AN OVERVIEW OF UPPER EXTREMITY INJURIES TO CAR OCCUPANTS IN UK VEHICLE CRASHES

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ABSTRACT

To date, little is known about the biomechanics and epidemiology (in car crashes) of upper extremity injury and yet this body region, consisting of the shoulder, arms and hands is perhaps the most useful and versatile segment of the human body. Injury to this region is rarely life threatening but can produce impairment and disability.

In this study, specifically AIS 2+ upper extremity injuries (most of which were fractures) were examined. In frontal struck side and rollover crashes, the risk of these injuries was found to be higher than that of AIS 3+ injuries to the head, chest or abdomen.

In frontal crashes the outboard limb was the most frequently injured at AIS 2+. Shoulder injury sources were identified as the seat belt and wrist-hand injury sources were identified as 'fling' into the side door structures and A-pillar. Injury contacts and mechanisms were difficult to determine for arm and forearm injuries and future study of x-rays to determine the fracture load paths was recommended. Struck side occupants also sustained AIS 2+ injuries predominantly to the outboard limb, associated with impact to intruding side structures. The inboard limb however, was injured frequently and there were indications that those injuries were caused by interaction with an adjacent occupant.

This study has produced a biomechanical reference, perhaps for the first time, of the types of upper extremity injuries that occur in crashes and provides a comparison reference which can be used to assess the contribution of airbags toward upper extremity injury.

THE UPPER EXTREMITIES, CONSISTING OF THE SHOULDER GIRDLE, arms and hands, in terms of movements are the most versatile segments of the human body as Backaitis and Hicks (1996) observe. They are an important part of the musculoskeletal system that can perform an amazing multitude of functions.

There is little available published data on the types and severities of upper extremity injuries in a traffic crash predominantly because such injuries rarely involve any degree of 'threat to life'. Furthermore, because of the versatility and functional properties of this body region, it is acknowledged that mitigation of this type of injury is potentially extremely difficult to achieve because of the variety of positions each arm can adopt both in a crash and indeed under normal travel.

Some studies have observed that the upper limb is particularly vulnerable in a rollover crash. For example, Mackay and Tampen (1970) found that 38% of drivers received injuries to the upper extremity which was the third most commonly injured body region. Similarly, Hight et al (1972) found that 48% of the occupants in rollovers sustained upper limb injury. More recently, a study by Teanby et al (1995) reports on the risk of upper limb injuries through ejection in a rollover crash.

However, attention to upper extremity injury is currently focused on the issue of interaction with a deploying airbag and several studies have highlighted a problem in this respect. Huelke et al (1994) observed that steering wheel airbag deployments can fling the hand-forearm into the instrument panel, rear-view mirror or windshield as well as cause contusions, abrasions and burns through direct interaction with the airbag. More recently, Huelke et al (1997) reviewed some 540 crashes in which the steering-wheel airbag deployed and found that 38% of drivers sustained some level of upper extremity injury. While the majority of these injuries were of a minor nature, there were reported cases of fractures to the radius, ulna and metacarpal bones all related to airbag deployments. Further, fractures were ascertained to have been caused by fling of the arm into interior vehicle structures.

In response to this, other studies have examined the feasibility of instrumenting the Hybrid III dummy in order to measure accelerations and bending moments as a potential injury index for arm fracture (Saul et al 1996).

However, there are no other available studies which examine the frequency and nature of upper extremity injuries. Specifically, the magnitude of the problems with airbags cannot be put into perspective because there is no previous documentation of the upper extremity injury situation in impacts other than rollovers. The aim of this study is therefore to provide a biomechanical reference for upper extremity injury in a sample of UK vehicle crashes.

METHODOLOGY

The data used in this paper 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 of accidents from the East and West Midlands holds information on some 5,362 crashed vehicles containing 8,970 occupants who sustained between them 29,437 injuries. Weighting factors can be applied to this data to ensure that analyses are representative of the crash population.

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

(iii)   that there was an injury in the vehicle according to the UK Police system of injury classification.

About 80% of serious and fatal accidents in each study area were investigated along with 10-15% of slight accidents according to the UK Police system of injury classification. The resulting sample represents all levels of injury outcome while being

biased towards more serious injuries. All occupants considered for this study were restrained by conventional three-point seat-belts. Medical data concerning each occupant was obtained from hospitals and each occupant was also requested to complete a questionnaire which provided additional data several days after the crash. 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).

RESULTS

GENERAL DEFINITION OF THE SAMPLE - In the sample of crashes from 1983-1992 there were a total of 4,717 occupants known to be belted with known injury outcome (MAIS 0-6). These cases were weighted to reflect the distributions of injuries in the population. The distribution of seating positions is shown in figure 1. 98% of all belted occupants were seated in the two front outboard seating positions and these occupants were chosen for study. It should be remembered that all cars in this sample were right hand drive and none were equipped with airbags.

