Chest Injuries in Real-World Side Impact Crashes - An Overview

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ABSTRACT

This study examines 282 individual AIS 2 or greater injuries to the chest that occurred in a sample of UK side impact crashes. The injuries were all sustained by front seat occupants seated on the struck side. Crash characteristics such as collision severity, object struck and injury contact source that were associated with the injuries are examined. Overall, the study reinforces the view that reduction of injury severity should rely on controlling the magnitude and distribution of the impact forces applied to the thorax when it collides with the vehicle side structure, chiefly the door.

IN RECENT TIMES, CHEST INJURY RESEARCH has focused on the chest in a side impact crash (Melvin, 1994) and chest protection in this type of impact is perceived to be a matter of controlling the magnitude and distribution of the impact forces applied to the chest when it collides with the vehicle side structure (Melvin, 1976).

Consequently, a number of chest injury criteria used in the design of interior vehicle structures have developed and these include Peak Thorax Compression, Viscous Tolerance Criterion and the Thoracic Trauma Index. All three criteria are thought to correlate with actual thoracic injuries (Hobbs et al 1987) yet all have developed largely from studies of cadaveric subjects.

At present, the criteria used in the existing US legislation (FMVSS 214) and the proposed European legislation (ECE 95) differ. In the US, the FMVSS 214 test procedure uses the Thoracic Trauma Index (TTI) as the chest injury criterion while in Europe, the proposed Side Impact test legislation ECE 95 will use dual criteria, namely rib deflection and Viscous Criterion (Peak Viscous Response - VC). Additionally, a European programme of crash-testing to evaluate the crashworthiness of new cars has just commenced (New Car Assessment Programme - NCAP) and included in the programme is a side impact test in which the chest injury criteria are the same as that for the ECE95.

Opinions vary as to which criterion or combination of criteria are the best predictor of injury (Mackay; 1989). Furthermore, how the injury criteria relate to actual response of live human car crash occupants is not clear. For example, Mertz (1993) observes that cadaveric response may not mimic the human response and this is especially true for responses that involve muscle tone such as neck bending, chest deflection and joint articulation. It is necessary therefore to consider data from real-world accidents. Such real-world studies which have examined the incidence and nature of thoracic injuries in side impacts have been well documented. Rouhana and Foster (1985) found that thoracic injuries accounted for 38% of AIS 3-6 injuries, 24% of AIS 4-6 injuries and 25% of 5-6 injuries while Mackay (1989) found that chest injuries (57%) were more frequent at AIS 4+ level compared to head injuries

(55%). Fildes and Vulcan (1990) found that of AIS>2 injuries, 53% of total injuries were to the chest while Haland (1994) found that the chest was most the commonly injured body region when studying AIS 3-6 injuries. Other studies have examined contact sources for chest injuries. Most have found that the door is an injury contact source; Hartemann (1976) found that 54% of AIS 4+ chest injuries were generated through contact with the door while Otte (1984) found that 41% of such injuries were caused by contact with the door. Harms et al (1987) found the door to be responsible in 66% of chest injuries while Rouhana and Foster (1985) observed that 54% of left struck-side occupants sustained a chest injury through door contact along with 67% of right struck-side occupants.

The relationship between intrusion and chest injury outcome remains controversial. Many authors have studied this issue in-depth. Danner (1977), Rouhana and Foster (1985) and Otte (1993) all observed a statistical correlation between intrusion extent and chest severity outcome. However, both Strother et al (1984) and Hobbs (1988) argue that both intrusion and injury are independently related to impact severity.

The aims of this study were as follows;

(1) to examine the nature and characteristics of UK side impact crashes that result in AIS 2+ chest injury;

(2) to examine the relationship between thoracic injury and collision severity;

METHODOLOGY

The data used in this study are from an on-going study of vehicle crash performance and occupant injury (the Co-operative Crash Injury Study - CCIS) which commenced in the UK in 1983. The database holds information on some 6,973 vehicles involved in crashes containing 11,866 occupant who sustained between them 42,876 injuries.

