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Factors Associated with Chest Injuries to Front Seat Occupants in Frontal Impacts

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ABSTRACT

Objective: Frontal impact chest protection in European cars has been highlighted as an area where possible improvements could be made. The chest is particularly vulnerable in older occupants whose numbers are forecast to increase significantly in the coming decades. This study aimed to provide some direction to areas for possible improvements in frontal crash chest protection.

Methods: Real world crash injury data were interrogated, focusing on cars with current restraint components. The research examined belted front-seat occupants in frontal impacts where air bags, pretensioners and load limiters were present.

Results: The chest was the most often injured body region at AIS 2+, 3+ and 4+ injury levels. The rate of AIS 2+ and AIS 3+ chest injuries was highest among elderly occupants and lowest among young occupants, and elderly occupants sustained proportionally more severe chest injuries in low/moderate speed impacts compared to young and middle-aged occupants. However, it should be noted that rates of AIS 2 chest injury were also significantly higher for middle-aged occupants compared to the young. The front passenger seat was shown to be more often associated with significant chest injury than the driver seat. The higher proportion of elderly female occupants was postulated as a reason for this. Skeletal injury was the most frequent type of AIS 2+ chest injury and the rate of injury for elderly occupants with such injuries was higher than for young and middle-aged occupants. With the increase in the number of rib fractures, the risk of pulmonary complications and organ injuries tended to increase. The major cause of chest injury was identified as restraining loads transmitted to the chest via the seat belt. The absence of intrusion in the majority of cases, suggests an opportunity for the restraint system to better manage the crash pulse. Not only for elderly occupants but for those who are middle-aged as well.

Conclusions: This study shows the necessity for safety interventions, through new vehicle crashworthiness systems to improve chest protection especially for middle aged and elderly car occupants. Deployment of appropriate injury risk criteria, use of an appropriate dummy thorax, development of a low energy restraint test, and the development of more adaptive restraints have been discussed as possible solutions to the problem.

Keywords: Real world crash, Chest injury, Older Occupants, Accident Analysis, Crash Tests

INTRODUCTION

Frontal impact protection in Europe is legally regulated by ECE R94. Introduced in 1996, it involves a frontal offset impact into a deformable barrier at 56 km/h, although the similar but higher severity EuroNCAP test has been a major driver for frontal impact safety since 1997. These tests resulted in the rapid adoption of more rigid frontal structures, and the introduction of frontal airbags, seat belt pretensioners and load limiters – the restraints that European cars are universally fitted with today. In an early study of R94 compliant cars, Kirk et al (2002) found that, in frontal impacts, the new design changes appeared to show very positive effects for head protection but there was a question mark concerning improvements to chest protection. A relatively high frequency of significant chest injury continued to be reported in subsequent European studies (Newstead et al. 2006; Carroll et al. 2009).

Occupant age is a factor in determining injury outcome in a vehicle crash. Older car occupants differ from young or middle age occupants in several respects including physiological tolerance, injury outcomes and crash exposures (Islam & Mannering 2006; Kent et al. 2009). Previous studies have shown that biomechanical tolerance to loading declines with age, so that a greater level of injury is sustained for a given magnitude of loading (Augenstein 2001; Welsh, Morris, Hassan, et al. 2006; Dejeammes & Ramet 1996; Kent et al. 2008). Additionally, older people are more frail, so they tend to have worse outcomes for the same injury (Kent et al. 2009). Specifically, age related vulnerability of the chest to crash loads in frontal impact have been highlighted by several authors (Augenstein et al. 2005; Mertz & Dalmotas 2007). This is an important factor to consider in frontal impact protection because, in Europe, the ratio of the number of people aged over 65 years to the population aged 15-64 years is projected to double between 2010 and 2050 (Lanzieri 2011), and it is expected that the number of older people using passenger cars will be greater than ever before.

In light of the increasing elderly car population, it was decided to re-visit the question of chest protection in European frontal crashes with a larger, more up to date and statistically weighted data set. The Newstead et al (2006) study was only able to access data up to 2005, whilst the Carroll et al study (2009) had analysed a small unweighted sample of UK CCIS data. This current study was able to access weighted UK CCIS data to 2010 and UK RAIDS data to 2018 to provide a picture of the current European situation.

METHODS

UK Co-operative Crash Injury Study (CCIS)

CCIS crash injury data collected between 2000 and 2010 were used for the most part in this study. Selecting vehicles which contained frontal airbags, pretensioners and load limiters ensured a large sample of cars complying with Regulation 94, most of which had also been EuroNCAP tested. CCIS collected in–depth crash and injury information from selected geographical regions representing urban and rural roads in Great Britain. The sampling methodology is described by Hassan et al. (1995). Injury outcome was recorded using the Abbreviated Injury Scale AIS 90, (Association for the Advancement of Automotive Medicine 1990).

Weighting factors were applied to the data, based on police recorded accident severity, in order to allow analysis of a representative sample of crashes. Further details of the CCIS study can be found in the Appendix.

The criteria used to select the frontal impact population are shown below:

- Single frontal crash or 2 impacts with frontal impact being the most significant in causing injuries.
- No underride or rollover crashes.
- Principal direction of force between -30^0 and +30^0.
- Three-point belted front seat occupant ≥15 years of age.

The unweighted accident sample consisted of 1,782 front seat occupants. Applying weighting factors gave 5,234 front seat occupants consisting of 4,301 (82%) drivers and 933 (18%) front seat passengers (FSP). For all statistical tests, the significance level was set at a 95% confidence level ($p<0.05$). Occupant age was categorised into three groups: a) young: 15-39 years, middle-aged: 40-64 years and c) elderly: 65+ years. This classification was based on that used in previous European real world accident studies (Welsh, Morris, Hassan, et al. 2006; Morris, et al. 2003).

