

# UPPER EXTREMITY INJURY STUDY: RECOMMENDATIONS FOR INJURY PREVENTION PRIORITIES

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## ABSTRACT

A large-scale accident study of injuries in Phases four, five and six of the UK CCIS accident database showed that upper extremity injuries were increasing in frequency in frontal impacts, particularly when an airbag deployed. However, it was difficult to identify injury mechanisms and costs from the information in the database. Therefore, an in-depth case-by-case study of upper extremity injuries has been undertaken to determine the mechanisms, costs and long-term consequences (disability or impairment) of the injuries, in order to set priorities for injury prevention. The study has been undertaken in three phases:

- A retrospective study of medical notes (74 cases), giving more detail on the specific upper extremity injuries and the mechanisms that could have caused them.
- A prospective study of patients recruited at an Emergency Department (25 cases), with a follow-up of up to six months to assess longer-term consequences of the injury.
- A review of physiotherapy treatment case notes (288 cases), looking at cases that may not have been assessed at a hospital Emergency Department.

Four hospitals and three physiotherapy practices were recruited to this study. Evaluations of short and long-term costs and residual impairment resulting from these injuries have been made. The long-term costs were assessed through surgical costs, cost of other treatment and time off work, whilst impairment was assessed qualitatively by range of motion, pain and functional impairments and quantitatively using the American Medical Association Guides.

This study offers a unique insight into the mechanisms causing and long-term consequences arising from specific upper extremity injuries. From this, priorities for injury prevention are presented. A potential limitation of the study is the extent to which the three samples are representative of the UK population.

## INTRODUCTION

An initial analysis of accident data (from Phases four, five and six of the Cooperative Crash Injury Study, CCIS (Mackay, 1985)) considered injury patterns for a variety of crash scenarios (e.g. frontal, side and rear impacts) and occupants, identifying priorities for further research. This stage of the research used the Abbreviated Injury Scale (AIS; AAAM, 1990) to assess injury severity, which is based on the threat to life. No consideration was given to the long-term outcomes or the disabling effects of the injuries seen. The top priorities were identified as MAIS 3+ (MAIS  $\geq 3$ ) thoracic injuries sustained by front occupants in frontal impacts and AIS 2+ upper extremity injuries sustained by drivers in frontal impacts where an airbag deployed. Upper extremity injuries were not identified as a priority in frontal impacts without airbag deployment. It was not clear from the accident analysis if airbags were contributing, in some way, to upper extremity injury risk. One alternative is that the relative importance of upper extremity injuries in frontal impacts with airbag deployment increases over impacts with no deployment as the airbag is effective at reducing the incidence of injuries to other body regions. Also, airbag equipped vehicles are effective at reducing the risk of fatal head injuries, so it may be that casualties who would have been fatally injured are now surviving accidents and their arm injuries may therefore be more likely to be recorded.

Following this initial analysis, a case study was conducted, which looked at these two priority areas in greater depth and showed that both needed further research. The upper extremity injuries were shown in many cases not to be a direct result of the airbag's deployment and had many locations (on the arm) and many different possible mechanisms.

To determine if similar findings had been found in other studies and to provide direction for further research in this area, accident analyses in the published literature were reviewed. From this review of the published material it seemed that there was general agreement that airbag deployment did not reduce upper extremity injury

risk (Cuereiden *et al.*, 2001, Huere *et al.*, 2001; Morris *et al.*, 2001; Lenard and Welsh, 2001; Siegel *et al.*, 2001; Kirk *et al.*, 2002; Jernigan and Duma, 2003 and Kent *et al.*, 2005). However, this review of previous and current research also identified several limitations of the investigations conducted prior to this study:

- Only hard tissue upper extremity injuries have been considered, not soft tissue injuries with low AIS scores. To overcome this deficiency, there is a need to investigate the frequency and effects of such injuries in terms of treatment and impairment rather than threat to life
- Only drivers' injuries have been investigated, in-depth, within the previous research.
- The CCIS samples accidents where a vehicle, which is less than seven years old, was towed-away. Therefore, the CCIS is biased towards more severe accidents. By investigating all injuries prospectively this bias can be avoided.
- The previous case study indicated that there was often no information about the specific types of injury sustained or their cause or mechanism.

The initial objective of this study was to address the limitations of the research conducted to date. Studies were proposed to investigate hard and soft tissue upper extremity injuries, sustained by drivers and passengers of cars or car-derived motor vehicles, using data from the CCIS and other sources. Particular attention was given to trying to identify mechanisms of injury and specific injury information, such as associated costs and impairments. Based on this information, the final objective was then to determine priorities for future injury prevention. If appropriate, the injuries identified could then be investigated further potentially using PMHS tests and possibly volunteer tests to improve biofidelity requirements for crash test dummies and develop injury criteria for use in regulatory approval tests. The ultimate aim of this work was to encourage effective countermeasures to be designed so as to reduce the incidence of upper limb injury in the future.

The study was conducted in three parts: a retrospective hospital study, a prospective hospital study and a physiotherapy study.

For these studies the upper extremity was defined as the arm and shoulder (where shoulder included the clavicle).

### **Retrospective Study**

From a review of the literature related to vehicle safety, it was observed that little is known about the nature of upper extremity injuries sustained in

frontal crashes in terms of associated impairment or difficulty of treatment and hence as yet, no particular injury has been identified as a priority. It was therefore necessary to select all cases where an upper extremity injury was sustained in a frontal impact.

The in-depth retrospective study required very specific knowledge of: the characteristics of the casualty, the nature and severity of the accident, any contact evidence within the car that could be correlated with the upper extremity injury mechanism, the seating position and seat-belt status of the injured individual and, whether any additional or supplementary restraint devices, such as an airbag, deployed.

The CCIS database was considered as an ideal source of accident information. However, additional information was required concerning the upper limb injuries. Therefore, CCIS cases were revisited and the judgement of medical personnel (mainly registrars and consultants) was sought.

### **Prospective Study**

The prospective study was to provide similar information to the retrospective study but would review casualty information at the time of presentation at the hospital with the potential for a follow-up meeting. This offered the potential to get more specific injury information and a more accurate evaluation of the resulting impairment than from the retrospective study, where impairment was estimated from a review of the patient notes only. Through recruiting patients directly from Accident and Emergency Wards, the prospective study would avoid the stratification bias in the CCIS. However, it was not possible to link cases with the detailed accident and vehicle information, as would be available with CCIS cases. Instead a first-person accident description was obtained from the participant. This offered the additional opportunity to gain information on occupants' perceptions of their accident directly from interviews with the patients.

### **Physiotherapy Study**

It was thought that there may be, proportionally, very few soft tissue injuries to the upper extremities evident in the CCIS data due to the case selection criteria used. It was also of concern that hospital records may indicate the length of stay in hospital associated with a particular injury but may not give any indication of the long-term effects and treatment associated with that injury. This would risk giving an underestimate of the potential whole cost of the injury. Therefore, another source was considered to be necessary to complete the

information on the disabling nature and societal costs associated with upper extremity injuries. For this reason, this third study was set-up to identify:

- Upper extremity injuries sustained as a result of a road traffic accident that resulted (directly or indirectly) in the patient requiring physiotherapy treatment;
- The priorities for prevention amongst those injuries based on: frequency, final level of impairment, duration of temporary impairment and the cost to society in terms of length and intensity of treatment required

## METHOD

### Retrospective Study

The retrospective study used existing accident information for individual casualties who were known to have sustained a specific upper limb injury and enhanced this with additional information on their injury and, where possible, on the injury mechanism. The study involved a retrospective examination of casualties admitted to selected hospitals during the period from 1998 to 2005. This retrospective investigation included: a review of medical notes and imaging (X-ray) results, and determination of the costs, the functional impairment resulting from the injury and the mechanism necessary to produce that injury.

