Influence of Ankle Posture and ATD Model on the Distribution of Forces on the Foot Under Impact Loading

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Introduction: Lower extremities are the most frequent injury site in frontal motor vehicle collisions, with the foot-ankle making up approximately 30% of all moderate to severe injuries [1]. Anthropomorphic Test Devices (ATDs) are used in industry to assess injury risk to the lower leg, including the foot-ankle complex, based on tibia peak axial force (Fz) or Tibia Index (TI). Although both posture and ATD model have been shown to affect injury risk, location, and assessment, these metrics do not account for the risk of injury to various regions of the foot [2, 3]. The goal of this study was to assess the force distribution across the plantar surface of the foot using two common ATDs, under frequently assumed ankle postures.

Methodology: A custom boot instrumented at the insole with eight piezoresistive sensors, calibrated to convert resistance to force [4], was applied to the Hybrid III Lower Leg (H3) and the Military Lower Extremity (MIL-Lx). Each ATD was axially impacted using a pneumatic impacting apparatus in three ankle postures: neutral, 26°-plantarflexion, and 15°-dorsiflexion at 6 m/s, representing a frontal collision. Five trials were conducted for each ATD at each posture. Force distribution from the boot insole were collected, and in accordance with industry standards, the tibia peak axial force from the distal H3 load cell, and the proximal MIL-Lx load cells were recorded [5], along with Tibia Index.

Results: In the neutral posture the average Fz in the H3 was 4.20 ± 0.30 kN, and the MIL-Lx was 3.29 ± 0.01 kN. In the dorsiflexed posture, Fz was 4.00 ± 0.20 kN for the H3 and 3.40 ± 0.04 kN for MIL-Lx. This decreased in plantarflexion (3.40 ± 0.20 kN for H3, 2.93 ± 0.08 kN for MIL-Lx). The TI values for the two models were similar in the neutral (0.43 for H3, and 0.44 for MIL-Lx) and dorsiflexed postures (0.42 for H3, 0.45 for MIL-Lx). The TI in plantarflexion did not change in the MIL-Lx (0.45) but increased to 0.67 in the H3.

Both posture and ATD model affected the load distribution across the insole of the boot. For plantarflexion, the sensors in the forefoot region increased substantially from neutral (from 14% to 24% for H3, and from 18% to 39% for MIL-Lx). In dorsiflexion, the forefoot loading was reduced (from 14% to 9% for H3, and from 18% to 7% for MIL-Lx) and mostly transferred to hindfoot sensors. The MIL-Lx consistently exhibited greater forefoot loads than the H3, with this effect being most pronounced in the plantarflexed condition.

Conclusions: This study demonstrated that ankle posture alters the force distribution on the plantar surface of ATD feet, highlighting the need for regional injury risk assessments in this vulnerable area. The increase in forefoot loading during plantarflexion was not captured in many of the standard industry metrics, suggesting that increased fracture risk to the forefoot would not be detected. The differences in load distribution between the models could also alter injury risk assessment in frontal collisions based on different attenuation.

References

[1] Yoganandan, N., Nahum, A. M., & Melvin, J. W., Eds. 2014, “Accidental injury: biomechanics and prevention,” Springer.

[2] Quenneville, C. E., and Dunning, C. E., 2012, “Evaluation of the Biofidelity of the HIII and MIL-Lx Lower Leg Surrogates Under Axial Impact Loading,” Traffic Injury Prevention, 13(1), pp. 81–85.

[3] Van Tuyl, J., Burkhart, T.A. and Quenneville, C.E., 2016. “Effect of posture on forces and moments measured in a Hybrid III ATD lower leg.” Traffic Injury Prevention, 17(4), pp.381-385.

[4] Acharya, Ishan, et al. "A Force-Sensing Insole to Quantify Impact Loading to the Foot." Journal of Biomechanical Engineering, 141.2 (2019): 024501.

[5] Carpanen, D., Masouros, S., and Newell, N., 2016. Surrogates of Human Injury. In: A.M.J. Bull, J.C. Clasper, and P.F. Mahoney, eds. Blast Injury Science and Engineering. Springer International Publishing, 189–198.