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Introduction

Field data have shown that elderly, female, and obese occupants sustained increased injury risks in frontal crashes compared to midsize young men, primarily because the current vehicle safety design process highly relies on crash tests using only midsize male and small female crash test dummies. This study attempted to use diverse HBMs to optimize vehicle restraint systems and gain insights on how to achieve better safety equity.

Objective

The objective of this study was to conduct restraint design optimizations in frontal crashes using parametric human body models (HBMs) and parametric vehicle models accounting for variations in occupant size and shape and vehicle types.

Methodology

Parametric finite element (FE) HBMs representing 30 male and 30 female occupants were developed by morphing the GHBMC midsize male simplified model into statistically predicted skeleton and body shape geometries with varied age, stature, and body mass index (BMI). A previously developed parametric vehicle compartment model was used in this study. This vehicle model was equipped with driver, front passenger, knee, and curtain airbags along with seatbelts with pretensioner(s) and load limiter, and has been validated against US-NCAP frontal crash tests. Ten 3-student groups were formed for this study. Each group picked a vehicle model (Corolla, Accord, RAV4, or F150), occupant side (driver vs. passenger), and an occupant model among the 60 HBMs. Each HBM was positioned into the vehicle based on a statistical driver/passenger seating posture model and automated belt fitting procedure. Frontal crash simulations with varied restraint design parameters and design optimizations were conducted by each student group to improve the protection of selected occupants.

Data

About 250 frontal crash simulations with 10 combinations of vehicles (n=4) and occupants (8 drivers, 2 passengers, 2 females and 5 males) were performed. The airbag inflation, airbag vent size, seatbelt load limiter, and steering column collapse force were adjusted to reach better occupant protection. The joint injury probability (Pjoint) combining head, neck, chest, and lower extremity injury risks was used for the design optimization. Injury risk curves were scaled based on the skeleton size and shape of each HBM.

Results and Conclusions

We observed that tall and heavier male occupants tend to strike through the airbag leading to higher head injury risk; older and/or female occupants tend to sustain higher chest injury risk; while obese occupants tend to have higher lower extremity injury risk. These findings are widely consistent with field data. After design optimizations, the Pjoint was reduced in 9 out of 10 occupant/vehicle conditions, and the average Pjoint was reduced from 0.415 (range: 0.056–0.991) to 0.149 (range: 0.053–0.278). The airbag inflation and venting were found to be highly effective in head protection, while the belt load limit and steering wheel column were sensitive to chest injury risks. Conflicting parameter effects were found between head and chest injuries and among different occupants, highlighting the complexity of achieving safety equity across the diverse population.