Development of Dynamic Muscle Activation System for the Investigation of Lower Extremity Function

W. Spivey, C. O'Cain, B. Gepner, E. Spratley, J. Kerrigan
Center for Applied Biomechanics, University of Virginia, Charlottesville, VA

Abstract

Prior to automotive impact, occupants often engage their muscles to brace themselves for collision (Hault-Dubrelle et al 2009). This is common in frontal crashes, where lower extremity injuries remain the most frequently injured body region (Ye et al 2015). Despite this typical occupant behavior, few injury prediction tools take into account the effect of active musculature during injury. Computational human body models (i.e. THUMS ActiveHuman) are beginning to include active musculature; however, validation data is currently limited to volunteer data. Biomechanics research on living subjects is limited to what can be measured non-invasively; consequently, injury cannot be systematically evaluated in volunteers. Post-mortem human surrogates (PMHS) remain the gold standard for human injury measures. However, PMHS lack muscle activation. Simulating the effects of active musculature in the lower extremity would allow for examining the bony dynamics that occur during gait or other natural loading scenarios. This study details the development and initial testing of a Dynamic Muscle Activation System (DMAS), which could eventually be used to examine the effect of musculature on injury. This study aims to develop a method to apply active musculature to PMHS leg/ankle/foot specimens that includes parallel controllers to adjust muscle forces and leg kinematics to produce biofidelic loading scenarios. This methodology was developed to examine how muscle loads affect injury risk and bony motion in the foot and ankle, and was applied to tune a PMHS specimen to simulate quarter to full body-weight gait to compare the test specimen responses to gait dynamics data captured in volunteer testing.

Development of the DMAS included coupling the control systems of a 6 degree of freedom (6-DoF) position and force/torque controlled serial robot with a set of nine linear actuators. By coupling these systems, the robot is able to control tibia kinematics and the linear actuators can control individual foot muscles. A single male PMHS (46 years, 99.3 kg, 175.3 cm) lower extremity was tested to evaluate the accuracy of the system. Tissue was removed circumferentially around the ankle to expose the tendons of the extrinsic muscles of the leg. Eight of the nine actuators were then affixed to tendons using polyester surgical thread with a Krakow stitch, and the Achilles was clamped though a custom cryoclamp. During testing, tendon force was generated

by displacement in the linear actuators using force control feedback. Tibial kinematics were imposed by the robot through displacement control. In order to capture kinematics in the hind- and mid-foot, 3D motion tracking arrays were rigidly affixed to eight bones and reaction loads were measured using a 6-DoF load cell.

Results demonstrate the system was able to generate kinetic data (ground reaction force) and kinematic data (calcaneus and navicular motions) consistent with published volunteer response. Moreover, all nine of the PMHS tendon forces were reproduced within 5% of the target trajectories. Preliminary results of this study suggest that the DMAS can generate a combination of biofidelic muscle forces, bony motion, and reaction forces that are all integral components to understanding how muscle activation could affect injury.