A stratified sampling system is used for selecting cases for study which entails that about 80% of serious and fatal accidents in each study area were investigated along with 10-15% of slight accidents according to the UK Department of Transport system of injury classification. The resulting sample represents all levels of injury outcome while being biased towards more serious injuries.

Each vehicle in the study was inspected within a few days of the collision. The general sampling criteria of the CCIS study are;

(i) that the vehicle involved was towed away from the scene of the accident to a garage or recovery yard.

(ii) that the vehicle was less than six years old at the time of the collision

Injury data concerning each occupant was obtained from Accident and Emergency Departments of hospitals and also from Her Majesty's Coroner's Office. Additional data was obtained several days after the crash via a questionnaire survey of occupants involved in non-fatal crashes. Injuries were coded according to the Abbreviated Injury Scale, 1985 revision (American Association for Automotive Medicine; 1985).

A more comprehensive overview of the Co-operative Crash Injury Study can be attained in Mackay et al (1985).

The sample of data for this study was selected such that only front seat occupant seated on the struck side in a side impact collision receiving injuries at severities of AIS 2 or greater to the chest were included. This resulted in a sample of 144 occupants (100 drivers and 44 passengers) in 144 vehicles who were involved in single impact side impact crashes. These occupants sustained between them some 282 injuries to the thorax. Of the 144 occupants, 4 were 'slightly' injured according to Police injury classification, 61 were 'seriously' injured and 79 were 'fatally' injured. Of the 79 fatally injured occupants, 15 (19%) were killed through sustaining chest injury and a further 22 (28%) sustained multiple injuries which according to the description in the post-mortem included a chest injury as a contributor.

Where appropriate, the Equivalent Test Speed (ETS) as calculated by CRASH3 was used as a measure of collision severity. While CRASH3 estimates of ETS in side impacts can never be taken as a true representation of the actual severity of side-damaged vehicles, an acceptable degree of estimation can be attained (Smith and Noga; 1982).

RESULTS

Table 1 shows causes of death for occupants in the whole CCIS study. As can be seen from this table, the risk of fatality from a chest injury in a side impact is greater when compared with a non-side impact. It was observed that injuries to the abdomen also involve an increased risk in a side impact.

Table 1 : Injuries as a Cause of Death in All Impacts and Struck-Side Lateral Impacts

	Non-side Impacts		Side Impacts	
Cause of Death	N	%	N	%
Head Injury	168	25	25	22
Chest Injury	**68**	**9**	**17**	**15**
Neck Injury	22	3	3	3
Abdomen Injury	12	2	4	4
Other Injury	40	6	2	2
Natural Cause	8	1	2	2
Multiple Injuries	327	49	54	47
Unknown	27	5	6	5
Total	672	100	113	100

Table 2 shows the numbers of injuries in each severity classification to different body regions sustained by struck-side occupants in single-impact side impact crashes in the whole CCIS study. Injuries of severities AIS 1 & 2 are mostly received by the upper and lower limb regions. However as the injury severity increases, the importance of the chest and the head as injured body regions becomes apparent. Only 11% of minor and moderate injuries are to the chest while 35% of serious to severe injury are to this region and this figure rises to 45% of injuries at higher severities (AIS 5-6).

Table 2 : Injury Severity by Body Region to Struck-side Occupants in Side Impacts

	AIS 1 & 2		AIS 3 & 4		AIS 5 & 6	
Body Region	N	%	N	%	N	%
Head	189	11	101	22	25	28
Spine	105	6	6	1	4	4
Face	222	13	9	2	-	-
Neck	15	1	1	0	0	0
Chest	191	11	143	31	45	51
Abdomen	91	5	29	6	15	17
Pelvis	113	7	30	6	0	0
Upper Limb	379	22	71	15.5	-	-
Lower Limb	415	24	71	15.5	0	0
Total	1720		461	100	89	

Table 3 : Types of Chest Injury in Side Impacts (N=282)

