

# CHEST AND ABDOMINAL INJURIES TO OCCUPANTS IN FAR SIDE CRASHES

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## ABSTRACT

This paper describes an analysis of collisions and injuries to occupants involved in far side collisions.

## INTRODUCTION

Side impacts are particularly severe collisions, especially when the vehicle is impacted with a pole or a tree. In the USA in 2004, it was claimed that 26% of fatal crashes involved a side impact and 31% of non-fatal crashes (Resource4accidents 2005; IIHS 2003)

Estimates of the proportion of side impacts deaths in Australia are similar (25% casualty crashes, 28% fatalities and more than 30% occupant Harm (Gibson et al 2001). While the majority of Harm occurs to occupants seated on the struck side of the vehicle in both the USA and Australia, 30% does occur to those seated on the far side, that is, the non-struck side of the vehicle (Gabler et al 2005).



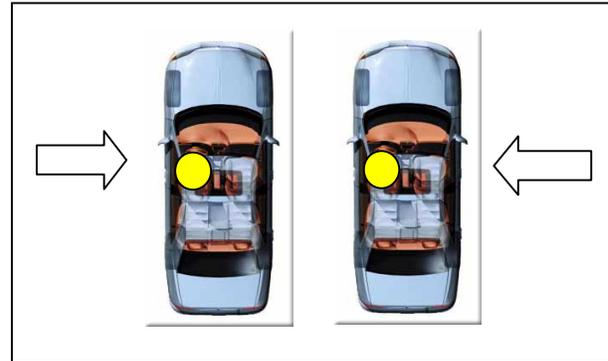
**Figure 1: Near and far side injured occupants, AIS3+ injured occupants and occupant Harm (Gabler et al 2005).**

Side impact vehicle regulations around the world quite rightly currently focus on near side collisions;

no provision is made for those seated opposite to the impacting source. Consequently, there are very few countermeasures available to improve far side occupant protection. Given that these occupants do experience a sizable amount of Harm in the collision, there is a real need to address this road safety problem urgently (Fildes et al 2005).

## Definition

Far side occupants in a crash as explained earlier are those seated opposite to the crash as shown in Figure 2.

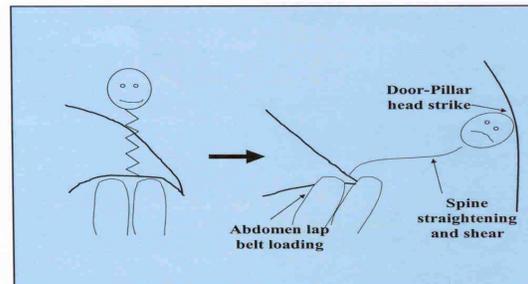


**Figure 2: Position of occupants in a near side collision (on the Left) and a far side collision (Right) for a US driver.**

They can be either the driver when struck on the passenger side of the vehicle or the passenger when struck on the driver's side. Near and far side definitions also apply to rear seated occupants in similar crash configurations.

## Far Side Kinematics

The kinematics of occupants in far side crashes are noticeably different to those on the near or struck side (see Figure 3). Because their 3-point belt is not designed to restrain them laterally, they are thrown towards the impacting object on the struck side, some 100msec from the moment of impact (see



Fildes et al, 2002).

**Figure 3 Far side occupant kinematics (Fildes et al 2002)**

## Study Objectives

This study set out to examine the extent of chest and abdominal injuries to occupants in far side crashes. These injuries are known to be life-threatening in side impact collisions generally and greater understanding of the Harm associated with these severe injuries will help identify opportunities for injury reduction countermeasures.

## METHOD

Two in-depth databases were used in undertaking the analyses reported. In the USA, 10 years of NASS/CDS data were available for the model years 1995-2004. In Australia, 15 years of MIDS data were available for model years 1989 to 2003. Comparative analyses were undertaken using weighted data which revealed similar trends across both these databases (Fitzharris et al 2005a; 2005b, Gabler et al, 2005).