UK Road Accident In-depth Studies (RAIDS)

This UK in-depth crash injury study replaced the CCIS programme in 2012 but collects comparable information, using the Abbreviated Injury Scale AIS 2005, (Association for the Advancement of Automotive Medicine 2005) for injury classification. Data collected between 2013 and 2018 were interrogated in the same way as for the CCIS data, but a smaller overall sample size (the unweighted accident sample consisted of just 309 front seat occupants) restricted many of the proposed analyses once additional data queries were applied. Therefore, the analysis presented in this paper primarily concerns the larger CCIS dataset, although it was possible to obtain some limited results from the RAIDS data, and this is flagged when it is presented.

RESULTS

General Sample Characteristics

Occupant age: More than half of all occupants (52%) were aged between 15 and 39 (young), 35% were aged between 40 and 64 (middle-aged) and 13% were aged over 64 (elderly). The proportion of elderly occupants in the front passenger seat (18%) was greater than in the driver seat (12%). The mean ages of drivers and front passengers were significantly different when compared using an Independent Samples T-test ($p<0.05$).

Occupant gender: Overall, 58% (n=3033) of occupants were male and 42% (n=2201) were female. The majority of drivers were male (63%), while the majority of front seat passengers were female (67%).

Crash severity by seating position: The distribution of crash severity was very similar between the two front seat occupant groups (Figure A 1, Appendix). The majority (69%) of impacts occurred between 20 and 45 km/h. The EES for 97% of all impacts was below 50 km/h and 99% occurred below 60 km/h. Therefore, most impacts did not exceed the crash severity of European frontal test requirements.

Crash severity by seating position and age: The mean crash severity (EES) was compared between age groups in each seating position. No significant differences were found for EES exposure between each age group in each seating position ($p>0.05$) (Table A 1, Appendix).

Facia intrusion: Of all occupants, 91% experienced intrusion below 3 cm, 4% had sustained intrusion between 3 and 9 cm, and 4% sustained intrusion greater than 10 cm. Intrusion was not known for 1% of the sample. The overall implication is that intrusion was well controlled in the sample of cars.

Maximum Abbreviated Injury Severity (MAIS) by seating position: The MAIS represents the overall injury severity to an occupant. The proportions of front seat passengers with MAIS 2 (16.7%) and MAIS 3+ (6.2%) injury were greater than those for drivers MAIS 2 (9.8%), MAIS 3+ (5.0%) (Table A 2, Appendix). The Chi Squared test showed a significant relationship between injury severity outcomes and front seating positions ($\chi 2 = 42.192$, d.f =2, $p<0.05$).

MAIS by age: Older occupants were over-represented at all levels of injury severity from MAIS 2 and above. The injury risk to middle-aged occupants from MAIS 2 and above was also greater than for young occupants (Figure A 2, Appendix). 29% of the older occupants had MAIS 2+ level injury compared to 18% of middle aged and 12% of younger occupants. A Chi Squared test found that the distributions of injury severity across the three age groups were significantly different ($\chi 2 = 186.75$, d.f =12, $p<0.05$).

MAIS by body region: Table 1 shows the rate of AIS 2+, 3+ and 4+ injury by body region, for all occupants. Injuries to the head at the AIS 2+ level were received by 1.9% of occupants. Only 1.1% of occupants had neck injury at the AIS 2+ level. The chest was the most frequently injured body region at all AIS severity levels. 6.5% of all occupants sustained AIS 2+ chest injury, while 2.3% of all occupants had sustained AIS 2+ abdominal injury. The second most frequently injured body region at the AIS 2+ level was the upper extremity (6.3%) followed by the lower extremity (5.1%). None of the injuries to the extremities were rated at AIS 4 or above.

Chest Injury

Chest injury severity rate by seating position: 244 drivers and 94 front seat passengers sustained chest injuries at the AIS 2+ level. The rate of chest injury for front seat passengers was higher than for drivers at AIS 1+, 2+ and 3+ levels. The rates of AIS 2+ and 3+ chest injury for the front seat passenger were 10% and 4% respectively. Those rates were 1.7 times higher than for drivers at the AIS 2+ level and twice as high as drivers at AIS 3+ (Figure A 3, Appendix).

Chest injury severity rate by age: Figure 1 shows the rate of AIS 2+ and AIS 3+ chest injury for occupants by age group. The rate of injury at both severity levels increased with the age. The rate of AIS 2+ injury for younger, middle-aged and older occupants was 2% (n=55), 9% (n=169) and 16% (n=114) respectively. 1% of younger occupants (n=33), 3% of middle-aged occupants (n=47) and 8% of elderly occupants (n=54) had sustained at least one AIS 3+ chest injury. Elderly occupants had much higher rates of both AIS 2+ and AIS 3+ injury compared to young and middle-aged occupants. Of particular note is the much higher rate of AIS 2+ chest injury for middle aged occupants compared to the young. Though a comparison of the AIS 3+ injury rates suggest that the major difference between young and middle-aged occupants is due to the latter’s higher susceptibility to AIS 2 chest injury.

Crash severity of chest injured occupants by age: 160 (47%) of all AIS 2+ chest injured occupants had sustained their injury with EES less than 30 km/h and 75% below 40 km/h. The rate of AIS 2+ chest injury at EES less than 30 km/h was 0%, 7% and 13% for younger, middle-aged and elderly occupants respectively. Considering EES above 50 km/h, the rate of AIS 2+ chest injury to younger, middle-aged and elderly occupants were 24%, 37% and 53% respectively.