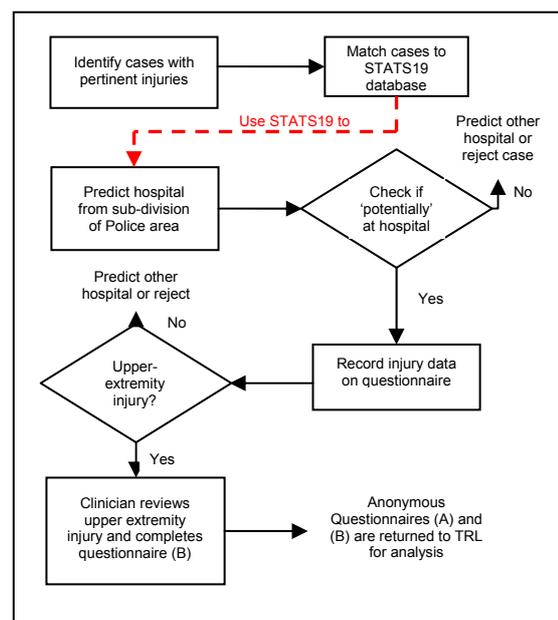
The additional detailed information on the injuries to the selected casualties was provided by medical researchers, primarily an Emergency Medicine Consultant, Orthopaedic Surgeon and Trauma Surgeon, sub-contracted from the hospitals local to the cases selected. The injury information from the medical researchers was complemented with input from the accident investigation researchers at TRL on the specific accident details. The assessments and conclusions are therefore those made by a collaboration of medical, accident investigation and biomechanics researchers.

The hospitals that contributed to the study were the City Hospital in Nottingham and the Heartlands, Solihull, and Selly Oak Hospitals, located in the Birmingham area. The Loughborough and Birmingham University based accident investigation teams (Ergonomics and Safety Research Institute, ESRI and the Birmingham Automotive Safety Centre, BASC, respectively) also contributed to the study.

To assure that the confidentiality of personal information is retained, use of information, such as names and addresses, is regulated on a legal and ethical level in the UK. This presented a challenge for the retrospective study. To be able to link detailed crash data back to the notes for that patient

at a hospital (to give the detailed injury information), with retention of patient anonymity, two existing crash injury databases had to be used, firstly the Co-operative Crash Injury Study (CCIS) and secondly the STATS19. The STATS19 Database is a source of data concerning national (UK) road accidents (STATS19 ref).

The procedure for linking the upper extremity injury case to the patient's notes was as follows and is shown by the flowchart in Figure 1: After cases of interest were identified from the CCIS database, those cases were linked to the STATS19 record for the accident, based on crash date, time and region. The accident location (which is quite imprecise), date and time were then used to identify hospitals that the injured person was likely to have attended. The hospital records for all road traffic accidents (RTAs) around the date and time of the STATS19 record were extracted and those with appropriate age, gender and arm and shoulder injuries (there may have been more than one case) were selected. The injuries for these occupants were AIS coded by the ESRI or BASC accident investigation teams, in the same way as for the CCIS case. This injury coding was used to confirm that the patient notes were for the same person as was listed in the CCIS database. Although there was no guarantee that the two people were the same using this method, it was chosen because it was expected that the number of false matches would be very low and the anonymity of the patient was assured. To comply with the Data Protection Act and ethical requirements, TRL only received anonymous injury information from the hospitals and has only anonymous accident data in the CCIS database.



**Figure 1. Schematic of the process to identify casualties and investigate their upper extremity injury**

Ethical approval in line with the requirements of the UK Department for Health, Central Office for Research Ethics Committees (COREC), was granted at the study and site-specific level.

Front and side impacts were selected for further review. The selection criteria for these groups were:

Frontal impacts;

- Met the injury criteria, one impact only (or the most severe impact with some minor other impacts), no rollover, seat-belted, occupant at least 16 years old, front seat occupant (driver or front seat passenger)

Side impacts;

- Met the injury criteria, one impact (or the most severe impact with some minor other impacts), occupant seated on the struck side, no rollover, occupant at least 16 years old.

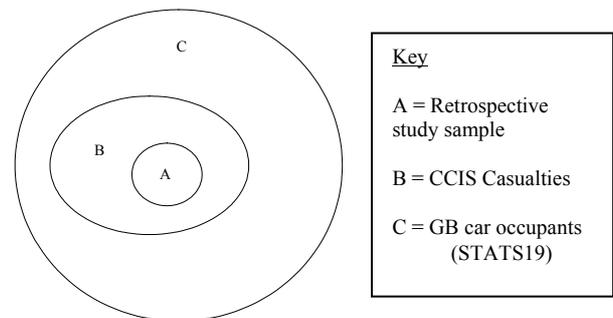
These two groups were principally different in that confirmed seat-belt use was not a selection criterion for side impacts. It was thought that confirming the use of a seat-belt in side impacts would be more difficult and less reliable than in frontal impacts and that arm and shoulder injuries would not be influenced by seat-belt use for occupants seated on the struck side.

Based on the inclusion criteria a group of the casualties from Phases five, six and seven of the CCIS were selected that had an upper extremity injury. However, at this stage, it was not known which of these selected casualties would have attended one of the contracted hospitals. To be a 'requested case', those CCIS cases, that met the study inclusion criteria, also had to have occurred in the police regions covered by either the Loughborough (ESRI) or Birmingham (BASC) accident investigation teams. In particular, cases were sought from the police regions that contained the hospitals which had agreed to participate in the study (Nottingham and Birmingham). The accident investigation teams involved in the study then had the responsibility of going to the participating hospitals and trying to identify the selected casualties who had attended there (from the requested cases). Overall, 65 cases were identified from the 227 that were requested (29 %).

It was expected that the main reason why cases were not found was that the casualty attended a hospital that was not participating in the study. In order to try and include more cases, some of the Phase seven CCIS cases were requested from the police region neighbouring the Nottingham hospitals (Leicestershire). This proved to be

successful with nine additional cases being returned. In total 74 cases were analysed.

In order to relate the findings of the retrospective study to implications for UK car occupants, it is important to understand the connection between the cases selected for the retrospective study, the in-depth data available from the CCIS and the national traffic injury statistics. A simple schematic of the relationship between the three sources of retrospective car occupant injury information used in this study is illustrated by Figure 2. It is important to note that there is not a simple one-to-one relationship between the data sources. For matching and scaling purposes detailed consideration has to be given to the sampling strategies and therefore injury severity rates (fatal, serious or slight), types of impact and other factors. However, it is useful to picture the three data sources as detailed in Figure 2, with CCIS being a sample of STATS19 and the retrospective study group being a sample of CCIS.



**Figure 2. Schematic of the relationship between the available databases.**

### Prospective Study

The prospective study consisted of information gathered from the casualty on admission to Hospital, the nursing staff in the Accident and Emergency Ward (A&E) and the opinion of the A&E Consultant with respect to the upper extremity injuries. The prospective study was devised to give complementary information to that obtained from the retrospective and physiotherapy studies, thus giving a more complete understanding of upper extremity injury in frontal impacts. In particular the prospective study offered the opportunity to gain more accurate impairment information than from the retrospective study.

The prospective study was undertaken in collaboration with the Queen's Medical Centre (QMC) in Nottingham. The Emergency Department at the QMC is reported as being the busiest in the country, with approximately 120,000

patients attending the department for treatment each year.

The protocol for the prospective study included direct contact with the patient by Hospital staff. This was necessary to obtain accurate, physical assessments of impairment (not estimates) and first-person patient accounts of the accident. The additional contact to gain the information necessary for the study required informed consent to be obtained from the patient, for which a patient information sheet and consent form were developed. Ethical approval in line with the requirements of the UK Department for Health, Central Office for Research Ethics Committees (COREC), was granted at the study and site-specific level.

Each casualty was approached by a member of the A&E staff to gain their permission and willingness to participate in the study. Then basic characteristics of the casualty were taken (such as age, gender, height, weight, etc.), as well as a basic description of the crash circumstances (completed with information supplied by the participant). Detailed information relating to the upper extremity injury, such as severity, estimate of the mechanism of injury and likely outcome was provided by the consultant at the hospital.

Between two and six months after sustaining the injury the participants were contacted, by telephone. This was to find out if they had any on-going impairment, in terms of their ability to work and perform activities associated with daily living, and whether they had received any treatment, since their discharge from hospital. Those subjects with continuing impairment were asked to attend the Hospital for a follow-up assessment by an appropriate clinician.

Participant recruitment and data collection began at the QMC at the end of May 2005. Patients were recruited until the end of 2005, with follow-up appointments (for the assessment of any continuing impairment) being available until the end of February 2006.

The impairment resulting from the upper extremity injuries in the retrospective and prospective studies has been coded using the American Medical Association Guides to the evaluation of permanent impairment (Cocchiarella and Andersson, 2001). This impairment rating system is used widely in the US medico-legal system.