Injury Description	**Abb. Injury Score**	**Number**
+ Aorta transection NFS	4	1
Aorta trans (incomplete)	5	8
Aorta trans (complete)	6	15
Pulmonary vessel injury	4	2
Other vessel injury	3	2
Lung contusion 1 lobe	3	21
Lung contusion 2 lobes	4	12
Lung laceration 1 lobe	3	17
Lung lac'n 1 lobe complex	4	7
Lung laceration 2 lobes	4	6
Lung lac'n 2 lobe complex	5	2
Diaphragm laceration	3	7
Cardio-contusion	4	3
Myocardium laceration	5	4
Myocardia lac'n complex	6	8
Pericardium contusion	3	3
Pericardia cont. complex	4	2
Pericardium laceration	4	5
Pericardia lac'n complex	5	2
Septum laceration	5	2
Pleural laceration	2	12
Thoracic cavity injury	3	6
Thoracic cav inj. complex	4	8
+ >1 rib # NFS	2	9
2-3 rib # stable chest	2	34
*2-3 rib # with ht, pt or hm	3	7
>4 ribs # stable chest	3	34
*4 ribs # with ht or pt	4	13
Flail chest	4	7
Severe flail chest	5	8
Sternum fracture	2	15

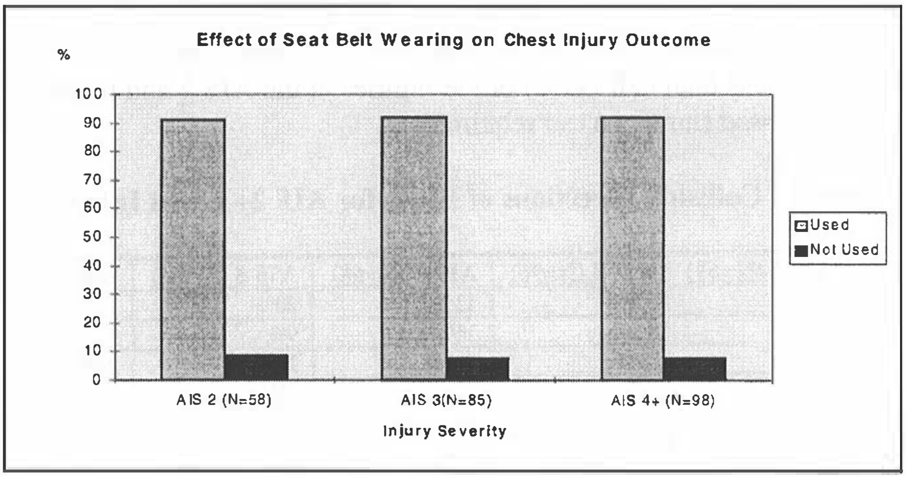
Notes

\+ NFS = Not Further Specified
* ht = haemothorax
pt = pneumothorax
hm = haemo-mediastinum

Table 3 above details the injuries at the AIS 2+ level. Overall, there were 28 injuries to the major vessels of the thorax (10% of total injuries), 127 injuries to the thoracic organs (45% of total injuries) and 127 injuries to the rib-cage (45% of total injuries). The most frequently occurring organ injury was a contusion to the lung and overall, injuries to the lung accounted for 23% of the total distribution. The most commonly occurring rib fracture injury was an injury involving fracture of two, three or more ribs. Overall 17% of injuries involved a fracture to three or more ribs.

AIS 2+ CHEST INJURY AND BELT USE The relationship between belt use and chest injury outcome was examined in all cases where the belt use status could be ascertained. The results are shown in figure 1. Of the occupants in this study, 108 were restrained and 10 were unrestrained. Additionally, there were 26 occupants whose restraint use could not be ascertained. The analysis was performed on an injury basis. As can be seen from the figure there was no effect of the seat belt on chest injury outcome in this study. The use of seat belts was not found to influence injury severity outcome (χ^2= 0.004 d.f. = 2 p= n.s). This result was intuitively likely in that the seat belt for almost all occupant sizes and vehicle geometries does not inhibit or alter the nature of the primary chest contact with the inner structure of the door. In cases where large amounts of intrusion occur, the seat belt does not appear to have a negative influence. There may be other benefits from belt use even for struck-side occupants in lateral collisions. For example, in car-to-car collisions, a seat belt diminishes the amount of head excursion out through the side window aperture by limiting the elevation of the buttocks off the seat. This can reduce the frequency and severity of the head contacts on the bonnet of the striking car.