Figure 1; Distribution of Seating Positions
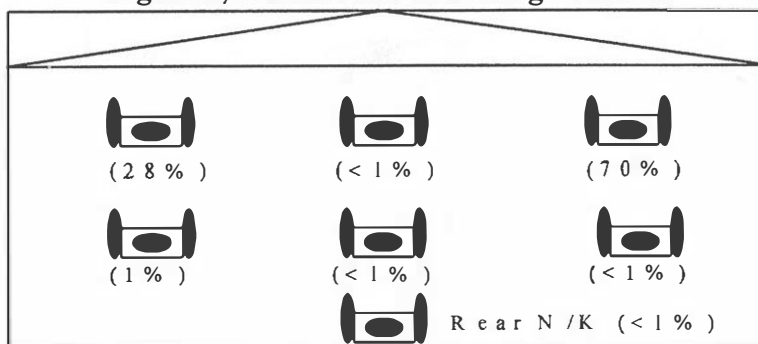
The most severe impact experienced by each occupant was defined and is shown in figure 2.

Figure 2; Impact Classifications for Occupants
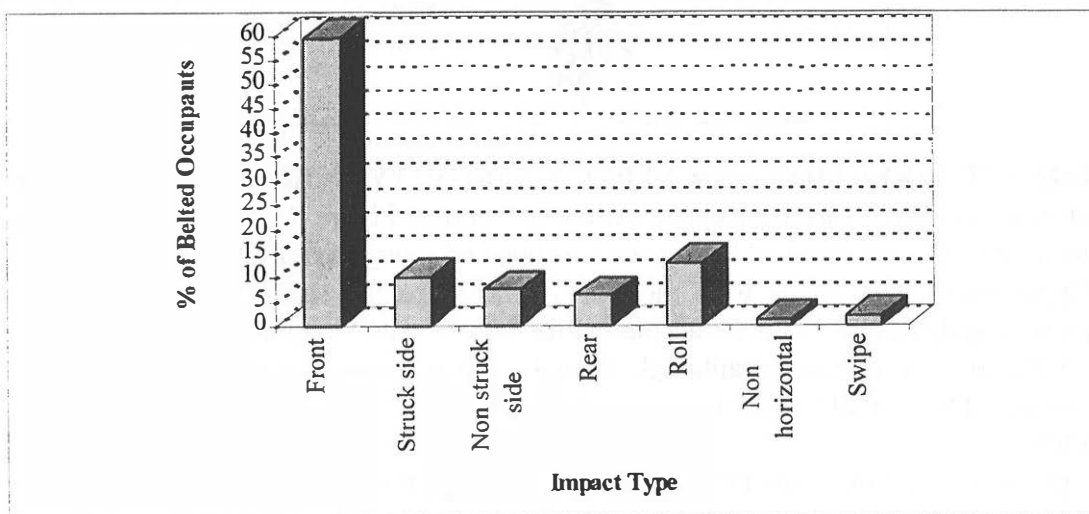
A struck side impact was one where the occupant sat adjacent to the impacted side and non struck side was where the occupant sat opposite the point of impact. Rollover was defined as a condition where the vehicle rolled more than 90 degrees from its' longitudinal or lateral axis. Swipes include impacts across the front or side of the car where there was no substantial engagement of the vehicle structure. Most occupants experienced a frontal crash (60%). The second most frequent impact experienced was a rollover (13%) and then a struck side impact (10%).

DEFINITION OF UPPER EXTREMITY IN THIS STUDY - Figure 3 illustrates the main skeletal components of the upper extremity. In this study the upper extremity has been divided into 5 sections. The shoulder comprises the skeletal components of the acromion, scapula and clavicle together with the various joint articulations which allow movement between the bones including the glenohumeral joint. The arm consists of the humerus and its associated muscles and soft tissues. The forearm consists of the radius and ulna, its associated soft tissues and includes the articular joint with the humerus. The wrist comprises the carpal bones and their associated articular surfaces. The hand includes the phalanges, metacarpals and associated soft tissues.

