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Injury Patterns In Side Collisions - A New Look With Reference To Current Test Methods And Injury Criteria

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ABSTRACT

The UK in-depth data, describing the causation of injuries to casualties in side impacts, was examined for crashes occurring between 1992 and 1998. Slightly more casualties died in side impacts than in frontal crashes, and one third were seated on the side away from the collision. The collision severity was compared with the European and US legal test procedures and most MAIS 3+ survivors were observed to be in crashes above the severity of the test. The mean delta-V for the fatal group was 48 km/h compared with typically 25 km/h in the test. The most commonly injured body regions of both survivors and fatalities were the head, thorax and lower extremity. The lower extremity was the most frequent site of AIS 2+ injuries of survivors and fractures to the femur and tibia were highlighted, these injuries are not assessed by existing dummies.

INTRODUCTION

The risk of injury in side impacts is generally higher than in frontal crashes because there is less vehicle structure within which to attenuate crash forces (it is claimed that the vehicle front structure can absorb 5 times as much energy as the side structure before injury occurs, Cesari and Bloch, 1984) and for an occupant sitting on the struck-side of the car there is little room for sideways movement before striking the interior. In comparison to frontal crashes, the side impact presents a more difficult challenge for occupant protection systems. Even though the risk of serious injury is higher in a side than in a frontal crash, previous accident studies have reported fatalities being more common in the frontal crash mode. In a European study, Cesari et al (1994), using 1982-83 data showed that 54% of car occupant fatalities occurred in frontal crashes compared to 28% in side impacts. Similarly, Mackay (1989) noted the frequency of side impacts as a collision type for car occupant fatalities in the US at 28%, while Fildes et al (1994), also found a figure of 28% in their Australian study. In recent years, the effects of legislation, consumer group safety ratings and the efforts of car manufacturers has been to improve frontal crash protection while side impact protection has not developed at the same rate.

In the late 1980s the German car magazine Auto-Motor und Sport and the owners club ADAC published the results of the then non-standard frontal crash tests. More recently the Euro-NCAP consortium has published the results of offset frontal collisions at a test speed of 64 km/h, higher than the 56 km/h of the European front impact Directive that came into force in 1998. In contrast, side impact safety has been publicly less prominent, although Euro-NCAP publish crash test results using identical test conditions to the European Side Impact Directive which also came into force during 1998 and ADAC have published the results of over 25 side impact tests.

In the US there has been a dynamic side impact test requirement (FMVSS 214) for cars that was phased in to cover all new cars from 1996, although a frontal crash test procedure has been in legislation since 1972 under FMVSS 208. The frontal crash test conditions have been exceeded by the US NCAP, published since 1979 but a higher speed crash of 56 km/h has been used.

In comparison to the real world studies of the 1980's, side impact research in the 1990's has tended to concentrate on crash testing, dummy development, crash simulation, interior component testing and development of advanced restraint systems. Of the real world studies conducted in the 1990's, many use retrospective data, essentially from crashes with 1980's vehicles, Cesari et al (1994), Haddak et al (1991), Lestina et al (1991), Fildes et al (1994), Hassan et al (1995). Therefore, much of the knowledge about real occupant injury in real side impacts comes from crashes involving vehicles essentially of 1980s design.

Field studies of side crashes have examined a number of parameters related to occupant injury outcome. Crash severity is usually assessed in terms of delta-V. Past research has suggested that the speeds at which serious and fatal injury occurred were above those used for crash testing. Thomas and Bradford (1989) examined UK data, showing a median delta-V of 31 km/h for seriously injured struck-side survivors and 43 km/h for fatalities in car-to-car collisions, while Cesari and Dolivet (1989) found similar results in a small study of 39 car-to-car side impact collisions. They reported the mean delta-V for AIS 3-5 injuries in survivors to be 30 km/h. Mackay (1989), summarising other studies describes the typical delta-V resulting in AIS 3+ injuries to be in the region of 30 km/h with the 75%ile delta-V for these injuries at 38 km/h. More recently Fildes et al (1994) investigating a sample of hospitalised and killed occupants found an average delta-V of 35 km/h.

The nature of the striking object (and hence the type of loading to the vehicle side) has also been examined. Thomas and Bradford (1989) showed that 31% of seriously injured struck-side survivors and 43% of fatalities had experienced a narrow impact into a tree or pole. Gloyns and Rattenbury (1989) however found that only 16% of fatalities were associated with narrow object impacts. For fatalities, they found that car-to-car crashes were more common, accounting for just over half of fatal impacts, while the Thomas and Bradford study found that only 30% of fatalities were related to car-to-car crashes.

Struck-side occupant injury patterns were examined by Thomas and Bradford (1989) who showed that the torso and head were the most common sites of AIS 4+ injury in fatalities, while seriously injured survivors had the legs, head and arms as the most common sites of AIS 2+ injuries. Fildes et al (1994) investigating side crashes between 1988 and 1992, found that the head and chest were the most frequently injured at the AIS 3+ level but the abdomen/pelvis and lower extremities were also important in terms of AIS 3+ injury risk. Gloyns et al (1994) were able to examine in detail, the head injuries of a small sample of fatally injured occupants in side crashes. They found that basilar skull fractures were much more common than vault fractures and questioned the use of the HIC as a predictor of serious head injury in side impact crash tests.

In view of the recent introduction of side impact legislation and new developments in side impact protection, it was considered timely to re-visit the real world data, with the opportunity to investigate crashes with more modern vehicles, in order to re-evaluate the conditions where occupants are injured in side impacts.

METHODS

The data collected within the UK Co-operative Crash Injury Study (CCIS) was used to investigate the causes of injuries in side impacts. The entry criteria for the sample analysed were that the cars were towed from the crash scene, they were aged 7 years or less at the time of the crash and at least one of the car occupants had been injured. Only 1% of the case vehicles in the sample were light trucks reflecting the frequency of these vehicles on UK roads. A stratified sampling system was used to select cases for investigation resulting in 83% of fatal crashes, 67% of serious injury cases and 13% of slight injury cases being investigated with data recorded for analysis. The objective of the analysis was to examine the events resulting in injury and the pattern of the injuries themselves and it was observed that fatal crashes tended to have different characteristics from non-fatal crashes. For these reasons the analysis focused on fatal crashes and those involving injuries for AIS 3 or above to survivors. The crashes were selected at random within these categories and all crashes occurred between 1992 and 1998. The data selected for this analysis comprised all occupants in vehicles with a direction of force within =/- 45 degrees of a perpendicular impact and with contact on the side of the car from the striking object. Results are presented as descriptive statistics and no tests of statistical significance were employed. Percentages shown in tables have been rounded to the nearest whole number so that totals do not always add to exactly 100% in some cases.

