

THE NATURE, TYPE AND CONSEQUENCES OF LOWER EXTREMITY INJURIES IN FRONT AND SIDE IMPACTS IN PRE AND POST-REGULATORY PASSENGER CARS

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ABSTRACT

Leg injuries in real-world crashes have been studied in order to examine the effects of design and regulation on leg injury outcome. Data from the UK Co-operative Crash Injury Study have been used in this study. Lower extremity injuries are by far the most costly injuries and account for some 43% of injury costs in both front and struck-side crashes. In terms of injury frequency, pelvis and lower extremity injuries account for 25.8% of AIS2+ injuries in frontal crashes in 'newer' vehicles (those manufactured post-1998) and 20.7% of pelvis and lower extremity injuries in struck-side crashes in newer vehicles. In terms of injury type, tibia and fibula fractures appear to have decreased dramatically in frontal crashes but femur and foot/ankle injuries have not decreased by the same extent. Examination of passenger car performance in frontal crashes shows some correlation with EuroNCAP test score for lower extremity injury risk in real-world crashes. A number of case studies have been used to highlight some of the findings in the study including the long-term consequences of lower extremity injury on quality of life.

Keywords; Leg injury Frontal Impact, Side Impact, Injury Cost, EuroNCAP

LOWER EXTREMITY INJURIES IN VEHICLE crashes are both common and costly and the mechanism of them is still not yet fully understood. Several studies have examined incidence and occurrence of these injuries in vehicle crashes. Thomas et al (1995) found that lower extremity injuries were the second most common site of AIS 2+ injuries to crash survivors. Taylor et al (1997) studied a sample of 194 AIS 2+ lower extremity injuries. In terms of frequency, the most common injuries were fractures to the femoral shaft followed by ankle malleolus and patella fractures. They also found that clinically, the most important injuries in terms of expected long-term impairment were pilon fractures, fractures of the talar neck and calcaneus and Lisfrancs fractures. In terms of mechanisms, femur and patella fractures were usually associated with knee contact on the fascia (dashboard) resulting in direct blow (patella) or bending/compression (femur) whilst malleolus fractures were associated with inversion/eversion, usually as a result of the foot rolling -off from the pedals.

Pilon and talus fractures were almost always associated with intrusion of the vehicle footwell (usually indicative of crash severity) resulting in severe axial load whilst Lisfrancs (and other forefoot) fractures were associated with contact with the pedals (direct blow) all of which support a similar study undertaken by Fildes et al (1995).

In terms of European regulation, the risk of injury to the lower extremity in frontal crashes is normally assessed by the Hybrid III dummy in both frontal seating positions. The same is true for non-compliance crash-testing procedures such as EuroNCAP. However, the Hybrid III dummy is not thought to fully represent or predict the risk of certain types of injuries, particularly to the foot/ankle because of lack of biofidelity of this body region on the dummy leg-form. This in turn is due to a general lack of information about true injury biomechanics. No instrumentation of the lower extremity (below the knee) exists in currently-used side impact dummies (e.g. SID II, BioSID, EuroSID). The ALEX leg is thought to provide better prediction of injury risk to the lower extremity due to a more complete range of movement in the foot/ankle region, including increased dorsi-

flexion/inversion/eversion capability although this leg-form is not currently used in regulatory compliance testing.

It is well recognised that lower extremity injuries affect quality of life. Luchter (1995) found that lower extremity injuries represented the second greatest impact in terms of Lives-Lost to Injury whilst in terms of costs, Miller et al (1995) noted that lower extremity injury costs to vehicle front seat occupants were in the region of \$8.2billion in the US alone.

The aim of this study was to compare the frequency, type and relative cost of lower extremity injuries in pre- and post-regulatory vehicles. The study examines where improvements in vehicle design in terms of lower extremity mitigation are evident and to try and identify where outstanding issues remain (part 1). This part of the study examines actual injury type, frequency and cost in both frontal and side impacts to examine whether there are specific injury types which are still prevalent should be addressed. The findings of the study are enhanced through case studies which take into which vehicle design in relation to injury outcome. The case studies also consider disability and impairment consequences for those afflicted.

The study also considers lower extremity injury outcomes compared to EuroNCAP ratings for lower extremity protection in frontal impacts as determined in the EuroNCAP test protocol (part 2). The aim of this part of the study was not to discriminate between individual injury types but to examine whether lower extremity injury rates have improved overall. This part of the study does not examine lower extremity injuries in side impacts since the EuroNCAP side impact procedure does not test for risk of lower extremity injury.