The mean EES for AIS 2+ and 3+ chest injured occupants by age is shown in Table 2. It shows that crash speeds were generally higher with higher injury severity. However, the mean EES for AIS 2+ chest injured elderly front seat occupants (30.8 km/h) was less than that for young (45.2 km/h) and middle aged (32.1 km/h) occupants. Similarly, the mean EES of AIS 3+ chest injured elderly occupants (36.0 km/h) was less than for young (49.9 km/h) and middle-aged (42.6 km/h) occupants. One-way analysis of variance (ANOVA) tests found a significant difference in the mean EES between age groups ($p<0.05$), for occupants who had sustained AIS 2+ and AIS 3+ level chest injuries. Table 2 also shows the mean EES for the weighted RAIDS data sample collected between 2013 and 2018. Similar to CCIS data, crash speeds were higher with higher injury severity. The mean EES for AIS 2+ chest injured elderly front seat occupants (39.1 km/h, n=68) was less than that for young (51.2 km/h, n=15) and middle aged (40.2 km/h, n=39) occupants. The mean EES of AIS 3+ chest injured elderly occupants (40.3 km/h, n=46) was less than for the young (70.8 km/h, n=4) and middle-aged (44.9 km/h, n=19) occupants. Although the small number of young occupants with AIS 3+ injury limits the accuracy of the mean EES value.

Type of AIS 2+ chest injury: There were 427 AIS 2+ chest injuries sustained (Table A 3, Appendix). Further details of these injuries are available in the Appendix. Some of the occupants had more than one AIS 2+ chest injury. If an occupant sustained skeletal fracture and pulmonary complications such as pneumothorax, haemothorax, haemo-pneumothorax, and flail chest, then the injuries were counted as a single injury. Skeletal injuries were the most common type of AIS 2+ chest injuries, followed by intrathoracic organ and vessel injuries.

Injury causation for AIS 2+ chest injuries: Of 338 occupants with AIS 2+ chest injury, 76% (n=257) had one or more chest injuries due to the occupant loading the seat belt alone. For a further 15% (n=52) of occupants, injury was caused by impact with the steering wheel. In 5% (n=15) of occupants, AIS 2+ chest injury was entirely due to impact with other components such as the airbag, side door, and vehicle interior panels. 8 occupants had chest injuries caused by a combination of loading. The components associated with AIS 2+ chest injury for the remaining 6 occupants were not known.

Injury causation for all AIS 2+ chest skeletal injury: Restraining loads transmitted via the seat belt were the single major cause of injury for all skeletal fractures. 79% (n=259) of all skeletal fractures were caused by this loading, 17% (n=55) were from steering wheel impact and 4% (n=14) from other sources. Belt loads were the cause of injury for 91% (n=190) of the sternum fractures, 54% (n=14) of the 2-3 rib fractures and 61% (n=53) of 4 or more rib fractures. There was no difference in the proportion of steering wheel impact (50%) to seat belt loading (50%) as a source of injury for single rib fractures (Figure 2).

Rate of AIS 2+ chest skeletal fracture by age: The rate of sternum and rib fracture for all front seat occupants who had sustained a chest injury (n=2211) is shown in Figure 3. In total, 328 skeletal fractures were reported in the sample. Some of the occupants had both sternum and rib fractures. Sternum and rib fracture combinations were most common with the elderly occupants and least common with the younger occupants. 16% (n=65) of the elderly occupants had sustained sternum fracture compared to 13% (n=123) for middle aged and 2% (n=21) for younger occupants. 12% (n=46) of the elderly occupants had reported with 4 or more rib fractures, which was the second most common type of skeletal fracture among the elderly occupants, compared to 3% (n=29) for middle-aged and 1% (n=12) for younger occupants.

Injured intra-thoracic organs and fractured ribs: Figure 4 shows a strong association between organ injury and number of rib fractures. Almost 60% (n=52) of the intra-thoracic organ injuries (not including pneumothorax and haemothorax) were associated with 2 or more rib fractures. The majority of lung injuries (56%, n=25) were associated with 2 or more rib fractures.

DISCUSSION

This study examined the factors associated with belted front seat occupant chest injury in real frontal impacts involving European cars complying with ECE R94. The chest was the body region most often injured at AIS 2+, 3+ and 4+ injury levels. Crash severity exposure was similar between different occupant age groups, yet the age groups were very different in terms of chest injury risk. The rates of AIS 2+ and AIS 3+ chest injuries were highest among elderly occupants and lowest among the young occupants. Moreover, elderly occupants tended to sustain their severe chest injuries in lower energy impacts compared to the other two occupant groups. This is in agreement with previous studies (Augenstein et al. 2005; Mertz & Dalmotas 2007). Younger occupants tended to receive proportionally less AIS 2+ chest injuries even in more severe crashes. In impacts with EES above 50 km/h, only 24% of the younger front seat occupants had sustained AIS 2+ chest injuries, whereas the corresponding rate of injury for middle-aged and older occupants were 37% and 53% respectively. The implication here is that young occupants are quite well protected compared to other age groups. The overall results highlight an on-going concern about protection for the elderly in relatively low severity crashes. AIS 2+ and 3+ chest injuries to elderly occupants were sustained with little intrusion and at relatively low mean crash severities (31 km/h for AIS 2+ and 36 km/h for AIS 3+). Even in the most recent cars from the 2013-2018 dataset, the mean crash severities were low (39 km/h for AIS 2+ and 40 km/h for AIS 3+). Frampton and Mackay (1994) found similar results in pre- R94/EuroNCAP vehicles. Half of their belted front seat passenger fatalities were elderly and had sustained significant chest injury in impacts below 50 km/h, with little or no passenger compartment intrusion.