RESULTS

COLLISION CONFIGURATION - There were 474 fatally injured casualties in the sample and 718 survivors with injuries of at least AIS 3. The collision direction and partners are shown for each group in Tables 1 and 2. Roadside objects below 41cm wide are classified as “narrow” in the tables and are typically road sign columns, lighting columns and some trees.

Table 1: Impact Direction and Collision Partner - MAIS 3+ Injured Occupants

	Collision partner	

	Count (row%)								Total (col%)
	No object	Car	Light Truck	Bus, Heavy Truck	Narrow roadside object	Wide roadside object	Other	Object n/k	
Frontal		230 (60%)	3 (9%)	57 (15%)	20 (5%)	41 (11%)	2 (1%)	1 (<0.5%)	386 (54%)
Side		105 (47%)	9 (4%)	28 (12%)	41 (18%)	41 (18%)	2 (1%)		226 (31%)
Rear		3 (19%)	2 (13%)	4 (25%)	2 (13%)	3 (19%)	1 (6%)	1 (6%)	16 (2%)
Roll	33 (100%)								33 (5%)
Other	1 (2%)	16 (28%)	1 (2%)	5 (9%)	12 (21%)	22 (38.6%)			57 (8%)
Total	34 (5%)	354 (49%)	47 (7%)	94 (13%)	75 (10%)	107 (15%)	4 (1%)	2 (<0.5%)	718 (100%)

Table 2: Impact Direction and Collision Partner - Fatally Injured Occupants

	Striking Object Count (row %)							Total (col%)
	No object	Car	Light Truck	Bus, Heavy Truck	Narrow roadside object	Wide roadside object	Object	
Front		86 (50%)	16 (9%)	43 (24%)	10 (6%)	23 (13%)	2 (1%)	180 (38%)
Side		83 (44%)	4 (2%)	21 (11%)	34 (18%)	44 (23%)	2 (1%)	188 (40%)
Rear		3 (23%)	1 (8%)	8 (62%)		1 (8%)		13 (3%)
Roll	17 (100%)							17 (4%)
Other	1 (1%)	15 (20%)		5 (7%)	10 (13%)	44 (57.9%)	1 (1%)	76 (16%)
Total	18 (4%)	187 (40%)	21 (4%)	77 (16%)	54 (12%)	112 (24%)	5 (1%)	474 (101%)

386 (54%) of the MAIS 3+ survivors had a frontal collision as their most severe and 230 (60%) of these were in a collision with another car. 226 (31%) were involved in side impacts and 105 (47%) were in car-to-car collisions. Roadside objects accounted for 61 (16%) of frontal collisions but were more common amongst the side impacts involving 82(36%) of these casualties.

Side collisions were the most common type amongst the group of 474 fatalities accounting for 188 (40%) of casualties. Frontal impacts occurred at a similar level with 180(38%) of the car occupants. Other cars were still the most common collision partner accounting for 86(48%) of front impact and 83(44%) of side impact fatalities. Off-road objects were again a more common collision partner for 78(42%) of those involved in side impacts compared with 33(18%) in front collisions.

SIDE SEATED - In side impacts a car occupant can be seated on the side of the car that is struck (struck-side) or on the side away from the collision partner (non-struck- side) as shown in Figure 1.

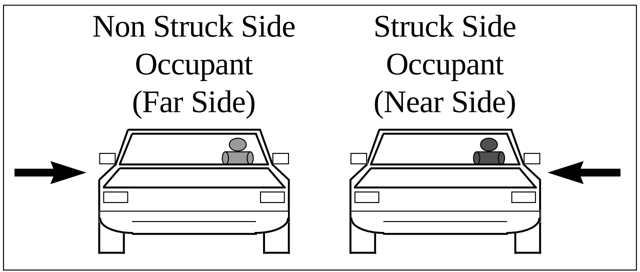

Table 3 shows that 148(66%) of the MAIS 3+ survivors and 127(68%) of the fatalities were seated on the struck-side.

Table 3: Side of Car Seated - MAIS 3+ Survivors and Fatalities

	MAIS 3+ Survivors	Fatalities
Struck-side	148 (66%)	127 (68%)
Non-struck-Side	78 (34%)	61 (32%)
Total	226 (100%)	188 (100%)

Table 4 shows the row of the vehicle in which each MAIS 3+ survivor and fatality was sitting. Typically each group had 90% of the occupants sitting in the front row of the vehicle whether they were sitting on the struck-side or non-struck-side. Only non-struck-side survivors had a higher portion of rear seat occupants with 17 (22%) of the casualties sitting in the rear seats.

Struck-side occupants who are killed or sustain MAIS 3+ injuries will tend to have different causes of injury from those seated on the non-struck-side, they frequently have injuries associated with direct interaction with the intruding side-structure of the vehicle while occupants seated away from the impact on the far side of the vehicle may have very different injury causation characteristics. Each group has been treated separately in this analysis.

Figure 1: Struck-side and non-struck side occupant

Table 4: Front and Rear Seating Positions

	Fatalities				MAIS 3+ Survivors			
	Front		Back		Front		Back	
Struck-side	113	(89%)	14	(11%)	134	(91%)	14	(9%)
Non-struck-Side	55	(90%)	6	(10%)	61	(78%)	17	(22%)

NON-STRUCK-SIDE OCCUPANTS - About a third of MAIS 3+ survivors and fatalities were seated on the non-struck-side. Those occupants may have a direct interaction with the far side structure but when a struck-side occupant is present, there may also be occupant to occupant interaction. So it is important to know when that situation occurs. Table 5 shows the frequency with which non-struck-side occupants were accompanied by a struck-side occupant.

Table 5: Occupancy of Struck-Side Seat for Non-Struck-Side Occupants

	MAIS 3+ Survivors	Fatalities
Occupant Alone	36 (46%)	32 (53%)
With Struck-Side Occupant	42 (54%)	29 (47%)
Total	78 (100%)	61 (100%)

About half of non-struck-side survivors and fatalities were accompanied by an occupant in the adjacent seat (the struck-side).

