Influence of Custom Dynamic Orthoses on Tibiotalar Joint Reaction Force: A Cadaveric Study

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INTRODUCTION: Post-traumatic osteoarthritis (PTOA) following tibial pilon fractures arises from elevated joint contact stress exposure [1]. Carbon fiber bracing with custom dynamic orthoses (CDOs) is a relatively new means to treat individuals with severe ankle injuries. A CDO functions by storing energy in a stiff posterior strut when deformed during the stance phase of gait and returning energy at the end of stance, helping propel the body forward. CDO design variations can be customized to each patient according to their specific needs. Clinicians are tasked with making numerous design choices during the fabrication and fitting process, including choosing the optimal stiffness to achieve the desired outcome for each patient. Studies have shown the effect of orthosis design on limb mechanics [2], but validation by direct measurement of joint reaction forces is lacking. CDO stiffness, an effective stiffness it exerts to limit sagittal plane rotation of the ankle, has been shown to alter limb mechanics with traditional orthoses, but the results are less clear for CDOs [3]. Previous computational studies have shown that stiffening the ankle by increasing CDO rotational stiffness decreases plantar flexor muscle force [4, 5]. Decreasing force production about the ankle may provide a meaningful way to reduce joint reaction force (JRF) and mitigate PTOA risk by reducing joint contact stress. The objective of this research was to determine the influence of CDO stiffness on ankle joint loading using a cadaveric testing platform.

METHODS: An MTS test frame was used to axially load four fresh-frozen cadaver ankle specimens tested within 24 hours of thawing. The ankle specimens were held by fixturing custom-designed to be able to vary the ratio of primary axial loading and Achilles tendon force while holding the ankle at a fixed flexion angle (Figure 1). Axial loading used scaled down ground reaction forces (GRF) to prevent damage to the cadaveric ankles (loads ranged from 240N to 330N). The Achilles tendon of each specimen was dissected, and a custom-designed clamp was used to attach the tendon to a pneumatic actuator. The ratio of GRF to Achilles tendon force and the ankle angle were chosen to reflect three key instances (20%, 60%, and 80%) in the stance phase of gait. Three bracing conditions with varied device rotational stiffnesses were tested: (1) No CDO – 0 Nm/°, (2) low CDO stiffness – 1.8 Nm/°, and (3) moderate CDO stiffness – 2.3 Nm/°. All testing used a semi-rigid footplate, including the No CDO condition, where the CDO proximal cuff was not affixed to the tibia. Orthosis design was consistent with clinical practice, but the stiffness was reduced to be consistent with the reduced limb loading. A Tekscan model 5033 pressure sensor was inserted into the tibiotalar joint to measure JRF. A Tekscan F-Scan plantar pressure sensor was placed between the bottom of the cadaveric foot and the CDO footplate to capture the interaction between the device and limb.

RESULTS: The F-Scan measured center of force progressed from under the heel toward forefoot, mimicking normal gait, when limb position and loading were progressed from 20%, to 60% and then 80% of the stance phase (Figure 2). Activation of the CDO strut consistently reduced tibiotalar JRF across three out of four specimens. In these instances, the low stiffness CDO contributed to reductions ranging from 0 to 29%, while the moderate stiffness CDO had reductions that ranged from 11 to 39% – all relative to the No CDO condition. As loading progressed from 20%, to 60%, and to 80% of the stance phase, the mean reduction in JRF for low stiffness CDO was 5%, 11%, and 11% (SD = 7% , 12%, and 12%), respectively. For the moderate stiffness CDO, the mean reductions were 8%, 18%, and 16% (SD = 9%, 19%, and 16%), resepctively.

DISCUSSION: This novel cadaveric testing platform facilitates systematic investigation of the influence of CDO design characteristics on limb loading, joint forces, and joint contact stresses in a controlled manner. The one ankle specimen that saw no reduction in tibiotalar joint reaction force was attributed to sensor misalignment within the joint that precluded reliable measurement of the JRF in the No CDO condition. The results presented are limited by the small sample size and by the need to apply scaled-down GRF and Achilles loads in this cadaveric preparation. Additionally, results were confined to assessing CDO influence only over the stance phase of gait.

SIGNIFICANCE/CLINICAL RELEVANCE: This cadaveric testing platform enables investigation of the influence of carbon fiber bracing on JRFs seen during the stance phase of gait. The work is being done in part to validate patient-specific computational modeling approaches that can enable prescribed bracing to achieve desired reductions in harmful contact stress exposure, thereby reducing the risk of PTOA after these intra-articular fractures.

REFERENCES: [1] Anderson DD, et al., J Orthop Res, 2011. 29(1):33-9. [2] Grunst MM, et al., Prosthet Orthot Int, 2023 Feb 10. Epub ahead of print. [3] Totah D, et al. Gait Posture. 2019. 69:101-11. [4] Silverman AK, et al., J Biomech Engineering, 2017. 139. [5] Yamamoto M, et al., IEEE Eng Med Biol, 2021. 9:98039-47.
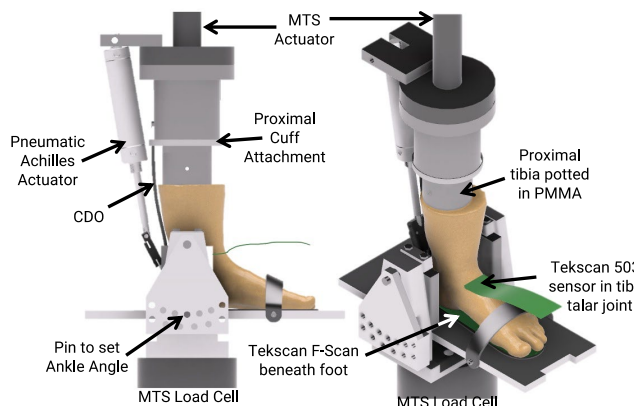
Figure 2: Schematic depicting cadaveric ankle loading and Tekscan sensor placement. Internal/external and inversion/eversion were constrained.
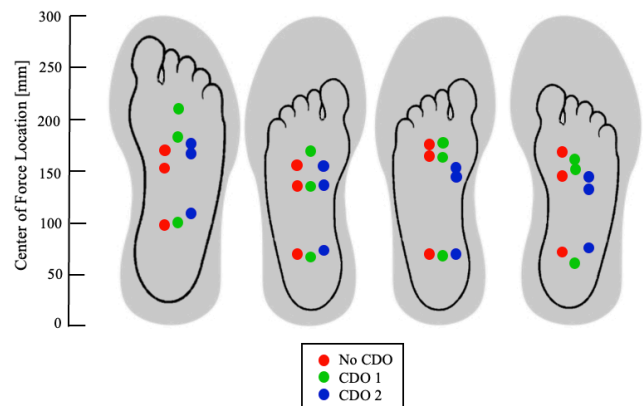

Figure 1: Anterior – Posterior migration of the center of force shifting from hindfoot to forefoot over stance. Medial/lateral shifts were omitted.