### **Physiotherapy Study**

From the retrospective study it is evident that there are relatively few soft tissue injuries to the upper

extremity in the CCIS database, compared with more severe injuries, due to the selection criteria used in the CCIS. It is also apparent that data in the CCIS taken from hospital records may indicate the length of stay in hospital associated with a particular injury, but in many cases will not give a detailed indication of the long-term effects and treatment associated with that injury. Therefore another source of information regarding the sequelae associated with soft tissue upper extremity injuries from RTAs was required.

This section of the project made use of anonymous information concerning upper extremity injuries supplied by physiotherapists working in connection with hospital outpatients, GP (General Practitioner) doctor's surgeries and private patients. The information from the physiotherapists provided details on the frequency, final level of impairment, duration of temporary impairment and the cost to society (in terms of length and intensity of treatment required) associated with upper extremity injuries from RTAs.

Eight physiotherapy practices across England contributed anonymous injury and impairment information to the study.

As with the retrospective and prospective studies, ethical approval in line with the requirements of the UK Department for Health, Central Office for Research Ethics Committees (COREC), was granted at the study and site-specific level.

## **RESULTS**

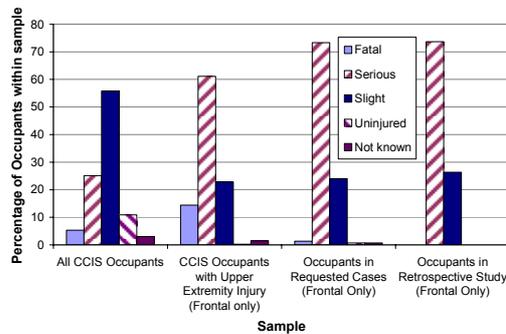
### **Retrospective Study Results**

**Sample Context:** In order to place the retrospective study in context, its sample was compared with the CCIS database. The CCIS database (Phases six and seven) was used for the analysis. This included all completed crashes investigated from June 1998 and released in December 2005 (CCIS Release P7k). This yielded some 6,689 crashes.

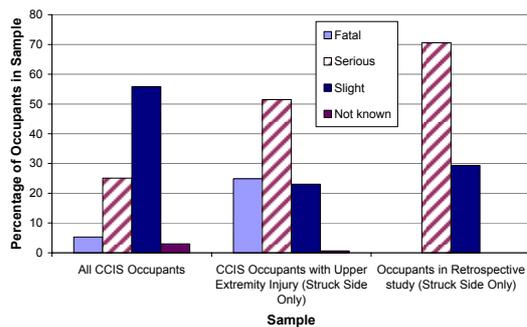
Analysis of the Co-operative Crash Injury Study showed that following road traffic collisions, moderate and serious upper extremity injuries are commonly suffered by car occupants. CCIS accidents are investigated according to a stratified sampling procedure which favours cars containing fatal or seriously injured occupants, according to the British Government definitions of fatal, serious and slight. Approximately 34 % and 23 % of the CCIS killed and seriously injured car occupants sustained an upper extremity injury respectively. Only 4 % of the CCIS casualties described by the police as slightly injured sustained an upper

extremity injury that met the criteria of this project. In 2004, there were 1,671 fatal, 14,473 serious and 167,714 slightly injured car occupants in Great Britain. Therefore, it can be estimated that over ten thousand car occupant crash survivors suffered a moderate or serious upper extremity injury in Great Britain in 2004. This estimate highlights the significant magnitude of the upper limb trauma experienced.

Within the CCIS, cases for the retrospective study were selected based on whether an upper extremity injury had been sustained. From these cases, a further selection was requested from regions around the hospitals that had agreed to participate in the study. Finally, the study itself used a selection of these cases that were returned with the available hospital injury and impairment data. Figure 3 and Figure 4 compare the proportions of fatal, serious and slight occupant injury cases as defined by the Police for each of the samples.



**Figure 3. Occupant distribution by police defined injury severity level within each frontal impact sample.**



**Figure 4. Occupant distribution by police defined injury severity level within each struck-side impact sample.**

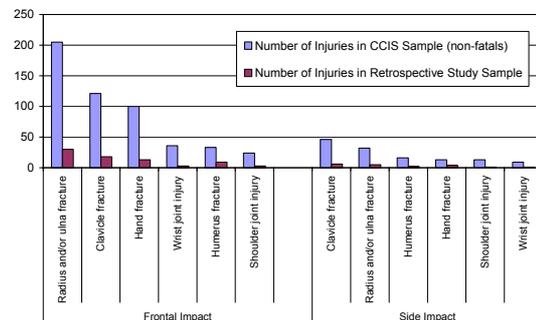
These figures illustrate that the selection of upper extremity injury cases altered the distribution of fatal, serious and slight injury cases in the sample but that once this initial selection was made, the other samples had similar proportions of serious and slight. The selection process reduced the proportion of fatal cases and effectively removed

all the uninjured cases and a large proportion of the slight injury cases.

**Frequency:** The sample of in-depth retrospective cases for struck-side impacts was too small to be able to predict confidently the relative importance of the different injuries. This was because some frequently occurring injuries seen in the CCIS were not included in the cases returned to TRL within the retrospective study. However, cost and impairment ranking has been performed with the limited data available to give some priority for the injuries found.

The front impact sample was larger than the side impact sample and the front impact retrospective cases can be said to be generally representative of the upper extremity injury cases in the CCIS population (Figure 3). Therefore it is thought that the relative injury priorities derived from the retrospective study front impact cases are likely to reflect the priorities for front impact cases in the CCIS population.

The largest injury groups in both the sample of the CCIS casualties with an upper extremity injury (meeting the inclusion criteria) and the retrospective study sample are shown in Figure 5.



**Figure 5. Frequency of the most common injuries in the CCIS sample (non-fatal) and the retrospective study sample.**

From this it is clear that the injury priorities, in frequency terms, are:

**Frontal impact**

- Radius and/or ulna fracture
- Clavicle fracture
- Hand fracture
- Wrist joint injury
- Humerus fracture
- Shoulder joint injury

**Side impact**

- Clavicle fracture
- Radius and ulna fracture

- Humerus fracture
- Hand fracture and shoulder joint injury
- Wrist joint injury

**Costs** from the retrospective study cover treatment only. This includes outpatient time and the associated staff time. The costs do not take into account physiotherapy or Accident and Emergency costs. Neither do they account for cost of living or impact on earning potential.

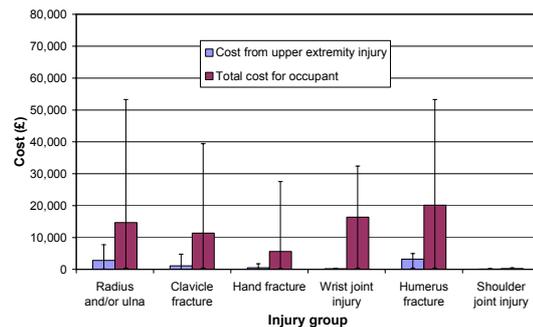
Difficulties in calculating the costs of injuries have been encountered. It was reported by the participating hospitals that it is particularly hard to calculate some staff costs as not all staff time is likely to be funded by the Hospital. For instance Junior Doctors, who do a large part of the work, are not paid by hospitals directly, since their funding would come out of training budgets. In general, the costs quoted in the retrospective study come from hospital managers and are typical costs for treatment types. It is suspected that these are underestimates, but they are the figures provided by the hospital. Whilst there may be underestimates and inaccuracies in the absolute values quoted for costs in this study, it is considered that the relative costs (whole body compared with arm injuries) should be accurate.

In some retrospective cases, the casualty received one upper extremity injury and the cost for this was provided. In other cases, more than one upper extremity injury was sustained and in these cases the medical reviewer did not always separate the injuries to provide individual injury costs. In these cases, the total upper extremity cost was distributed to each individual injury based on the relative mean single injury costs from other cases.