Seat belt usage also has a significant affect on the injury outcome for non-struck-side occupants. Previous research by Frampton et al (1998) showed that belt use reduced MAIS 2+ injury rates from 32% to 16% (a 50% reduction). The most recent belt usage rates for front seat occupants in the UK are shown as 91% for drivers and 92% for front seat passengers (Transport Research Laboratory, 1998). Because the belt has a major effect on injury outcome for non-struck-side occupants and because of the high front seat usage rates, only belted non-struck-side occupants have been considered here. Tables 6 and 7 show the injury rates by body region for the belted non-struck- side occupants who were alone, or accompanied by a struck-side occupant. For MAIS 3+ survivors, AIS 2 and above injuries were considered, while for fatalities, key injuries were considered to be those of AIS 3 and above. Injury rates in these and subsequent tables are calculated as the percent of eligible casualties with the relevant injury. For example in Table 6 52%, i.e. 11 of the 21 lone non-struckside occupants with any AIS 3+ injuries sustained an AIS 2+ injury to the head.

Table 6: AIS 2+ Injury Rates for Belted Non-struck-Side Survivors with MAIS 3+

Body Region	Occupant Alone N=21	With Struck-Side Occupant N=23
Head	52%	56%
Face	5%	4%
Neck	14%	4%
Thorax	19%	52%
Abdomen	5%	13%
Pelvis	14%	30%
Upper Extremity	38%	39%
Lower Extremity	14%	4%

With no struck-side occupant present, the head and upper extremity sustained the highest AIS 2+ injury rates. Head, face and upper extremity injury rates were not substantially affected by the presence of a struck-side occupant but there was a marked decrease in neck and lower extremity rates. With an adjacent occupant present, there was an increase in injury rates to the pelvis and abdomen and markedly to the thorax.

Table 7: AIS 3+ Injury Rates for Belted Non-struck-Side Occupant Fatalities

Body Region	Occupant Alone N=22	With Struck-Side Occupant N=12
Head	68%	83%
Face	5%	-
Neck	18%	-
Thorax	86%	75%
Abdomen	41%	33%
Pelvis	9%	-
Upper Extremity	9%	-
Lower Extremity	18%	-

Non-struck-side occupant fatalities sustained AIS 3+ injuries mainly to the head, thorax and abdomen, whether or not there was an adjacent occupant. The presence of a struck-side occupant did however result in a decrease of AIS 3+ injuries to the face, neck, pelvis and the extremities. These conclusions need caution however, because the sample size is small.

STRUCK-SIDE OCCUPANTS - A frequent measure of collision severity is delta-V, the change of velocity during the crash phase. Although this does not have a useful causal relationship with injuries sustained by struck-side casualties, due to the timing of the injury mechanisms, it does provide a description of the impact conditions to the vehicle. This can be used to relate the collision severity of real-world crashes with that of experimental or legal crash tests. The CCIS data uses the

CRASH 3 algorithm to estimate delta-V and comparisons between the estimated and true values in Euro-NCAP deformable barrier tests indicates that CRASH 3 produces a mean under-estimate of 6% (1.5km/h at 25 km/h) in side impacts (Lenard et al, 1998). The distribution of delta-V values for struck-side occupants for car-to-car, car-to-roadside-object and car to all collision partners is shown in Figures 2, 3 and 4. The figures also show the range of delta-V's measured in the Euro-NCAP Phases 1 - 3 which also represent the delta-V's in the very similar European legal test procedure.

The median delta-V for MAIS 3+ survivors seated on the struck-side in car-to-car collisions was 33 km/h, higher than the typical Euro-NCAP values. Collisions with wide roadside objects had a similar median value but narrow objects were struck giving lower delta-V's with a median of 19 km/h.

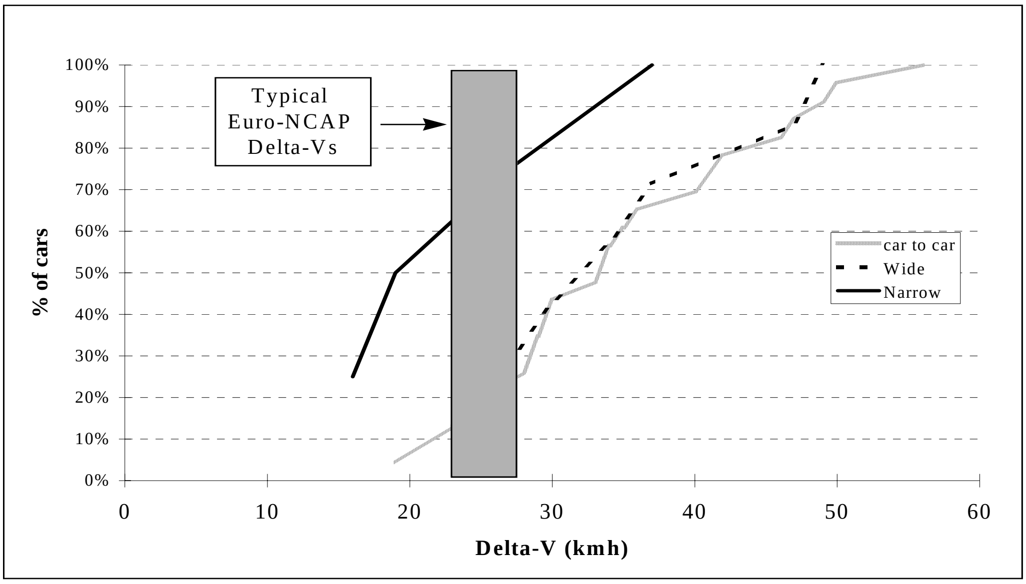

Figure 2: Delta-V Distributions, MAIS 3+ Struck-side Survivors by Collision Partners

