CAR OCCUPANT INJURY PATTERNS WITH SPECIAL REFERENCE TO CHEST AND ABDOMINAL INJURIES CAUSED BY SEAT BELT LOADING

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ABSTRACT

This is a two-part paper. The first section concerns the circumstances and injuries of front seat car occupants who received injuries of severity AIS ≥ 2 in a car crash, compared to a group of fatal occupants. The paper compares the nature and severity of injuries sustained by survivors and fatalities in comparable collision circumstances. In frontal impacts, restrained front seat occupants tend to receive injuries from the steering wheel and/or seat belt, to the head and chest respectively. Many occupants survived but with serious thoracic injury caused by seat belt loading. This problem is addressed by specifically examining seat-belt induced injuries to the chest and abdomen.

In part two, AIS 1 injuries to the chest and abdomen were found to be very common. 6.1% of the total database were found to have sustained an AIS ≥ 2 injury to either the chest or abdomen caused only by the seat belt, the majority of these injuries being fractures to the ribs and sternum. The chest was more frequently injured than the abdomen. Types of injury, trends in injury severities, and factors such as speed change and occupant characteristics are discussed. 0.4% of occupants on the database sustained fatal injuries from their seat belt.

THE DATABASE

An ongoing study into vehicle crash performance and occupant injury has been underway in Great Britain since November 1983. Cars are examined at garages and scrap yards within a few days of the accident occurring. Only cars less than six years old at the time of the accident are considered. Injury details are obtained from medical notes, and questionnaires sent to car occupants. All fatal accidents are investigated together with some 50 % of serious accidents according to the British government system of classification, and a further 12 % of slight accidents. The resulting sample represents all levels of injury outcome while being biased towards the more serious and fatal cases.

PART ONE

INTRODUCTION

The first part of this paper is concerned with the circumstances and injuries of front seat car occupants who received injuries of severity AIS ≥ 2 in a car accident compared to a group of fatal occupants. Cases are taken from accidents occurring in the Midlands of England between November 1983 and August 1988. The object is to compare the nature and severity of injuries sustained by survivors and fatalities in comparable accident circumstances. These are summarised below -

1. Front seat occupants who experienced a frontal impact.

2. An occupant was described as being 'seriously' or fatally injured according to the U.K. Police accident classification system.

3. The occupant was wearing a seat belt, the effectiveness of which was not compromised by other factors such as rear loading from another occupant.

4. An occupant received a Maximum AIS (MAIS) injury ≥ 2 to one or more of the following body regions; head or face, spine, thorax or abdomen.

5. Velocity change at impact was assessed using the CRASH3 computer programme (Noga et al, 1981).

These criteria resulted in 85 survivors and 9 fatalities. The fatally injured occupants coincide with cases used by Mackay et al (1990). They reviewed fatalities in detail, here the cases are used for comparison with survivors.

RESULTS

Table 1 shows the distribution of AIS ≥ 2 injuries and their causes to these 85 casualties.

Table 1: The Causes of AIS ≥ 2 Injuries to Front Seat Occupants

Body Region	Cause of Injury: Steering Wheel	Seat Belt	Facia	'Other'	Not Known	Total
Head/Face	42	0	5	7	8	62
Thorax	0	44	0	1	1	46
Spine	0	1	0	6	3	10
Abdomen	0	3	0	0	0	3
Total	42	48	5	14	12	121

Clearly trauma to the head, face and thorax are the most prevalent, accounting for over 89% of all injuries. The steering wheel and seat belt are responsible for over 74% of all AIS ≥ 2 injuries; 67.8% and 95.6% of head and thoracic injuries respectively.

The causes and nature of these thorax and abdominal injuries will be explored in greater detail in the following analysis, which includes more recent data and investigates the role of the seat belt as a cause of trauma. The types of head injury are shown in table 2.

Table 2: Types of Head Injury

Injury	Frequency	%
Laceration	11	17.7
Amnesia	10	16.1
Concussion	3	4.8
Unconsciousness	24	38.7
Fracture	14	22.6
Total	62	

(Lacerations are external injuries; all others are intracranial)

The most common types of head trauma are those involving diffuse brain injury, rather than a fracture. Fatal head injuries tend to involve more substantial intracranial trauma, for example haemorrhage and haematoma.

Comparison with Fatally Injured Occupants

The 31 fatalities studied by Mackay et al (1991) tended to involve mainly head and thorax injuries of AIS ≥ 3 severity. In those frontal impacts head and neck injuries dominated as the major causes of death. Chest and abdominal trauma were also significant. Death

Table 3: Cause of Death

Cause of death	N
Multiple injuries	5
Head injuries	1
Haemocardium	1
Fractured skull and pulmonary contusion	1
Fat embolism	1

from burns or limb injuries was not a common event. Multiplicity of severe injuries was the rule, and combinations of AIS $\geq$ 4 injuries to the head and thorax occur most frequently.

Only 9 (29%) of the 31 fatally injured casualties involved in frontal collisions fulfil the selection criteria outlined earlier for this study. The main cause of death among the 9 cases was listed as "multiple injuries" on the autopsy report, and these can be summarised as in table 3.

The distribution of the MAIS for these patients is shown in Table 4. Only 1 casualty suffered an AIS 6 injury, the majority receiving AIS 5 injuries.

Table 4: MAIS Frequencies for Fatalities

MAIS	N
3	1
4	1
5	6
6	1

The injury associations for these 9 fatalities, and the number of AIS $\geq$ 3 injuries in each region are shown in Table 5. Limb injuries were responsible for just one fatality, as a result of post traumatic fat embolism. Head injuries are the most common. Abdominal injuries are a relatively common feature, occurring in 4 of the 9 casualties. Abdominal injury (ruptured aorta) was directly responsible for the death of one patient.