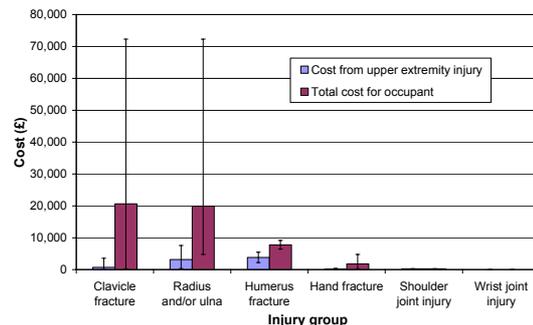
The mean cost of each of the main injury groups identified according to the frequency with which that injury occurs compared with the average cost of all injuries to the same occupants are shown in Figure 6 for frontal impact cases and Figure 7 for struck-side impact cases.

The mean cost for the upper extremity injuries in the retrospective study was £ 2,154, with a median value of £ 835. The minimum cost was £ 0. This was reported in two cases. In one of these cases, the patient had a thumb dislocation which required no treatment. In the other case the three injuries were a left forearm haematoma, a left wrist sprain and a neck strain. It was the opinion of the medical expert that these injuries should be assigned no monetary cost, in terms of primary care at the hospital attended, when considered in the context of the total accident cost.

The most expensive cost for the upper extremity injuries from one patient was £ 9,951. This cost was derived from the treatment for two injuries: a displaced fracture of the left humerus and an open complex Monteggia fracture of the right forearm. A Monteggia fracture is a fracture of the proximal ulna associated with anterior dislocation of the radius (radial head) at the elbow. Despite this large cost from the upper extremity injuries, they still only contributed 19 % of the total injury cost, with a further cost of £ 43,326 arising from other injuries sustained.



**Figure 6. Mean (max and min) cost of upper extremity injury and total injury costs for retrospective study frontal impact cases.**



**Figure 7. Mean (max and min) cost of upper extremity injury and total injury costs for retrospective study side impact cases.**

On average, the costs associated with a single upper extremity injury represent about 20 % of the total injury costs. This is lower than the typical value for lower limb injuries as typical clavicle and wrist fractures do not involve a stay in hospital (which is the largest cost in treatment).

To provide an indication of the injury priority based on cost, the mean cost per injury in each of the main groups was multiplied by the frequency of injury in the whole CCIS upper extremity injury sample (excluding fatalities). It should be noted that the retrospective study contains more complex fractures than the selected upper extremity injuries from the CCIS. Therefore, the mean individual injury cost values for the humerus and radius

and/or ulna groups may be slightly too high for the group on which the frequency is based. However, this slight inaccuracy due to a sample bias is not considered large enough to alter the priorities that have been derived. The priorities for injury groups based on the mean cost multiplied by the frequency of injury in the CCIS database are:

**Frontal impact**

- Radius and/or ulna fracture
- Clavicle fracture
- Humerus fracture
- Hand fracture
- Wrist joint injury
- Shoulder joint injury

**Struck-side impact**

- Radius and ulna fracture
- Humerus fracture
- Clavicle fracture
- Shoulder joint injury
- Hand fracture
- Wrist joint injury

**Impairment:** The American Medical Association Guides to the evaluation of permanent impairment (Cocchiarella and Andersson, 2001) define impairment as “a loss, loss of use, or derangement of any body part, organ or system, or organ function.” As examples of upper extremity impairment, the guide rates amputation of the arm through the humerus (at the top of the arm) as 100 % upper extremity impairment, this is equivalent to 60 % impairment of the whole person. Whereas, an inability to flex the finger at the proximal inter-phalangeal joint, for the little finger, corresponds to 60 % finger impairment, which is 5 % impairment of the upper extremity.

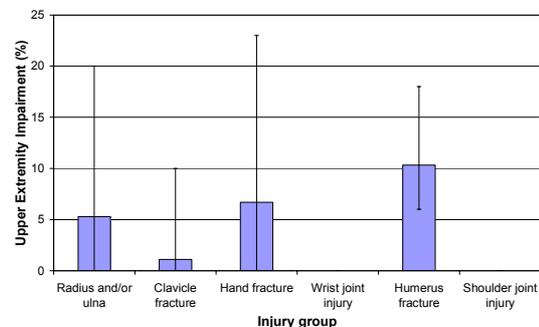
The mean residual impairment for the six most frequent injury groups in frontal impact is shown in Figure 8 for frontal impacts and Figure 9 for side impacts. It should be noted that the number of cases with reported long-term impairment was relatively low, so these figures are likely to have wide error bands.

The mean impairment from an injury in the retrospective study was a 5 % impairment to the upper extremity, which corresponds to about a 3 % whole person impairment.

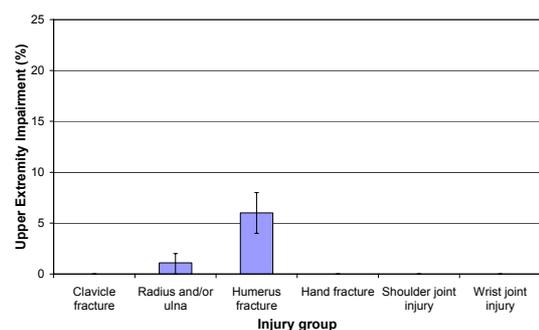
The maximum impairment at the time of presenting, or on first examination in hospital, was 56 % impairment of the upper extremity and 34 % of the whole person. This impairment was caused by a Monteggia fracture of the right arm. On presentation at the Hospital, the patient reported that they could not move their fingers and had no

flexion, extension, supination or pronation of their elbow. On leaving tertiary care, one year later, this impairment had dropped to 8 % upper extremity and 5 % whole person. At this time, they had decreased forearm rotation and elbow flexion and decreased finger flexion and grip strength. The patient still could not return to their job.

The maximum impairment, on leaving tertiary care, was 23 % of the upper extremity, which was 14 % of the whole person. This patient received several upper extremity injuries including three finger fractures of the left hand, one of which was open and comminuted, as well as a fracture of the right humerus in a supra-condylar position. This impairment level was the combined result of the three left hand fractures. Despite the reduced function of their upper extremities, the patient could return to work as a teacher and was assessed as being able to do other office work and maybe light manual work.



**Figure 8. Mean (max and min) residual impairment from upper extremity injury for retrospective study frontal impact cases.**



**Figure 9. Mean (max and min) residual impairment from upper extremity injury for retrospective study side impact cases.**

Humerus fractures accounted for the highest mean functional impairment in both frontal and struck side impacts. In frontal impacts, there were nine humerus fracture injuries. Of these, only two injuries were constrained to the shaft of the humerus. In the other humerus fracture cases, there was some involvement of a joint and this is likely

to have exacerbated the functional impairment caused by the fracture.

The mean impairments were multiplied by the frequency of upper extremity injuries to non-fatal cases in the CCIS sample in order to determine an injury prevention priority ranking based on impairment. The final impairment was not explicitly reported for all cases. In the cases where it was not reported, it was assumed that there was no final impairment.

As discussed in relation to the costs derived above, the retrospective study contains more complex fractures than the selected upper extremity injuries from the CCIS. Therefore, the mean individual injury impairment values for the humerus, and radius and/or ulna groups may be slightly too high for the group on which the frequency is based. This slight inaccuracy due to the sample bias will not have altered the priorities that have been derived.

The priorities for injury groups based on the impairment multiplied by the frequency of injury to non fatal occupants in the CCIS database are:

#### Frontal impact

- Radius and/or ulna fracture
- Hand fracture
- Humerus fracture
- Clavicle fracture

#### Struck-side impact

- Humerus fracture
- Radius and ulna fracture

The retrospective study cases were generally representative of the CCIS database and are used to prioritise the specific injuries in terms of frequency, cost and impairment, for the given impact types. However, the potential bias and error margins associated with developing a model to scale the retrospective study findings to a national level were judged to be too large for this to be useful.

Based on the frequency of the main injury groups, the average cost of treatment and the average impairment for each group, an overall priority for injury prevention was determined. For this, equal weighting was given to the cost and impairment priorities. The priorities for upper extremity injury prevention in frontal and side impacts, based on retrospective case data, are:

#### Frontal impact

- Radius and/or ulna fracture
- Hand, humerus and clavicle fractures

#### Struck-side impact

- Humerus fracture

- Radius and ulna fracture
- Clavicle fracture

**Injury Mechanism:** One of the objectives of the retrospective study was to re-examine accident cases in order to get more detailed information on the mechanism of the upper extremity injuries. For fractures, the medical team were able to examine the x-rays and other injury information and from this to estimate the type of loading that would have led to each fracture. For instance, many fracture types are associated with a particular type of loading - spiral fractures from torsional loading, distal fractures of the articular surface of the radius at the wrist due to direct load with the hand fully extended.