Figure 1 : Seat Belt Use and Injury Outcome



CHEST INJURIES AND COLLISION CHARACTERISTICS Figure 2 shows the distribution of the type of object struck and injury severity outcome for the 282 chest injuries in the study. Car-to-car impacts account for about 50% of the injuries at all severities. This figure actually diminishes as the severity increases. Of note also is the fact that as the severity increases, so the object struck becomes arguably more hostile. For example, the incidence of car-to-truck, pole/post and tree impacts all increase correspondingly as the injury severity increases.

Fig 2 : Type of Object Struck and Injury Severity Outcome

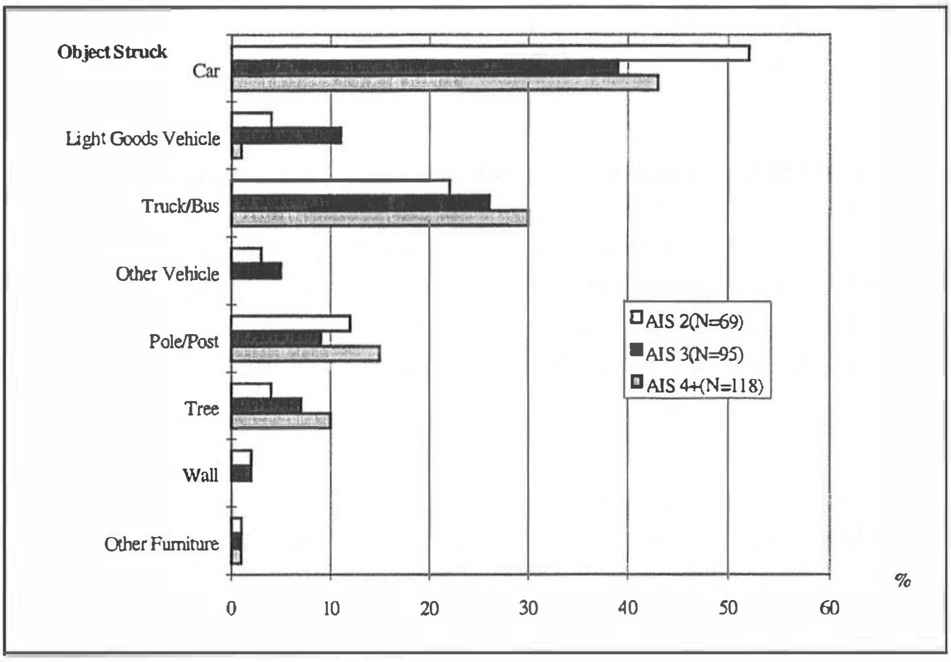


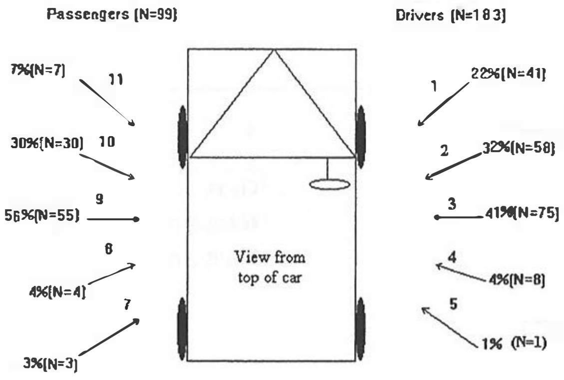
Table 4 breaks down the severity of injuries according to collision directions of force. It can be seen from the table that there is a trend towards higher severity injuries occurring in perpendicular type crash conditions. However, even for AIS 4, 5 and 6 injuries, over half are occurring when the collision direction of force (DOF) is markedly different from that of the proposed European test requirement which may be compromised. Figure 3 shows the collision directions of force (DOF's) for the 282 injuries that are included in this investigation. A little less than half (47%) of the injuries at the AIS 2 and higher level will be addressed by the proposed European test requirement.