For both these databases, case selection criteria comprised the following:

- 3-Point Belt Restrained Occupants
- Front seat only
- 12 years and older occupants
- Occupant on Opposite Side of Impact
- Passenger Cars or LTV vehicles Only
- GAD = Left or Right Side
- No Rollovers

## Analytical Approach

Even with such extensive databases, the number of far side cases available was rather small (106 cases in MIDS and 4570 cases in NASS/CDS) especially after slicing these data into various crosstabs. Thus, the analysis described here was essentially confined to a descriptive analysis of far side cases. For reasons of consistency, most analyses involved weighted data for both data sets.

## Harm

Harm is a method of analysing crashes using frequency times the societal cost of injury as a measure of the extent of trauma. The measure used here was developed from early work in the USA by Malliaris and his colleagues during the 1980s but was extended in Australia in the early 1990s using a more reductionist approach to quantify the benefits of reducing the number of crashes or injuries (see MUARC 1992 for a more full description of the Harm approach).

In the use of the Harm method described here, Harm was expressed as a “relative” cost across all AIS and body region cells in the Harm matrix, based on the figures published in MUARC (1992).

## RESULTS

### Harm and AIS3+ Injuries

The first analysis undertaken here was to examine the incidence of AIS3+ injuries and Harm across all body regions for far side occupants, shown in Figure 4. Severe head injuries predominated both in terms of frequency and Harm for these far side cases. Interestingly, upper and lower extremity injuries were also quite frequent. Of particular note was that chest injuries were the fourth leading cause of Harm but the highest proportion of severe (AIS3+) injuries. This discrepancy can be explained by the low relative cost ascribed to extremity injuries in MUARC (1992). Nevertheless, severe injuries to the chest and abdomen are clearly both frequent and Harmful to occupants in far side crashes among these data.

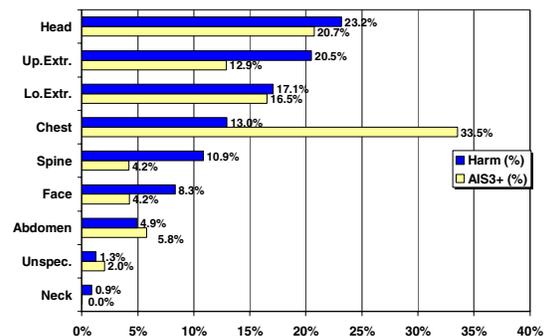
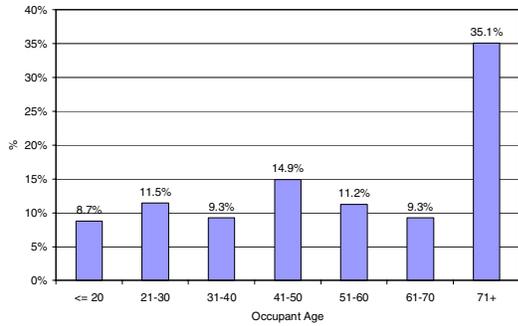


Figure 4: Harm and AIS3+ injuries for occupants in far side crashes (NASS/CDS 1995-2004)

### Chest Injuries by Age

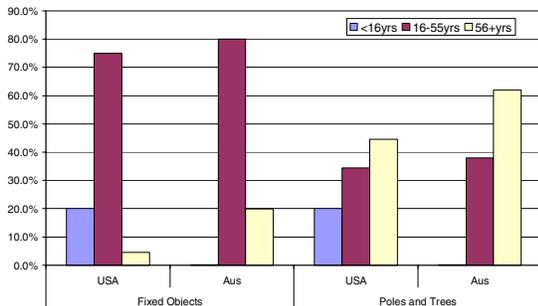
Figure 5 shows the breakdown of age across the chest injuries sustained by far side occupants in side impact collisions. While the proportion of severe chest injuries reduces as age increases among younger adults, this trend reverses for those age 70 years and older.



