foot; (b) Foot positioning prior to a forceful external rotation (shown: initial position combining a dorsiflexion of 15° and an eversion of 15°; forefoot not displayed)

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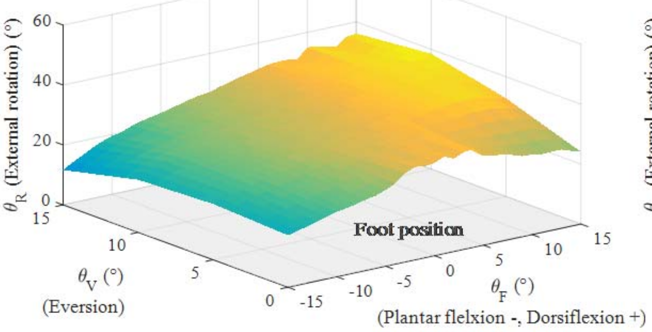
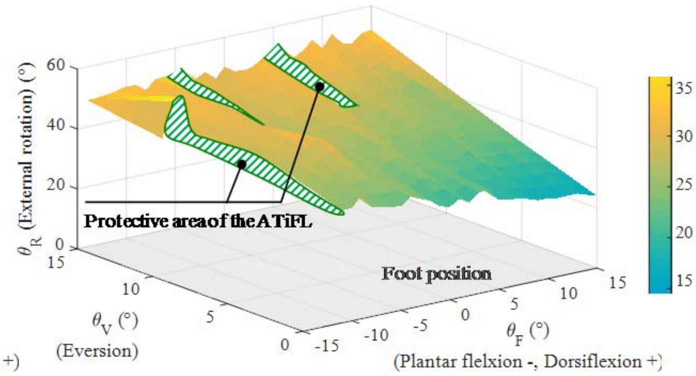
III. INITIAL FINDINGS

Compared to a neutral position, foot flexion resulted in a ligament injury that initiated at a lower angle of external rotation ($\theta_{R,\ Inj}$); the influence of eversion was insignificant unless when combined with dorsiflexion (Fig. 2a). For a foot initially in flexion and eversion, injury initiation to any ligament occurred at a higher $\theta_{R,\ Inj}$ than a purely everted foot, e.g., 36.1-38.5° (θ_F 15°, θ_V 10-15°) compared to 27.0°- 28.5° (θ_F 0°, θ_V 10-15°). When considering the syndesmosis sprains, plantar flexion and/or eversion was protective with ATiFL injury initiation occurring at increasing $\theta_{R,\ ATiFL}$ (Fig. 2b). ATiFL injury was absent for a foot with approximately 12° of plantar flexion and 0°-10° of eversion prior to external rotation. In contrast, dorsiflexion focused loading through the syndesmosis during external rotation and shifted injury initiation of the ATiFL to a lower $\theta_{R,ATiFL}$ than a neutral foot, e.g., 24.1° (θ_F 15°, θ_V 0°) compared to 30.9° (θ_F 0°, θ_V 0°).



(a)



(b)

Fig. 2. Simulated injury initiation subjected to different foot positions under external rotation: (a) Injury initiation to any ankle ligament; (b) Injury initiation to the ATiFL.

IV. DISCUSSION

Foot position prior to forceful external rotation influences the transfer path of force among ligaments and the distribution of loads across the fiber microstructure. This observed change in ligament injuries agreed with recent PMHS studies using matched pairs legs performed in our group (the experimental details will be published in a subsequent paper). Specifically, dorsiflexion widened the ankle mortise and forced the talar dome into the syndesmotic joint, led to lateral tibiofibular diastasis during the subsequent external rotation. In contrast, plantar flexion moved the talus anteriorly and out of the mortise, placed the deltoid ligaments in tension before loads were passed to the syndesmosis region, and resulted in ATiFL injury initiation at a high rotation angle.

This computational investigation suggests a mechanism in shifting injury initiation across ankle ligaments due to initial foot positioning. Further studies are underway to quantify the effects of foot position on injury propagation across ligaments, injury tolerance at the structural level, and the associated uncertainty of the injury prediction. Application of this improved understanding is necessary to facilitate prevention efforts against syndesmosis sprains in athletes.

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VI. REFERENCES

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