Table 4 : Collision Directions of Force for AIS 2+ Chest Injuries

	AIS 2 (N=69)	AIS 3 (N=96)	AIS 4 (N=68)	AIS 5 (N=26)	AIS 6(N = 23)
1 o'clock	10%	18%	13%	20%	13%
2 o'clock	34%	18%	16%	9%	9%
3 o'clock	**24%**	**26%**	**29%**	**28%**	**26%**
4 o'clock	5%	1%	4%	1%	0
5 o'clock	1%	0	0	0	0
7 o'clock	1%	1%	2%	0	0
8 o'clock	2%	1%	0	0	4
9 o'clock	**10%**	**22%**	**22%**	**25%**	**26%**
10 o'clock	11%	10%	6%	12%	22%
11 o'clock	0%	2%	6%	4%	0%

(Figures in bold denote the injuries that are covered by the proposed test condition).

Figure 3 : <u>Directions of Force for 282 Chest Injuries to Struck-side Occupants</u>



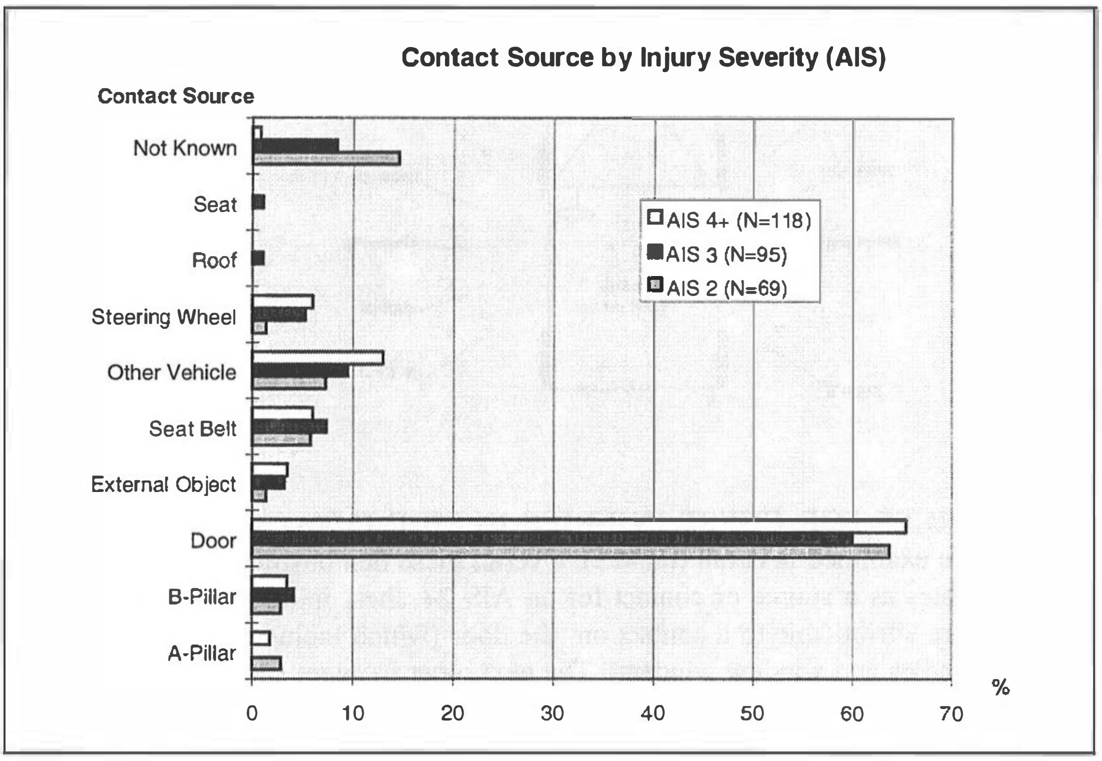
CONTACT SOURCES FOR CHEST INJURIES IN SIDE IMPACTS Contact sources for the injuries were examined in detail (table 5). Overall these demonstrate quite clearly that the door predominates as a source of contact for an AIS 2+ chest injury. Nearly two-thirds (62%) of injuries are attributable to a contact on the door (which includes the door fixtures such as the grab handles and window winders). The next most frequent source of contact was with the other vehicle involved in the collision (indicating partial ejection of the occupant in some cases). The seat-belt as an injury source for the thorax accounted for 6% of the injuries. Seat-belt injuries to the thorax can be a feature in a side impact when the principle direction of force of the impact is somewhat oblique (e.g. DOF at 2 o'clock, 10 o'clock etc.).