**Figure 5: Distribution of occupant age for those sustaining a MAIS3+ chest injury (NASS/CDS 1993-2004)**

Moreover, the pattern of injury varied across the type of crash (single vehicle vs. car-car collisions) as shown in Figure 6. Younger adults were more likely to be involved in collisions with fixed objects while older drivers were more likely to be involved in car-car collisions. Of particular note, older people were more likely to have sustained a severe chest injury than younger ones for both these collision types.

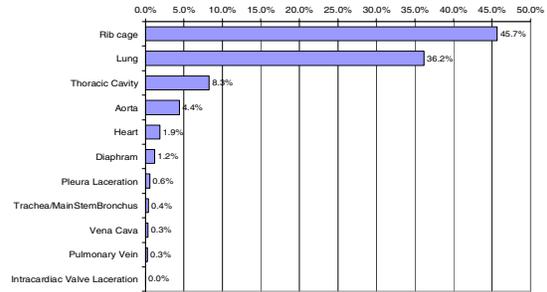
Differences between US and Australian finding here can be explained by differences in age of first licensing between these countries.



**Figure 6: Distribution of occupant age by crash type (NASS/CDS and MIDS)**

### MAIS3+ Chest Injury Lesion

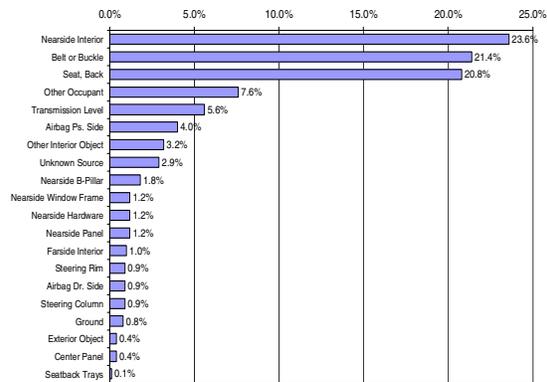
Figure 7 shows the distribution of AIS3+ chest injuries by anatomic structure in far side crashes. The rib cage and lung were most frequently severely injured, accounting for more than 80% of these AIS3+ injuries and a considerable proportion of chest Harm. Injuries to the internal organs (heart, aorta and veins) occurred in 6.9% of occupants injured in far side crashes.



**Figure 7: Distribution of AIS3+ Chest Injuries by Anatomic Structure (NASS/CDS 1995-2004)**

### MAIS3+ Chest Injury by Source

The sources of chest injuries are shown in Figure 8. Impact with the nearside interior, the seatbelt or buckle and the adjacent seat were ascribed to over two-thirds of the injuries, while other occupants (7.6%), the centre console (6.0) and near side door and associated components (5.4) were noteworthy sources of injuries for far side occupants.

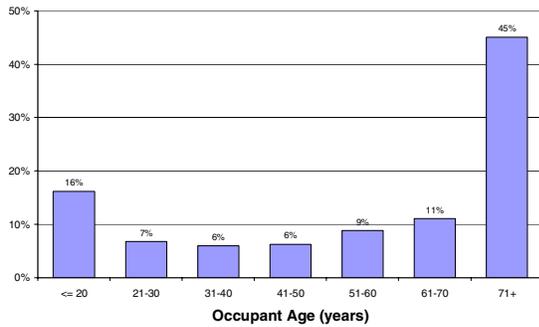


**Figure 8: Source of AIS3+ chest injuries to far side occupants (NASS/CDS 1995-2004)**

### Abdominal Injuries

Figure 4 illustrated the extent of abdominal injuries to occupants in far side crashes. About 5% of the Harm in these crashes can be attributed to abdominal injuries which are also around 6% of the incidence of AIS3+ injuries. While these figures are less than the equivalent ones for chest injuries, they are, nevertheless, of a size to be concerned about, especially given the life-threatening nature and long-term consequence of these injuries.