**Figure 3; The Upper Extremity**
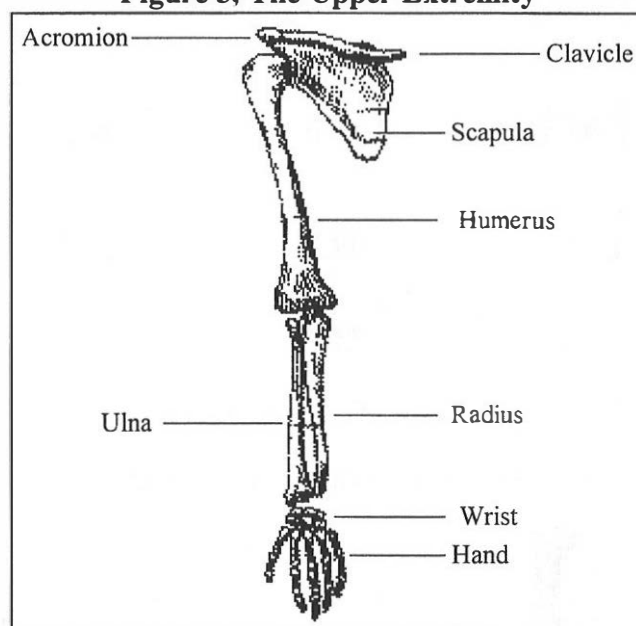
IMPACT DIRECTION AND UPPER EXTREMITY INJURY - 42% of belted front seat occupants sustained upper extremity injuries. Figure 4 overleaf shows how those injuries were distributed by impact direction and injury severity.

Upper extremity injuries were most prevalent in frontal, struck side and rollover impacts. Together, those impacts accounted for 85% of AIS 1+ injuries, 92% of AIS 2+ and 97% of AIS 3 injuries, although frontal impacts alone account for most upper extremity injuries at all levels of severity (57% of AIS 1+, 61% of AIS 2+, 71% of AIS 3 injuries).

The greatest reduction in the number of upper limb injuries would therefore be realised by preventing those that occur to occupants in frontal crashes, rollovers and seated on

the struck side. Those were also the impact types occurring most frequently for all occupants in the study sample.

Figure 4; Impact Direction and Injury Severity
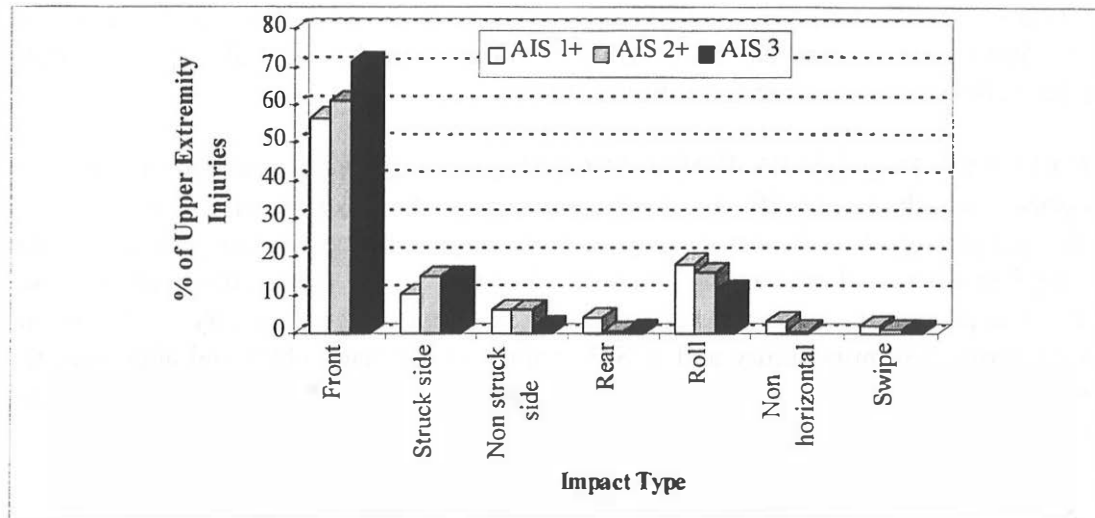
In frontal, struck side and rollover crashes, 86% of upper limb injuries were at the AIS 1 level. Those injuries are shown below in table 1.

Table 1; AIS 1 Upper Extremity Injuries - Front, Struck Side, Roll

AIS 1 Injury	% of Total
Abrasion NFS	<1%
Abrasion Minor	17%
Contusion NFS	3%
Contusion Minor	46%
Laceration NFS	2%
Laceration Minor	26%
Penetrating Injury (No Tissue Loss)	<1%
Degloving Injury NFS	<1%
Degloving Injury < 10%	<1%
Elbow Sprain	<1%
Elbow - Interphalangeal Dislocation	<1%
Shoulder Sprain	2%
Sternoclavicular Joint NFS	<1%
Wrist NFS	<1%
Wrist Sprain	3%
Finger NFS	<1%
Finger Fracture	1%
Finger Sprain	<1%
Total Injuries	**100%**
Unweighted Total AIS 1 Injuries in Sample = 2276	

Most AIS 1 injuries were minor surface injuries. Minor abrasions made up 18%, minor contusions 49% and minor lacerations 28% of these injuries. Such injuries are not without cosmetic considerations but are less important to the upper limb than to the face where they cannot be easily hidden. If injury reduction is to be prioritised, then the AIS 2 and above (AIS 2+) injuries are those to be considered because these are the ones with the greatest potential for impairment. AIS 2+ injuries formed 14% of all upper extremity injuries in frontal, struck side and rollover crashes.