METHODOLOGY

PART 1: INJURY TYPOLOGY AND RELATIVE COST IMPLICATIONS The data for this part 1 of this study were gathered as part of the UK Co-operative Crash Injury Study (CCIS). The CCIS data use a stratified sampling criterion to identify crashes to be investigated. 100% of 'Fatal', 80% of 'Serious' and 10-15% of 'Slight' injury crashes (according to the UK Government's accident classification) that occur within specified geographical regions throughout the UK are investigated. The sampling criteria also specify that injury must have occurred in at least one car that was at most 7 years old at the time of the accident. The CCIS data can be weighted in order to address the sampling bias towards 'Serious' injury outcome so that they were deemed representative of the population of all injury crashes involving cars 7 years old or less in the United Kingdom.

The analysis distinguishes between 'Newer' and 'Older' vehicles –the 'Older' designs of vehicles that were manufactured between 1985 and 1992. These vehicles were designed and manufactured distinctly before the introduction of regulation/EuroNCAP test programmes. The second group were 'Newer' designs of vehicles which were manufactured from 1998 onwards, distinctly after the introduction of regulation/EuroNCAP test programmes. Vehicles manufactured between 1993 and 1997 were not included in this study (N=359). These classifications (in terms of date of manufacture) were used in an attempt to assess the effects of regulation/EuroNCAP introduction. For costing of injuries, the injury cost model developed by Morris et al (2006) was used which is based on a UK 'willingness to pay' study (Hopkin and Simpson, 1994). This approach looks at individual injury types and applies a cost for each. However, it does not take into account individual differences in injury outcomes between occupants whereby multiplicity of injury may be a factor.

For injury typology, AIS 2+ injuries only were considered and therefore the data are un-weighted data in order to retain the diversity of injury types. All injuries were coded according to AIS 1990.

The sample sizes used in the analysis are as follows;

Table 1: Sample sizes

	FRONT IMPACTS		STRUCK-SIDE IMPACTS	
	Old Cars	New Cars	Old Cars	New Cars
Vehicles	393	1298	82	403
Occupants	461	1628	82	403
MAIS 2+ Occupants	162	393	30	121
AIS 2+ Injuries	526	1122	143	498

All of the occupants in this part of the study were known to be belted.

PART 2; INJURY OUTCOMES IN RELATION TO EURONCAP RESULTS Part 2 also uses real-world data collected as part of the CCIS study and for this study eligible accidents up until 2003 have been included. To compare EuroNCAP body region ratings to real-world injuries the EuroNCAP lower leg rating in frontal impacts was compared to the risk of AIS 2+ injuries below the knee and above the ankle. The AIS 2 margin was chosen to include all fractures to this body region. The foot/ankle protection rating was compared to the risk of AIS 2+ injuries to the ankle and foot, again to include all fractures to these body regions.

Case studies have been used to illustrate typical real-world events in which moderate lower extremity injuries occur and also to emphasise the dramatic effects that these injuries have on quality of life to these afflicted. Follow-ups have been conducted using structured telephone interviews using the EQ-5D and SF-36 health outcome measures (Barnes, 2006).

RESULTS PART 1;

1. 1; RELATIVE FREQUENCY AND COSTS OF INJURIES IN FRONT AND SIDE IMPACTS

Figures 1 and 2 show the analysis of costs of injury (to all body regions) in frontal and side impacts in the CCIS database. The injuries in this analysis occurred to crash *survivors*. For frontal impacts (figure 1), lower extremity injuries accounted for 43% of the total cost of injuries at the AIS2+ level whilst accounting for 32% of the total number of AIS 2+ injuries. In side impact crashes (figure 2), the corresponding figures are similar with side impacts accounting for 43% of the total cost of AIS 2+ injury in side impacts whilst accounting for 35% of the total numbers of injuries. These figures alone justify the need for closer scrutiny of the data.