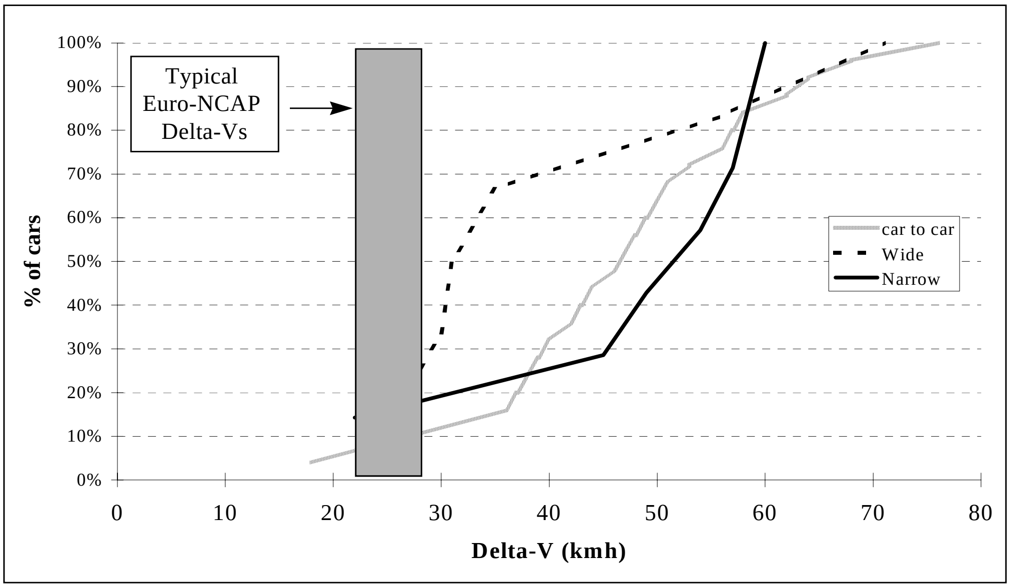

Figure 3: Delta-V Distributions, Fatal Struck-side Occupants by Collision Partners

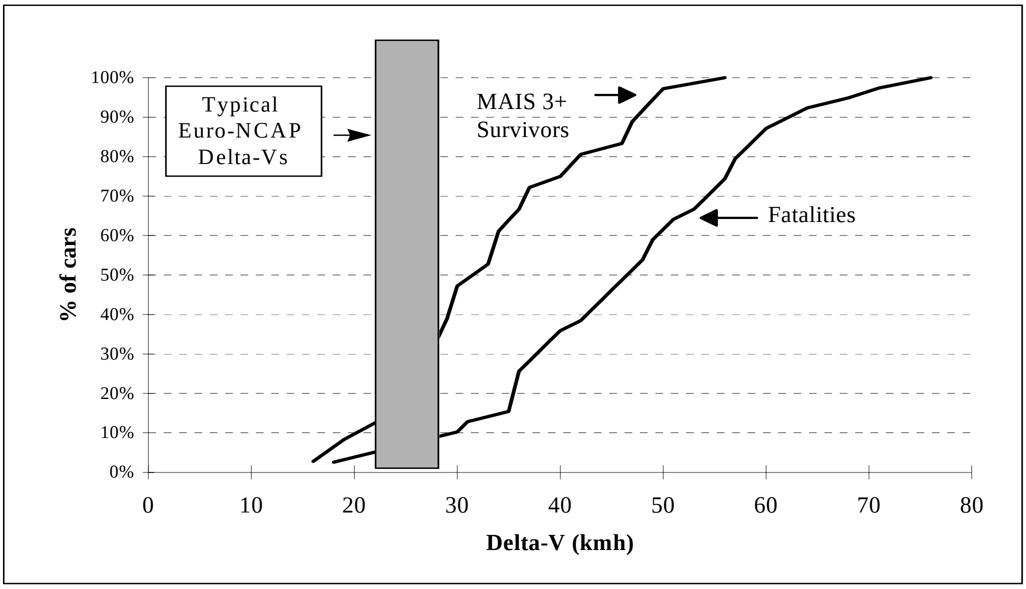

Figure 4: Delta-V Distributions, All Collision Partners for Struck-side Fatalities and Survivors

Very few fatalities occurred in crashes with a delta-V within the Euro-NCAP range. Out of the 39 cases where it was possible to estimate the delta-V, only three occupants died in collisions with a delta-V below 26 km/h and only one of these was involved in a car-to-car side impact. The median delta-V of fatalities in car-to-car side impacts was 47 km/h, in collisions with narrow roadside objects it was 52 km/h and in wide objects it was 31 km/h.

STRUCK-SIDE OCCUPANTS - INJURY PATTERNS - Full injury details were available for all 148 of the MAIS 3+ struck-side survivors and 124 of the fatalities. Table 8 shows the pattern of injuries of the survivors while Table 9 shows that for the fatalities. In Table 8, the key injuries of the survivors have been taken to be any injury of AIS 2 or above. The most commonly injured body region of the survivors was the lower extremity including the pelvis, 81 (55%) sustained an injury of at least AIS 2. 72 (49%) sustained an AIS 2+ injury to the thorax while 59 (40%) sustained such an injury to the head. The HARM scale (Malliaris et al, 1985) was to used to provide a measure of the economic burden of the injuries in each body region. The total HARM was calculated for all injuries to each body region including AIS 1 injuries and the portion of this total represented by all injuries to each body region is shown. In Table 8, injuries to the lower extremity accounted for 34% of the total economic cost compared with thorax and head injuries which accounted for 23% and 16% respectively.

Table 8: Injury Pattern of MAIS 3+ Survivors

Body Region	No with AIS 2+ Injuries (% of total AIS 3+ survivors)		% of total HARM
Head	59	(40%)	16%
Face	8	(5%)	2%
Neck	6	(4%)	9%
Thorax	72	(49%)	23%
Abdomen	20	(14%)	4%
Upper	44	(30%)	12%
Lower	81	(55%)	34%

The key injuries of the fatalities were taken to be the injuries of AIS 3 and above. Unlike the survivors the most commonly injured body regions at this level were the thorax, with 110 (89%) casualties and the head with 87 (70%) casualties who sustained AIS 3+ injuries. The thorax accounted for 34% of the total HARM while the head accounted for 25%. Only 43 (35%) fatalities were recorded as sustaining AIS 3+ injuries to the pelvis and lower extremity and the region accounted for 11% of the HARM.

Neck injuries, which were rare at AIS 2+ levels in the survivors, were only sustained at AIS 3+ level by 9% of the fatalities. However the HARM scale gives the higher severity neck injuries very high economic costs regardless of survival so this body region accounted for 17% of the total. Each fatality sustained an average of 2.35 body regions injured to AIS 3 or above.