RATES OF INJURY BY BODY REGION - In crash safety research, much effort has gone into addressing life threatening injuries to the head, chest and abdomen in frontal and side crashes. However, as those body regions become better protected so the relative importance of preventing impairing injuries to the extremities will increase. Figure 5 compares the rate of sustaining AIS 2+ upper extremity injury to the risk of AIS 2+ lower extremity injury and AIS 3+ injury to the head, chest and abdomen, for belted front seat occupants in frontal, rollover and struck side impacts. The unweighted number of occupants in each crash type is shown at the top of the graph.

Figure 5; Injury Rates by Body Region
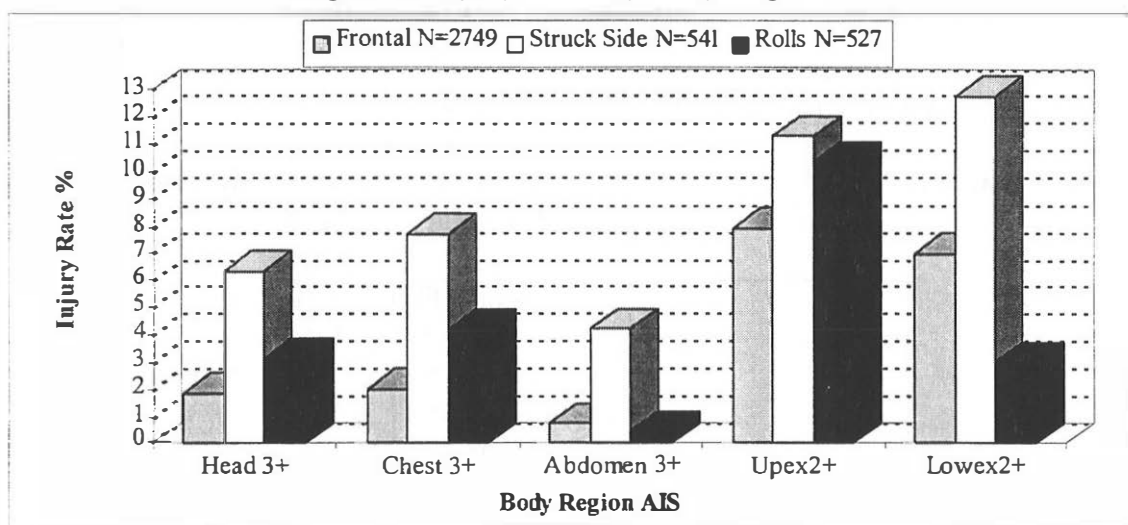
The rate of AIS 2+ upper extremity injury is quite clearly greater than the rate of AIS 3+ injury to the head, chest and abdomen for all types of impact. Struck side crashes show a higher rate of upper extremity injury than either frontal crashes or rollovers. For occupants in frontal and rollover impacts the AIS 2+ upper extremity injury rate is higher than that for the lower extremity and this result alone emphasises the importance of considering upper limb injury.

TYPES OF AIS 2+ UPPER EXTREMITY INJURIES - The majority of AIS 2+ upper extremity injuries were specified anatomically and these are shown in table 2 below. The table is a reference for the kinds of injuries that are perhaps more important for consideration and also provides information on the relative frequency with which each region of the upper extremity is injured in differing impacts.

Table 3; AIS 2+ Upper Extremity Injuries by Impact Direction

UPPER EXTREMITY REGION	IMPACT DIRECTION		
	FRONT	STRUCK-SIDE	ROLL
SHOULDER			
Major Abrasions	<1%		
Major Contusions			1%
Major Lacerations			1%
Glenohumeral Joint Dislocation	<1%	4%	
Sternoclavicular Joint Dislocation	1%	3%	
Acromioclavicular Joint Dislocation		8%	
Clavicle Fracture	15%	33%	62%
Acromion Fracture	<1%		
Scapula Fracture	1%	2%	
% of Total Injuries	**18%**	**50%**	**64%**
ARM			
Humerus Fracture	9%	15%	7%
% of Total Injuries	**9%**	**15%**	**7%**
FOREARM			
Radial Nerve Laceration	<1%		
Elbow Dislocation into Radial Head	1%	5%	
Radius Fracture	26%	13%	10%
Ulna Fracture	19%	11%	12%
Traumatic Amputation		1%	
% of Total Injuries	**46%**	**30%**	**22%**
WRIST			
Dislocation at Radiocarpal, Intercarpal or Pericarpal Articulations	1%	<1%	<1%
Wrist Crush	<1%		
% of Total Injuries	**1%**	**<1%**	**1%**
HAND			
Major Abrasions	2%		
Major Contusions	<1%		
Tendon Laceration	7%		2%
Carpal-Metacarpal or Metacarpal-Phalangeal Dislocation	1%		3%
Carpal or Metacarpal Fracture	14%	4%	
Finger Amputation	1%		1%
% of Total Injuries	**25%**	**4%**	**6%**
Total Injuries	**100%**	**100%**	**100%**
Unweighted Total AIS 2+ Injuries in Sample	**405**	**127**	**87**

It can be seen from table 3 that most AIS 2+ injuries are fractures whatever the impact type. In frontal crashes 85%, in struck side 77% and in rolls 92% are fractures.