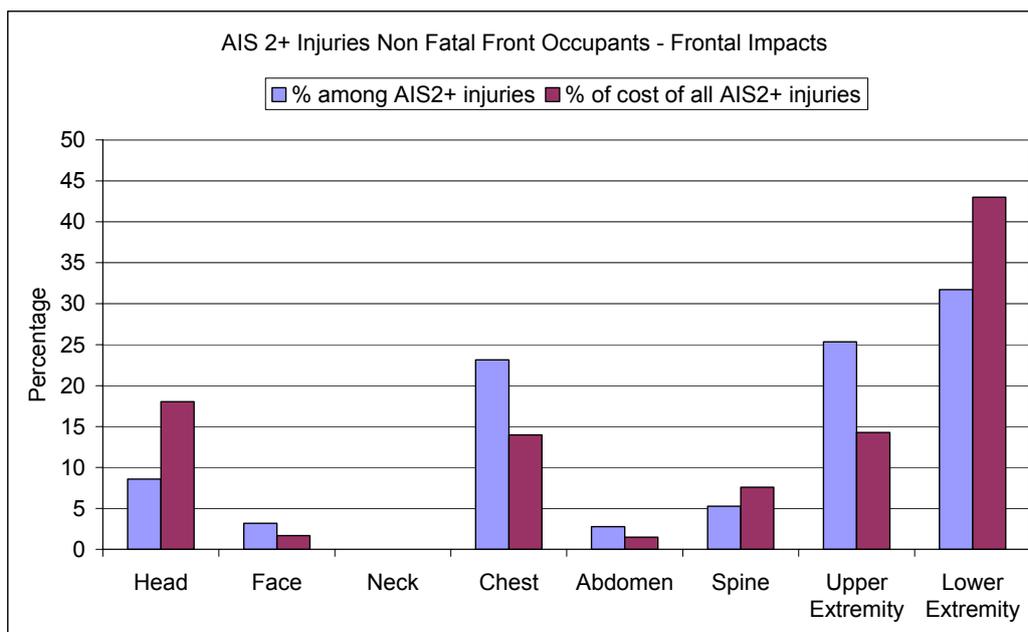


Figure 1

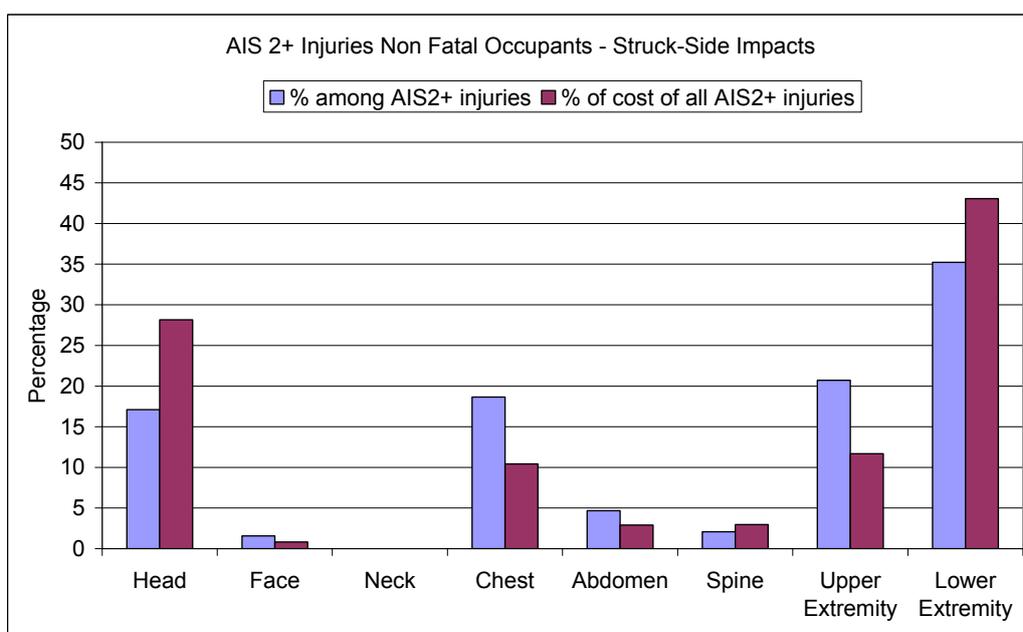


Figure 2

In both front and struck-side impacts lower extremity injuries are the most frequent and the most costly injuries sustained by non-fatal front seat occupants. AIS 2+ lower extremity injuries are not only one of the most frequently occurring injuries. The costs are recognised as being a significant factor in these types of injuries since they are often associated with long-term disability and impairment which are quite often permanent.

1.2 LOWER EXTREMITY INJURY FREQUENCY IN FRONTAL AND SIDE IMPACT CRASHES

An initial exploration of the data was made in order to establish what if any differences in terms of crash characteristics exist between the new and old car samples. Delta V, object struck and occupant age were considered.

Table 2: Delta V

	FRONTAL IMPACTS		STRUCK-SIDE IMPACTS	
	Old cars	New Cars	Old Cars	New Cars
Mean	37 km/h	34 km/h	28.2 km/h	28.1 km/h
Median	34 km/h	31 km/h	26.5 km/h	26.0 km/h
Standard Deviation	16.8 km/h	14.2 km/h	13.2 km/h	11.6 km/h
Range	10-92 km/h	10-96 km/h	12-61 km/h	10-65 km/h

Using Delta V as a measure of crash severity, the new and old car samples are comparable for both front impacts and struck-side impacts.

Table 3: Object Struck

	FRONTAL IMPACTS		STRUCK-SIDE IMPACTS	
	Old cars	New Cars	Old Cars	New Cars
Car	90.1%	65.9%	85.4%	55.0%
Pole/Narrow object	1.4%	6.7%	0.0%	7.2%
Wide Object > 41 cm	2.2%	10.8%	6.1%	17.7%
HGV/PSV	3.6%	8.8%	4.9%	12.2%
Other	2.7%	8.1%	3.6%	7.9%

There are clear differences in the object struck between the new and old car samples. For both the front and struck side impacts the old car sample comprises predominantly car to car impacts whereas there are more pole, wide object and HGV impacts in the new car samples. This result is a product of the CCIS sampling criteria according to the age of the vehicle. Generally older cars are included on the data set if they are the collision partner of a newer car which falls within the sampling criteria.