For soft-tissue injuries, similar additional information was recorded. For instance, the CCIS case file may note a shoulder sprain, but the detailed medical records enable the clinicians to determine specifically what part of the shoulder was strained and thereby whether the joint was loaded in flexion or extension, etc. This information is useful, in combination with the vehicle information, for determining whether the injury was from bracing (forced extension of the joint) or inertial loading from the arm moving forwards once the shoulder had been restrained by the diagonal seat-belt (flexion of the joint).

Based on an interpretation of the accident information and discussion with the medical staff, where necessary, a mechanism was proposed as the cause for the 106 individual upper extremity injuries from the retrospective study cases. This mechanism consisted of a loading strategy responsible for the injury, as was suggested by the medical personnel, together with potential contacts around the vehicle.

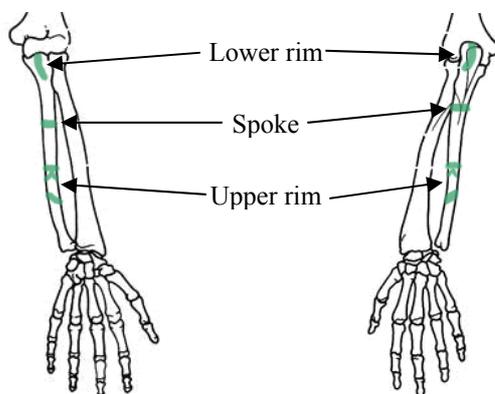
The injury mechanisms for the priority injury groups were investigated in more detail, based on the detailed injury information provided by the medical review, combined with the CCIS accident information.

For upper extremity injuries in general, it was found that there was no one injury mechanism that stood out as a priority for prevention. Instead it appears that the upper extremity injuries investigated in the retrospective study were caused by several different mechanisms and injurious contacts. The wide variety of specific injuries, contact locations and accident configurations in the retrospective study cases make it difficult to suggest a strategy for mitigating these injuries or for replicating them in the laboratory. Where substantial patterns could be determined for a

particular injury group, then they are discussed below.

#### Frontal Impact - Radius and Ulna Fractures

- Just over half of the 30 radius and ulna fractures were due to direct impact loading with a wide range of contact points (A-pillar, fascia top, fascia panel, steering wheel, own side door, windscreen and other vehicle).
- Nine of the radius and ulna fracture cases involved extension or hyperextension of the wrist combined with direct contact. This may imply that the hand was in a bracing position or simply holding the steering wheel. All but one of these involved contact with either the fascia, fascia top or the steering wheel. The contacts and the nature of the injuries imply that reducing the stiffness of the fascia and steering wheel may reduce the risk of these injuries, although it may not be practicable to alter the stiffness of the steering wheel in vehicles equipped with a steering wheel airbag, because the steering wheel is a support plane for the deploying airbag.
- Two injuries were probably caused indirectly by the steering wheel airbag. The forearm had probably been parallel to the steering wheel at impact and the airbag had deployed over the forearm, trapping it against the rim and/or spokes of the steering wheel. When the airbag was then loaded by the head and thorax, this load was transferred to the forearm causing it to be fractured at each contact point with the steering wheel. In one case the ulna had been fractured in three places, apparently at the upper rim, spoke and lower rim of the steering wheel (Figure 10). It should be possible to reproduce this injury mechanism in the laboratory, although it may be difficult to get good repeatability with the complex loading environment.



**Figure 10. Ulna fracture pattern.**

- In two cases involving front seat passengers, one injury was directly attributable to the passenger front airbag or airbag cover and one

possibly involved loading from the airbag or airbag cover. In the first case, the palm had burn marks from the airbag (and a fractured thumb), so direct loading from the airbag or airbag cover seemed most likely. In the second case, the most likely contact was the airbag - the CCIS case recorded this as the contact and on review there was no evidence to suggest any other contact. This loading mechanism is quite well defined and it would be possible to replicate in a laboratory. It may well be important that the arm is straight in order to generate the loads required for the more serious injuries seen in these cases and some replication of the extension moment in bracing may be required.

#### Frontal Impact - Clavicle Fractures

- 17 out of 18 clavicle fractures were caused by the seat-belt webbing. Additional inertial loading from the arm was considered by the medical review to have been important in 12 of these fractures.
- If this loading was to be recreated in a laboratory, then a whole body dummy or PMHS would be necessary. Given that the inertial loading from the arm was considered to be important in the majority of the clavicle fracture cases, this should be reproduced. The bending moment on the clavicle should be monitored as the parameter most likely to reflect injury risk for the occupant accurately. Alternatively the relationship between belt load and clavicle fracture injury risk should be investigated and established.

#### Struck Side Impact - Humerus Fractures

- There were two cases of humerus fracture caused in struck side impacts that were linked with an injury mechanism in the retrospective study. Both had high treatment costs and associated impairment. Both injuries were caused by direct loading from the door of the vehicle or perhaps the B-pillar.

#### Struck Side Impact - Clavicle Fractures

- There were six clavicle fractures in struck side impacts, all due to contact with some part of the vehicle side structure.
- The mechanism of injury was thought to be lateral compression for five of these six cases. PMHS tests to develop an injury criterion and injury risk function for these injuries were recently completed by INRETS as part of the SIBER EC project (Compigne *et al.*, 2003). The WorldSID crash test dummy is instrumented to measure lateral shoulder forces and compression.

For the specific injury priorities identified in this study, only two cases were identified where the airbag was the most likely cause of the injury to a driver. This does not seem to support a hypothesis that airbag deployment increases upper extremity injury risk for drivers in frontal impacts. However, it is possible that this result could be an anomaly due to sampling: it is possible that the previous observations could be due to an increase in the stiffness of steering wheels, necessary to give adequate support to the airbag - many of the priority injuries from this study had the steering wheel as a potential injury causing contact.

A further two cases were identified where the airbag was the most likely cause of the injury to a front seat passenger, one of which involved serious wrist and distal forearm injuries. This is a cause for concern and should be investigated further.

As the incidence of seat-belt caused clavicle fractures was higher than had been expected, the potential for technology to reduce the number of clavicle fractures was investigated. From the seat-belt label information in the CCIS database, it was often possible to determine whether the vehicle had a load-limiter or pre-tensioner fitted in the seating position in which the upper extremity injury occurred. Table 1 shows that the presence of a seat-belt load limiter did not significantly affect the rate of right shoulder AIS2+ injury induced through seat-belt webbing loading suffered by drivers. The CCIS database only started to code load limiter presence accurately and routinely in 2002 and this accounts for the large number of 'not known' entries in Table 1.

**Table 1. Load limiter presence versus driver AIS 2+ right shoulder injury**

Right shoulder AIS2+ injury	Load limiter present			Total
	No	Yes	Not known	
No	760 26.2%	516 17.8%	1620 55.9%	2896 100.0%
Yes	24 23.3%	21 20.4%	58 56.3%	103 100.0%
<b>Total</b>	<b>784</b> 26.1%	<b>537</b> 17.9%	<b>1678</b> 56.0%	<b>2999</b> 100.0%

For the cases in the retrospective study, no significant difference was found in the probability of clavicle fractures when either a load-limiter or pre-tensioner was fitted in that seating position, compared with the probability of clavicle fracture

without that device. However, it was not known what load limit was used with the load limiters in these cases and this may be significant in determining the likelihood of injury for a particular occupant.

### Prospective Study Results

In the Emergency Department (ED) at the QMC, they received 851 drivers or front seat passengers during the period of this study. However, only 75 of these were involved in a (self-reported) front or side impact and had an upper extremity injury. Of the 75 patients who were initially recorded as being eligible, only 25 were recruited and followed through the data collection process. The main reason that eligible patients were not recruited was that they could not be recruited during the time when they received their treatment in the ED, due to medical work pressures on the ED staff. This problem was anticipated when planning the study. Therefore, the protocol and ethical approval for the study included a provision for the study researcher at QMC to follow cases up either later in the day or during the following day, based on 'consent to participate' and contact details taken in the ED. Unfortunately, the pressures on the ED staff meant that in many cases no contact details or unreliable contact details had been taken at the initial contact with the patient.