Crash severity exposure was similar for both front seating positions, it was also similar between different occupant age groups in each seating position, yet chest injury outcome was very different for drivers and front seat passengers. The front passenger was more often associated with significant chest injury compared to the driver. The rate of chest injury was higher for passengers than for drivers at all levels of severity. At the AIS 2+ level, passengers sustained chest injury at 1.7 times the rate of drivers, and AIS 3+ injury occurred at twice the rate of drivers. Examination of seat occupant factors suggested an explanation. The proportion of elderly occupants in the front passenger seat was higher compared to the driver seat (18% compared to 12%). The driver seat had the highest proportion of younger occupants, 52% were below 40 years of age. Differences in the gender proportion were also observed between the two front seating positions. The majority of drivers were male (63%), while the majority of front seat passengers were female (67%). The difference in injury risk between the two seating positions could be due to the overrepresentation of older, female occupants in the passenger seat. Which in turn questions whether restraint systems are better optimised for drivers than for passengers. Thoracic protection related to age, gender and seat position combinations appear to be an important consideration for future restraint development.

In this study, skeletal injury was the most frequent type of AIS 2+ chest injury. Injuries to intrathoracic organs were the second most frequently occurring AIS 2+ chest injuries followed by injuries to vessels. Skeletal injury mainly comprised of sternum and rib fractures. Sternum fracture, four or more fractured ribs and lung contusion were the most frequent injury types. Sternum fractures are usually coded at the AIS 2 level. They are generally less severe when occurring alone and are less likely to cause any further complication. The lungs were by far the most frequently injured intra-thoracic organs. This was followed by the pericardium and the heart. Injuries to vessels were less common in the sample, however, those injuries are mostly rated at the AIS 4+ level, and are life threatening, so should not be disregarded based on a low frequency of occurrence.

The rate of injury for elderly occupants with skeletal injuries (sternum, single rib, 2-3 rib and 4+ rib fractures) was higher than for the other two age groups. Particularly, the difference in the rate of sternum and AIS 4+ rib fractures between elderly and young occupants. However, the higher rate of skeletal injuries to middle aged occupants compared to the young was also notable. Fractures to the ribs and sternum were mainly caused by restraining loads transmitted through the belt, clearly reinforcing the idea that the restraint system performs optimally for young occupants. An observation supported by the much higher rate of AIS 2+ chest injury for middle aged occupants compared to the young.

This study was also extended to look at the relationship between rib fractures and the occurrence of intrathoracic injuries. With the increase in the number of rib fractures, the risk of pulmonary complications and organ injuries tended to increase, concurring with previous studies (Kent et al. 2008; Thor & Gabler 2008). To understand the nature of the injury occurrence for the different age groups, the crash severity of such injury types should be further studied. Such analysis could give an association between the crash severity (i.e. magnitude of the force experienced) and the number of rib-intrathoracic injuries. What is important to note is that nearly 40% of lung contusions occurred with one or no rib fracture. The injury mechanism for this is not clear and deserves further consideration.

This study has highlighted the continuing issues related to chest injury with older occupants in frontal impacts. Particularly in relation to the front passenger seat where a large proportion of the occupants are elderly and female. The major cause of chest injury was identified as restraining loads transmitted to the chest via the seat belt, and in the absence of intrusion, it is suggested that the opportunity exists for restraint system improvements to better manage the crash pulse. There are efforts to promote this in European frontal crash test protocols. EuroNCAP introduced a 50 km/h full overlap frontal test of the restraint system in 2015, but it does not include a belted 5th percentile Hybrid III dummy on the front passenger seat. European frontal impact compliance testing still does not assess the vehicle restraint system under a high ‘g’ scenario. The European Commission is considering a new frontal test, UNECE R137, in its type approval system from September 1st, 2020. This specifies a 50 km/h, full width rigid barrier impact with driver and passenger 50th and 5th percentile Hybrid III dummies respectively. The introduction of restraint testing for European vehicles is welcome, since offset testing has promoted stiffer and stiffer front crash structures which do not improve crash safety in all conditions. The imminent introduction of the THOR dummy by EuroNCAP is also welcomed, since it has improved biofidelity and is capable of utilising age dependent injury risk functions. However, results of this study suggest that a 50 km/h impact speed may be too high to address the crash conditions where middle aged and elderly occupants sustain AIS 2+ and AIS 3+ chest injuries. Instead, it suggests that there could be a large target population who might benefit from a low energy restraint test.

Single point restraints optimised for specific crash conditions have difficulty in addressing the full range of occupant and crash diversity. Evidence for this is clearly visible in cars that perform very well in EuroNCAP offset tests but fare rather worse in full overlap testing. The overall value of the seat belt in reducing serious crash injuries has been verified in countless studies and is not questioned here. Instead, the results suggest there may be an opportunity to improve the efficacy of current restraint systems by making them more intelligent. Such a system could vary load limiting, pretensioning and airbag deployment according to crash type, occupant type, and seating position, for optimal occupant protection. Indeed, a recent study by Ekambaram et al. (2015) showed some promising results when just the load limiter component of the restraint system was intelligently varied.

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References

Abbreviated Injury Scale 2005. Association for the Advancement of Automotive Medicine (AAAM). Barrington, Illinois, U.S.A. 2005.

Abbreviated Injury Scale 1990 Revision. Association for the Advancement of Automotive Medicine (AAAM). Des Plaines, Illinois, U.S.A. 1990.

Augenstein, J. Differences in clinical response between the young and the elderly. Proceedings of the Aging and Driving Symposium, Association for the Advancement of Automotive Medicine. 2001.