Table 4: Occupant Age

	FRONTAL IMPACTS		STRUCK-SIDE IMPACTS	
	Old cars	New Cars	Old Cars	New Cars
Mean	36	40	42	41
Median	33	37	37	38
Standard Deviation	17.7	18.0	20.8	17.9
Range	0-87	0-91	16-79	1-87

The age of the occupants is comparable between the old and the new car samples and for both front and struck-side impacts.

Table 5 shows the distribution of all AIS2+ injuries to front seat occupants in frontal and struck-side crashes to compare AIS2+ injury frequencies in 'Newer' and 'Older' cars. As can be seen from the table, the lower extremity is the most common body region injured at the AIS2+ level in both 'Older' and 'Newer' cars. In both front and struck-side crashes, the frequency of AIS2+ lower extremity injuries has decreased slightly. The shift in *injury pattern* toward head injuries in new cars in struck-side impacts is most likely a product of the differences in the object hit between the two samples, with a higher proportion of impacts with narrow objects (such as poles and trees) in the new car sample (table 3)

Table 5: Distribution of AIS 2+ Front Seat Occupant Injury Types in Front and Struck-Side Impacts

	Front		Struck-Side	
	Old N=526	New N=1,122	Old N=143	New N=498
Head	16.7%	13.1%	16.8%	28.1%
Face	4.6%	2.5%	1.4%	2.0%
Neck*	0.0%	0.2%	0.0%	0.2%
Chest	22.6%	25.0%	32.1%	24.7%
Abdomen	6.9%	6.7%	16.1%	9.9%
Upper Extremity	15.4%	20.6%	4.9%	12.2%
Lower Extremity**	29.5%	25.8%	23.1%	20.1%
Spine	4.3%	6.0%	5.6%	2.8%

*Excluding cervical spine **Including pelvis

Frontal Impacts

Table 6 shows the Maximum AIS score to the leg (including the pelvis) for front seat occupants in frontal impacts.

Table 6: Leg Injury Outcomes to Front Seat Occupants – Front Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
52.1%	47.9%	17.9%	8.7%	61.4%	38.6%	11.1%	5.4%

As can be seen from table 6, improvements in the rates of maximum AIS score to the leg are seen in new cars compared to old cars at all levels of severity.

Types of leg injuries observed in frontal impacts are shown in table 7 which shows the distribution of injury type in frontal impacts according to vehicle age. The figures are shown as a proportion of the total number of AIS2+ injuries sustained in all frontal crashes in the CCIS study. For example, in older vehicles, there were 526 individual AIS2+ injuries to all body regions in frontal crashes. Of these, 155 (29.5%) were to the pelvis and lower extremity and the percentages are shown as a proportion of this total (i.e. 526) rather than the total number of injuries to the pelvis and lower extremity (i.e. 155).

As can be seen in table 7 below, femur fractures were found to be the most common AIS 2+ lower extremity injury in ‘newer’ cars in frontal impacts accounting for 6.5% of all AIS 2+ injuries in these vehicles. The corresponding figure for ‘older’ cars is 5.5%. When foot/ankle injuries are viewed collectively (including malleoli, talus and calcaneus fractures), this injury type accounts for 8.2% of all AIS2+ injuries in frontal impacts in ‘newer’ cars. The corresponding figure for ‘older’ cars is 6.1%.

Table 7: Distribution of injury type in frontal impacts – old and new cars

Injury Type	Older Vehicle (N=526 AIS2+ injuries – all body regions)		Newer Vehicle (N=1,122 AIS2+ injuries – all body regions)	
	N	%	N	%
Muscle, tendon, ligament injury	1	0.2	11	1.0
Joint injury*	11	2.1	16	1.4
Ankle fracture**	12	2.3	37	3.3
Calcaneus fracture	6	1.1	17	1.5
Fibula fracture (excluding malleolus)	19	3.6	10	0.9
Femur fracture	29	5.5	73	6.5
Foot fracture***	14	2.7	38	3.4
Patella fracture	5	1.0	24	2.1
Tibia fracture	34	6.5	33	2.9
Pelvic fracture	24	4.6	31	2.8
Total	155	29.5	290	25.8

*Joint injuries involve ankle, knee and hip

**Ankle fracture includes fractures to the talus, malleoli, and ankle fractures not further specified

***Includes tarsal, meta-tarsal and phalange

The data in table 7 table can be further summarised as shown in table 8 to show changes in the overall injury type. The proportion indicates the relative frequency of the injury type among all AIS 2+ injuries (N=526 AIS 2+ injuries old cars and N=1,122 AIS 2+ injuries new cars). The rate of injury type gives the proportion of **all** belted occupants in frontal impacts (N=461 occupants old cars and N=1,628 occupants new cars) with this injury type irrespective of multiplicity of injury within a given injury type. Additionally the final percentage, injury rate, gives the rate of injury type among **all** front seat occupants in frontal impacts when multiplicity of injuries within injury type is excluded, i.e. if an occupant has more than one femur injury they will only score once in that injury type. Thus, the proportion is calculated on an injury basis and the two rates are calculated on an occupant basis.