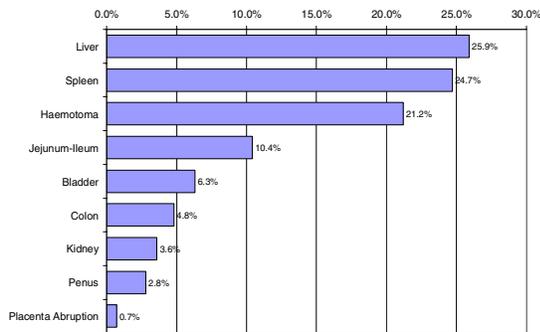
## Abdominal Injuries by Age



**Figure 9: Distribution of occupant age for those sustaining an MAIS3+ abdominal injury (NASS/CDS 1993-2004)**

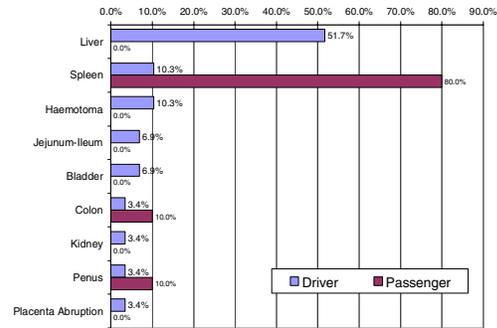
The findings in Figure 9 show that the incidence of an abdominal injury is much higher for older occupants in far side crashes (they represented 45% of the population of those sustaining a serious abdominal injury). However, care should be taken in interpreting too much from this finding as there were only minimal numbers of abdominal injuries before weighting (124 AIS2+ injuries and 43 AIS3+ cases).

## MAIS3+ Abdominal Injury lesions



**Figure 10: Distribution of AIS3+ abdominal injuries by Anatomical Structure (NASS/CDS 1995-2004)**

Figure 10 shows the distribution of lesions in the abdominal area to occupants injured in far side crashes. The liver and spleen were particularly over-represented among these crash victims and to a lesser extent, kidney and colon. Haematoma including retroperitoneum haemorrhage also occurred in over 20% of the far side cases examined. These are particular nasty and severe injuries to these occupants with potential ongoing long-term consequences.

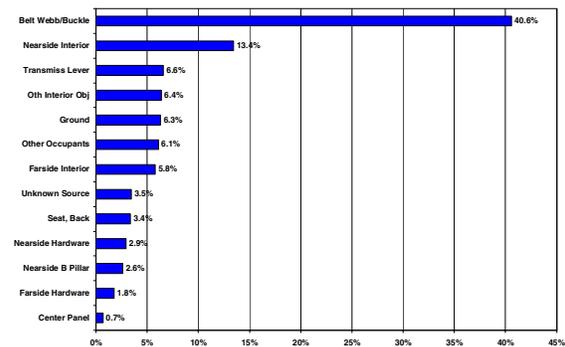


**Figure 11 Distribution of AIS3+ abdominal injuries by Anatomical Structure by seating position (NASS/CDS 1995-2004)**

In addition, as Figure 11 shows, the incident of lesion by seating position in a far side crash. While the number of cases here was small, it does suggest that liver injuries primarily occurred to drivers (seated on the LH side of the vehicle) and spleen injuries to front seat passengers seated on the RH side of the vehicle. These findings need to be taken with some care because of the small number of cases but do highlight an asymmetry in injury mechanism of potential importance for injury prevention.

## MAIS3+ Abdominal Injury by Source

Figure 12 shows the sources of these severe abdominal injuries, where the predominant contact source was the seatbelt and buckle. This may help to explain why the liver, spleen and retroperitoneum haemorrhage were over-represented among these abdominal injuries. It might also help explain the liver and spleen asymmetry described above, too.



**Figure 12: Source of AIS3+ abdominal injuries to far side occupants (NASS/CDS 1995-2004)**

While the seatbelt and buckle assembly was the predominant cause of abdominal injury, again, other occupants featured quite highly in these far side abdominal injuries. This is difficult to explain

as supposedly all these occupants were wearing their seatbelts (a case selection criterion). This will be discussed in more detail later on.