In frontal crashes the most frequently injured region is the forearm (46% of injuries) and radius fractures make up the majority of forearm injuries (60%) followed by ulna fractures (38%). In struck side crashes 42% of forearm injuries are radius fractures and 38% are ulna fractures. In rollover crashes 44% of forearm injuries are radius fractures with 56% to the ulna.

The shoulder is the region most frequently injured in struck-side crashes (50%) and rollovers (64%) but less frequently injured in frontal crashes (18%). The major shoulder injury is a clavicle fracture which makes up 80% of shoulder injuries in frontal impacts, 66% of shoulder injuries in struck side impacts and 97% of shoulder injuries in rollovers.

Hand injuries are rare in rollovers and struck sides but form a quarter of injuries in frontal crashes.

Arm injuries are most common in struck side impacts (15% of AIS 2+ injuries) but are not common in frontal and rollover crashes.

INJURY CONTACTS AND MECHANISMS OF INJURY - Occupants in Frontal Crashes - Causes of injury to the upper extremities are notoriously difficult to determine in real world crashes. Dents and scuffs are frequently found on upper interior structures. However, they may not be readily correlated with upper extremity injuries due to the unpredictable kinematics. In rare instances, a small windscreen fracture is likely due to a flailing limb if it correlates with a hand injury to a belted occupant and there is little windscreen level intrusion. However, in frontal crashes the upper limbs flail forward and sideways with possible contact on the facia, the steering wheel and column switchgear, the windscreen or the side structures of the interior such as the A-post, side door structures and side door glass. In general it is rarely possible to identify the exact location of upper limb contact and therefore to define the injury mechanism.

Despite these uncertainties, there are other pointers which can be used to determine sources of injury. These concern the rates of injury between the inboard and outboard limbs and the different nature of the envelopes in which they are free to move. In frontal crashes, outboard refers to the upper limb closest to the front door. With right hand drive cars in the UK this will be the right limb for drivers and the left limb for front seat passengers. Table 4 shows the location of AIS 2+ upper extremity injury to front seat occupants by limb in frontal crashes

Table 4; Location of AIS 2+ Upper Extremity Injury to Front Seat Occupants in Frontal Crashes

Injury Location	Inboard Limb Only	Outboard Limb Only	Both Limbs	Total	Unweighted Number of Occupants with Injury	Significance of Bias to Outboard Limb (unweighted sample)
Shoulder	13%	86%	1%	100%	75	p < 0.001
Arm	27%	68%	5%	100%	58	p < 0.001
Forearm	38%	59%	3%	100%	133	p < 0.001
Wrist-Hand	21%	77%	2%	100%	68	p < 0.001

It is clear from table 4 that both limbs are rarely injured together. The outboard limb is injured more often than the inboard, a result which is shown to be statistically significant using chi-squared tests. This effect is particularly strong for the shoulder.

The environment for the inboard and outboard shoulder differs in that the diagonal section of the seat belt lies over the outboard shoulder.

The environment for the other parts of the inboard and outboard limb also differs. The outboard limb is immediately adjacent to the stiff structures of the door, door glass, window frame and A-pillar and it would be reasonable to assume that contact on those structures are responsible for the bias toward outboard limb injury; But care needs to be exercised in any such conclusion. Greater facia intrusion in front of the outboard limbs could increase the likelihood of contact and be responsible for the injury bias. Unfortunately, intrusion information for the occupants' inboard side was not available in this study. Information on what the upper limbs impacted is therefore at a premium.

Information on how the upper limbs were impacted was also difficult to determine in this study since the precise medical detail needed to determine the types of forces fed through the limb was mostly unavailable.

Struck Side Occupants - One situation where injury sources can perhaps be predicted with greater certainty are those cases where the occupant is seated on the struck side in a side impact. For struck side occupants, a greater number of injuries to the outboard limb would be expected given that it is immediately adjacent to the side structures of the car. Table 5 shows that both limbs are rarely injured together and the outboard limb is injured more often than the inboard. Chi-squared tests show this result to be statistically significant for the shoulder, arm and forearm. No statistic was calculated for occupants with wrist-hand injury because of the small sample size. The outboard bias was particularly strong for the shoulder. Overall, 83% of all struck side occupants with outboard limb injury experienced intruding adjacent side structures.