Table 5 : Contact Sources for AIS 2+ Chest Injuries in Side Impacts

Contact Source	Number	%
A-Pillar	4	1.5
B-Pillar	10	3.5
Door	176	62
External Object	8	3
Seat Belt	18	6
Other Vehicle	30	11
Steering Wheel	13	4.5
Seat	1	0.5
Not Known	22	8
Total	282	100

However, it is also necessary to show the distribution of injury severity according to contact source and figure 4 shows this. As can be clearly seen from the figure, door contacts predominate at all injury levels of chest injury. At each level of severity, over 60% of the injuries are generated through contact with the door. The next highest source of injury is contact with other vehicles. This contact source increases correspondingly as the injury severity increases from AIS 2 upwards.

Figure 4 : Distribution of Source of Injury



CHEST INJURY AND INTRUSION The effect of intrusion on each chest injury outcome was evaluated with the prediction being that the extent of the intrusion would influence the severity and type of chest injury. Intrusion was measured at the door adjacent to the struck-side occupant. Injuries were categorised according to AIS. Cases where residual intrusion could not be calculated because of excessive rescue damage were not included in the analyses. These results are shown in table 6.

Table 6 : Mean Intrusion values at Door-level for AIS 2+ Chest Injuries (cm's)

	Driver	Passenger
Injury Severity		
AIS 2	26cm (n=43)	33cm (n=17)
AIS 3	34cm (n=50)	44cm (n=34)
AIS4+	37cm (n=54)	41cm (n=42)
All Injuries	32cm (n=147)	41cm (n=94)
Injury Type		
Rib Only Injury	24cm (n=46)	31cm (n=13)
Organ Only Injury	39cm (n=34)	49cm (n=21)
Rib & Organ Injury	35cm (n=67)	42cm (n=42)
All Injuries	32cm (n=147)	41cm (n=94)

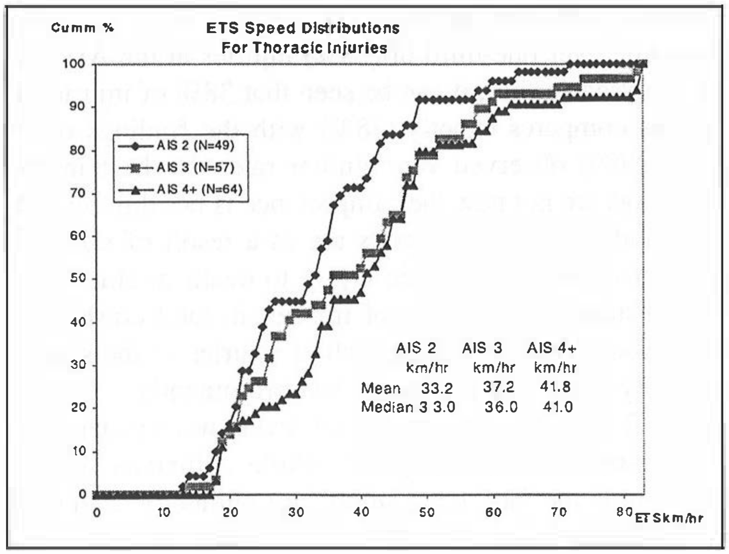
There were 21 injuries which were found to occur in the absence of intrusion. 13/21 of these injuries were to the rib-cage and there were 4 major vessel injuries and 3 thoracic organ injuries. The mean Equivalent Test Speeds (ETS) for these injuries was 34 km/hr and the mean age of the occupants was 39 years. 8/21 (38%) of these injuries were AIS 2, 4/21 (19%) were AIS 3 and there were 9 AIS 4+ injuries (43%).