Table 8: Overall leg injury type in frontal impacts

Injury Type	Old cars			New Cars		
	Proportion of all AIS 2+ injuries N=526	Rate of injury type among all occupants N=461	Injury Rate Among all occs N=461	Proportion of all AIS 2+ injuries N=1,122	Rate of injury type among all occupants N=1,628	Injury Rate Among all occs N=1,628
Pelvis	4.5 %	5.2%	4.6%	2.8%	1.9%	1.7%
Femur	5.5 %	6.3%	5.6%	6.5%	4.5%	3.9%
Tibia / Fibula	10.1 %	11.5%	6.1%	3.8%	2.6%	2.0%
Foot / ankle	6.1 %	6.9%	6.1%	8.2%	5.7%	4.1%

As can be seen from table 8, considering the rates of injury (irrespective of multiplicity of injury type), an improvement is observed in the newer cars compared to the older cars for all injury types. The greatest improvement is seen for Tibia/Fibula injury whilst less dramatic improvements have been recorded for the Femur and Foot/Ankle. This is also the case for the injury rate excluding multiplicity of injury type.

Side Impacts

Analysis of the data on lower extremity injuries for front seat occupants involved in struck-side crashes has also been undertaken.

Table 9 shows the Maximum AIS score to the leg (including the pelvis) for front seat occupants in struck-side impacts.

Table 9: Leg Injury Outcomes to Front Seat Occupants – Struck-Side Impacts

Old Cars				New Cars			
maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+	maxAIS 0	maxAIS 1+	maxAIS 2+	maxAIS 3+
38.5%	61.5%	21.8%	11.5%	64.1%	35.9%	14.0%	7.0%

Improvements in the rates of maximum AIS score to the leg are seen in new cars compared to old cars.

Table 10 shows the injury type for AIS 2+ leg injuries in struck-side impacts. The percentages indicate the proportion of each injury type among all AIS 2+ injuries received by front occupants in struck-side impacts as was the case in frontal impacts.

Table 10: Distribution of injury type in side impacts – new and old cars

Injury Type	Older Vehicle (N=143 AIS2+ injuries – all body regions)		Newer Vehicle (N=498 AIS2+ injuries – all body regions)	
	N	%	N	%
Surface injury	1	0.7	2	0.4
Joint injury	0	0	4	0.8
Ankle fracture*	2	1.4	7	1.4
Calcaneus fracture	0	0	1	0.2
Fibula fracture (excluding malleolus)	2	1.4	10	2.0
Femur fracture	5	3.5	18	3.6
Foot fracture**	0	0	5	1.0
Patella fracture	0	0	0	0
Tibia fracture	4	2.8	12	2.4
Pelvic fracture	19	13.3	44	8.8
Total	33	23.1%	103	20.1%

*Joint injuries involve ankle, knee and hip

**Ankle fracture includes fractures to the talus, malleoli, and ankle fractures not further specified

**Includes tarsal, meta-tarsal and phalange

As can be seen from table 10, the most frequently occurring AIS 2+ injury in side impacts is fracture to the pelvis which accounts for 13.3% of all AIS 2+ injuries occurring in side impacts in 'Newer' cars compared with 8.8% of all AIS2+ injuries in side impacts. In both the 'Older' and 'Newer' car sample, femur fractures are the next most common AIS2+ lower extremity injury. In general, foot/ankle injuries do not appear to be frequently occurring injuries in struck-side crashes.

The above table can be further summarised as shown in table 11 to highlight changes in the overall injury type. Again, the proportion indicates the relative frequency of the injury type among all AIS 2+ injuries (N=143 old cars and N=498 new cars). The rate of injury type gives the proportion of *all* belted occupants in struck-side (N=82 old cars and N=405 new cars) impacts with this injury type irrespective of multiplicity of injury within a given injury type. Additionally the final percentage, (injury rate), gives the rate of injury type among *all* front seat occupants in struck-side impacts when multiplicity of injuries within injury type is excluded. Thus, the proportion is calculated on an injury basis and the two rates are calculated on an occupant basis.