Table 5: Body Region Injured by Case Number

Case	N of Injuries $\geq$ AIS 3			
	Head	Thorax	Abdomen	Limbs and Pelvis
1	1			
2	2			
3		3		
4		4		
5	2	1		
6	2	1		
7	2		2	+
8	1		1	+
9			1	+
Total	10	9	4	

(Injuries to the limbs and pelvis are included as present or absent (+).)

AIS 4 is the upper severity limit for limb or pelvic injuries. With one exception, they did not influence survivability.

Head Injuries

Skull fractures are more common in fatally injured occupants than those that survived, accounting for 41.7% of head injuries. Some of the fractures had associated brain injury (4 out of 7), the brain injury being more severe than the fracture.

Thoracic Injuries

There were 9 thoracic injuries occurring in 4 out of the 9 fatal casualties, compared with 46 among the 85 seriously injured occupants. These thoracic injuries are summarised in Table 6.

Table 6: The Nature of Thoracic Injuries.

Casualty Severity	Type of Injury Internal	Skeletal	Total
Serious	4	42	46
Fatal	6	3	9
Total	10	45	55

The majority of injuries are skeletal. Internal injuries of the thorax are those of the organs and soft tissues within the skeletal thoracic cage. Internal injuries are relatively more common in fatally injured occupants. 5 of the 6 fatal thoracic injuries resulted from seat belt loads.

Abdominal Injuries

There were 4 intra-abdominal injuries occurring in 3 out of the 9 fatalities, a higher rate than for the casualties of serious accidents. All were due to seat belt loading. A total of only 3 abdominal injuries (2.5%) occurred to seriously injured occupants.

PART TWO

INTRODUCTION

The following study concentrates on aspects of chest and abdominal injury caused by seat belt loading. Initially all restrained front seat occupants were taken for analysis from accidents that occurred in the Midlands between November 1983 and August 1990. All varieties of vehicle impact configuration were considered.

In a frontal crash the seat belt acts by greatly reducing the forces which act on the whole body to bring it to rest over a longer distance compared to the unrestrained occupant. The lap-diagonal belt acts in two ways; firstly, the belt stretches to allow forward movement of the body by some 6 to 10 inches. Secondly, because the occupant is tied to the car, some of the crushing distance is also added to the stretch of the belt, contributing to the total ridedown distance of the occupant in the crash.

One consequence of being correctly restrained in frontal vehicle crashes is that the restraint systems themselves can generate injuries on the load-bearing areas of the body, usually the pelvis, chest and shoulder. In most frontal collisions, injuries to these body regions amount to nothing more than simple surface injuries such as abrasions and contusions. However under more extreme conditions, more serious types of injury, occasionally fatal, can occur.

THE CHEST

Structurally the chest consists of the ribs, vertebrae and sternum with cartilaginous connections enclosing a cavity containing the major organs of the circulatory and respiratory systems as well as other structures.

Patrick (1976) found that the thorax is one of the body areas most frequently injured in automobile collisions. Rattenbury et al (1979) found a statistically significant relationship between crash severity as assessed using the equivalent test speed (ETS) and intrusion and chest injury severity. They found that (for occupants with MAIS 2 and above injuries) 76% of front seat passengers sustained their injuries solely through belt loading while for drivers the figure was 37%. They also found that occupants who sustained additional loading to their seats from luggage or rear seat occupants had a significantly increased risk of sustaining serious chest injury. Their study also found a significant correlation between age and chest injury severity with chest injury severity increasing with age.

Chapon (1983) reports that fractures of the sternum are not rare in restrained occupants. He claims that the fracture is often in continuation of fractures of ribs along the strap path and although the sternal fracture is itself not very severe, it may be an indication of possible underlying lesions of the heart.

THE ABDOMEN

The abdomen is the largest body cavity immediately below the thorax, separated by the diaphragm and partly shielded by the lower part of the ribcage. It is enclosed largely by muscle and facia and is therefore capable of changes in size and shape. It is lined with a serous membrane, the peritoneum, which is also a covering over most of the abdominal organs.

Many prior studies show that the abdomen is less frequently injured than the thorax. One early study by Kulowski (1960) found that injuries to the thorax and back occurred in 39.6% of occupants, to the abdomen and lumbar region in 17.8% and to the pelvis in 12.4%. Walz (1984) reports that around 5% of all injuries to traffic accident victims are confined to the abdomen. Furthermore, he found that in 10% of fatally injured victims there is a fatal abdominal injury.

It has been suggested that intra-abdominal injuries associated with seat belts are the result of improper application of the belt such that the lap portion of the belt is worn directly over the abdomen and its 'soft' contents, exposing them directly to crash loads in the collision condition. Furthermore, the abdomen may be injured as a result of the 'submarining' effect which is defined by Dejammes and Biard (1983) as a 'downward and forward sliding of the body relative to the safety belt which consequently submits various body regions to dangerous loading'. Walz (1984) claims that intra-abdominal injuries (mainly liver ruptures) may result through such a mechanism.

Rattenbury et al (1979) however found that fracturing of the lower ribs was an important factor in the causation of serious abdominal injuries. They found that of 31 cases of serious abdominal injuries, 23 involved multiple rib fractures. They proposed that abdominal injuries caused by rib fractures (such as ruptured liver and ruptured spleen) were more likely to be associated with the diagonal rather than the lap portion of the belt.

RESULTS

Out of 3276 restrained front seat occupants, 1679 (51.3%) had at least one chest/abdominal injury. The cause of their injuries were investigated to assess the role of the seat belt.

Cause Of Injury

Where possible, each individual injury was assigned a cause. When the injury occurred in the region of seat belt webbing, buckle, or stalk lie, then 'seat belt' was considered as a cause. Additional evidence may have been available in the form of surface bruising characteristic of seat belt loading, or questionnaire statement from the injured occupant. The seat belt was only assigned as the cause providing the post impact state of the vehicle interior components, and any evidence of occupant contact, did not suggest that another cause of injury was likely. 7.1 % of all 3276 occupants had at least one chest/abdominal injury ≥ AIS 2 caused by the seat belt (table 1). A large proportion (29.6 % of 3276), had an AIS 1 injury due to that cause. In fact, far more occupants had a chest/abdominal injury due to the seat belt than any other cause. The small number of minor thoracic/abdominal injuries from side components is noteworthy. In lateral collisions the shoulder and arm protect the torso from injury in minor collisions.