It was the intention for the prospective study to compliment the retrospective study adding more accurate injury and impairment information through the direct contact with the casualties. However, the unexpected low rate of eligible patients seen in the ED, together with the unexpectedly low recruitment and follow-up rate of only 33% (25 out of 75 eligible cases), meant that the number of complete cases in the prospective study is insufficient to be able to make useful generalisations about the frequency and mechanisms of specific upper extremity injuries. Despite this, the following key results are thought to be of interest.

One of the objectives of the study was to inform future work and it is clear that this type of study would require recruitment over a much longer period of time, or at a larger number of hospitals, to yield significant case numbers. The complexity of, and time required for, the ethical approvals process would suggest that a small increase in the number of participating hospitals (to three or four) combined with an increase in recruitment period (to 12 to 18 months) would provide the most efficient approach for a future study.

One of the anticipated benefits of the prospective study was the opportunity to interview the injured

person in order to understand better the loading conditions that led to their injury. This meant that ‘informed’ consent to participate was required from each patient as part of the ethical approval for the study. However, it should be noted that the relatively high rate of non-recruitment, because not all eligible patients could, or would, consent to participate in the study, will have introduced an uncontrolled bias in the sample.

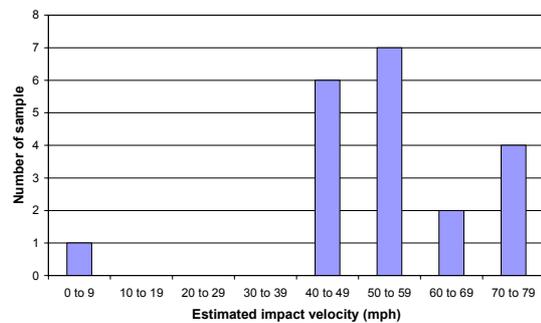
In addition to the interviews and follow-up assessment, recruited patients were asked to give permission for photographs to be taken of the vehicle. It was not considered ethical for the participant to take the photographs, therefore if the vehicle was at a garage or breakers yard, a disposable camera was provided. Photographs were taken by the garage or breakers yard staff. For the eight sets of photographs that were returned, care had clearly been taken to follow the template that had been given and the photographs were of good quality.

Of the 25 completed cases, 13 occupants (52 %) were male and 12 occupants (48 %) were female. The mean and median ages of the sample were 43 and 34.5 years, respectively, and the distribution of age amongst the male and female participants was similar. Comparison of the height and weight of the prospective study participants with average national (UK) figures showed that the participants were, on average, of relatively normal height and weight. The level of fitness of the participants was described by the QMC staff to be good in 13 cases, average in 10 cases and poor in one case only. Osteoporosis was evident in three of the 25 patients, as a ‘pre-existing condition.’

The principal impact angles for each accident were self reported by the participant relating the impact angle to the hours of a clock. In addition to the impact direction, rollover occurred in six out of the 25 cases (24 %). This is much higher than the national average, with 12 % of car crashes incorporating rollover (average figure for 1999-2003 from STATS19). This is a clear bias in the data set, although the upper extremity injuries in these cases were remarkably slight with only contusions, slight lacerations and abrasions being reported.

The approximate impact velocity for the accident is shown in Figure 11. Both the impact angle and velocity are estimates based on the report of the participant. The approximate nature of these estimates is particularly important for the impact velocity where accurate relative velocities cannot always be established. Indeed the distribution of impact velocities seems highly improbable for the range of injuries seen in this study.

In the few cases, where it was possible to compare the reported impact speed and angle with photographs of the vehicle, it was expected that the reported vehicle speeds would have resulted in greater damage to the vehicle than was evident from the photographs. This supports the observation that the impact velocities, inferred from the reporting of the patient, were higher than would be expected for the injuries recorded in the study.



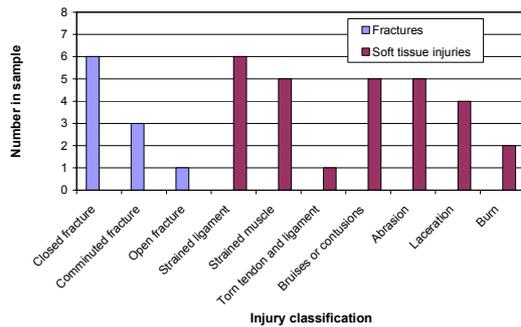
**Figure 11. Approximate impact velocity for impacts in the prospective study.**

Once the patient had given consent to participate and at a convenient time for the ED staff, the participant was asked for further information on their recollection of the accident. In particular, 13 (54 %) of participants reported that they were aware of the forthcoming impact before it happened. Of the 25 participants, 22 (88 %) said they were wearing a seat-belt. This is similar to the seat-belt wearing rate in a recent national study at 32 different sites around the country, which was determined to be 93 % for car drivers (TRL, 2005).

When asked whether they were braking before the impact, 41 % of the participants reported that they were, and 39 % were bracing in some manner when the impact occurred. 71 % of the participants reported that they made contact with some part of the interior of the vehicle during the impact. Whilst, 13 % said that they were hit by another object (either another object in the vehicle or by an intruding vehicle in a side impact). Two participants reported that they had no recollection of the accident. One of these had a blackout at the wheel. 44 % reported activation of an airbag. In every case, the activated airbag was a frontal airbag.

**Frequency:** The injury sustained by the occupant was reported to be a fracture in nine of the 25 cases. In three cases, the fracture was comminuted, which would be associated with a score of AIS 3 and in one case the fracture was open and comminuted. The total distribution of injuries is given in Figure 12. These classifications were not exclusive and often the participant would have more than one of these types of injuries. Nine

occupants in the prospective sample had one or more fractures.



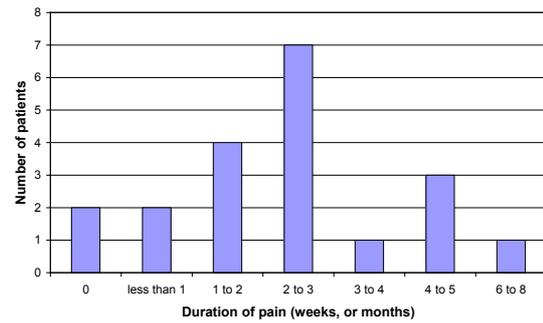
**Figure 12. Distribution of reported injury classifications.**

**Costs** were not reported for all injuries but, where reported, the fractures tended to have the highest treatment cost, with an average cost of nearly £2,000. This compares well with the mean cost from the retrospective study for fracture treatment, which was about £1,900. The average cost of the three intra-articular and open fractures from the prospective study was just over £3,500. Of the soft tissue injuries, the mean reported cost was just under £400, with a maximum of £947 for a thumb sprain. These soft tissue treatment values are higher than those from the retrospective study, from which the corresponding costs were £93 and £358.

**Impairment:** A limitation of the retrospective study was that the value reported for the impairment, which may have been caused by an injury, was the estimation of the medical researcher based on the patient notes. The accuracy of this assessment depends on the experience of the researcher with assessments of recovery following similar injuries. One anticipated benefit of the prospective study was that, by including a follow-up consultation, the longer-term implications of injuries could be determined much more accurately than from retrospective data. The participant would either report no further impairment or their impairment would be assessed directly by the medical team. As a result, it is probably true that the prospective impairment information, as assessed by the medical team, is more accurate than the information gathered in the retrospective study. However, the small number of cases means that only limited conclusions about impairment can be drawn.

Most of the upper extremity injuries from the prospective study resulted in two to three weeks of pain for the patient. The mean time recorded was between three and four weeks. The expected duration of pain for the patients in the study is shown in Figure 13. In two cases, not shown in

Figure 13, pain was expected to continue for three months.



**Figure 13. Expected duration of pain for prospective study participants.**

At follow-up, (between two and six months after initial presentation), the participants were contacted and asked whether they had any impairment remaining due to their injury. They were also asked about the level of impairment that they had experienced following discharge from the Emergency Department.

From the 25 prospective study cases, only one was lost to follow-up. Six of these patients have also attended a follow-up session with the Emergency Department Consultant.

Of the 24 study participants for whom the follow-up was successful, 13 reported full function from the time of discharge from the hospital.

Whilst some impairment was generally reported following initial discharge from the hospital, six participants reported continuing impairment at the time of follow-up. Two of these participants had received soft tissue injuries to the shoulder. The other four had bone fracture injuries.

