Longitudinal Trend and Patterns in Lower Extremity Injuries Sustained in Frontal Motor Vehicle Crashes

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Introduction

Lower extremity injuries are common in frontal crashes. The resulting impairment is long-term and the cost is expensive.

While improvements to vehicle frontal crashworthiness have been responsible for mitigating the likelihood of knee, thigh and hip injuries, field data suggests no change in the incidence of foot and ankle injuries.

This study aims to investigate changes in frequency, risk, and patterns of lower limb injuries as a function of vehicle and occupant parameters. Another objective is to describe the injury causation scenarios and mechanisms for specific hind-foot injury patterns in selected cases.

Methods

- 10988 cases were sampled and analyzed from the National Automotive Sampling System-Crashworthiness Data System, representing 4.7 million belted drivers involved in frontal crashes for the year 1998-2010.
- A logistic regression model was developed to estimate the risk of sustaining moderate or severe (AIS2+) lower limb injuries as a function of vehicle type and model year, toe pan and instrument panel intrusion, as well as occupant's age, sex, height and weight.
- Data from moderate offset frontal crash tests performed by the Insurance Institute for Highway Safety (IIHS) was examined, including vehicle models from 1995 to 2013.
- 34 cases were selected from the Crash Injury Research and Engineering Network (CIREN). Case inclusion criteria involved adult drivers with AIS2+ hind-foot ankle injuries. An in-depth analysis using crash, occupant and medical information was performed to identify the loading mechanism, injury contributing factors, involved vehicle components and applicable injury and orthopedic codes.

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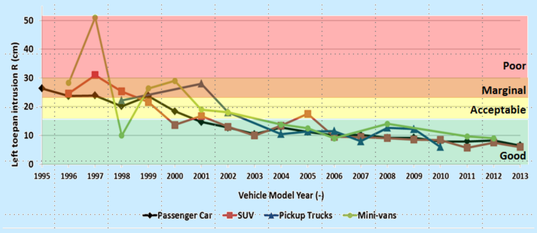
The views expressed by the authors do not necessarily represent those of the sponsor.

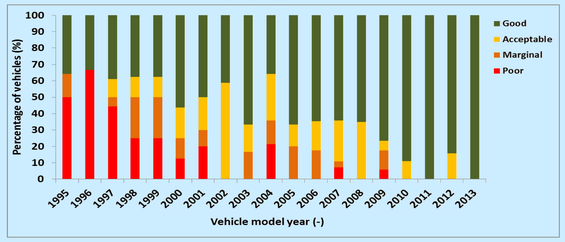
Results

IIHS Frontal Crash Tests

Data indicated a decreasing trend in vehicle foot well intrusion, foot accelerations, tibia axial forces and the tibia index in relation to increasing vehicle model year. Over 90 percent of vehicles reached the highest rating (i.e., Good) derived based on a composite score from the upper and lower tibia index, tibia axial force and the resultant foot acceleration considering both extremities. Passenger cars achieved the highest rating followed by SUVs and light trucks, while vans attained the poorest performer.



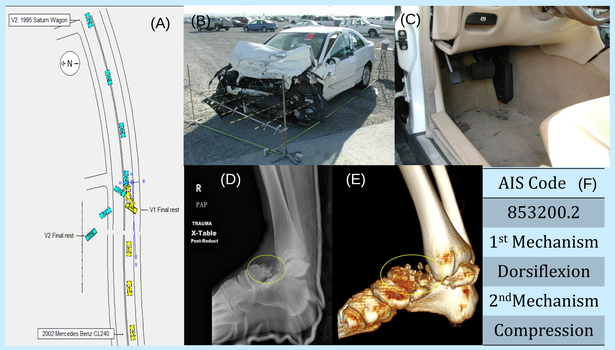
Left Toe-pan Intrusion (resultant) by Vehicle Category and Model Year



Overall Lower Limb Rating for Passenger Cars by Model Years

CIREN Case Review

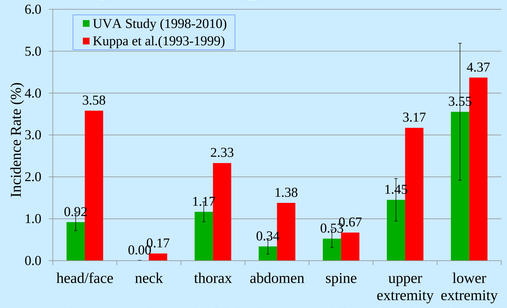
Talus fractures (20 cases, 59%) and calcaneus fractures (10 cases, 30%) were the most frequent hind-foot skeletal injuries observed among the reviewed cases.