Carroll J A. COVER D5 – Main summary report: Matrix of serious thorax injuries by occupant characteristics, impact conditions and restraint type and identification of the important injury mechanisms to be considered in THORAX. THORAX project GA. 2009.

Dejeammes M, Ramet M. Aging process and safety enhancement of car occupants. In Proceedings: International Technical Conference on the Enhanced Safety of Vehicles, vol. 1996, pp. 1189-1196. National Highway Traffic Safety Administration, 1996.

Ekambaram K, Frampton R, Bartlett L. Improving the chest protection of elderly occupants in frontal crashes using SMART load limiters. Traffic injury prevention. 2015 Oct 8;16 (sup2):S77-86.

Frampton RJ, Mackay GM. The Characteristics of Fatal Collisions for Belted Occupants. In SAFETY. Technical papers from the 25th FISITA Congress, Beijing, 1994, Vol 4. Technical Paper No. 945167 1994.

Hassan AM, Hill JR, Parkin S, Mackay GM. Secondary Safety Developments: Some Applications of Field Data. Autotech 1995; ImechE. 1995.

Islam S, Mannering F. Driver aging and its effect on male and female single-vehicle accident injuries: Some additional evidence. Journal of safety Research. 2006 Jan 1;37(3):267-76.

Kent R, Trowbridge M, Lopez-Valdes FJ, Ordoyo RH, Segui-Gomez M. How many people are injured and killed as a result of aging? Frailty, fragility, and the elderly risk-exposure trade off assessed via a risk saturation model. InAnnals of Advances in Automotive Medicine/Annual Scientific Conference 2009 Oct 5 (Vol. 53, p. 41). Association for the Advancement of Automotive Medicine.

Kent R, Sang-Hyun L, Darvish K, Wang S. Structural and material changes in the aging thorax and their role in crash protection for older occupants. Stapp car Crash journal. 2005 Nov 1;49:231.

Kent R, William W, Ola B. Fatality risk and the presence of rib fractures. In Annals of Advances in Automotive Medicine/Annual Scientific Conference, vol. 52, p. 73. Association for the Advancement of Automotive Medicine, 2008.

Kirk A, Frampton RJ, Thomas PD. An Evaluation of airbag benefits/disbenefits in European vehicles-a combined statistical and case study. In IRCOBI Conference Proceedings, Munich, 18-20 September., 2002.

Lanzieri G. The greying of the baby boomers. Eurostat Statistics in focus, 2011.

Lenard J, Hurley B, Thomas PD. The accuracy of CRASH3 for calculating collision severity in modern European cars. 1998.

Mertz HJ, Dalmotas DJ. Effects of shoulder belt limit forces on adult thoracic protection in frontal collisions. No. 2007-22-0015. SAE Technical Paper, 2007.

Morris A, Welsh R, Hassan A. Requirements for the crash protection of older vehicle passengers. In Annual Proceedings/Association for the Advancement of Automotive Medicine, vol. 47, p. 165. Association for the Advancement of Automotive Medicine, 2003.

Newstead S, Delaney A, Cameron M. Use of in-depth data in comparing EuroNCAP and real-world crash results. SARAC II (Quality criteria for the safety assessment of cars based on real-world crashes) Report of sub-task 2.3. 2006. Available from the EC internet site: http://ec.europa.eu/transport/road/publications/doc/sarac2_2.3.pdf.

Thor CP, Gabler HC. The relationship between thoracic organ injuries and associated rib fractures. LUNG 339 (2008): 246.

Welsh R, Morris A, Hassan A, Charlton J. Crash characteristics and injury outcomes for older passenger car occupants. Transportation research part F: traffic psychology and behaviour 9, no. 5 (2006): 322-334.

Figures and Tables

Table 1 Injury Severity Rate for Each Body Region

	Head	Neck	Chest	Abdomen	Upper Ex.	Lower Ex.
AIS 2+	1.9% (n=98)	1.1% (n=59)	6.5% (n=338)	2.3% (n=122)	6.3% (n=331)	5.1% (n=268)
AIS 3+	0.9% (n=47)	0.2% (n=8)	2.5% (n=133)	0.7% (n=39)	0.9% (n=49)	2.2% (n=116)
AIS 4+	0.4% (n=24)	0.0% (n=1)	1.0% (n=52)	0.2% (n=8)	0.0% (n=0)	0.0% (n=0)

Table 2 Mean EES of Chest Injured Occupants by Age Group

	Mean EES (km/h)		
	Young	**Mid**	**Elderly**
Chest AIS 2+	45.2 (51.2)	32.1 (40.2)	30.8 (39.1)
Chest AIS 3+	49.9 (70.8)	42.6 (44.9)	36.0 (40.3)

(RAIDS data in parentheses)