**Injury Mechanism:** In each case, for the prospective study, the medical researcher at the Queen's Medical Centre was asked to comment on the likely mechanism responsible for causing the upper extremity injury.

Steering wheel interaction during the accident was responsible for two of the injuries, although both of these injuries were minor.

An airbag was cited as the cause of two of the injuries. Both of these were airbag friction burns and were expected to have healed within two to three weeks. However, airbag involvement was also suggested to have been potentially significant in a further three cases with more serious injuries (one finger fracture and two wrist fractures).

When developing the protocol for this study it was hypothesised that one benefit of a prospective study would be the opportunity to interview the patient and therefore determine more precisely the contact point within the vehicle and the nature of the loading that caused the injury. The contact was clearly identified for many of the soft tissue injuries for which contact and loading information would be difficult to determine from a retrospective case study. However, for many of the fractures several possible contact sites (such as dashboard, airbag or door) were given. Assuming that the fractures generally occurred in higher severity impacts (which is not clear from the self-reported impact speeds), it is inferred that the patients were not able to recall accurately what had happened during the impact. This implies that in any future studies, it would be most likely that interviews with patients would only be of benefit in determining injury mechanism and contact points in low-severity impacts. The exception to this is bracing, which was reported by nine out of the 25 participants and was unknown for only two participants. If bracing was suspected as being important to an injury mechanism under investigation, a prospective study would clearly be of benefit.

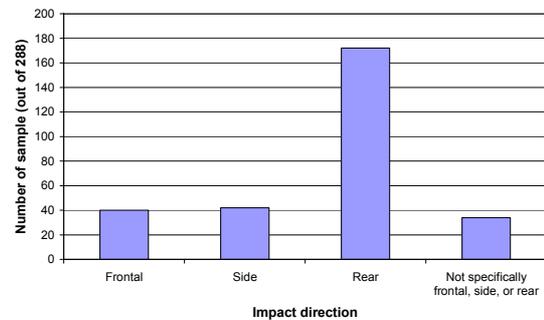
### Physiotherapy Study Results

The physiotherapy study is based on retrospective information from physiotherapists on patients who had sustained an upper extremity injury from a road traffic accident. From the three participating physiotherapy practices, TRL received 288 completed case report forms, containing anonymous information on injuries and impairment.

It was intended that the physiotherapy study would compliment the retrospective and prospective study by providing information on injuries that are less threatening to life but that may have longer-term consequences (costs and impairment) associated with them. Unlike the retrospective and prospective studies, the physiotherapy study did not have an exclusion criterion to rule out patients involved in a rear impact. The impact configurations, as determined from the response of the physiotherapists, responsible for causing the injury to the patients are shown in Figure 14. From this figure, it can be observed that the majority of the injuries reported by the physiotherapists were a result of rear impacts.

In the CCIS Phase six and seven sample, rear impacts were responsible for 7.6 % of the injuries to car occupants and 2.7 % of the occupants who received an upper extremity injury, that met the inclusion criteria for the retrospective study. These

percentages are far smaller than the corresponding percentage for the accidents reported in the physiotherapy study, where rear impacts accounted for 60 % of the patients. This suggests that the injuries treated by a physiotherapist (from a practice of the type used in the physiotherapy study) are not well represented in the CCIS and that the CCIS rear impact and low severity sample may well be under reported.



**Figure 14. Distribution of impact direction within the physiotherapy study sample cases.**

It appears that the cohort of patients treated in the physiotherapy study is not the same as that of the retrospective or prospective studies. The result of the physiotherapy study being based on a different sample of accidents from the retrospective and prospective study is that the results may not be directly comparable. However, the key results are presented below.

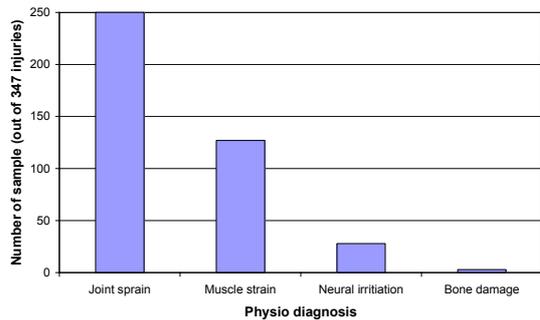
Of the physiotherapy study cases returned to TRL, 17 had no age or gender information. Of the remaining 271 out of the 288 patients comprising the physiotherapy study cases, the 31 to 40 year old group is the mean and median age group. This is also the mean and median group for the male and female subsets, although there were proportionally more young adult females than young adult males.

The majority of the vehicle occupants in the sample were drivers (88 %). In the CCIS database, 64 % of occupants were reported as drivers at the time of the accident. This shows that drivers were more prevalent in the physiotherapy study than in CCIS.

As reported by the physiotherapists 95 % of the patients were reported as wearing a seat-belt at the time of the accident. This compares well with the belt wearing rate for car drivers in 2005 of 93 % (TRL, 2005).

Four types of injury were suggested in the questionnaire for the physiotherapists to code their diagnosis of the injury of the patient. The results of the diagnoses are shown in Figure 15. It is clear to see that a joint sprain was the most common injury type, in the sample. A muscle strain or a joint

sprain with associated muscle strain were the next most frequently occurring injuries.



**Figure 15. Diagnosis of the physiotherapist, from the four available options.**

An injury mechanism was proposed for each case report. This was the opinion of the reporting physiotherapist. Injury trends were difficult to determine for the frontal and side impact scenarios with mechanisms being particular to individual cases.

In rear impacts, it was found that ‘whiplash’ was the most common form of injury mechanism for all of the physiotherapists.

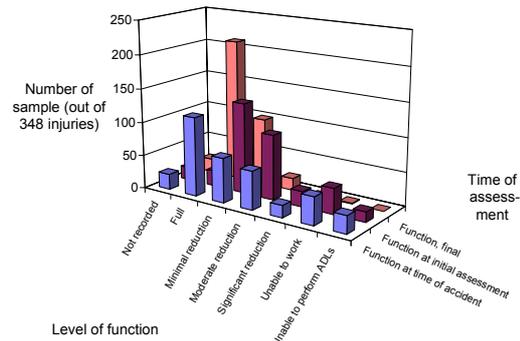
The physiotherapists reported on three impairment criteria (level of function, pain, and range of motion) at three different times in their treatment of the injury (at the time of the accident, at the initial assessment by the physiotherapist, and a final assessment after the course of physiotherapy). The assessments to determine the initial and final levels of impairment were made by the physiotherapist. The ‘time of accident’ impairment level was based on what the patient relayed to the physiotherapist.

The level of function was rated using six levels from ‘full’ function to ‘unable to perform Activities associated with Daily Living (ADLs)’. The ten-item version of the ADLs is reproduced in the AMA Guides to the evaluation of permanent impairment (Cocchiarella and Andersson, 2001).

The results from the level of function assessments are shown in Figure 16. From this figure it can be seen that at the time of the accident, there are more patients with full function than at the initial assessment. It is expected that this relates to injuries where the functional impairment comes on after the accident. For example, a muscle strain that stiffens the following day with increased inflammation or irritation.

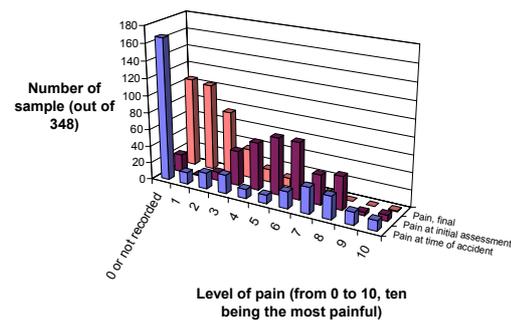
Comparing the functional impairment at the initial assessment, with that of the final assessment, it can be seen that the majority of patients appear to have returned to having full function at the time of the

final assessment – their last physiotherapy appointment.



**Figure 16. Level of function as assessed by the physiotherapists.**

The level of pain for the patient was rated on a scale from 0 to 10. On this scale, 0 corresponded to no pain and 10 to the most pain conceivable. This information was reported by the physiotherapist based on what the patient told them. The pain impairment, as reported by the physiotherapists, is shown in Figure 17.