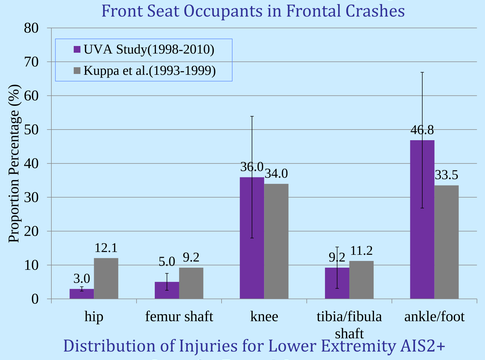
Images from one CIREN case. (A) crash reconstruction diagram. (B) view of vehicle showing damage in frontal plane (C) 4cm longitudinal intrusion in left toe pan (D) CT image showing right talus neck fracture (E) 3D Reconstruction of DICOM files (F) injury mechanism summary

NASS-CDS Data Analysis

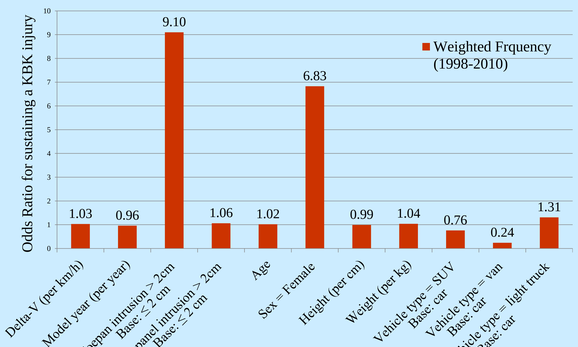
Toe pan intrusion greater than 2cm was significantly associated with an increased injury risk (OR: 9.10, CI: 1.82-45.42). Females had a higher likelihood for sustaining distal lower limb injuries (OR: 6.83, CI: 1.56-29.93) than males. Weight was found to be correlated (OR: 1.04, CI: 1.02-1.06), while occupant age and height were not significant associated with injury risk (ORs of 1.02 and 0.99, respectively). Relative to passenger cars, vans exhibited a significant decrease in sustaining lower limb injury (OR: 0.24, CI: 0.07-0.78), whereas light trucks(OR: 1.31, CI: 0.69-2.49) and SUVs(OR: 0.76, CI: 0.28-2.02) showed no significant association.



Incidence Rate of AIS 2+ Injuries of Body Regions for Front Seat Occupants in Frontal Crashes



Distribution of Injuries for Lower Extremity AIS2+ Cases for Frontal Occupants



The Odds Ratio for Sustaining a AIS2+ Knee or Below Knee(KBK) Injury

Discussion

1.Increase of talus fractures in reviewed cases suggested a substantial shift in the pattern of below knee injuries over the years. Below-knee lower limb injuries have been a problem and, despite modest improvements with newer vehicles, account for 45% of all AIS2+ injuries in frontal crashes.

2.74.4% of lower extremity AIS2+ injuries sustained in crashes with less than 2cm of toe pan intrusion and 62.4% occurred with vehicle delta-V below 30 km/h. In-depth assessment of ankle injury mechanisms found that while axial compression was the dominating loading mechanism in selected cases, 11 injured ankles involved inversion or eversion motion, and 7 of them involved dorsiflexion as the injury mechanism. The injured ankle was more biased towards the right aspect (19 cases) with foot pedals attributed to injury in 11 out of 34 cases.

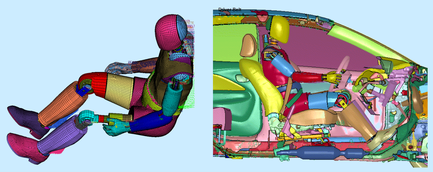
3.The apparent injury risk for the lower limb as a function of vehicle type for IIHS crash tests differed from the NASS-CDS findings and may be due to a combination of the weighting factors used in analysis of specific injury predictors and differences in occupant position and across vehicle types.

4.The results presented demonstrate that while there has been steady improvement in vehicle crash test performance, below-knee lower extremity injuries remain the most common AIS 2+ injury in frontal crashes. The analysis of ankle injury mechanisms suggests efforts to limit axial loading of the lower limb should continue to be prioritized in future injury evaluation and in the development of appropriate countermeasures.

Future Work

Future work will be conducted on evaluating countermeasures, especially knee airbags inside the occupant compartment.

1. 29 CIREN cases with knee airbags are to be compared to see the effectiveness of knee airbags in preventing lower extremity injuries.
2. Computational modeling with knee airbags will be performed to examine injury differences and vehicle coverage. THOR and GHBMC model will be introduced.



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