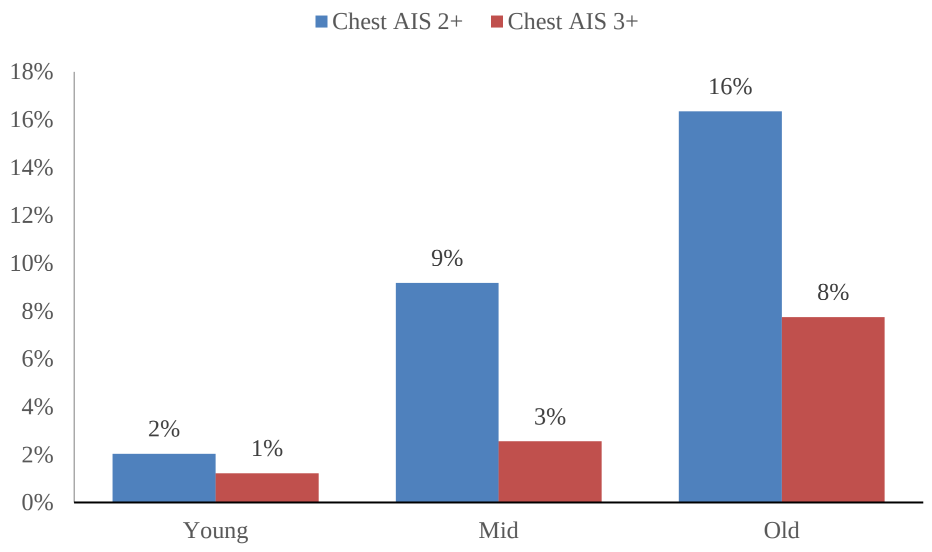

Figure 1 Chest Injury Severity Rate by Age

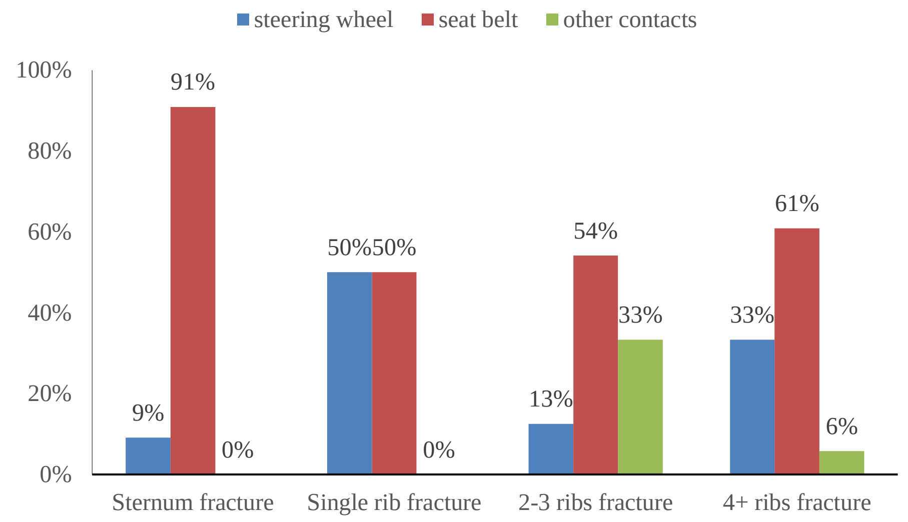

Figure 2 Component Associated with AIS 2+ Skeletal Injury

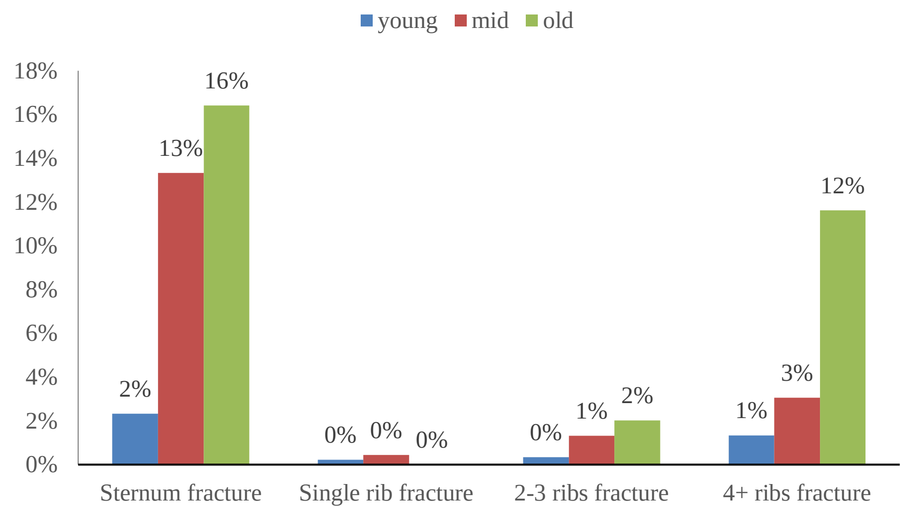

Figure 3 Rate of Chest Skeletal Fracture by Age

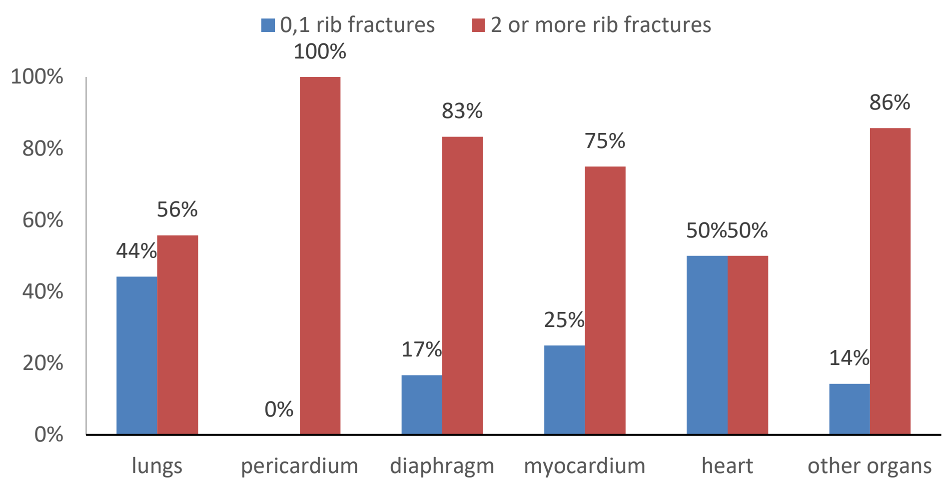

Figure 4 Association of Chest Organ Injury with Number of Rib Fractures

Appendix

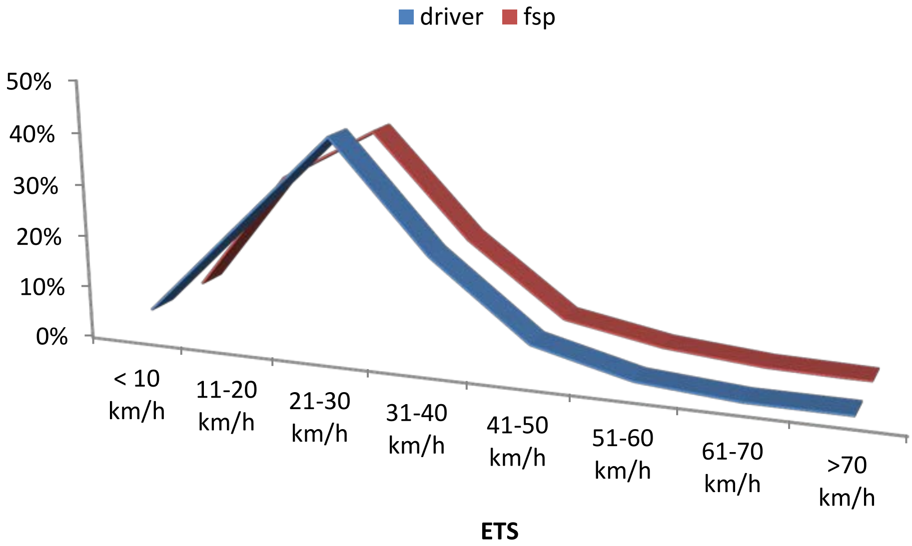

Figure A 1 EES Distributions by Seating Position

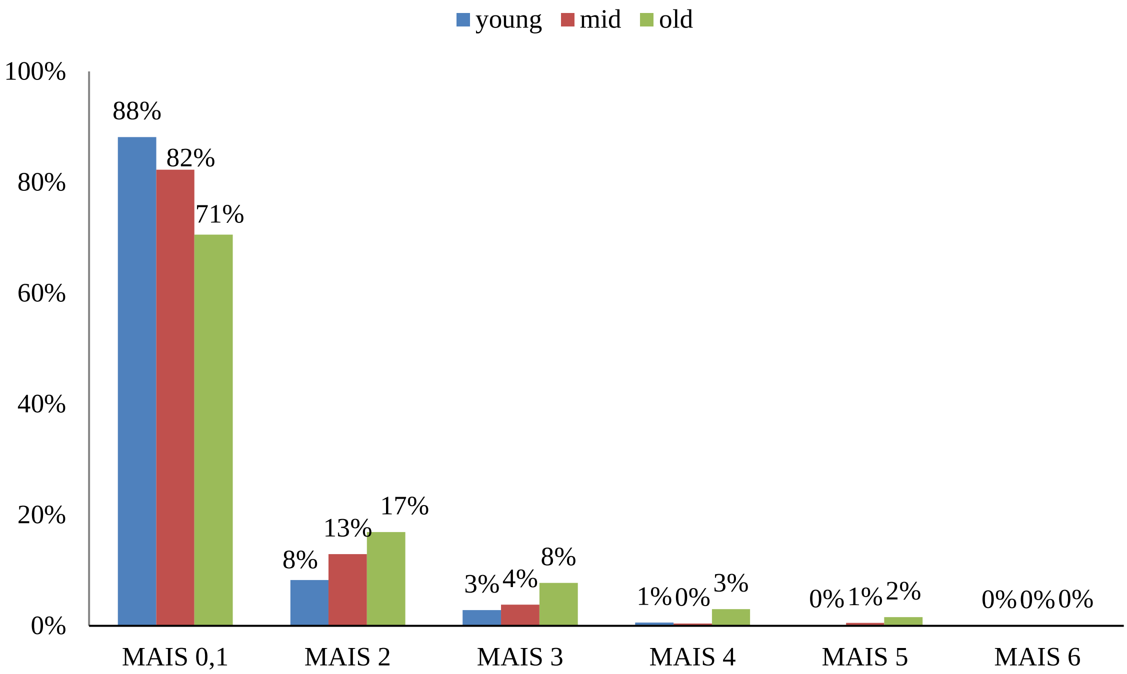

Figure A 2 MAIS by Age Group

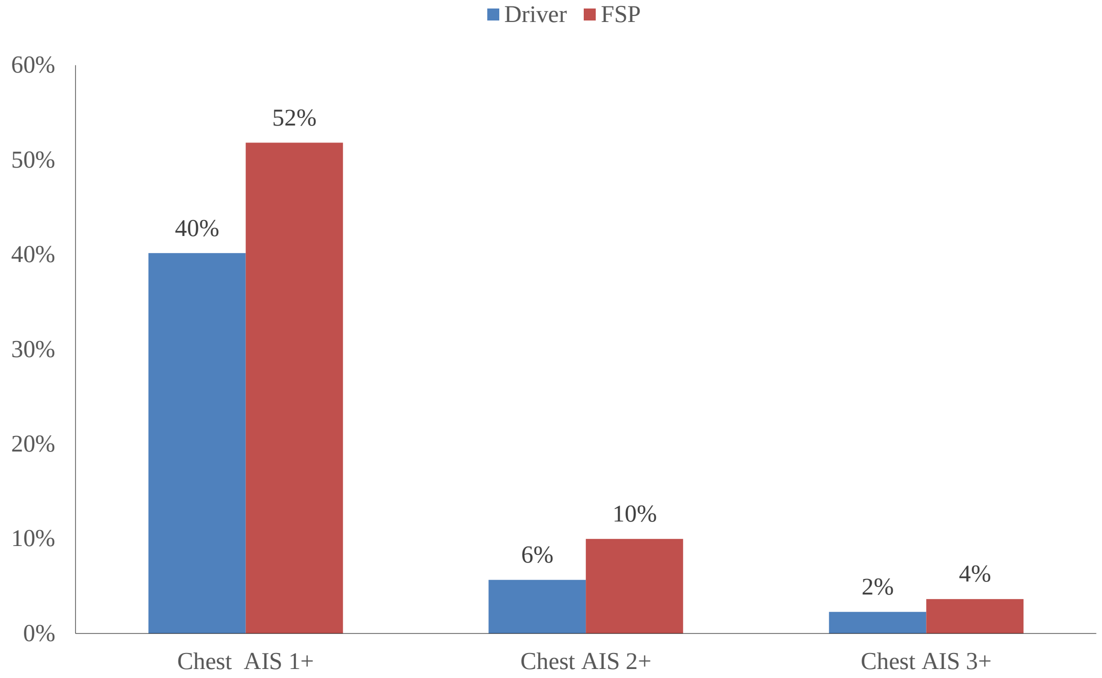

Figure A 3 Chest Injury Severity by Seating Position

Table A 1 Mean ETS by Seating Position and Occupant Age

Seating Position	Mean ETS (km/h)		
	<40 (Young)	**40-64 (Middle-aged)**	**65+ (Old)**
Driver	26.68	26.20	25.88
FSP	26.13	25.16	25.24

Table A 2 MAIS for Front Seat Occupants

Injury Severity	Front Seating Position		
	Driver	**Front passenger**	**All occupants**
MAIS 0,1	85.2% (n=3666)	77.0% (n=718)	83.8% (n=4384)
MAIS 2	9.8% (n= 422)	16.7% (n=156)	11.0% (n=578)
MAIS 3+	5.0% (n=213)	6.2% (n=59)	5.2% (n=272)

Table A 3 List of AIS 2+ Chest Injury

Injury Area	Injury Description	
Skeletal Injury (328)	Single rib fracture (6)	pneumothorax (5)
		haemothorax (1)
	2-3 ribs fracture (26)	Stable chest (13)
		pneumothorax (7)
		haemothorax (3)
		haemo-pneumothorax (3)
	4+ ribs fracture (87)	stable chest (42)
		pneumothorax (7)
		haemothorax (16)
