The Effect of Impulse on the Axial Fracture Tolerance of the Isolated Tibia During Automotive and Military Impacts

Alberto Martinez[1], Cheryl E. Quenneville[1,2]

[1]Department of Mechanical Engineering, McMaster University, Hamilton, ON
[2]School of Biomedical Engineering, McMaster University, Hamilton, ON

Abstract

Axial impacts to the lower leg during events such as frontal automotive collisions and military underbody blasts can cause significant injuries to the tibia. Although damage to this region is typically not life-threatening, it can result in disability, which leads to emotional distress, decrease in workplace productivity, and long-term healthcare costs. In order to reduce these negative outcomes and design suitable protective measures, the injury tolerance of the lower leg must be well understood.

Frontal automotive collisions and military blasts cause injuries to the same bones in the lower leg by means of an analogous loading mechanism; however, the magnitude of velocity and duration of impact varies between the two. Automotive floor plate impacts typically have velocities ranging from 2.0 to 6.0 m/s and impact durations of 40 ms, while floor plate velocities during military underbody blasts have been reported to exceed 12 m/s and impact durations less than 10 ms [1]. Several studies have conducted axial impacts to determine the injury limits of the lower leg, mostly focused on automotive intrusions. These studies suggest a peak axial force between 5.5 kN and 10.2 kN represents a 50% risk of fracture [2]; however, these force values give no indication of impact duration (and correspondingly, impulse). Due to the viscoelastic properties of bone, it remains unclear whether results from automotive experiments can be successfully applied to higher-rate military blasts. Thus far, none of the studies have varied the duration of impacts to determine its effects over a range of loading rates. The hypothesis of this work is that varying the duration of the axial load will have an effect on the risk of fracture of the tibia.

To test this hypothesis, six pairs of male isolated cadaveric tibias (mean age: 62 ± 8 years) were subjected to axial impact loads using a custom-built pneumatic impactor. This apparatus is capable of generating loads at different velocities using a projectile of variable mass. Foam of varying levels of compliance was attached to the foot plate to control the impact durations. One specimen from each pair was tested for the military blast condition and the contralateral for the automotive condition, with right-left selection randomized. Impacts were applied in increasing levels of intensity (defined using energy levels) until fracture occurred. Impact levels were selected to limit the number of strikes to each specimen (to minimize any accumulated damage).

A best subsets regression analysis will be used to identify the factors that influence fracture risk (options included applied force, impact duration, energy, momentum, impulse, loading rate, and acceleration).

The main outcome of this work will be an injury risk function for the lower leg under both military and automotive impact conditions. The Hybrid III and MIL-LX anthropomorphic test device (ATD) lower legs will be tested under similar impact conditions as the cadaveric specimens to transfer the cadaveric risk equation into functional values that can be used by industry. This comprehensive equation will be useful for developing and evaluating appropriate protective systems, regardless of the impact duration.

[1] McKay and Bir, Stapp Car Crash J, 2009.
[2] Bailey et al., Traffic Inj Prev, 2015.