### **Aorta Injuries**

While aorta injuries were not specifically tested for in this far side research program, nevertheless, a number of observations were possible from the data analysis and from earlier findings.

- Aorta rupture was noted in 4.4% of occupant injuries from these far side crashes.
- Aorta injury tended to occur in low severity near- and far-side crashes.
- They were frequently occult injuries with no physiological cues.
- They frequently lead to a fatal outcome (it is estimated that 80-88% of occupants who suffer TRA die at scene of crash).
- When successfully identified and treated, there was usually complete recovery.

A previous study by Franklyn et al (2002) found that the risk of aortic injury was greater for near-side crashes than for far side crashes, and that given a near-side crash, the risk of aortic injury is greater when struck on the left rather than the right. They also found that the risk of aortic injuries is 1.4 times higher when the struck vehicle is an MPV / SUV, compared to that of another passenger car or a derivative.

### **DISCUSSION**

These results have highlighted a number of potentially interesting findings.

First, head injury is clearly the most common injury type for occupants injured in a far side crash. Roughly one-quarter of all far side Harm involved a head injury, predominantly caused from contact with the struck side of the car or the intruding object (Gibson et al, 2001).

Chest and abdominal injury together, however, accounted for around 18% of the Harm but an alarming 40% of all AIS3+ injuries. These injuries were particularly evident among older occupants. Common lesions among chest injuries included the rib cage, lungs or the thoracic cavity, and often, these injuries were caused from contact with the nearside interior, the seat or seat back, the seatbelt or buckle, other occupants or the transmission lever.

This illustrates the ineffectiveness of the current restraint system to prevent injuries to far side

occupants in side impact collisions. As shown in Figure 3, the shoulder belt offers little restraint in this crash configuration to the chest, allowing the occupant and his or her chest to move freely out of the belt and contact a range of adjacent objects. The high incidence of seatbelt or buckle-related injuries is a matter of some concern as seatbelt is the primary means of restraint in vehicle crashes. Current designs clearly need further design improvement for far side crashes.

For severe abdominal injuries, common lesions included the liver and spleen and retroperitoneum haemorrhage or haematoma. Interestingly, the incidence of liver injuries was higher for the driver and the spleen, higher for the front passenger among US crashed vehicles. The seatbelt or buckle was seen to be the most common source of abdominal injury by far. Current generation buckles and tongues were designed primarily for frontal crashes over decades ago and from these results, suggest they are not optimised for far-side protection. Improvement to the restraint capabilities of the seatbelt in a far side crash would seem to be warranted from these findings, although some care needs to be taken with these findings given the small number of cases involved.

### **Older Occupants**

Older occupants appeared to be over-represented in far side crashes. Those aged over 60 years sustained high numbers of chest and abdominal injuries, which is not too surprising from earlier research (Foret-Bruno et al, 1998; Zhou et al, 1996; Augenstein 2001; Kent et al 2005; Welsh; 2006). This can be explained from their frailty and especially brittle bony structures that fracture relatively easily (reference). Interestingly also, older drivers seem to be more involved in car-car intersection crashes than their younger counterparts who were more likely to be injured in a single-vehicle far side crashes with poles and trees. The over-involvement of older people in intersection crashes has also been reported elsewhere (Oxley et al 2006; Eberhard 2007) and confirms earlier reports that older people have difficulty judging when to turn in front of oncoming traffic (Andrea 2003).

### **Other occupants**

Other occupants were seen to be a source of chest and abdominal injuries to occupants relatively frequently in these far side crashes (chest 7.6% and abdomen 10.2%). Given that the 2-occupant exposure rate in the front seat is around 20%

(Fildes et al, 2002), this suggests that occupant to occupant contacts are a major problem in side impacts when both front seats are occupied (up to 5 times the rate for this seating configuration).