		haemo-pneumothorax (13)
		flail chest (9)
	Sternum fracture (209)	stable chest (200)
		pneumothorax (8)
		haemothorax (1)
Organ Injury (88)	Pneumothorax (9)	
	Haemothorax (3)	
	Pneumomediastinum (1)	
	Lung (44)	laceration (2)
		contusion (42)
	Pleural cavity/ sac (2)	tear (1)
		laceration (1)
	Parietal pleura laceration (1)	
	Pericardium (7)	contusion (2)
		rupture (1)
		disruption (1)
		haemorrhage (3)
	Myocardial (4)	tear (2)
		contusion (2)
	Heart contusion (3)	
	Atrium (3)	tear (2)
		laceration (1)
	Ventricle disruption (1)	
	Diaphragm (8)	tear (3)
		laceration (2)
		rupture (3)
	Oesophagus tear (1)	
	Chordae tendineae rupture (1)	
Vessel Injury (11)	Aorta (9)	laceration (3)
		rupture (1)
		transection (5)
	Venacava avulsion (1)	
	Subclavian artery rupture (1)	

CCIS In-depth Crash Injury Database

The CCIS sampling prescribed passenger cars, less than 7 years old, with at least one injured occupant and towed away from the crash scene. The database contained detailed information on vehicle crash severity, estimated by the Equivalent Energy Speed (EES), structural performance and restraint performance together with photographic documentation of the vehicle exterior and interior. Occupant injury mechanisms were deduced by the case investigators based on forensic evidence in each vehicle and an assessment of occupant kinematics. The EES was evaluated on the assumption that the vehicle deformation was caused by an impact with a rigid, immovable object (Lenard, Hurley, et