Table 1 - The Major Causes of Individual Chest/Abdominal Injuries

Cause of Injury	N of Occupants AIS 1	N of Occupants AIS ≥ 2
Seat Belt	970 (29.6 %)	231 (7.1 %)
Door, Pillars & Side Components	82 (2.5 %)	103 (3.1 %)
Steering Wheel	42 (1.3 %)	61 (1.9 %)
Occupant's Own Seat	44 (1.3 %)	4 (0.1 %)
Other	41 (1.3 %)	48 (1.5 %)
Two Causes Above, Combined	53 (1.6 %)	69 (2.1 %)
Not Known	139 (4.2 %)	45 (1.4 %)

(Percentages are of 3276 occupants. Occupants with more than one chest/abdominal injury, from different causes, were counted more than once)

Few individual injuries were caused by the seat belt together with another cause. Twenty six occupants had an injury ≥ AIS 2 due to contact on the steering wheel combined with seat belt loading. A further nine injuries were exacerbated by a rear occupant thrown forward thus loading the front occupant's seat back.

The Role Of Seat Belts In Causing Injury ≥ AIS 2

Chest/abdominal trauma ≥ AIS 2 occurred in 512 front seat occupants. Some occupants had more than one chest/abdominal injury, each with a different cause. For example, seat belt loads and steering wheel could inflict separate injuries to the same occupant.

Belt Only
199
38.9 %

Belt & Non-belt
100
19.5 %

Non-belt only
213
41.6 %

Fig. 1 - The Role of Seat Belts in Causing Chest/Abdominal Injury ≥ AIS 2
(Percentages are of 512 occupants)

Allowing for that type of multiple cause, figure 1 shows the overall role of the seat belt in AIS ≥ 2 injury causation. 38.9 % of 512 occupants sustained one or more chest/abdominal injuries solely due to their seat belt. For a further 19.5 % trauma was caused by the seat belt and another cause, for some the seat belt may only have caused an AIS 1 injury while another cause resulted in injury ≥ AIS 2. For 41.6 %, chest/abdomen injuries were entirely due to another cause.

Seat Belt Injury

The following analysis will focus on occupants who sustained some chest/abdominal injury caused solely by their seat belts. 1025 such occupants were identified, 31.3 % of all 3276 belted, front seat occupants. As figure 1 shows, 199 (6.1 % of 3276) had this type of injury at AIS ≥ 2.

Cervical spine injuries have been excluded as beyond the scope of this paper. Such injuries to restrained occupants are very common (Larder et al, 1985). They are almost always due to motion of the head relative to the restrained chest. In our data base there were only two cases of spine injury caused by direct load from the seat belt itself.

Types Of Thoracic Injury

Seat belt injury types are listed in table 2. If external injuries are excluded, then sternum fractures make up 48% of all chest injuries while rib fractures make up 33%. 6% of injuries involved the lung (either a laceration or contusion) and 5% of injuries were to the thoracic cavity. Other intra-thoracic organs are injured somewhat more sporadically. If rib and sternum fractures are excluded, then 39% of injuries are AIS 3 and 34% are AIS 4. Only 7% are AIS 2. 8% of occupants in the study sustaining AIS ≥ 2 injuries sustained some intra-thoracic injury usually associated with rib and/or sternum fractures (table 3). Most of the occupants injured in this way were elderly.

Table 2 - Thoracic Injury Types

	N of Occupants	AIS
Massive Chest Crush	1	6
Aorta Transection	3	5
Vein Laceration	1	4
Lung Contusions(1 Lobe)	8	3
Lung Contusions(2 Lobe)	4	4
Lung Laceration	1	3
Lung Laceration With haemothorax	2	4
Myocardium Laceration		
Simple	2	5
Complex	1	6
Pericardium Contusion	1	3
Pericardium Laceration		
Simple	4	4
With Haemomediastinum	2	5
Pleural Laceration	2	2
Thoracic Cavity Inj.	12	2,3
Rib Fractures		
Single	20	1
2-3 & Stable Chest	25	2
2-3 & Haemothorax	5	3
2-3 & Pneumothorax	1	3
>4 & Stable Chest	8	3
>4 & Haemothorax	5	4
>4 & Haemomediastinum	1	4
> 1, details not known	17	2
Open fracture & Haemothorax	1	4
Flail Chest	1	4
Sternum Contusion	5	1,2
Sternum Fracture	124	2
External Contusion	742	1,2
External Abrasion	36	1
External Laceration	4	1

Table 3 - Rib and Sternum Fractures Influencing Intra-thoracic and Intra-abdominal Injuries (16 cases)

Injury Combination	Rib Fracture	Sternum Fracture	Occupant Characteristics		δV/ETS*
(1)Lung contusion	yes		male	64	45km/h δV
(2)Lung contusion	yes		male	39	n.k.
(3)Lung contusions Myocardium lac. Pericardium lac.	yes	yes	female	91	31km/h ets
(4)Lung contusions Pericardium lac. Myocardium lac. Liver laceration	yes		male	67	68km/h δV
(5)Pleural lac. Myocardium lac. Liver laceration	yes	yes	male	82	79km/h δV
(6)Pericardium lac.	yes		female	81	79km/h δV
(7)Aorta laceration Pericardium lac. Lung contusions Liver laceration	yes	yes	female	75	n.k.
(8)Lung contusions	yes	yes	male	40	64km/h δV
(9)Lung contusions	yes		male	17	70km/h δV
(10 Pleural lac. Myocardium lac. Pericardium lac.	yes	yes	female	97	37km/h δV
(11)Lung contusions		yes	female	53	21km/h δV
(12)Lung laceration	yes		male	32	n.k.
(13)Thoracic cav. Injury		yes	male	42	28km/h ets
(14)Lung laceration Liver contusion	yes		male	41	37km/h δV
(15)Spleen lac.	yes		male	63	n.k.
(16)Lung laceration	yes		male	35	83km/h ets

* Delta V only calculated when details were available about case vehicle and object struck, otherwise ETS calculated where possible.