Table 9: Injury Pattern of Fatalities

Body Region	No with AIS 3+ Injuries (% of total fatalities)		% of total HARM
Head	87	(70%)	25%
Face	0	(0%)	1%
Neck	11	(9%)	17%
Thorax	110	(89%)	34%
Abdomen	33	(27%)	8%
Upper Extremity	7	(6%)	4%
Lower Extremity	43	(35%)	11%

STRUCK-SIDE OCCUPANTS - INJURY PATTERNS AND COLLISION PARTNER - The incidence of head injuries may be related to the nature of the collision partner. Objects that extend above the level of the head of the struck-side occupant may be more likely to be contacted by the head of the casualty either as the striking object intrudes into the car or as the head moves through the plane of the side-glass towards the object. Injuries to other body regions may also be influenced by the nature of different types of striking objects. Table 10 shows the incidence of AIS 2+ injuries amongst the survivors and AIS 3+ injuries amongst the fatalities.

The incidence of injuries amongst the whole group of casualties is dominated by those in car-to-car side impacts. Narrow roadside objects were not associated with appreciably higher rates of head injury either amongst the survivors or the fatalities compared with the complete group of casualties. However collisions with wide roadside objects resulted in 50% of the survivors sustaining AIS 2+ head injuries compared with 38% of those in car-to-car side impacts. The rate of AIS 3+ head injuries amongst fatalities was also higher at 79% compared with 67% for car-to-car impacts. Thorax injuries were more common in car-to-car side impacts for both the survivors and the fatalities however abdomen injuries were more common in collisions with wide roadside objects. Lower extremity and pelvis injuries were less common at AIS 2+ levels in impacts with wide roadside objects but more common at AIS 3+ levels in narrow roadside object collisions.

Table 10: Injury Incidence and Collision Partner

Injury	Collision Partner			
	All collision partners	Car-to-car	Wide roadside object	Narrow roadside object
MAIS 3+				
Head	40%	38%	50%	39%
Face	5%	4%	8%	4%
Neck	4%	4%	4%	7%
Thorax	49%	53%	42%	43%
Abdomen	14%	16%	21%	11%
Upper Extremity	30%	28%	25%	32%
Lower Extremity	55%	65%	50%	68%
Fatalities				
Head	70%	67%	79%	71%
Face	0%	0%	0%	0%
Neck	9%	12%	7%	13%
Thorax	89%	94%	82%	83%
Abdomen	27%	25%	39%	13%
Upper Extremity	6%	4%	10%	8%
Lower Extremity	35%	35%	29%	50%

Table 11: Combination of Skull Fracture and Brain Injury - Fatal Occupants with AIS 3+ Head Injury

AIS-Skull Fracture	AIS- Brain Injury (row%)					Total (col%)
	0	3	4	5	6	
0		2 (23%)	6 (7%)	8 (9%)	1 (1%)	35 (40%)
2		2 (2%)	1 (1%)	2 (2%)		5 (6%)
3	9 (10%)	8 (9%)	5 (6%)	6 (7%)	3 (3%)	31 (36%)
4	3 (3%)	2 (2%)	4 (5%)	4 (5%)	3 (3%)	16 (18%)
Total	12 (14%)	32 (37%)	16 (18%)	20 (23%)	7 (8%)	87 (100%)

STRUCK-SIDE OCCUPANTS - HEAD INJURIES - The nature of the common injuries to each body region can indicate the nature of the applied loads and hence support decisions over sensor arrangements in ATDs. The relation between brain injury and skull fracture of the 87 fatalities with an AIS 3+ head injury is shown in Table 11. The post-mortem examinations conducted in the UK are known to reliably identify the presence of focal lesions but a microscopic tissue examination is not always performed so non-focal lesions may be under-reported. Amongst these 87 fatalities all but 12 (14%) sustained a diagnosed brain injury, however, only 52 (60%) sustained a skull fracture.

An indication of the nature of the loads causing these brain injuries may be inferred by the types of skull fracture sustained. Table 12 shows the distribution of vault and basal skull fractures amongst the fatalities. There were 87 fatalities with an AIS 3+ head injury and 54 (62%) sustained either a vault or basilar fracture. The most common type was a base-of-skull fracture, sustained by 47 (55%) fatalities, vault fractures were only sustained by 25 (29%). Thirty-six (42%) casualties sustained separate fractures to the vault and base. Generally vault fractures are a result of direct loads being applied to the vault, either at the fracture site or remote but still to the vault. On the other hand basal skull fractures can frequently be a result of shearing loads across the base from a contact higher on the vault or the face. This pattern indicates the need for ATDs to assess the head injury potential both of direct contact loads and of indirectly applied shearing loads with acceptance levels appropriate for the type of injuries sustained.

Table 12: Nature of Skull Fracture - Fatal Occupants with AIS 3+ Head Injury

AIS - Vault Fracture	AIS- Base-of-skull Fracture (row%)			Total (col%)
	0	3	4	
0	33 (38%)	19 (22%)	10 (12%)	62 (71%)
2	5 (6%)	6 (7%)	2 (2%)	13 (15%)
3	2 (2%)	5 (6%)	4 (5%)	11 (13%)
4			1 (1%)	1 (1%)
Total	40 (46%)	30 (34%)	17 (20%)	87 (100%)

The nature of all head injuries is shown in Table 13 which includes the AIS 3+ injuries of the 87 fatalities and the AIS 2+ injuries of the 59 survivors with head injury. The injuries are classified by the description of the code in the Abbreviated Injury Scale (1990 revision). The MAIS 3+ survivors sustained a total of 99 AIS 2+ injuries between them and the most common 47 (47%) were diagnosed purely by loss of consciousness. Only 27 of these 47 injuries were sustained with other diagnosed head injuries including 13 cerebral injuries and 9 skull fractures.

Table 13: Anatomical Location of Head Injuries - AIS 3+ Injuries of Fatalities and AIS 2+ Injuries of Survivors

	Fatalities		Survivors	
	Freq	%	Freq	%
Scalp			1	(1%)
Brain stem	22	(10%)	1	(1%)
Cerebellum	16	(8%)		
Cerebrum	105	(50%)	32	(32%)
Other	3	(1%)	1	(1%)
Skull	62	(30%)	17	(17%)
Loss of Consciousness	2	(1%)	47	(47%)
Total	210	(100%)	99	(99%)

Injuries to the cerebrum were also common amongst the 59 survivors accounting for 32 (32%) of the 99 injuries while skull fractures were less common with 17 injuries sustained.