Overall, these results may suggest some relationship between intrusion and injury severity but this relationship is not necessarily causal since it is certain (due to the seating position of the occupant) that the injury occurs before the peak deformation of the door is reached. Both injury severity and intrusion are outcomes of crash severity; one is not causally related to the other. Furthermore, the figures shown represent the residual rather than dynamic intrusion and are the maximum values at door level which are not necessarily the same as the actual chest contact point. Statistical analysis of these data was not considered in this study because of the complexity of these and other issues surrounding injury and intrusion but will form the subject of another study.

THE RELATIONSHIP BETWEEN COLLISION SEVERITY AND INJURY SEVERITY AND TYPE FOR AIS 2+ INJURIES ETS was used as measure of collision severity. When using this measure, it should be remembered that this does not imply the absolute speed of the striking vehicle but an approximation to the speed change experienced by the occupant. Figure 5 shows the relationship between collision severity and chest injury. Collision severity appears to have some overall effect on chest injury. The median ETS values of AIS 2 and AIS 4+ injuries differ statistically significantly ($\chi 2 = 4.39$, d.f. = 1; $p<0.05$). The difference in collision severity between AIS 3 and AIS 4+ is less pronounced and the median ETS values are not differ statistically significantly ($\chi 2 = 0.38$, d.f. = 1; $P>0.30$). Furthermore, the median ETS values of AIS 2 and AIS 3 injuries are not statistically significantly different.

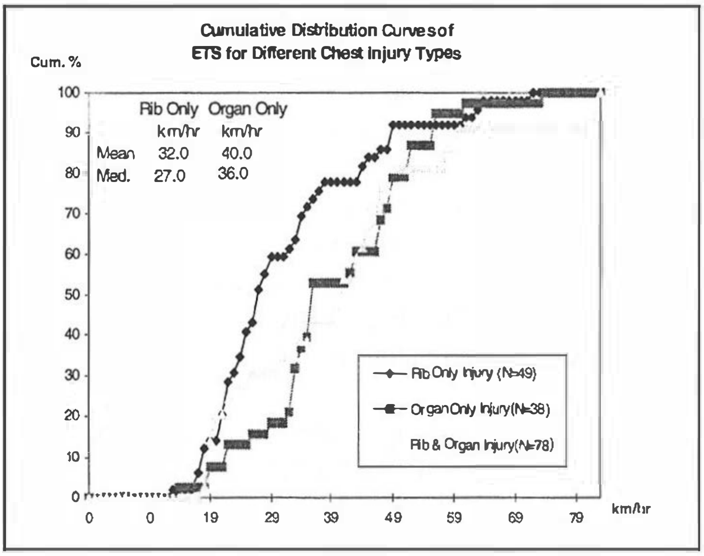
Some 80% of both AIS 3 and AIS 4+ injuries occur when the ETS is less than 55km/hr while over 90% of AIS 2 injuries (predominantly rib fractures) occur before this collision severity is reached. Given that the change in velocity in the proposed side impact test in Europe is in the order of 25 km/hr, it is clear that such a condition does not address the great majority of severe chest injuries in real-world crashes.

Figure 5 : Distributions of ETS for AIS 2+ Injury Severities



The relationship between collision severity as measured by ETS and chest injury type was examined and was found to apply only when the two types of injuries were compared (i.e. rib fracture only and chest organ injury only). This relationship is shown in figure 6 below. When comparing these two classifications of injury, rib fractures occurring without thoracic organ injuries were found to occur at significantly lower collision severities than thoracic organ injuries which occurred without rib fractures ($\chi 2 = 9.24$, d.f. =1; $p<0.005$).
However, no significant differences were observed when comparing the collision severities for different groups of numbers of rib fractures, these being 2/3 rib fractures versus 4+ rib fractures ($\chi 2 = 0.08$, d.f. = 1, p = n.s.).