Types Of Abdominal Injury

These are listed in table 4. Details about external injuries are often obtained from questionnaire information, meaning that precise injury location can be uncertain. There were in total 23 intra-abdominal injuries ≥ AIS 2. Five of these injuries were associated with rib fractures as can be seen in table 3. Whilst the number of intra-abdominal injuries is relatively low, these 26 cases illustrate the limits of protection against life-threatening injuries of current three point belts.

Table 4 - Abdomen Injury Types

	N of Occupants	AIS
Unspecified Injury	1	1
Injury - not further specified, with Haematuria	4	1
Complex Stomach Injury	1	4
Retroperitoneal Injury - not further specified	1	3
Colon Contusion	2	2
Colon Laceration		
Simple	2	3
Complex	1	5
Mesentary Contusion	1	2
Jejunum Laceration		
Simple	1	2
Major	2	3
Complex	2	4
Liver Contusion	2	2
Liver Laceration		
Minor	2	2
Major	1	3
Complex	1	4
Spleen Contusion	1	2
Spleen Laceration	3	2
External Abdomen/Pelvic Contusion	392	1,2
External Abdomen/Pelvic Abrasion	46	1
External Abdomen/Pelvic Laceration	4	1

A Comparison With Head Injury Severity

Apart from chest and abdomen the head, excluding face, is the other body region where life threatening injury is a likely occurrence. Table 5 considers the occurrence of head injury together with seat belt injury. Head injury equal to, or more serious, than seat belt injury was a common occurrence (232 occupants, 7.1 %). However, 166 (5.6 %) had a non-trivial (AIS ≥ 2) seat belt injury with no, or less severe, head injury.

Table 5 - Seat Belt Injury Versus Head Injury

Maximum Head AIS	Chest/Abdominal Injury Caused Solely by Seat Belt Maximum AIS 1	2	3	4	5	6	Total
0	627	123	14	4	6	2	776
1	71	8					79
2	112	17	4		1		134
3	15	1		4			20
4		2	2	1			5
5	1	1	3	2			7
6		1		2	1		4
Total	826	153	23	13	8	2	1025

Impact Type

Occupants were classified by impact type. Cases included single and multiple impacts, or for example an impact then a rollover. Each case was examined and classified according to the event which was injury-producing. The majority of occupants experienced a frontal impact (79.6 %, table 6). However, other crash configurations were well represented. Table 6 also compares the rate of seat belt injury ≥ AIS 2, by impact type. Clearly front impacts are responsible for more of this type of injury at or above AIS 2. In front impacts we might expect a greater load to be applied to the occupant through the seat belt. Unless there are significant contacts against the steering wheel, facia or footwell, all restraint force will be applied via the belt. In all other impact configurations occupants have other restraint factors such as the door in a side impact, and seat in rear impacts. Non-struck side occupants may have another occupant beside, and frequently come out of their diagonal belt (Mackay et al 1991) so that injury to the chest is less likely from that cause.

Table 6 - AIS ≥ 2 Rate by Impact Type.
Showing the maximum AIS for seat belt injury.

Occupant Impact Classification	N	%	AIS ≥ 2 Rate
Front	816	79.6 %	21.3 %
Struck Side	50	4.9 %	14.0 %
Non-struck Side	64	6.2 %	7.8 %
Rear	13	1.3 %	7.7 %
Roll Over	36	3.5 %	13.9 %
Other Configuration	42	4.1 %	16.7 %
Not Known	4	.4 %	-
Total	1025	100.0 %	-

Speed Change At Front Impact

A velocity change at impact, Estimated Test Speed (ETS), was calculated for many of the vehicles from a damage profile, vehicle mass and stiffness coefficients. Figures 2 to 5 show cumulative % distributions for ETS experienced by occupants in this study. These results are confined to vehicles with front impact damage because the appropriate stiffness coefficients were derived from front impact crash tests (Noga et al, 1981).

Four types of seat belt injury outcome were considered. Predominant, were occupants with only chest and/or abdominal injury of AIS 1, an ETS was known for 632 of these (figure 2). The figure shows 25th and 75th percentiles at 25 to 44 km/h respectively. Figure 3 shows that a greater speed change was not generally associated with chest injury of AIS 2. However a higher speed change was typical of cases resulting in just chest injury of AIS ≥ 3, figure 4 shows the inter quartile range from 31 to 59 km/h. Figure 5 includes occupants with abdominal injury ≥ AIS 2, with or without any level of chest injury. These were typically the outcome of the most severe impacts, the inter quartile range being 33 to 63 km/h.

