Identification of Accident Representative Scenario for Elderly Female Occupants in Side Impact

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ABSTRACT: The high fatality rate of the elderly in traffic accidents is one of the important issues in traffic safety. It is necessary to consider the influence of age and gender to reduce traffic fatalities of elderly occupants according to previous studies. The objective was to identify representative accident scenarios for elderly female occupants in side impacts. The Delta-V, PDOF and the most common seat track were identified using accident statistics. In addition, The influence of the seat track on thoracic injuries was investigated against the standard side impact protocol using a simulation model.

KEY WORDS: Safety, Protection of older people, Occupant, Accident analysis/ Thoracic injury, Side impact [C1]

1. Introduction

In the U.S., the elderly population, age 65 or older, reached 47.8 million in 2015; accounting for nearly 15 percent of the total U.S. population (1). The number of licensed elderly drivers increased by 33% from 2006 to 2015, reaching 40.1 million (1). In addition, the number of elderly fatalities increased by 3% from 2006 to 2015, while the overall number of fatalities decreased by 19% (1). Furthermore, it has been predicted that the elderly population will expand to 83.7 million by the year 2050 (2). Therefore, it is likely that the number of elderly fatalities in traffic accidents will increase in the near future, resulting in a growing need for the protection of the elderly in traffic accidents.

A previous study done by NHTSA analyzed the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and found that the percentage of drivers sustaining MAIS4+ injuries relative to the number of drivers involved in accidents is significantly larger for the elderly population over 65 year-old than the age group between 25 and 44 years old, 1.85% compared to 0.76%, respectively.

Fatal injuries to the elderly population is the fragility of the elderly. For example, previous studies have shown that the tensile failure strain of the cortical bone in the rib is significantly decreased with aging (4,7). As areal bone mineral density (aBMD) has been shown to correlate with fracture risk, elderly females may demonstrate poorer quality bones compared to males due a higher probability of osteoporosis (5). A previous study revealed that the probability of AIS3+ injury depends on gender. According to the study, in near-side impacts, the probability of injury to the thorax and the ribs were significantly higher for females than for males within the elderly population (9). This suggests that female drivers in near-side impacts are the more susceptible group to thoracic injuries such as rib fractures. Despite the growing importance of the protection of elderly females in near-side impacts, few studies to date have investigated this impact configuration. One recent study by Shurtz et al. (10) conducted side impact sled tests using two elderly female post-mortem human surrogates (PMHS). A Delta-V of approximately 28 km/h was applied to the base sled, however, the representativeness of the testing condition used in these tests needs to be further investigated.

In order to protect elderly females in near-side impacts, the effectiveness of safety technologies needs to be evaluated using boundary conditions that specifically represent crashes in which elderly female occupants were injured, which has not been done in past studies. The objective of this study is to identify representative crash scenarios which resulted in different injury severity levels to elderly female occupants in near-side impacts.
2.Method

2.1 Identification of Representative Crash Scenario for Elderly Females in Near-Side Impacts

This study aimed to determine the boundary conditions of representative crash scenarios, including Delta-V, Principal Direction of Force (PDOF) and seat track position, which significantly correlate with injury severity and are also independent of vehicle type. An accident database was mined to determine representative values for Delta-V, PDOF and seat track position for elderly female occupants in near-side impacts which resulted in different levels of injury severity.

The NASS-CDS database was used to identify representative values for there parameters. Non-weighted data from 2000 through 2015 were filtered to include elderly female drivers or front seat passengers, age 60 years and older, involved in near-side impacts who sustained thoracic injuries. These data were classified by MAIS levels of thoracic injuries, specifically AIS2, AIS3 and AIS4, to determine the representative values for Delta-V, PDOF and seat track position, for each given injury severity level. For comparison purposes, Delta-Vs between 10 km/h to 65 km/h were divided into 11 groups with 5 km/h increment.

2.2 Comparison of thoracic injury between standard testing protocol and representatative impact mode for elderly female

A near-side impact simulation model using a human body model (HBM) in LS-DYNA developed and validated in a previous study (11) was used to compare thoracic injury including rib fractures between the current standard side impact testing protocol and representatative impact mode identified in the previous section.

The HBM developed by Dokko(11) was used in this study. They developed two HBMs representing adult (35 years old) and elderly (75 years old) male occupants by incorporating changes in the rib cage geometry and altering the material properties of the ribs. The rib cage geometry of the adult model was morphed to match the average geometry of a set of CTs from elderly individuals. The material properties of cortical bone of the ribs were determined using tensile test results reported by Kemper et al. (6)(12). The elderly model was validated against thoracic impact tests documented in ISO-TR9790 (13) along with side and frontal sled tests conducted by Lessley et al. (14) and Shaw et al. (15). The biofidelity score for the tests ranged from 0.39-1.36 based on the assessment scheme proposed by Rhule et al. (16). The elderly HBM was then scaled to the size of a 5th percentile female, using a representative anthropology for female crash test dummies. The same scale factor of 0.86 was used in all three directions to reproduce the size of the 5th percentile female. In addition, the mass of the HBM was adjusted using mass density of organs to match the target weight of 46 kg.

Due to the sedan vehicle type being the most common in the sales market, a sedan body was selected for the side impact simulations as shown in Fig. 1 (A). The sedan model developed by Shibata et al. (17) was used. The airbag used in the near-side impact model is shown in Fig. 1 (D). The significant parameters for an accurate airbag model, including airbag inflator mass flow rate, gas temperature, mesh size and timesteps were taken from Sugaya et al. (18). The airbag firing timing used in the simulation was set to 5 msec.

In this simulation, a seatbelt pretensioner was not applied for simplification. The standardized moving deformable barrier defined in FMVSS 214 was used to represent the striking vehicle.

