In Situ Force in the Calcaneofibular Ligament and the Contribution of the ligament to Ankle Joint Stability

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Disclosures:

Introduction: Lateral ankle ligament injuries are one of the most common injuries. Among the lateral ankle ligaments, the anterior tibiofibular ligament (ATFL) is the most frequently injured; however, the incidence of combined injuries to the calcaneofibular ligament (CFL) is a significant prognostic factor after lateral ankle ligament injuries [1]. The extent of the role of the CFL in stabilizing the ankle joint remains unclear. Biomechanical studies were performed to reveal the contribution of the ligaments to ankle rotation and version stability but did not include translational stability [2]. Another study reported on the contribution of the medial and lateral ligaments to ankle stability but did not include the contribution of each component of the ligaments [3]. These studies were performed under a constraint condition. We developed a robotic system and used it to perform biomechanical tests on the knee to determine the biomechanical characteristics of the anterior cruciate ligament [4]. This system has a 6-degree-of-freedom (6-DOF) manipulator and allows unconstrained joint motion while applying loads. We applied this system to a biomechanical study of the ankle joint. The purposes of this study were to measure the in situ force in the CFL in the loaded ankle and to determine the contribution of the CFL to ankle stability using the robotic system.

Methods: Six intact human cadaveric ankle joints were used. The mean age of the specimens was 81 years (range, 76-93 years). The cadaveric ankles were mounted in a 6-DOF robotic system. This system consisted of a 6-DOF manipulator, servomotor controllers, and a control computer [4]. The leg clamp was fixed to the lower mechanism, and the calcaneal clamp was fixed to the upper mechanism by a universal force/moment sensor (UFS). Its position and force controls allowed a hybrid 6-DOF control of the target displacement and force/moment of the ankle. The anterior-posterior translation (AP), inversion-eversion rotation (IVEV), and internal rotation-external rotation (IRER) tests were performed for the intact ankle joints at the neutral position, at 10° of dorsal flexion, and at 15° and 30° of plantar flexion. During the AP test, the AP DOF was translated under the displacement control up to ±60 N at a rate of 1 mm/s while all the DOFs, except the AP and dorsal-plantar flexion (DFPF) DOFs, were set under the force control with the prescribed force/moment at zero. During the IVEV test, the IVEV DOF was rotated under the displacement control up to ±1.7 N-m at a rate of 1 degree/s while all the DOFs, except the IVEV and DFPF DOFs, were set under the force control with prescribed force/moment at zero. During the IRER test, the IRER DOF was rotated under the displacement control up to ±1.7 N-m at a rate of 1 degree/s while all the DOFs, except the IRER and DFPF DOFs, were set under the force control with the prescribed force/moment at zero. The CFL was transected, and the robot system reproduced the previously recorded motion of the intact ankle. By measuring the forces required to move the CFL-deficient joint through the same path of motion as recorded for the intact ankle with the UFS, the in situ force in the CFL and the contribution of the CFL to ankle stability were determined. One-way repeated measures analysis of variance (ANOVA) was used to evaluate the relationship between the in situ force in the CFL or the contribution of the CFL and the ankle positions. Differences among the parameters were checked for significance using the Tukey test. A P value of .05 was chosen as the level of significance.

Results: The in situ forces in the CFL are shown in Fig. 1. The mean in situ force in the CFL in response to an anterior load of 60 N reached a peak of 40 ± 15 N at 10° of dorsiflexion. The in situ forces in the CFL to anterior loads were significantly higher than those in response to posterior loads in 15° of plantar flexion, neutral position and 10° of dorsiflexions. To AP, IVEV and IRER loads, the in situ forces were significantly different in each ankle position. The relative contributions of the CFL to joint stability are shown in Fig. 2, ranging from 12% to 39% for anterior translation and from 6% to 18% for posterior translation. The contribution of the CFL to anterior translation was significantly higher in 15° of plantar flexion and neutral positions than in 30° of plantar flexion. The relative contribution of the CFL to inversion ranged from 48% to 71%. The contribution of the CFL to inversion was significantly higher in 10° of dorsiflexion than in 15° of plantar flexion.
The relative contribution of the CFL to external rotation ranged from 21% to 35%. The contribution of the CFL to external rotation was significantly higher in the neutral position and 10° of dorsiflexion than in 30° and 15° of plantar flexion.

Discussion: To the best of our knowledge, this is the first study to determine the in situ force in the CFL using a robotic system. The in situ force in the CFL was influenced by the applied load and ankle position. The in situ forces in the CFL were higher in dorsiflexion than in plantar flexion in the multiple directions of loadings. These results support that the CFL is taut in ankle dorsiflexion and relaxed in ankle plantar flexion [5].

Previous studies did not examine the contribution of the CFL to translational ankle stability. In our unconstrained condition, the relative contribution of the CFL to anterior translation was higher than its contribution to posterior translation. The relative contribution of the CFL to inversion was more than 50%. This result showed that the CFL was the primary restraint to inversion.

Significance: The information regarding in situ forces in the CFL should be helpful to determine the adequate initial tension of the graft for CFL reconstruction for chronic lateral ankle instability. This study revealed the importance of reconstructing not only the ATFL but also the CFL. Such information will contribute to improved postoperative results.

Acknowledgments:

Fig. 1. In situ force in the calcaneofibular ligament in response to anterior 60N load, posterior 60N load, inversion 1.7N•m load and external rotation 1.7N•m load. The level of significance was set at p < 0.05. 30° PF = 30° of plantar flexion, 0° = neutral position, 10° DF = 10° of dorsiflexion. *1 Significantly different from 30° PF. *2 Significantly different from 15°PF. *3 Significantly different from 0°.
Fig. 2. Contribution of calcaneofibular ligament to ankle stability, to anterior translation, posterior translation, Inversion and external rotation. The level of significance was set at $p < 0.05$. 30° PF = 30° of plantar flexion, 0° = neutral position, 10° DF = 10° of dorsiflexion. *1 Significantly different from 30° PF. *2 Significantly different from 15° PF.