The fatalities sustained a greater number of more severe head injuries as expected. Very few were observed to have injuries described by the AIS codes for unconsciousness as they died immediately at the crash. The most common types of injury were cerebrum injuries (105 cases - 50%) and skull fractures (62 injuries - 30%). Despite the 48 fractures to the base of the skull there were only 22 (10%) brain stem injuries. Within the injuries of the fatal group there were only 3 instances of diagnosed non-focal brain injury although there were 145 focal lesions. The nature of the normal post-mortem examination carried out in the UK is such that a microscopic examination of brain tissue is not always carried out and it is possible that some non-focal lesions were missed.

STRUCK-SIDE OCCUPANTS - THORACIC INJURIES - There were 72 (49%) MAIS 3+ survivors with at least an AIS 2+ thorax injury and 110 (89%) of fatalities with an AIS 3+ injury. Table 14 shows the location of the injuries according to the organ or skeleton involved.

Table 14: Anatomical Location of Thorax Injuries - AIS 3+ Injuries of Fatalities and AIS 2+ Injuries of Survivors

	Fatalities		Survivors	
	Freq	%	Freq	%
Diaphragm	19	(8%)	3	(3%)
Heart	19	(8%)	3	(3%)
Thoracic veins and arteries	38	(16%)	1	(1%)
Lungs	86	(36%)	16	(17%)
Oesophagus/trachea/bronchus	4	(2%)		
Ribcage	65	(27%)	62	(67%)
Thoracic spine	3	(1%)	2	(2%)
Other	4	(2%)	5	(5%)
Total	240	(100%)	92	(98%)

Skeletal injuries were the most common AIS 2+ injuries of the survivors accounting for 62 (67%) of all their AIS 2+ chest injuries while lung contusions and lacerations comprised the majority of the remainder with 16 cases (17%). Skeletal injuries only formed a small part of the AIS 3+ thorax injuries of the fatalities - there were 65 injuries accounting for 27% of the total of 240 injuries indicating there were at least 45 fatalities with an AIS 3+ thorax injury but no AIS 3+ ribcage injury. The most common were injuries to the lungs with 86 cases (36%). Notable amongst the fatalities were the frequent cases of aorta injury. These comprised 34 of the 38 thoracic vein and artery injuries. They are normally fatal almost immediately but there was one case of a survivor with such an injury who had an aorta that ruptured while being treated for his other injuries.

STRUCK-SIDE OCCUPANTS - ABDOMINAL INJURIES - There were 20 (14%) survivors and 33 (27%) fatalities who sustained 33 and 54 injuries to their abdominal contents respectively. Table 15 shows the organs injured to AIS 2 and above amongst the survivors and to AIS 3 and above amongst the fatalities.

Table 15: Anatomical Location of Abdomen Injuries - AIS 3+ Injuries of Fatalities and AIS 2+ Injuries of Survivors

	Fatalities		Survivors	
	Freq	%	Freq	%
Abdomen Veins and Arteries	5	(9%)	2	(6%)
Stomach and Bowel	2	(4%)	2	(6%)
Kidney	8	(15%)	5	(15%)
Liver and Pancreas	21	(39%)	9	(27%)
Spleen	14	(26%)	8	(24%)
Bladder	1	(2%)	2	(6%)
Other	3	(6%)	5	(15%)
Total	54	(101%)	33	(99%)

Although injuries to this body region are relatively rare in comparison with thoracic injuries they typically have a high AIS value and can be important when considering fatalities. The most common sites of AIS 3+ abdomen injuries to the fatalities were the liver and pancreas (21 cases - 39%) followed by the spleen (14 cases - 26%). Both of these organs lie partially under the lower rib cage and may be associated with rib fracture and loading higher up the torso. The liver and spleen were both also the most frequent sites of the AIS 2+ injuries of the survivors.

STRUCK-SIDE OCCUPANTS - UPPER EXTREMITY INJURIES - 64 upper extremity injuries of AIS 2+ were sustained by 44 of the 148 survivors and they accounted for 12% of the total HARM. The injury descriptions are shown in Table 16 together with those 12 AIS 3+ injuries sustained by 7 fatalities.

Table 16: Anatomical Location of Upper Extremity Injuries - AIS 3+ Injuries of Fatalities and AIS 2+ Injuries of Survivors

	Fatalities		Survivors	
	Freq	%	Freq	%
Shoulder			22	(34%)
Upper Arm	3	(25%)	15	(23%)
Forearm	8	(67%)	22	(34%)
Wrist/Hand			5	(8%)
Other	1	(8%)		
Total	12	(100%)	64	(99%)

Injuries to survivors were most commonly observed to the shoulder and forearm which each showed 22 (34%) injuries. These included 14 clavicle fractures and 5 scapula fractures while there were also 14 humerus fractures.

STRUCK-SIDE OCCUPANTS - LOWER EXTREMITY INJURIES - Lower Extremity injuries were the most commonly injured body region of the MAIS 3+ survivors at AIS 2+ level, 81 (55%) of the 148 survivors sustained injuries to this body region. At AIS 3+ levels they were relatively less common amongst the fatalities who more commonly sustained thorax and head injuries. The sites of the AIS 2+ injuries of the survivors and the AIS 3+ injuries of fatalities are described in Table 17.

Table 17 : Anatomical Description of Lower Extremity Injuries - AIS 3+ Injuries of Fatalities and AIS 2+ Injuries of Survivors

	Fatalities		Survivors	
	Freq	%	Freq	%
Pelvis	22	(42%)	60	(40%)
Femur	26	(49%)	35	(23%)
Knee			6	(4%)
Leg	5	(9%)	44	(29%)
Other			5	(3%)
Total	53	(100%)	150	(99%)

The most common site of injury in the lower extremities of the survivors was the pelvis where 60 (40%) of injuries were sustained. Typically the injuries were simple, closed fractures of the pelvis ring. Of note were AIS 2+ fractures to the femur of which 35 (23%) were sustained with 28 to the shaft. Only 5 were to the neck or trochanteric region. Also of note were fractures to the leg including 27 (18%) tibia fractures, 4 of which were to the tibial condyles.

DISCUSSION

One effect of the focus on frontal impact has been to improve the level of protection offered and the UK in-depth data reported in this analysis has shown that the numbers of those killed in frontal impact is now slightly below those killed in side impact. Thus the predominance of fatalities in frontal crashes reported by Cesari et al (1994), Mackay (1989) and Fildes et al (1994) appears to have diminished with advances in frontal crash protection. The introduction of more advanced restraint systems for frontal impact is likely to have the potential to improve front crash protection still further while, in Europe the first generation of side impact protection systems that meet the new legal requirements is only now generally entering the car fleet.