Using this side impact simulation set up, predicted thoracic injuries were compared between current standard side impact testing protocol and representative impact mode identified in the current study.

![Fig. 1 Near-side impact simulation model](image_url)

(a)Sedan car, (B)Moving deform barrier, (C)Human Body Model, (D)Side airbag model.
3. Result

3.1. Identification of Representative Crash Scenario for Elderly Females in Near-Side Impacts

The representative Delta-V, PDOF and seat track position for elderly female occupants in near-side crashes were identified from non-weighted data in NASS-CDS. The distribution of Delta-V and PDOF are presented in Fig. 2 and 3. The mode of Delta-V corresponding to AIS2, AIS3 and AIS4 for elderly female occupants were 17.5 km/h, 27.5 km/h and 32.5 km/h, respectively. The PDOF was similar for all AIS levels at approximately 300 degrees. It was found that the PDOF was similar with the Federal Motor-Vehicle Safety Standard (FMVSS) 214 Moving Deformable Barri re (MDB) testing condition used in the United States regulation. The position of the seat track was found to be mid-track for all of the AIS levels investigated in this study as shown in Fig. 4.

![Fig. 2 Frequency distribution of Delta-V by each AIS level for elderly female occupants](image)

![Fig. 3 Frequency distribution of PDOF for each AIS level for elderly female occupants](image)

3.2. Comparison of thoracic injury between current standard side testing protocol and representative impact mode for elderly female

It is clarified that the PDOF was close to FMVSS214 MDB testing condition in the previous section. However, representative seat track position for elderly female was different from the one used in the current standard side testing protocol. In the current standard side testing protocol defined for American Female fifth percentile dummy, seating position was set frontal most track position, while middle track position was most frequent in the representative impact configuration identified in the current study for elderly female.

![Distribution by AIS (%) by seat track position](image)

Table 1 Summary of the thoracic injuries in frontal and middle seat track position

| Mode                     | Current standard side testing protocol | Representative side impact |
|--------------------------|----------------------------------------|----------------------------|
| Striking velocity        | 53 km/h                                | 53 km/h                    |
| Delta-V                  | 30 km/h                                | 30 km/h                    |
| PDOF                     | 297 degree                              | 297 degree                 |
| Seat position            | Front most track                       | Middle track               |
| Occupant                 | Elderly HBIM scaled to AIS3            | Elderly HBIM scaled to AIS5|
| Number of rib fractures  | Struck 7                                | 9                          |
|                          | Non struck 2                            | 2                          |

![Fig. 5 Time histories of number of rib fractures-time histories in both frontal and middle seat track position](image)
Using the side impact simulation model, predicted thoracic injuries were compared between these seat track positions at 54 km/h of the striking velocity, which corresponds to approximately 30 km/h of Delta-V, defined in FMVSS214 Moving Deformable Barrier (MDB) testing condition.

The results of side impact simulations were summarized in Table 1. Fig. 5 shows the the time histories of the number of rib fractures in the frontal and middle seat track position. Two more rib fractures at the 6th and 10th ribs occurred in the representative side impact relative to those seen in the current side impact testing protocol.

4. Discussion

In the previous section, the most common PDOF was found to be 300 degrees for elderly female drivers injured in near-side impacts. A previous study found that the ratio of crashes involving a left-turn maneuver by elderly drivers (ages 64 or older) drivers was significantly higher than other age groups in the U.S. (2) Another study indicated that elderly drivers tend to wait significantly longer than younger drivers before making a left-turn (20). According to these studies, it is assumed that elderly drivers tend to make conservative decisions in determining timing to start making a left-turn, which may lead to a delay in turning the vehicle and thus result in having less distance between their cars and oncoming traffic. This delay typically results in a side crash with the oncoming vehicle colliding with the near side of the driver, which would explain why 300 degrees of PDOF is the most frequent direction of impact for elderly drivers.

The crash data analysis clearly showed that the mode of Delta-V increased as the AIS level of thoracic injury increased. This clearly suggests that an increase in impact energy generally results in an increase in severity of thoracic injury.

This study results were compared with near-side impact sled testing using elderly female PMHS reported by Shurtz et al. (10) They used a Delta-V of approximately 28 km/h, which is close to the mode of Delta-V in AIS3 thoracic injury identified in this study. In the experiment, all PMHS sustained AIS3 thoracic injury, suggesting the validity of the mode of Delta-V determined in this study for AIS3.

As shown Fig. 4, the number of fractures in middle track position is more than in that frontal track. 6th and 10th ribs were additionally fractured in the case of middle seat track position relative to the frontal seat track position. Fig.6 shows the down view of the transverse section of the elderly model used in the current study at the 6th rib. Body intrusion in the rear part of the door section is larger than that of the front part due to the direction of 300 degree of PDOF. Therefore contact force to thorax from the doorliner in middle track position is more larger than in frontal track position, which is 1768 N, 1634 N, respectively, then leading to more fractures in middle track position. In terms of seat position, it is assumed that middle track position is more severe for elderly female than frontal position.

Fig. 6  Down view of the section of rib 6th in (A) the current standard side testing protocol and (B) the representative side impact

5. Limitation

The HBM used in this study represented small elderly female stature. However failure characteristics of the ribs corresponding to 50% probability for elderly male was used in this study. In addition, the material properties of the rib is from elderly male subjects. The HBM used in this study needs to be further validated against human response data specific to elderly female.

6. Conclusion

The representative crash conditions such as Delta-V, PDOF and seat track position for elderly female occupants in near-side impact crashes were identified for different injury severity levels: AIS2, AIS3 and AIS4.

The representative Delta-Vs for AIS2, AIS3 and AIS4 are 17.5 km/h, 27.5 km/h and 32.5 km/h, respectively, while PDOF is similar for all AIS levels at 300 degrees.

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