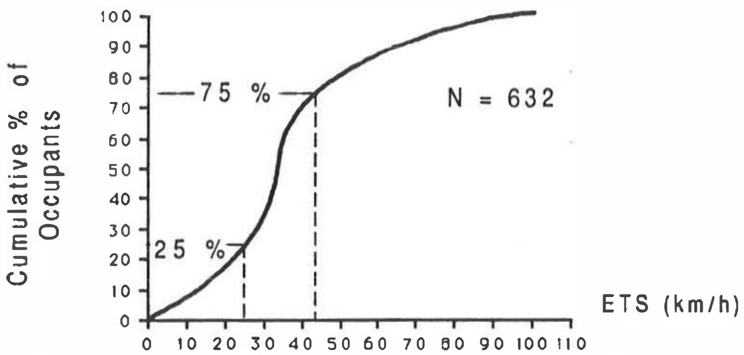

Fig. 2 - Chest and/or Abdominal Injury, AIS 1

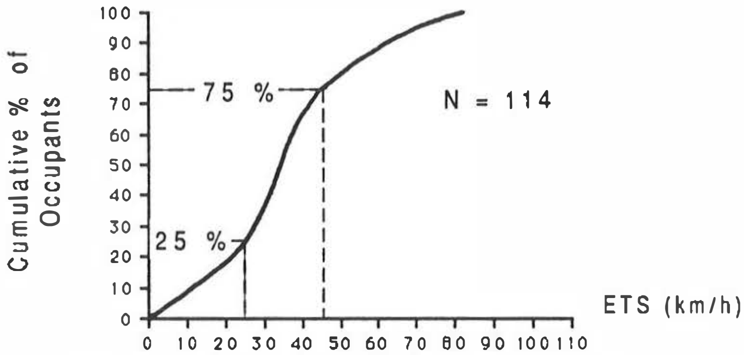

Fig. 3 - Only Chest Injury, AIS 2

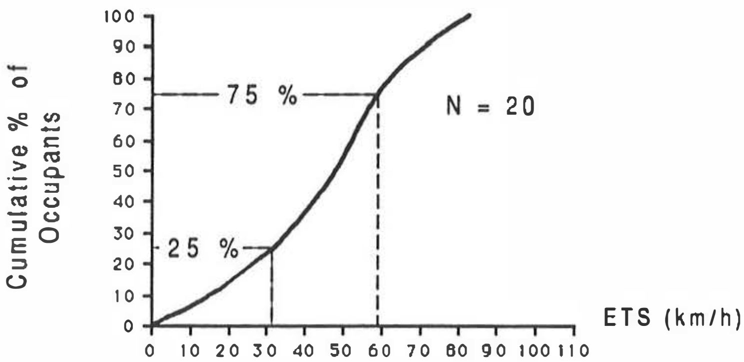

Fig. 4 - Only Chest Injury, AIS 3+

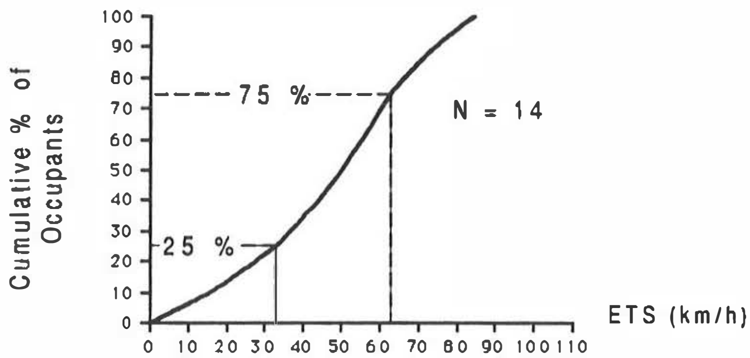

Fig. 5 - Abdominal Injury, AIS 2+; With/without Any Level of Chest Injury

Chest Injury - Occupant Characteristics

Gender - The sample was made up of 53 % male, and 47 % female occupants; gender having been established for all occupants. Gender did not appear to influence the maximum injury severity at the chest or abdomen.

Height and Weight - We wished to establish if occupants with seat belt injuries were particularly heavy, light, tall or short. The whole database at the Accident Research Centre, consisting of adult car occupants in crashes, was used to establish heights corresponding to the 25th and 75th percentile adult male and female. Male and female subdivisions were further banded by height, and 25th and 75th percentile values of weight obtained for each band. The results were used as a comparison for occupants in this study.

We looked for any relationship between occupant height, weight, injury severity and gender. Two trends were apparent and are shown in tables 7 and 8.

Table 7 shows the proportion of tall occupants against chest injury severity. Occupants were considered tall if their height was greater than the upper quartile value described above. It can be seen that a high proportion (50.0 %) of males with chest injury ≥ AIS 3 were tall. This trend in male occupants was significant ($p < 0.01$).

Other work has shown that occupant age can influence chest injury outcome (Rattenbury et al, 1979). Table 7 included four tall male occupants with chest injury of AIS ≥ 3, three were aged between 20 and 30, the other was aged 42. Thus advanced age was not thought to be a contributory factor in those cases. Interestingly, the remaining four non-tall, AIS ≥ 3 males, were over 60 years old suggesting that their injuries may have been age related.

Table 8 shows the proportion of light weight occupants against chest injury severity. Male and female counts are combined because no differences were apparent. Over half (54.5 %) of occupants with chest injury ≥ AIS 3 were light in weight. The result was statistically significant ($p < 0.05$).

We were alert for any misleading influences of high speed change or occupant age; none were found.

Table 7 - Incidence of Chest Injury in Tall Occupants

Maximum Chest AIS	Occupants					
	Total N		N > Upper Quartile		% > Upper Quartile	
	Male	Female	Male	Female	Male	Female
0-1	298	257	40	57	13.4 %	22.2 %
2	44	53	4	16	9.1 %	30.2 %
≥3	8	10	4	1	50.0 %	10.0 %

(Occupant height known in 65.4 % (670/1025) of cases.
Testing only males, Maximum Chest AIS versus tall or otherwise:-
$X^2 = 9.717$, $N = 350$, $df = 2$, $p = 0.0078$)

Table 8 - Incidence of Chest Injury in Light Weight Occupants

Maximum Chest AIS	Occupants		
	Total N	N < Lower Quartile	% < Lower Quartile
0-1	547	123	22.5 %
2	95	22	23.2 %
≥3	11	6	54.5 %

(Occupant weight known in 63.7 % (653/1025) of cases,
$X^2 = 6.235$, $N = 653$, $df = 2$, $p = 0.0443$)