Table 5; Location of AIS 2+ Upper Extremity
Injury to Front Seat Occupants Seated on the Struck Side

Injury Location	Inboard Limb Only	Outboard Limb Only	Both Limbs	Total	Unweighted Number of Occupants with Injury	Significance of Bias to Outboard Limb (unweighted sample)
Shoulder	20%	80%	0%	100%	54	$p < 0.001$
Arm	38%	54%	8%	100%	22	$p < 0.001$
Forearm	40%	57%	3%	100%	26	$p < 0.01$
Wrist-Hand	29%	57%	14%	100%	9	No statistic calculated

What was unexpected was that injuries did occur to the inboard limb. In total, 34% of AIS 2+ upper extremity injuries were to the inboard limb and 28% of occupants with AIS 2+ upper limb injury had sustained at least one AIS 2+ injury to the inboard limb. For only two of these occupants was there a clear indication of the injury source, the evidence being a buckled adjacent front seat back caused by the struck side occupant being pushed across the car into the adjacent seat. However, 85% of struck side occupants with inboard arm injury had an occupant sitting in the adjacent front seat; 76% of those adjacent occupants were belted. Hill et al (1991) have already shown that

belted occupants on the non struck side can slip out of the diagonal section of the belt to contact the struck side occupant therefore it is quite possible that the adjacent occupant was the cause of many inboard upper extremity injuries.

Occupants in Rollovers - In rollover crashes the upper limbs can flail around in all directions and can also be ejected through the side door glass aperture. The presence of dirt and grit in wounds can sometimes indicate whether a limb has been ejected but such evidence is extremely scarce because occupant medical notes rarely list this level of detail. The complicated upper limb kinematics during rollover precludes any meaningful analysis of injury contact sources using the present data set. However, table 3 showed that most AIS 2+ injuries were clavicle fractures, indicating that contact on the side door or seat belt loads could account for the majority of injuries rather than upper limb ejection.

INTRUSION AND EES IN FRONTAL CRASHES - Intrusion and collision severity as measured by the Equivalent Energy Speed (EES) were examined for AIS 2+ upper extremity injuries to the outboard limb. The outboard limb was chosen because it was the most frequently injured. Figure 6 shows the outboard facia intrusion associated with occupants who sustained arm, forearm and wrist-hand injury. The shoulder was not considered because it was felt that the effects of intrusion would be minimal for injury to that body region. The unweighted number of occupants with injury to each region is shown at the top of the graph. Intrusion values were not known for all occupants.

Most occupants with outboard wrist-hand injury (77%) had experienced no intrusion at the outboard facia, whilst no intrusion was the case for only 9% of occupants with outboard arm injury and 19% of those with outboard forearm injury. That means most AIS 2+ outboard wrist-hand injuries occurred without corresponding arm and forearm injuries to the same limb.

Intrusion was highest for occupants with arm injuries as 72% of those experienced intrusion over 25 cm. Occupants with forearm injuries were generally in a lower intrusion environment because 55% experienced less than 25 cm of intrusion which means that at least half of AIS 2+ forearm injuries occurred without a corresponding AIS 2+ arm injury to the same limb.

Figure 7 shows the EES experienced by occupants with AIS 2+ outboard upper extremity injury. The unweighted number of occupants with injury to each region is shown at the top of the graph. EES values were not known for all occupants.

Quite clearly forearm and arm injuries occurred at higher speeds than shoulder and wrist hand injuries. Only 10%-20% of arm and forearm injuries occurred below 40 km/h. Few occupants with arm injuries (8%) and few with forearm injuries (20%) experienced an impact below 40 km/h, while 55% of those with shoulder and 48% of those with wrist-hand injuries were in a crash below that EES. The majority of occupants with shoulder injuries (74%), wrist-hand injuries (85%) and arm injuries (62%) experienced an EES below 55 km/h while half of occupants with forearm injuries (50%) were in a crash above 55 km/h.