Table 11: Overall leg injury type in side impacts

Injury Type	Old cars			New Cars		
	Proportion of all AIS 2+ injuries N=143	Rate of injury type among all occupants N=82	Injury Rate Among all occs N=82	Proportion of all AIS 2+ injuries N=498	Rate of injury type among all occupants N=405	Injury Rate Among all occs N=405
Pelvis	13.3%	23.2%	17.1%	8.8%	10.9%	7.9%
Femur	3.5%	6.1%	6.1%	3.6%	4.4%	4.2%
Tibia / Fibula	4.2%	7.3%	6.1%	4.4%	5.9%	3.2%
Foot / ankle	1.4%	2.4%	2.4%	2.6%	3.2%	2.2%

As can be seen from Table 11, good improvements are apparent for pelvis injury rate (both including and excluding multiple injury types) in newer cars compared with older cars. Benefits are also seen for femur and tibia/fibular injury rates. There does not appear to have been an improvement in the rate of foot/ankle injury for front seat occupants in struck-side crashes, but this injury type is relatively uncommon among AIS 2+ injuries in struck side impacts. The leg injuries comprising the highest proportion of all AIS 2+ injuries in newer cars remain pelvis injuries followed by injuries to the femur.

PART 2; LEG INJURY OUTCOMES IN RELATION TO EURONCAP TEST EVALUATION

Table 12 shows left leg injury outcome in real-world crashes in relation to EuroNCAP test evaluation. As can be seen from the table, vehicles with a good EuroNCAP test rating show a very low rate of AIS 2+ injury in real-world events. However, this rate is similar to the rate for protection given as marginal. There is no overall statistically significant difference in AIS 2+ left leg injury rates between left lower leg protection ratings (at the 5% level).

Table 12; Left Leg Injury Compared to Left Lower Leg Protection Rating

Left Lower Leg Rating	Maximum Left Leg AIS			Total N (1,385)
	0	1	2+	
Good	89.3 %	10.0 %	0.6 %	309
Adequate	92.8 %	5.9 %	1.3 %	471
Marginal	89.5 %	9.9 %	0.7 %	304
Weak	92.6 %	5.8 %	1.6 %	243
Poor	93.1 %	6.9 %	0 %	58

Chi-sq=10.213, df=8, p=0.250

Table 13 shows right leg injury outcome in relation to EuroNCAP test evaluation. Vehicles with a ‘weak’ rating show the highest rate of AIS 2+ injury. Conversely, cars with a ‘poor’ rating show the lowest rate of AIS 2+ injury (in real-world crashes). There is no statistically significant difference in AIS 2+ right leg injury rates between right lower leg protection ratings (at the 5% level).

Table 13; Right Leg Injury Compared to Right Lower Leg Protection Rating

Right Lower Leg Rating	Maximum Right Leg AIS			Total N (1,385)
	0	1	2+	
Good	96.1 %	2.6 %	1.3 %	77
Adequate	90.5 %	8.5 %	1.1 %	650
Marginal	92.3 %	6.6 %	1.0 %	196
Weak	88.9 %	9.0 %	2.0 %	199
Poor	94.3 %	4.9 %	0.8 %	263

Chi-sq=8.821, df=8, p=0.358

Table 14 shows foot/ankle injury according to EuroNCAP test evaluation. Vehicles with a poor rating show the highest rate of AIS 2+ injury by a large margin. However, cars with a marginal rating show the lowest rate of AIS 2+ injury by a large margin.

There is a statistically significant difference in AIS 2+ foot/ankle injury rates between foot/ankle protection ratings at the 1% level. This difference is largely due to the serious injury risk for drivers in the marginal and poor categories. Therefore, the ‘marginal’, ‘weak’ and ‘poor’ categories appear to predict the injury rate in real crashes.

Table 14; Foot/ankle Injury Compared to Foot/ankle Protection Rating

Foot/ankle Rating	Maximum Foot/ankle AIS			Total N (1,374)*
	0	1	2+	
Good	89.0 %	6.4 %	4.6 %	218
Adequate	91.4 %	4.0 %	4.5 %	198
Marginal	85.3 %	11.9 %	2.7 %	293
Weak	91.4 %	3.5 %	5.1 %	257
Poor	83.6 %	7.8 %	8.6 %	408

Chi-sq=31.048, df=8, p=0.000

* The injury severity for 11 occupants was unknown compared to tables 12 and 13.

Finally, case studies are used to illustrate some of the issues that have been discussed in this study. Case study 1 is used to illustrate that serious injuries can be sustained in crashes involving minimal intrusion and relatively low delta-V. Long-term consequences of injury in terms of effect on quality of life are shown in case studies 2 and 3. The crash circumstances in relation to injury outcomes are also reviewed.

Case Study 1 (86099)

In this case, the vehicle was involved in a moderate frontal impact with a tree.

The Delta-V in the crash was calculated at 21km/h and the impact damage was located to the centre front of the vehicle. There was minimal intrusion of the passenger footwell and facia region. The driver was a 17-year old male who sustained a fractured right and left femoral shaft (both AIS=3), a fractured radial styloid (AIS=2) and a fractured neck of talus (AIS=2).