The European side impact test (EU Directive 96/27/EC) uses a mobile deformable barrier to impact the side of a car with a collision speed of 50 km/h. There is one Eurosid-1 dummy seated in the front seat which measures the risks of head, rib, thoracic organ, abdomen organ and pelvis injury. The US requirement (FMVSS 214) simulates an intersection collision and uses a mobile deformable barrier, with different deformation characteristics, to strike the side of a car with a crabbed collision speed of 54 km/h. The two SID dummies are seated on the struck-side of the car in the front and rear seating positions. They have a different design and use different injury assessment measures from the dummies to estimate the risks of chest and pelvis injury. The test conditions are illustrated in Figure 5. Head injury in the US regulations is covered by FMVSS 201 which utilises a series of impacts using a free motion headform. Comparison between the two sets of test conditions and the manner in which injuries are sustained in real-world side crashes reveals a number of areas of divergence.

Both the US and the European crash tests simulate the characteristics of a car-to-car side collision. This corresponds to 44% of the fatal casualties and 46% of the MAIS 3+ survivors. While a car is the most common type of collision partner, other objects, particularly off-road objects, are also frequent accounting for 41% of the fatalities and 36%

of the MAIS 3+ survivors. The side impact study by Thomas and Bradford (1989) showed very similar occurrences. These roadside objects are frequently trees, lighting columns, direction signs or other narrow, tall structures, they can have the effect of concentrating loads into a small part of the cars length and also providing a ready contact zone for the head. There is clearly a need to examine the effects of collisions with these objects in more detail to identify suitable occupant protection systems and vehicle structures. In comparison Light Trucks now represent over 50% of the passenger car fleet in the US and consequently have a considerably higher crash involvement. Hollowell and Gabler (1998) indicate that 57% of US side impact fatalities in 1996 were in vehicles struck by a light truck. The front structures of a light truck may be very different from those of a car and this difference between the US and European fleets may prohibit identical side impact legislative requirements in the two territories.

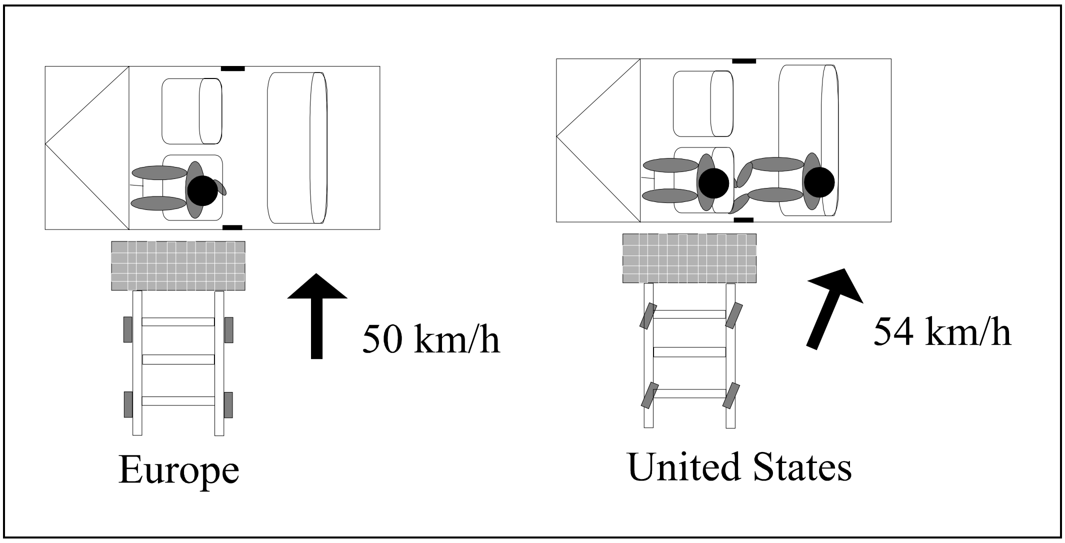

Figure 5: US and European Legal Side Impact Test Conditions

The US legal test utilises two side impact dummies seated in the front and back seating positions on the struck-side while the European test only uses one in the front seat. The UK data indicates that both fatalities and MAIS 3+ survivors may be rare in the rear struck-side positions which represent only 10% of the total injured. The crash tests may not reproduce the conditions where serious and fatal injuries are sustained by rear occupants but the group is sufficiently small that other areas may have greater potential for improvement.

Occupants seated on the side of the vehicle opposite to the impact (the non-struck- side) are currently not considered in any legal or consumer crash tests. Yet they constituted about a third of MAIS 3+ survivors and fatalities in side crashes and so are a group worthy of protection. Previous work by Frampton et al (1998) showed that while seat belts were effective in reducing injury risk to these occupants, there was further potential to increase belt effectiveness, especially in perpendicular side crashes. Subsequently, Stolinski et al (1999) have shown that deploying belt pre-tensioners in a side impact can significantly reduce lateral excursion of non-struck- side dummies and reduce lap belt loads. The extent of both lateral excursion and opposite side intrusion are likely associated with injury risk. The situation is further complicated however, when a struck-side occupant is present. In this analysis, that was the case for about half of non-struck-side occupants and had important implications for large increases in AIS 2+ injury rates, especially to the thorax, abdomen and pelvis of seriously injured survivors. For fatally injured occupants, the presence of a struck-side occupant marginally decreased AIS 3+ injuries to the thorax, abdomen and pelvis. The reasons for this trend are unclear and possibly due to the small sample size of non-struck-side occupant fatalities with a struck-side occupant present. The nature of the interaction between struck-side and non-struck-side occupants is still unclear and would benefit from further investigation. However, it does occur, which means any evaluation of non-struck-side safety would need to consider the presence of a struck-side occupant. Additionally, any measure which reduces non-struck-side occupant excursion across the car could also benefit the struck-side occupant because it is reasonable to assume that any additional loading incurred by the struck-side occupant would not be beneficial. Thomas and Bradford (1989) estimated that 39% of fatal struck-side occupants sustained additional loading from a non-struck-side occupant as did 24% of seriously injured survivors. Gloyns and Rattenbury (1989) estimated that 50% of their fatally injured occupants had sustained additional loading. In this study, a little over half of both struck-side survivors and struck-side fatalities were accompanied by an occupant in the adjacent seat.