Figure 6; Outboard Facia Intrusion Related to Occupants with AIS 2+ Outboard Upper Extremity Injury
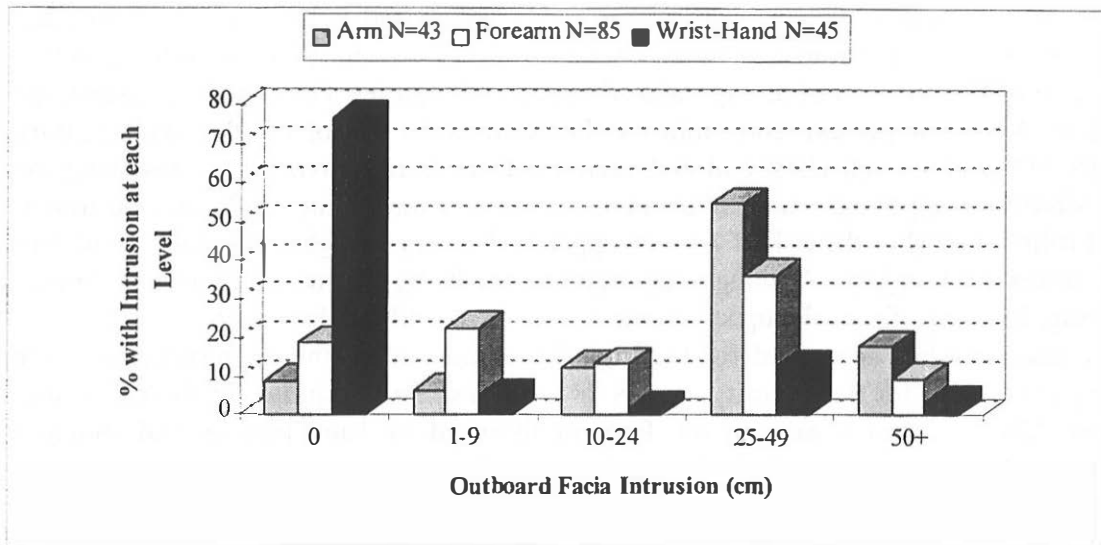
Figure 7; EES Related to Occupants with AIS 2+ Outboard Upper Extremity Injury
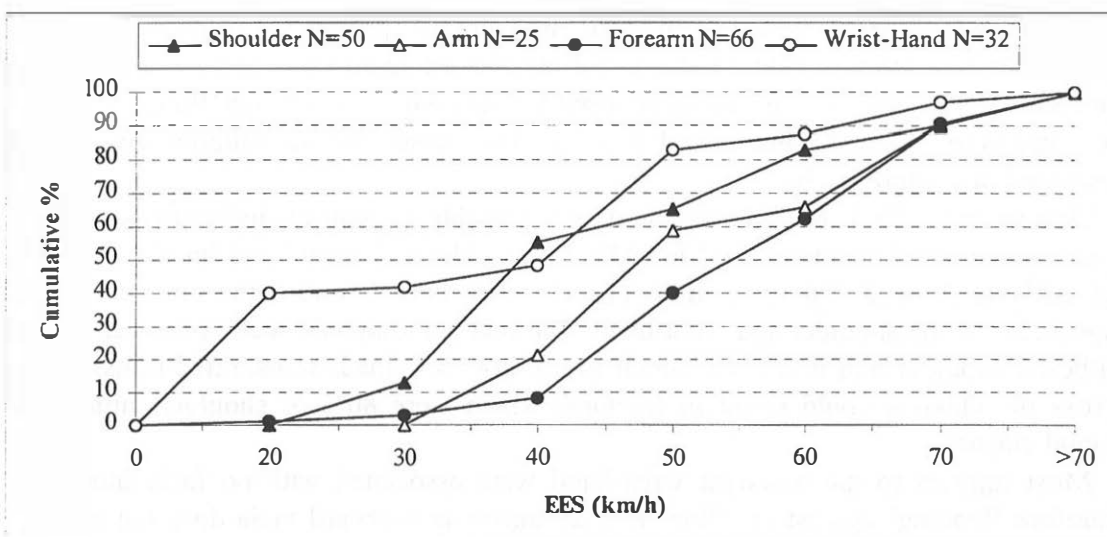
DISCUSSION

This study has examined the nature of upper extremity injuries in a sample of UK car crashes. The study has concentrated specifically on those injuries rated as AIS 2 and 3, most of which were fractures. Not all AIS 2+ injuries carry long term impairment but even minor structural injuries can be important to what is perhaps the most versatile segment of the human body. Because of the paucity of information on the types of upper extremity injuries which occur in crashes, a list of AIS 2+ injuries has been compiled as a biomechanical reference for future work. Specifically, there is a need to address impairments and disability outcomes which are associated with these types of injuries and a follow-up study is planned in this regard.

One of the major findings of the present study is that AIS 2+ upper extremity injuries do in fact occur frequently in frontal, side and rollover impacts. They are not a new phenomenon only associated with airbag deployments and it is highly recommended that this study be compared to future studies of airbag equipped cars in order to define the size of the problem of airbag induced upper limb injuries. For belted occupants, the risk of AIS 2+ upper extremity injury is higher than the risk of life threatening injury (AIS 3+) to the head, chest and abdomen yet there is no provision for assessing the possibility of upper extremity injury in any current or impending crash tests. In frontal and rollover crashes the risk of AIS 2+ upper limb injury is higher than the risk of AIS 2+ lower limb injury. Although leg injuries are being addressed in frontal impact testing, in terms of risk, the upper extremity may be equally as deserving.

Frontal crashes accounted for the majority of impacts in this representative study sample and also for the majority of AIS 2+ upper extremity injuries. In frontal crashes most AIS 2+ injuries were to the forearm followed by hand injuries and shoulder injuries. Arm injuries, all of which were humerus fractures, were not common.

