

Numerical Analysis of Driver Thoracolumbar Spine Response in Frontal Crash Reconstruction

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Despite recent advancement in vehicle crashworthiness, the incidence rate of thoracolumbar fractures in frontal crashes increased in the past decade. The objective was to reconstruct 11 real-world motor vehicle crashes (six with AIS 2+ thoracolumbar fractures and five without thoracolumbar fractures), and to analyze the fracture mechanism, fracture pattern, as well as the associated vehicle parameters and driver attributes affecting fracture risk.

Eleven frontal crashes from the CIREN and NASS-CDS database were reconstructed with a finite element simplified vehicle model (SVM) using a semi-automated optimization method. The SVM was tuned to each case vehicle and the Total HUMAN Model for Safety (THUMS) v4.01 was scaled and positioned in a baseline configuration to mimic the documented pre-crash driver posture. The event data recorder crash pulse was applied as the boundary condition. Additionally, for the six cases with thoracolumbar injury, 120 simulations to quantify the uncertainty and response variation were performed varying the following parameters using a Latin Hypercube Design of Experiments (DOE): seat track position, seatback angle, steering column angle, steering column position, and D-ring height. Cross-sectional vertebral loads and bending moments were analyzed, with injury metrics derived to quantify the combined loading effect of compression and flexion. Maximum principal strain and stress data were collected in the cortical and trabecular bone of each vertebra. Additionally, kinetic and kinematic data from the 120 simulation DOE were analyzed and fit to regression models to examine correlations between occupant positioning and thoracolumbar spine response.

Of the 11 real-world crashes, both the vertebral axial compression force and bending moment progressively increased from superior to inferior vertebrae, regardless of injury outcome. Two cases with thoracic vertebra fractures resulted in higher average compression force across all thoracic vertebra levels, as well as higher flexion bending moment, compared to the nine cases without thoracic vertebra fractures (force: 1200.6 N vs. 640.8N; moment:13.7 Nm vs 9.2 Nm). While there was no apparent difference in terms of bending moment magnitude at the L1 and L2 vertebrae corresponding with fracture outcome, lumbar fracture cases exhibited higher vertebral bending moments in the L3 and L4 vertebrae (fracture/non-fracture: 45.7 Nm vs. 33.8 Nm). The difference in lumbar compression force between fracture and non-fracture cases was also noticeable at each lumbar vertebra level. For example, one case with L1-L2 fractures had the highest compression forces (2083.8 N; 2112.5 N). A rearward seat track position and more reclined seat back increased the thoracic bending moment by 111-329%. A more reclined seat back also increased the lumbar force and bending moment by 16-165% and 67-172%, respectively.

This study provides a computational framework for assessing thoracolumbar injury metrics and fracture risk. The study also revealed the effect of pre-crash driver posture on thoracolumbar fracture risk. Results from the study aid in the evaluation of real-world vertebral fracture data and the understanding of factors contributing to thoracolumbar injury risk.