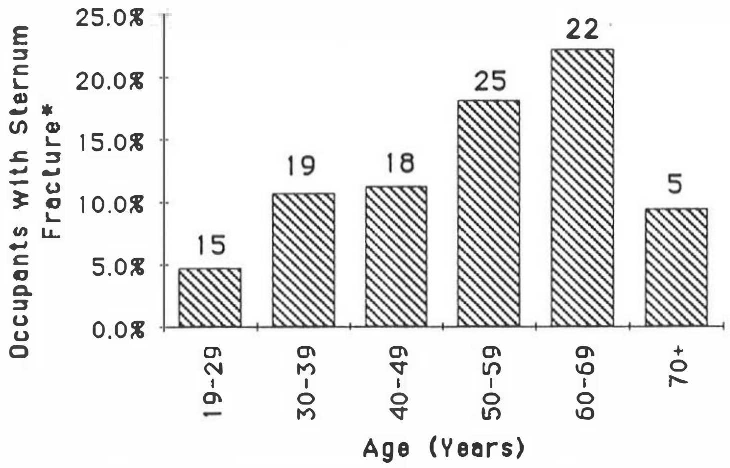

Fig. - 6 Sternum Fracture and Age

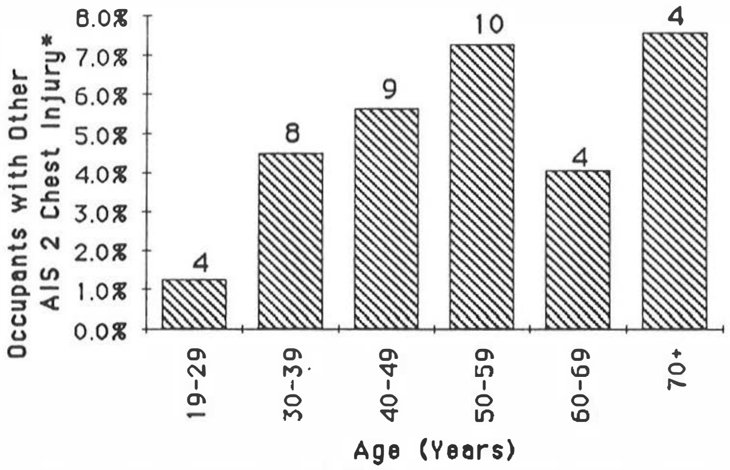

Fig. - 7 Other AIS 2 Chest Injury and Age

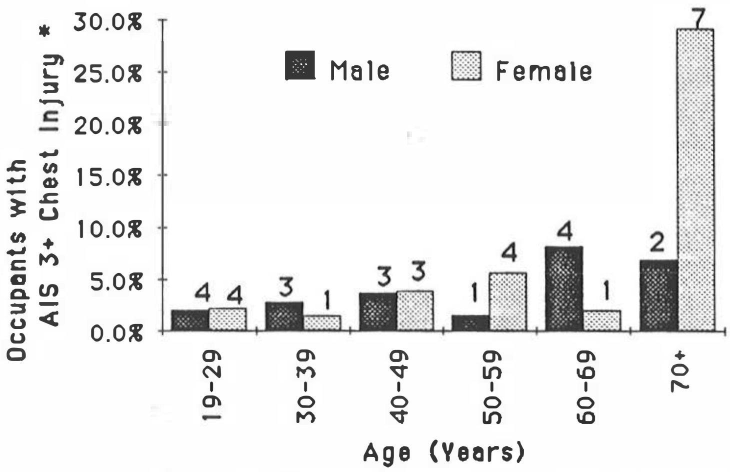

Fig. - 8 AIS 3+ Chest Injury, Age and Gender

*Percentages are of all seat belt injured occupants known to be of the given age (and also gender in figure 8). The number of occupants that sustained each type of chest injury is shown above each bar.

Age - Age was established for 1020, or 99.5 %, of the 1025 seat belt injured occupants. Their median age was 37 years, and age ranged from 10 to 97 years.

Three types of chest injury, rated ≥ AIS 2, are compared with age in figures 6 to 8. Age was known for all but one of the 190 occupants who sustained seat belt chest injury at that level of severity. Only mature occupants, ≥ 19 years, were considered in figures 6 to 8 so that trends due to aging might be seen.

It has already been noted that simple sternum fracture (AIS 2) was often the most severe injury sustained, such occupants are shown in figure 6, where a clear trend towards greater risk of injury with increasing age can be seen. Figure 7 includes occupants that scored some other type of AIS 2 chest injury, with or without sternum fracture. Here again, risk of injury increases with age. Crash severity did not increase with age.

Other workers (Rattenbury et al, 1979) have shown that age has a significant effect on chest injury from age 50 onwards, and the data for sternum fracture (figure 6) appear to show a definite step up in the level of risk at that age. However, the likelihood of other injury of AIS 2 (figure 7) tends to increase more gradually from 30 years onward.

Considering chest injury ≥ AIS 3 (figure 8), a tendency for risk to increase from childhood to age 70 is not very apparent for males or females. However, figure 8 does not show that four males aged less than fifty years were known to be tall, whereas no older males were known to be tall. Bearing in mind the above results, those younger males may be injured as a consequence of their tallness, and age could be the principal cause of injury for those aged over fifty years. That is to say that the trend towards increased risk of AIS ≥ 3 chest injury with age might be stronger than is apparent from figure 8.

Females age 70 and over had a very much greater proportion of chest injury ≥ AIS 3. Of 24 females aged ≥ 70, there were seven (29.2%) with that level of chest injury severity. There was no difference in crash severity for that age group in comparison to the mean.

Summarising this data, elderly females (≥70 years) were clearly at much greater risk of serious chest injury, but effects of aging were more obvious in the less severe cases of AIS 2 injury. It appears that serious chest injury (AIS ≥ 3) is predominantly a function of higher speed change, not occupant age.

Geometry and Usage Problems

Generally, this study found that poor belt geometry and restraint misuse were not common problems. There were cases of belt twisting and belt roping in the swivel but no relationship was found between this occurrence and injury severity. There were also instances of belts worn with excess slack which had exacerbated injuries but such instances were of no statistical relevance (see cases of interest).

Submarining has previously been shown to be a problem in several studies. In this particular study, there were again, only isolated cases of submarining which did, however, result in serious injuries.