Case Study 2 (15144)

In this case, the vehicle was involved in a head-on collision with another vehicle. The Delta-V was 30km/h. The driver was a 44-year-old male who sustained a fractured left talus (AIS=2), fractured pelvis (AIS=2) fractured right ribs (AIS=2) and a laceration to the knee (AIS=1).

The driver was followed up at 3, 6 and 12 months to assess his mobility and any subsequent impairment sustained as a result of the crash. Prior to the crash, he had been an area Sales Executive and was a part-time sports coach.

At 3 months he was unable to work or do hobbies and whilst his company provided sick pay he was losing sales commission. He was totally reliant on others for transport.

At 6 months, he still used crutches or a walking stick, and couldn't get a normal shoe properly onto his left foot. He was still in substantial pain.

At 12 months he had returned to work on restricted capacity only, but could not carry his sales stock. He was using a walking stick. He was earning a basic wage but was losing commission.

He had had a total of 216 days off sick and stated that he had still not recovered at 12 months as a result of pain, swollen foot, tiredness and still could not do his sporting hobbies. He also experienced flashbacks of the crash.

The total costs of his injuries were calculated (by the willingness to pay cost model) at £326172.



Case Study 3 (15147)

In this case, a 49-year old female was driving a car that was in collision with another vehicle after losing control on a bend in wet weather. The crash severity (Delta-V) was calculated at 35km/h.

The driver sustained a fractured right patella (AIS=2) together with general bruising. She claimed that the key fob (from the steering wheel) had penetrated her knee.

She spent 2 days in hospital to have her patella 'wired'. At 11 months the wires were removed. She was a head-teacher by profession.

At 3 months she was back at work, able to drive but remained in pain and could not undertake any normal everyday activities which involved bending or kneeling.

At 6 months she was finding it difficult to swim and this activity would leave her in more pain than before the swim.

At 12 months stated that she had recovered on the whole, having had the wires removed from her knee but she still could not kneel and therefore struggled with everyday tasks. She still experienced substantial pain in her knee at 12 months.

She was required to take 8 days off sick in total and received sick pay. Her total injury costs according to the 'willingness to pay' calculation were £84288.



DISCUSSION

The data in this study indicate that foot/ankle and femur fractures are still an important issue in frontal crashes. Foot/ankle injuries in the UK sample now comprise 8.2% of all AIS2+ injuries received in frontal impacts. They are an important sub-set of injuries because although they are not especially life-threatening, some injuries are invariably associated with long-term disability and impairment and for this reason there is a good indication that such injuries are expensive in nature as highlighted in the data analysis.

Overall, improvements in AIS2+ injury rates have been observed when 'new' cars are compared to 'old' cars (which are similar in terms of crash severity and occupant age) but there has also been a shift in AIS2+ injury patterns to the effect that the proportion of pelvis and tibia/fibula injuries has fallen whilst the proportion of femur and foot/ankle injuries has increased. It should be noted that there are differences in the object struck in the 'old' car and 'new' car sample - whilst these differences are not thought to explain improvements in lower extremity injury outcomes, they could account for differences in injury patterns (e.g. increase in head injury in side impacts, table 5).

It should be observed that in frontal impacts, good, almost dramatic reductions are seen in the CCIS sample terms of tibia/fibula fracture rate. It is suggested that this is clearly the result of improved capability for measuring axial load through the tibia in the HybridIII dummy which in turn makes it easier to control for this injury in real-world situations.

However, the same cannot necessarily be said for ankle/foot injuries. Looking more closely at the specific injury types, in terms of ankle injury, it is lateral and medial malleoli fractures, calcaneus fractures and talus fractures that have not necessarily decreased dramatically in incidence. Metatarsal fractures are also still common. The specifics of injury mechanisms for these injuries, whilst not fully understood are thought to at least be partially established and it is suggested that continued use of crash-dummies in regulatory compliance testing which cannot accurately detect significant inversion/eversion and dorsi-flexion/plantarflexion will leave the problem unresolved. Introduction of the ALEX leg-form may serve to ensure that the risk of these injuries can be predicted with greater certainty but it is acknowledged that this may be some way off. In the meantime, greater prevalence of footwell airbags could serve as an interim measure although the effects of these devices in real-world situations are as yet not fully understood.

The issue of femur fracture injury rate is also interesting. Currently, the risk of this injury is predicted by load-cells positioned in the mid-shaft region of the Hybrid III dummy but this may not be a suitable test to examine the potential for injury to the distal and proximal femur. Another issue is that

the true mechanism may be more complicated than simplistic axial loading and the Hybrid III dummy may not adequately predict bending as an injury mechanism.

Although in-depth accident data can be highly beneficial in terms of problem definition, it may be necessary to take an even more detailed approach whereby femur injury mechanisms are established in more detail. This work should involve Orthopaedic experts and accident researchers working together studying X-rays, clinical notes and vehicle damage details. A pan-European study including data from other accident studies would significantly enhance the understanding of femur fractures since more cases would be available for analysis.

