Investigation of the Biofidelity of the MIL-Lx Foot

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Background

In the automotive industry, typical injury risk assessment uses Anthropomorphic Test Devices (ATDs), with injury risk to the foot/ankle grouped and evaluated using load cells in the tibia. Although the impact response of the ATD tibia has been investigated, the foot has historically been ignored. Load is transmitted through the foot/ankle to the tibia, where injury risk is assessed; therefore, if the foot/ankle does not transmit load correctly, tibia assessments may be inaccurate. It is important to examine the biofidelity of the ATD foot to either validate the current ATD model or provide data for an improved design. The objective of the current study was to develop a technique to mount cadaveric feet to an ATD tibia, to investigate potential differences in load transmission.

Methodology

Six cadaveric lower legs ('intact', 80 ± 12 years, 3 male) were supported in a pneumatic impacting apparatus and fitted with an instrumented boot. The boot insole has an array of eight piezoresistive sensors, divided into fore-, mid- and hindfoot regions. They were axially impacted at 5 m/s (sub-failure energies), and force distribution and net force on the boot insole were recorded for each specimen. The Military Lower Extremity ATD ('MIL-Lx,' Humanetics Innovative Solutions, Farmington Hills, MI, USA) was similarly impacted, with boot measures as well as tibia load cell forces and moments recorded. The cadaveric specimens were then disarticulated at the ankle joint, preserving surrounding soft tissue. The distal tibia and fibula were optically scanned to 3D print a mating surface for the talus (minimizing unnatural stress concentrations). The 3D printed component was mounted to the MIL-Lx and included attachment points to suture tendon and ligament bundles. Each cadaveric foot was mounted to the adapted structure and tested at similar impact conditions ('adapted'), with boot measures and tibia load cell measurements recorded.

Results and Discussion

No statistical differences in boot forces were found among lower leg representations, suggesting that overall reaction force at the plantar surface was comparable (p=0.48). No statistical differences were found among lower leg representations for the forefoot force (p=0.7) or hindfoot force (p=0.2) regions, however the intact specimen midfoot force readings were significantly higher than the 'adapted' and MIL-Lx midfoot force readings (p<0.05). Furthermore, the proximal and distal tibia load cells recorded significantly higher forces in the MIL-Lx than the 'adapted' leg (p<0.05), suggesting the MIL-Lx foot is stiffer and dissipates less energy than cadaveric feet.

Conclusions

This study found that the MIL-Lx foot may be an overly stiff representation and collected data that may be used for an improved ATD foot design. Furthermore, a technique was developed that combines collecting the realistic response of cadaveric feet with industry-relevant ATD metrics, which will be used for future cadaveric failure tests. By focusing on isolated cadaveric feet, while also collecting tibia load data, this study assessed the impact characteristics of feet specifically. The differences in load distribution and attenuation between cadaveric specimens and ATDs could alter injury risk assessment in frontal collisions and should be addressed in future ATD lower extremities.