It is not clear from these data however how the near side occupant can inflict damage to the far side occupant's abdomen as these occupants were all belted. It may be that the struck-side occupant is pushed into the far side occupant during the kinematic movement during the crash although generally, the far side occupant is still in contact with the seat through the lap belt. Alternately, the near side occupant's arms and legs seem to flail considerably in side impacts and they could play a role in these injuries. This warrants further investigation in helping determine ways of minimising these serious injuries.

### **Aorta**

Aorta rupture was noted in 4.4% of occupant's chest injuries from these far side crashes. These are serious injuries that frequently lead to death. It is estimated that 80-88% of occupants who suffer TRA die at scene of crash. However, when successfully identified and treated, there was usually complete recovery (Digges and Augenstein 2006).

The injury mechanisms for these potentially fatal injuries are not well known for far side occupants. Digges and Augenstein (2006) argued that they commonly occur in low severity near-side crashes and are frequently occult, that is, there are no physiological cues.

They claimed that in nearside crashes, they tend to occur to front seat occupants, those sitting on the struck side of the vehicle and usually when their vehicle is struck by another vehicle, rather than a fixed object or pole. They propose that the thorax is impacted by a force component from the front; it experiences a severe vertical spinal stretching that causes the artery to stretch and fracture. Clearly, more research is needed to understand how these injuries occur to far side occupants.

### **COUNTERMEASURE OPPORTUNITIES**

The results from this analysis highlight a number of possibilities for reducing injuries through improved vehicle design.

#### **Restraint Systems**

The obvious strategy for improving far side occupant protection is to better restrain the occupant in the seat. It was clear from these results

that a 3-point seatbelt alone is not sufficient for far side occupant protection. Across-belt configuration involving an additional belt on the inward side was proposed by Fildes et al (2003) as a possible measure to restrain the far side occupant, along with an additional side support on the seat. However, they argued that this configuration was not necessarily optimal as it had the potential to apply additional load to the occupant's neck.

Rouhana (2004) published an alternative 4-point belt configuration, which could also have the potential to provide improved restraint in a side impact. However, it is understood that this belt system has been primarily designed for frontal crashes and needs to be evaluated for improved protection for near and far side occupants in a side impact collision.

#### **Physical Separation**

A number of other opportunities exist for improved far side protection. A more scalloped seat, in conjunction with a pretensioned belt system might be an option, as well as side supports on the seat and even an internal seat-mounted airbag system (inflatable inboard torso side-support; Bostrom and Haland 2003). The efficacy of these systems, though, is still to be firmly established.

#### **Test and Injury Criteria**

Importantly, though, it is fundamental that injury criteria and test methods need to be determined to provide governments and auto manufacturers with the necessary tools to develop new and innovative in-vehicle solutions to protect far side occupants in these crashes.

#### **Older Occupants**

It is unlikely that any generic in-vehicle solution will suit all occupants. Older people are more frail and suspect to a poor outcome, especially in a side impact collision (Augenstein 2001). Thus, the best solution for them (and indeed for all vehicle occupants) is to prevent the crash from happening in the first place. The evidence collected here showed that older people were more likely to be severely injured in an intersection crash. Road design and traffic management solutions are desperately required here to address this problem.

### **CONCLUSIONS**

This analysis set out to examine the extent of chest and abdominal injuries to occupants in far side crashes, that is, side impact crashes where the

occupant is seated on the opposite side of the vehicle to the side where it is impacted. This is commonly referred to as the non-struck or far side seating position. The study also aimed to examine a range of potential countermeasures to prevent or mitigate these injuries.

It is clear that side impact collisions are severe events with little room for energy management, compared with frontal crashes. While the current focus on side impact protection is for the nearside occupant, there is clearly a need to address ways of providing greater protection for the far side occupant.

Current restraint systems do not offer optimal restraint for far side occupants. A number of possible opportunities exist for better restraining them in a side impact collision for which more research and development effort is needed.

### Limitations

This analysis suffered from small in-depth case numbers in spite of the use of one of the largest in-depth databases available. Combining additional case details from other databases would be useful in addressing this shortcoming.

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