Figure 6 : Distribution of ETS for Chest Injury Types



DISCUSSION

This study reinforces the view that the chest is a body region prone to life-threatening injury in a side impact compared with other impacts. Over half (51%) of all injuries at the AIS 5 & 6 level are to the chest while over one-third of (35%) injuries at the AIS 3 & 4 level are to the chest. If the data are analysed further, it can be seen that 38% of injuries at the AIS 3-6 level are to the chest and this compares exactly (38%) with the findings of Rouhana and Foster (1987). Mackay also (1989) observed very similar rates of chest injury by severity at all levels. While these findings are not new their importance is not diminished.
In this study, 15% of fatalities in side impacts are as a result of trauma to the chest alone. However, the actual contribution of thoracic injury to death in side impact is much greater since many occupants sustain a multiplicity of injuries in fatal crashes with some degree of injury to the chest. As a sole cause of fatality, chest injuries in the study are second only to head injury and other body regions feature much less prominently.
It can be seen from fig. 2 that chest injuries at all levels were generated most frequently in both car-to-car or car-to-other vehicle impacts. While collisions with other cars is to be expected, more interesting is the fact that a significant number (32%) of injuries occurred in collisions with vehicles other than cars. This suggests that to have a mobile barrier force

modelled on the 'average European car' is not addressing a major proportion of the collision circumstances which generate serious injuries. Perhaps a higher, stiffer barrier face, more representative of sport utility vehicles and light trucks should be considered particularly because of the high growth rates of such vehicles in the European fleet.

Collisions with other narrow objects such as poles and trees feature only when the injury level is AIS 4+ but otherwise in this study, they do not appear to be related to serious chest injury as is the case with, for example, head injury (Morris et al; 1995). Whilst at all levels of injury severity many of the injuries are occurring when the directions of force (DOF's) are at 90 degrees to the vehicles, approximately half of the injuries in each AIS severity classification occur when the Directions of Force (DOF's) are more oblique. Even though the relationship between ETS and Delta-V for the struck car is not precise, it is clear that the speed of the barrier in the proposed European test procedure represents only the lower quarter of all severe injury cases.

The actual injuries themselves should of course ultimately influence the injury criteria that are used in a side impact test procedure. Overall, 65/282 (23%) of injuries were to the lung while 112/282 (40%) were to the ribs. Figure 6 suggests that at lower collision severities, rib injuries are significantly more likely while at higher collision severities, there is a transition towards thoracic organ injuries. Therefore, the mechanism of injury in each case may be somewhat different and therefore this may provide some justification for dual injury criteria that are to be included in the proposed European test procedure. However consideration should be given to the fact that these criteria were based on cadaveric subjects and the relationship between injuries to cadavers and live human subjects is not clear for obvious reasons.

When examining the sources of injury as is shown in figure 4 and table 5, it is clear that the door is by far the most frequent injury source with 62% of injuries occurring through such contacts. The frequency of door contact in this study is comparable with other studies such as Hartemann et al (54%), Otte et al (41%), Harms et al (66%), Mackay (86%) and Huelke (77%). Furthermore, there is no real trend in terms of injury severity for at both AIS 2, 3 and 4+ levels of severity, over 60% of injuries are generated through contact with the door. It is therefore the door area where maximum attention should be focused when designing for reduced chest injury. Padding of the door will go some way towards the mitigation of chest injury by both increasing the effective acceleration distance and distributing the impact forces (as was postulated by Strother et al). However, padding is probably not the ultimate solution because only a limited attenuation of impact force is attainable given the available space in most conventional vehicles. Side airbags which are essentially an extension of the padding concept are obviously a better compromise since until deployment, they do not encroach on the available space on the interior and when they do deploy, they provide scope for greater energy absorption which is necessary for enhanced injury prevention. For this reason, the door is perhaps the optimal position for side airbag location and it will be interesting to evaluate the effects of side airbags in future field studies. Figures 5 and 6 examine the relationship between collision severity and injury outcome. In this study, more severe injuries (as measured by AIS) and organ injuries are associated with higher collision severities which supports the view that techniques aimed at protecting the chest should be focused on controlling the magnitude and distribution of the force at impact and side airbags should help to achieve this.

In this study, higher injury severity appears to be associated with higher levels of intrusion but this does not necessarily imply a causal relationship.

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