There is a considerable difference between the collision severity of the test procedures and the speeds of side impacts that result in serious or fatal injury. The delta-V of the crash tests conducted by Euro-NCAP ranges between 22km/h to 28 km/h (depending on structural differences and the mass of the car) and this is a good indication of the distribution within the European legislative tests. In contrast, car-to-car impacts showed the median delta-V for MAIS 3+ survivors was 33 km/h and 47 km/h for fatalities, these delta-V's are only slightly higher than the respective values reported by Thomas and Bradford (1989) and the value for seriously injured survivors reported by Cesari and Dolivet (1989). In this current study only 8% of fatalities and 20% of MAIS 3+ survivors were in crashes below 25 km/h delta-V. The crash injury data does not take account of the effects of the very recent European side impact Directive, which has the intention of reducing injury severities, as vehicles which comply only form a very small part of the car fleet. Clearly the effectiveness of side impact protection systems in most cars is unlikely to disappear at slightly higher speeds although some cars may be highly optimised with sharply reduced benefits above the test velocity. The disparity between the test speeds and the circumstances of serious and fatal injury is important though and one objective that remains for side impact protection is to extend the protection offered to higher collision speeds.

The distribution of injuries of both fatalities and MAIS 3+ survivors supported the injury assessment priorities of both the European and US test on head, thorax and pelvis injuries. Injuries to these body regions are common to both the MAIS 3+ survivors and the fatalities and are recognised by the distribution of HARM between body regions. However there are a number of points of note. The head injuries of both groups of casualties occurred at similar rates for both car-to-car collisions and narrow, pole type, roadside objects. This indicates there may be a need to clarify the mechanism of evaluation of head injury risk in the US test procedure. Also the types and combinations of injuries observed provide some indications as to research priorities. Sixty percent of the 87 fatalities with an AIS 3+ head injury sustained a brain injury together with at least one skull fracture and 47 of the 54 with a skull fracture sustained a basilar fracture. This result correlates with a study by Gloyns et al (1994) which found that basilar skull fractures were more common than those to the vault for fatally injured occupants in side crashes. The 87 fatalities sustained a total of 210 AIS 3+ head injuries overall and there were 148 diagnosed brain injuries including 105 to the cerebrum. All but three of these injuries were focal lesions. The nature of the post-mortem examinations was such that microscopic lesions may have been under-reported and it is quite possible that non-focal lesions may have been sustained in addition to the focal injuries. Equally it is possible that some of the remaining 37 fatalities with no diagnosed AIS 3+ head injury may also have non-focal injuries. However, the predominance of fatalities with focal lesions highlights the importance of prevention of these injuries.

In 22 out of 48 cases base-of-skull fractures were associated with injuries to the brain stem or cerebellum as well as with the cerebrum. An examination of the relation between injury prediction indices, such as HIC, and applied loading conditions is beyond the scope of this paper but base-of-skull fractures in particular are rarely observed in experimental studies supporting HIC. It has to be questioned whether HIC is a suitable parameter that represents the risk of the types of severe head injuries observed in typical fatal side impacts. Further investigation of this area may be desirable.

Current thoracic injury criteria are primarily based on the risks of multiple rib fracture with consequent thoracic organ injury. The data for the fatalities showed that 65 fatalities did sustain their life-threatening thorax injuries with accompanying ribcage injury but 45 did not. The number with organ injury alone raises questions over the sufficiency of the side impact injury criteria employed if they do not fully assess all injury types observed in the real-world data. Additionally, Cesari et al (1994) report that, for struck-side occupants, placing the arm on the impacted side of the vehicle along the thorax offers some protection by distributing impact forces on the chest. Some further work could be carried out on the crash injury data to investigate whether arm position affects chest injury. The CCIS data does not describe arm position but an increase in upper arm injury with a corresponding decrease in chest injury might suggest the arm placement between the chest and the door. Exploring this avenue could have important implications for the design of current side impact dummies.

Injury to the lower extremity was observed at AIS 2+ levels amongst 55% of the survivors. In fact it was the most commonly injured body region at these levels being associated with 34% of the total HARM. Injuries most commonly occurred to the pelvis in the survivors which was the site of 40% of the 150 injuries. The pelvis also accounted for 42% of the AIS 3+ lower extremity injuries of the fatalities. Notable amongst both groups of casualties was the rate of femur fractures which were almost exclusively mid-shaft fractures. These comprised 23% of the survivors injuries and 49% of the fatalities injuries. AIS 3+ femur fractures were more common in the fatal group than AIS 3+ pelvis injuries. Amongst the survivors AIS 2+ tibia fractures were almost as common as femur fractures and again were most frequently mid-shaft. Both Thomas and Bradford (1989) and Fildes et al (1994) noted the importance of lower extremity injury in side impact but did not examine injury rates to each part of the limb. Neither Euro-SID or US SID have the capability of measuring the risk of injury to the lower extremity below the pelvis yet the UK data suggests that these injuries are relatively common. These injuries have been identified as requiring costly treatment and have high levels of short term impairment as the limb heals. This research suggests that there is a need to examine the circumstances of the injuries in more detail with a view to developing suitable injury assessment devices and criteria.

CONCLUSIONS

The UK in-depth crash injury data describing fatal and MAIS 3+ survivors have been examined. The following main points were noted:

The numbers of occupants killed in frontal impact is now slightly below those killed in side impact.

While the most commonly injured seating position was in the front seat on the struck-side, non-struck-side occupants formed a large minority of the injured group. The rear seating position was seldom used by seriously or fatally injured casualties.

The presence of an adjacent occupant modified the injury outcome of seriously injured non-struck-side survivors, increasing the rates of AIS 2+ injury to the thorax, abdomen and pelvis.

The collision severity used in the European legal crash test is below that where MAIS 3+ injuries are frequently sustained and considerably below typical fatal crash speeds.

Fatalities typically sustained AIS 3+ injuries to the head, thorax and lower extremity; survivors sustained their AIS 2+ injuries most commonly to the lower extremity as well as the thorax and head. The pattern of these injuries varied little between collision partners.

The incidence of base-of-skull fractures and brain stem injury was noted amongst the fatalities indicating a need to confirm that injury assessment criteria are appropriate for head injury sustained from lateral loading. Most of the fatalities with head injury sustained a focal lesion although any accompanying non-focal lesions may be under-reported in the post-mortem reports.

Lower limb injuries were most common to the pelvis but femur and tibia fractures were also frequent. Femur and tibia injuries are not assessed by existing legislative side impact dummies.

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