Of six occupants with serious abdominal injuries whose height and weight were known, three were in the upper-quartile for height/weight ratio (i.e. overweight for height). Possibly such occupants sustain injuries of this type because it is difficult or impossible to align the lap-section of the belt with the iliac crests of the pelvis due to body shape. Thus a certain amount of slack is inherently introduced into the belt system by virtue of the occupant's dimensions. With such individuals, the belt is forced to lie on the abdomen during normal travel and thus the soft abdominal contents are directly exposed to belt loads when impact occurs.

Fatalaties

28 occupants with seat belt injury died because of injuries sustained in their crashes. Post mortem reports showed that the seat belt injury caused death in 12 cases. 18 fatalities had belt injury ≥ AIS 4 so that that would most likely have reduced their chance of survival. Head injury was noted as the cause of death in eleven instances.

Fatalities ranged in age from 18 to 97. The median age was 44 years, 7 years older than that for all 1025 seat belt injured occupants.

The fatality rate for all 3276 restrained front-seat occupants was 6.0 %; and 0.4 % (12/3276 occupants) died from seat belt injury.

CASES OF INTEREST

(1) The driver of an Austin Metro lost control of the vehicle on an icy road surface and the vehicle collided with a lamp-post. The Delta-V and ETS were both calculated to be 21km/h. The restrained 53-year old female occupant, height 5 feet 4 inches, weight 9 stone 10 pounds, sustained a displaced fracture to the sternum (AIS = 2) and also lung contusions as a result of the sternum fracture (AIS = 3). The injuries were sustained through normal seat-belt usage.

(2) The male driver of a Triumph Dolomite lost control of the vehicle on a right-hand bend and collided with a lamp-post. The Delta-V and ETS were calculated to be 46km/h. The driver, a 30-year old male (height and weight not known) sustained a perforation of the upper jejunum (AIS=4) and a tear of the ascending colon without perforation (AIS=3). The injuries corresponded to the lap-portion of the belt lying over the abdomen rather than the pelvic area.

(3) A 53-year old female occupant (height 5 feet 4 inches, weight 10 stone) was driving an Opel Kadett which collided with a lamp-post. ETS and Delta-V were calculated to be 23km/h. The occupant sustained a fractured sternum which was the only clinically diagnosed injury. Although the injury was assigned to the belt webbing, a klunk-klip device was used. Such devices are designed for comfort but can be set with excessive amounts of slack. That occurred in this case.

(4) A 39-year old female (height 5 feet 2 inches, weight 11 stone 10 pounds) was a front seat passenger in a Lada which span out of control and had a frontal impact with an estimated Delta-V of 25km/h. In addition to minor surface injuries, this occupant sustained a complex but unspecified stomach injury which required surgery (AIS=4). The occupant submarined in her seat and thus the injury was from the belt webbing.

(5) A 75-year old female (described as average height, weight not known) was a front passenger in a Ford Fiesta which collided head-on with an heavy goods vehicle. Delta-V was estimated to be 18km/h. She received fatal injuries to the chest and abdomen including sternum fracture (AIS=2) rib fractures (all on right-hand side; AIS=4), right lung contusions (AIS=3), a haemopneumothorax in the left lung (AIS=3), tearing to the pericardium with associated rupture to the right ventricle wall (AIS=4), a tear in the aorta (AIS=5) and a laceration to the liver (AIS=2). All the injuries were either directly or indirectly from the seat-belt.

(6) An 84-year old 'obese' female (height not known) was a passenger in a Rover 213 struck head-on by a Talbot Horizon (Delta-V was estimated to be 28km/h). The occupant was fatally injured. A post-mortem examination revealed severe injuries; rib fractures (AIS=2) had allowed the sternum to become displaced crushing the heart against the vertebral column. The right atrium had ruptured (AIS=6). The pathologist reported that the rupture to the heart and bony fractures were directly below a seat-belt bruise.

(7) A 67-year old male, described as of average stature and well-nourished, was a front seat passenger in a Ford Fiesta struck by an oncoming Opel Manta. The Delta-V was calculated at 68km/h and ETS 70km/h. His injuries were all generated by the seat-belt. They included fractured ribs (AIS=2), intra-parenchymal lung haemorrhaging (AIS=3), laceration to the pericardium (AIS=4), laceration to the right ventricle of the heart (AIS=5) and considerable lacerations to the liver (AIS=5).

(8) A Vauxhall Chevette collided with a public service vehicle with an ETS of 26km/h. The 19-year old female occupant, height 5 feet 5 inches, weight not known, was found initially to have sustained bruising across the front of the abdomen. However two days after the accident, she collapsed at home and was certified dead on arrival at her local hospital. A post-mortem examination revealed that she had a perforated jejunum left of mid-line of 1cm diameter with extensive contusion to the mesentary of the small bowel (AIS=4) and a minor degree of bruising to the underlying transverse colon. In addition, scattered petechial bruising was found on the pericardial surface. All injuries were generated by the seat belt.

DISCUSSION

In the first part of this study, there are similarities between casualties who are either killed or seriously injured in front impacts. Head injuries from the steering wheel and thoracic injuries from the seat belt are largely responsible for these trauma. Head trauma which occur in survivors tend to be diffuse brain injuries (DBI) whereas fatally injured occupants exhibit more severe intracranial trauma. These more severe injuries are also associated with skull fractures. Death due to limb injuries or burns are uncommon. Survivors rarely sustain internal soft tissue chest injuries; injuries to such occupants are mainly skeletal. This contrasts with fatally injured patients, where internal thoracic injuries are more common. Most of the fatal chest injuries were caused by excessive seat belt loads. Abdominal injuries to all occupants were due to seat belt loads and while these were rare in survivors, they were more frequent in the fatally injured.

The second part of this study concentrates solely on injuries to the chest and abdomen caused by the seat belt. For restrained occupants, the seat belt is responsible for generating more injuries than any other contact source within the vehicle. This fact should nevertheless be viewed in context; the majority of these injuries are AIS 1 and therefore are the product of the belt system operating in the manner in which it is designed - i.e. preventing an occupant contacting other structures within the vehicle.