al. 1998). Injury outcome was recorded using the Abbreviated Injury Scale AIS 90, (Association for the Advancement of Automotive Medicine 1990). Additional injury coding using AIS 2005 (Association for the Advancement of Automotive Medicine 2005) was added in the latter stages of the study, but was only available for a limited number of cases. AIS 90 was available for all cases and was therefore chosen as the injury scale for analysis.

Type of AIS 2+ chest injury:

The recorded numbers of injuries to the thoracic skeletal, organ and vessel were 328 (77%), 88 (20%) and 11 (3%) respectively. Sternum fractures made up a large proportion of all AIS 2+ chest injury occurring in 209 occupants. Multiple rib fracture with more than 4 fractured ribs was the second most common type of skeletal chest injury occurring in 87 occupants. 26 occupants had fractures to 2 or 3 ribs. Injury to the lungs was the most common type of intrathoracic organ injury, 44 such injuries were recorded in the sample. Lung contusion was the most common type of lung injury (n=42) and was mostly rated at AIS 3 or 4 levels. Pneumothorax (n=9) was the second most common type of intra-thoracic organ injury followed by injury to the diaphragm (n=8) and pericardium (n=7). Other intrathoracic organ injuries occurred for fewer occupants. Vessel injuries were most likely to be rated at AIS 4+ and occurred more sporadically. Injury to the aorta (n=9) was the most common type of vessel injury.