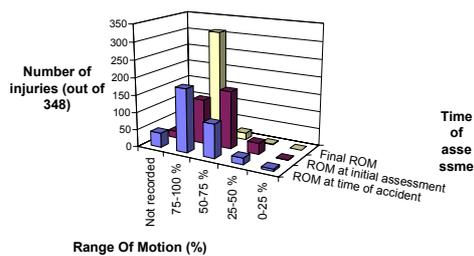


**Figure 17. Level of pain reported by the physiotherapists.**

At the time of the accident, there are a large number of injuries that had either no pain associated or the level of pain was not recorded. This may be a result of the patient not remembering accurately their pain level at that time or not passing this on to the physiotherapist, or, as with the level of function, the pain could have increased with time after the accident.

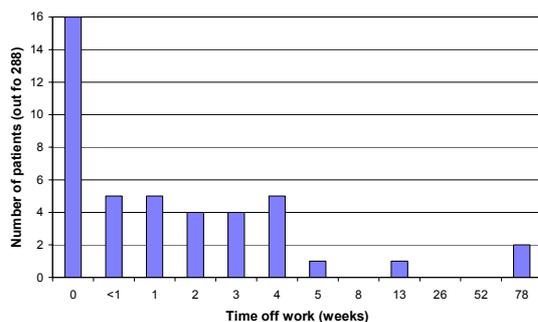
The modal levels of pain, as reported by the patient at the time of the initial assessment and at the final assessment by the physiotherapist indicate that the treatment by the physiotherapists was effective in reducing the level of pain impairment for the patient. However, for 243 of the 348 injuries the reported level of pain, at the final assessment by the physiotherapist, was not equal to zero.

As with the functional and pain impairments, the Range Of Motion (ROM) for the patient was assessed at the same times. The reported levels for range of motion are shown in Figure 18. As with both the function and pain, the ROM impairment increased between the time of the accident and the time of the initial assessment by the physiotherapist. Whilst the physiotherapy treatment generally reduces the ROM impairment, two persons were left with significant loss in their ROM at the end of the physiotherapy treatment (final assessment).



**Figure 18. Patient range of motion as assessed by the physiotherapists.**

In 43 out of the 288 cases, the physiotherapists were able to report on the time off work that the patient had incurred as a result of the injury, from what the patient had told them. The results of the time spent off work, due to the injuries, are shown in Figure 19. In addition to those cases shown in Figure 19, there was one case where the patient was off work for three months and another two cases where the injury resulted in 18 months off work for the patient.



**Figure 19. Time the patient spent away from work due to their injuries, as reported by the physiotherapist.**

As a time off work figure was reported for such a small proportion of the cases, it is difficult to draw conclusions from this data. However, applying the cost of taking a day off work due to sickness as produced by the Chartered Institute of Personnel and Development (CIPD, 2005) to the mean five weeks off work caused by the injuries in the physiotherapy study sample, then the mean cost due to the injuries is £ 1,810. The median figure of

one week off work would result in a cost of £ 358. This is assuming a five day working week and that the figures from the CIPD are appropriate for the physiotherapy study sample.

These calculations have not included a value for the blank responses from the other 245 questionnaires. It is possible that the physiotherapists were less likely to report time off work if it was 'no time off work'. Therefore, the results may overestimate the mean time resulting from the injuries reviewed by the physiotherapists. The duration of the treatment and the cost for the treatment were also recorded by the physiotherapist. Average values for these data are shown in Table 2, together with the expected duration of the impairment.

From Table 2, it can be seen that the average duration for the physiotherapy treatment was about two months. The maximum treatment duration was 14 months. The modal cost associated with the physiotherapy treatment was £ 100. This relates to four sessions or two hours with the physiotherapist. The maximum cost was £ 1,000.

**Table 2. Duration of treatment, treatment cost, and duration of impairment**

	Duration of treatment (weeks)	Cost	Duration of impairment (weeks)
Mean	9	£ 184	23
Median	6	£ 150	13
Mode	8	£ 100	8

## CONCLUSIONS

Approximately 19 % of all AIS injuries in Phase six and seven of the CCIS database were sustained to the upper extremity. Injuries to the upper extremity comprise 21 % of all AIS 1 injuries and 23 % of all AIS 2 injuries. The analysis of the Co-operative Crash Injury Study showed that, following road traffic collisions, moderate and serious upper extremity injuries are commonly suffered by car occupants. It was estimated that over ten thousand car occupant crash survivors suffered a moderate or serious upper extremity injury in Great Britain in 2004. For 21 % of casualties with known MAIS of 2 to 6, their upper extremity injury was the most severe or equal to the highest AIS code.

It was not possible to develop a robust and accurate cost model to reflect the monetary and impairment implications of the upper limb trauma identified at

a national level. However, the retrospective study cases were generally representative of the CCIS database and were used to prioritise the specific injuries in terms of frequency, cost and impairment, for the given impact types.

Based on the frequency of similar injuries in the CCIS database and the cost and impairment information from the 74 medical and accident review cases in the retrospective study, the priorities for future upper extremity injury prevention are:

In frontal impacts:

- Radius and/or ulna fracture
- Hand, humerus and clavicle fractures

In struck-side impacts:

- Humerus fracture
- Radius and/or ulna fracture
- Clavicle fracture

Soft tissue injury groups were not found to be priorities based on the criteria used in the retrospective study. The prospective and physiotherapy studies did not suggest that soft tissue injuries should be a higher priority than indicated by the retrospective case data.

The injury mechanisms for the priority injury groups were investigated in more detail, based on the detailed injury information provided by the retrospective medical review combined with the CCIS accident information. In many cases, the in-depth medical review was able to provide additional information on the injury that helped to determine the specific mechanism of injury.

For the specific injury priorities identified in this study, only two cases were identified where the airbag was the most likely cause of the injury to a driver. This apparent anomaly could be due to sampling: airbag equipped vehicles are effective at reducing the risk of fatal head injuries, so it may be that casualties who would have been fatally injured are now surviving accidents and their arm injuries may therefore be more likely to be recorded. It could also be due to an increase in the stiffness of steering wheels, necessary to give adequate support to the airbag - many of the priority injuries had the steering wheel as a potential injury causing contact.

A further two cases were identified where the airbag was the most likely cause of the injury to a front seat passenger, one of which involved serious wrist and distal forearm injuries. This is a cause for concern and should be investigated further. Many of the retrospective study injuries, from frontal impacts, for which a medical review was conducted, were caused through some direct loading with the structures in front of the occupant

(e.g. facia, A pillar or steering wheel). The effective stiffness of the parts of the vehicle interior in front of the front seat occupants is regulated according to the Interior Fittings Regulation (ECE, 1993, as amended). This regulation includes a dynamic test simulating contact between the head of an occupant and that part of the interior of the vehicle. It may be possible for this regulation to be upgraded or amended to make contacts between the upper extremities of occupants and the vehicle interior less likely to cause injury.

A large proportion (~90 %) of the drivers or front seat passengers seen at the QMC Emergency Department in the prospective study sustained their injuries as a result of a rear impact or multiple impacts. A 'whiplash' injury mechanism was reported as being responsible for many of the injuries reviewed in the physiotherapy study. As whiplash is often associated with rear impact or multiple impact shunts, it is suggested that rear and multiple impacts are considered a priority for future investigation.

The confidence with which the cost, impairment and injury mechanism conclusions from the retrospective study can be related to the national situation was limited by the number of cases reviewed and how representative those cases were of the national accident statistics. A study in which a larger number of cases was reviewed would allow greater confidence. However, this greater confidence is not expected to change the order of the injury priorities for future prevention. Based on the logistics of setting-up a larger study of this type, it is recommended that this is currently not worthwhile for upper extremity injury.

## ACKNOWLEDGEMENTS

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This report uses accident data from the United Kingdom Co-operative Crash Injury Study (CCIS) collected during the period July 1998 to November 2005. Currently, the CCIS is managed by the Transport Research Laboratory (TRL Limited), on behalf of the United Kingdom Department for Transport (DfT) who fund the project along with Autoliv, Ford Motor Company, Nissan Motor Company and Toyota Motor Europe. Previous sponsors of CCIS have included, Daimler Chrysler, LAB, Rover Group Ltd, Visteon, Volvo Car Corporation, Daewoo Motor Company Ltd and Honda R&D Europe (UK) Ltd. Further information on CCIS can be found at <http://www.ukccis.org>.

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