When the belt is correctly positioned on the occupant the restraining forces will act upon the chest shoulder and pelvis in order to bring the occupant to rest. We can therefore expect a degree of trauma to these body regions. In this particular study which examined solely chest and abdomen injuries, it was found that the chest was injured far more frequently than the abdomen. However, this again is to be expected, when the belt is worn correctly, the abdomen should not be subjected to belt load unless the occupant is overweight. In this study, there were 29 injuries ≥ AIS 3 to the abdomen. Generally, the average car occupant is not instructed about the correct method of wearing the seat belt (i.e. with the lap-portion positioned on the iliac crests). Perhaps therefore, individuals are unwittingly travelling with the belt out of position because they remain relatively uninformed.

The majority of chest injuries caused by the seat belt are minor in nature. Rib and sternum fractures are rarely dysfunctional but can cause extreme discomfort. Again such injuries should be put into perspective; they should be viewed against injuries that would occur if the restraint was not worn and evidence supports the view that predicted outcome in an unrestrained condition would be considerably worse.

A small percentage of occupants were actually killed through wearing seat belts. That observation refers only to the deaths following chest/abdominal injury. Of course the seat belt will be a causal factor in all types of injury sustained by the restrained occupant, his kinematics at impact being deliberately controlled by it. Considering the head, it's excursion must be influenced by occupant restraint, and head injury may be more likely with 'restraint' if, for example, the seat belt allows the occupant to strike the dash rather than the windscreen. It follows that a broader classification of seat belt injury might also have included head and neck injury.

Fatal seat belt injury was not necessarily an indication that impact severity was high or that the occupant was elderly in nature although undoubtedly such variables contribute to the risk of fatal injury.

When elderly people are involved in moderately high energy collisions, it appears that they may be at risk of sustaining serious internal injuries to the abdomen and chest through splintering of the ribs and/or the sternum. This phenomenon applies particularly to older females and raises the question of more stringent injury criteria for the elderly.

An unexpected finding of the study was the fact that tall males and thinner people generally were found to sustain chest injury more frequently than their shorter and heavier counterparts. The effect of height may be because the shoulder belt on a tall person is passing across a lower part of the rib cage than for a shorter person. The lower ribs are likely to be more susceptible to fracture because of the intrinsic geometry of the rib cage.

Trends toward more serious injury in elderly females, tall males and light weight occupants are here presented tentatively. A larger sample size would be required to fully isolate the many factors that can influence injury outcome. Nevertheless, the sample size was large enough to allow tests of significance of these observations, and they are not chance findings. They are, at least, important pointers for future investigation.

Driver injury outcome may frequently be influenced by the steering wheel, but this is not so for passengers. This study attempted to focus on seat belt injury by excluding any drivers suspected to have contacted their wheels. An obvious difficulty in any retrospective study is the correct identification of the seat belt as an injury source. Medical data and evidence obtained from vehicle examination does not always indicate conclusively that an injury originated from the seat belt. Other possible contact sources can be overlooked. This is especially so for drivers because the steering wheel can produce similar injuries to both chest and abdomen without any evidence that it was the cause; therefore the investigator may assume that the belt is the injury source. An important development of this work will be to separate drivers from passengers. That will require more cases than were available to the present study.

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REFERENCES

American Association for Automotive Medicine. The Abbreviated Injury Scale 1985 Revision. Arlington Heights, Ilinois. AAAM, 1985.

Chapon, A. Thorax and Upper Abdomen; Anatomy, Injuries and Possible Mechanisms of Injury. Proceedings of The Biomechanics of Impact Trauma, Amalfi, Italy. May-June 1983.

Dejammes, M. and Biard, R. Avoiding Submarining with a 3-Point Belt. Proceedings of the International Research Committee on the Biomechanics of Impact Trauma, 1983.

Garrett, J.W. and Braunstein, P.W. The Seat Belt Syndrome. Journal of Trauma 2:220, 1962.

Grimes, G. The Protection Afforded by Seat Belts. TRRL Supplementary Report 449.

Kulowski, J. In "Crash Injuries". Charles C. Thomas. Springfield, 1960.

Larder, D.R., Twiss, M.K., and Mackay, G.M. Neck Injury To Car Occupants Using Seat Belts. Proceedings of the 29th Annual Conference of A.A.A.M. Washington, D.C. 153-165. October 1985.

Mackay, G.M., Galer, M.D., Ashton, S.J., and Thomas, P.D. The Methodology of In-depth Studies of Car Crashes in Britain. SAE Technical Paper Series 850556, 1985.

Mackay, G.M., Cheng, L., Smith, M.T. and Parkin, S. Restrained Front Seat Car Occupant Fatalities. The Nature and Circumstances of Their Injuries. 34th. Annual Proceedings. Association for the Advancement of Automotive Medicine, 1990.

Mackay, G.M., Parkin, S., Hill, J and Munns, J.A.R. Restrained Occupants on the Non-struck Side in Lateral Collisions. Proceedings of the 35th Annual Conference of A.A.A.M. Toronto, Canada. 119-132. October 1991.

Noga, T. and Oppenheim, T., CRASH3 User's Guide and Technical Manual, USDOT, 1981.

Patrick, L.M. The Human Thorax - Injury and Biomechanics. Proceedings of the Society of Automotive Engineers Annual Conference, 1976.

Rattenbury,S.J., Gloyns, P.F., Hayes, H.R.M., and Griffiths, D.K. The Biomechanical Limits of Seat Belt Protection. Proceedings of the 23rd AAAM Annual Conference, October 1979.

Walz, F.H. Abdomen. In: Anatomy, Types and Mechanisms of Injury, Tolerance, Criteria and Limits and Injury Factors. 119-130. Paper presented at the AAAM Copper Mountain Seminar. 1984.