Knee bolsters and knee airbags may offer good potential for injury reduction as has been suggested in laboratory crash-testing. However, until the injury mechanism can be fully determined, it is difficult to predict the entire injury prevention benefit of such devices in the real-world or indeed to establish whether there is any potential for unexpected injury from such devices. A further consideration is that the crash-testing conditions may not match the conditions in which femur fracture occurs (for example, the dummy knee may not contact the facia). Also, the real-world conditions under which such injuries are prevalent are not the same as the crash-testing conditions (for example, angle of impact). It should be noted that previous studies (e.g. Hardy et al, 2005) have found femur fractures to be prevalent across all population groups and not necessarily an older occupant issue.

Regarding struck-side impacts, lower extremity injuries are relatively frequent and costly accounting for 43% of the total cost of AIS2+ injuries in such crashes although the majority of these injuries are fractures to the pelvis and femur (which account for over 60% of injuries). The rates of pelvic fractures in side impacts appear have decreased particularly markedly (from 13.3% to 8.8%). On the whole, the data on side impacts do not suggest that lower extremity injuries are particularly problematic although it should be highlighted that there is no discernible decrease in injury rates to the femur, tibia/fibula and foot/ankle. This could be expected since this body region is not instrumented in current regulatory crash-test dummies.

The results presented here should be considered with those presented in the EuroNCAP data analysis which suggests that foot/ankle injuries diminish in higher star-rating vehicles. This indicates to some extent that the countermeasures for foot/ankle injury are already available and that it could simply be a matter of knowledge transfer – it is thought that the higher star-rating vehicles manage to control intrusion of the footwell completely in the frontal impact test procedure. However, there are two points of note; firstly, the data analysed in this study include some vehicles that have not been subject to the EuroNCAP test procedure therefore may not be designed to control footwell intrusion in the same manner as vehicles that have been subjected to the EuroNCAP test. Secondly, it should be noted that foot/ankle injuries are not necessarily associated with intrusion and this latter point is sometimes overlooked.

It would be beneficial to examine the mechanism of foot/ankle injuries in frontal crashes in more detail (using techniques developed in the LLIMP project, Taylor et al, 1997; Morris et al, 1997), especially in newer vehicle designs where intrusion is not a factor.

The case studies presented in this study serve to illustrate some of the issues raised in this study. In case study 1, the driver has sustained bi-lateral femoral shaft fractures and a fracture to the talus. Such injuries were sustained in a moderate severity frontal crash with minimum intrusion. The main issue raised is that such injuries, which could have serious long-term consequences have occurred in a moderate energy frontal crash in the absence of intrusion of both front footwell and facia. In both case studies 1 and 2, the drivers have sustained injuries at the AIS 2 level, not normally considered life-threatening. However, examination of the impact that the injuries have had on the individuals suggest that the consequences for both drivers are somewhat substantial. Such consequences are not well predicted by the Abbreviated Injury Scale and therefore the use of a validated impairment scale would be a valuable tool in crash research in order to discriminate between injuries that are most and least consequential.

CONCLUSIONS

- Lower extremity injuries are by far the most costly injury according to a UK ‘willingness to pay’ study. In this sample of crashes which is known to be reasonably representative of ‘serious’ crashes in the UK), they account for 43% of the total cost of AIS2+ injuries in frontal crashes and a similar proportion in side impacts;
- When comparing ‘older’ car designs to ‘newer’ car designs in frontal impacts, tibia and fibula fractures show a marked reduction in frequency of occurrence. However, foot/ankle injuries have not reduced by the same rate. Femur fractures have reduced but not dramatically;
- In side impacts,
- Left upper leg protection ratings do not appear to delineate between better and worse protection to this body region in real crashes. Right upper leg protection shows a non-statistically significant trend toward poorer protection with lower NCAP ratings. However, the serious injury rate in the group rated as weak protection is much higher than the group rated as poor. The opposite should be true providing the ratings correlate to real injury outcome;
- Left lower leg protection ratings do not appear to delineate between better and worse protection to this body region in real crashes. It should be noted that serious injury (fractures) to this body region appear to be very rare;
- Right lower leg protection ratings do not appear to delineate between better and worse protection to this body region in real crashes. Of all the NCAP body region risk ratings, that for the foot/ankle shows the closest correlation to real world outcome. The weak thru marginal categories especially show a good link to the real world serious injury trends;
- Case studies emphasise the dramatic consequences that moderate severity injuries (AIS 2) have on quality of life to those afflicted.

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ACKNOWLEDGEMENTS

This paper uses accident data from the United Kingdom Co-operative Crash Injury Study. CCIS is funded by the Department for Transport (Vehicle Standards and Engineering Division), Autoliv, Daimler Chrysler, Ford Motor Company, LAB, Nissan Motor Europe, Toyota Motor Europe and Visteon. Further information on CCIS can be found at <http://www.ukccis.com/>