It was recognised that contact sources and injury mechanisms were extremely difficult to isolate. The lack of contact evidence effectively precluded the accurate determination of many sources of injury while the precise medical detail needed to determine the loading path through the limb was mostly unavailable. Often, identification of fracture types can indicate the way in which loads were imparted. A Colles fracture for example would indicate that there was palmar extension of the wrist, while a Smith's fracture would indicate palmar flexion against a hard structure such as the facia. These 'bracing' injuries as opposed to those where the limb is 'flung' against a hard structure might be determined if x-rays indicating fracture patterns were to be examined in a future study.

Despite these limitations however, it was possible to gain an indication of injury contacts and mechanisms at least for AIS 2+ shoulder and wrist-hand injuries because the analysis showed that upper limb injuries were biased toward the outboard limb, especially for the shoulder and wrist-hand. The seat belt diagonal section lies across the outboard shoulder and it is not difficult to see how belt loads transmitted transversely across the clavicle could result in fractures which were 80% of shoulder injuries in frontal crashes.

Most injuries to the outboard wrist-hand were associated with no facia intrusion, therefore 'bracing' against or 'fling' into an intruding outboard facia does not explain the reason for the predominance of these injuries to the outboard limb. Additionally, if the steering wheel or windscreen were major causes of wrist-hand injuries we might expect a more even distribution between inboard and outboard limbs. When the upper limbs flail forward and sideways, the major differences in the flail envelope are that the outboard wrist-hand is immediately adjacent to the stiff structures of the door, door glass, window frame and A-pillar and it would be reasonable to assume that 'fling' onto those hard structures was responsible for the bias toward outboard wrist-hand injury.

Any safety device which effectively directs the outboard limb into these hard structures (such as a deploying airbag) might actually increase the likelihood of wrist-hand injury. Similarly this might also occur for injuries to the forearm if transverse loads caused by 'fling' into the side structures are identified as a major injury mechanism. Although 80% of forearm injuries occurred over 40 km/h, airbags generally

deploy below this speed, so lower speed crashes of airbag equipped cars also need to be monitored to ensure there is no increase in forearm injury. It should be remembered that the majority of real-world crashes occur below 40 km/h so the exposure of the accident population will be high and any increase in injury risk will be important.

Levels of outboard facia intrusion associated with AIS 2+ injuries to the outboard limb suggest that most wrist-hand injuries occurred without either forearm or arm injury and that at least half of forearm injuries occurred without corresponding arm injury. The distributions of EES for arm and forearm injuries are very similar but arm injuries generally occurred with much higher levels of intrusion. However, care should be exercised in speculating that only reducing intrusion would reduce forearm and arm injuries because injury severity is dependent on the rate of application of impact loads which are not always related to intrusion levels.

Although frontal crashes account for most upper extremity injuries the rate of sustaining AIS 2+ upper limb injury is one and a half times higher for struck side occupants. For these occupants most of the AIS 2+ injuries were to the shoulder followed by forearm injuries and then those to the arm. Wrist and hand injuries were not common.

For struck side occupants the distribution of injuries between inboard and outboard limbs also showed a bias toward outboard limb injury and this effect was greatest for shoulder injury. Most occupants with outboard limb injury (83%) had experienced intrusion to the side structure and lateral loading on the shoulder. Like frontal crashes, the clavicle formed the majority of shoulder injuries but its fracture will have been caused by a different kind of loading. This side loading condition also produced some acromio-clavicular joint dislocations which were not found in frontal crashes.

The intruding side structure can easily be associated with outboard limb injuries but given the struck side occupants' kinematics toward the impact site it was initially difficult to see how the inboard limb could be injured at all. Yet one third of AIS 2+ injuries were to the inboard limb. Closer investigation showed that most of the occupants with inboard injury had another occupant sitting next to them most of whom were belted. A study by Hill et al (1991) has already shown how a non struck side occupant can move out of the diagonal section of the seat belt to contact the struck side occupant and it is highly likely that impact by non struck side occupants was the cause of inboard upper extremity injuries. If future side impact testing is to assess the potential for injury to the upper extremity then instrumentation of both the outboard and inboard upper limb would be desirable together with the use of a belted surrogate sitting on the non-struck side.

In many ways, this study of upper extremity injuries has raised more questions than answers, especially concerning the sources and mechanisms of injury. In summary, such injuries occur through several possible mechanisms and these are not always easy to establish in a retrospective study such as this. A future study should consider more in-depth medical information. Certainly, these injuries are not seen as a new phenomenon in the advent of new safety technology such as airbags and because airbag interaction has been found to be one source of injury does not preclude their occurrence through other sources. Any moves to instrument a dummy for detection of loading would need

to consider this. Finally the issues of associated impairment and disability need to be considered. A future study examining this issue in-depth is now being planned.

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