Leg Injuries in Car Accidents - Are We Doing Enough ?

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ABSTRACT

The major objective of car accident research over the last 25 years has been to reduce the number of fatalities following car accidents. However relatively little research has addressed the injuries that can result in long term disability and heavy economic cost to society. A major site of these injuries is the lower limb.

This paper examines the factors that result in the lower limb injuries of restrained front seat occupants who are involved in frontal collisions.

Analysis of the U.K. Cooperative Crash Injury Study data shows that the lower limbs are more frequently injured than any other body region. They are also the most common site of injuries with severities between AIS 1 and AIS 3. However they are only rarely life threatening.

The paper shows that the most frequent sites of leg contact are the facia, footwell and the steering column. Injuries from these contacts are frequently made worse by the presence of footwell intrusion; in turn this is more likely when the impact configuration is a partial overlap. The effects of impact severity and car size are also examined along with the age and sex of the occupant.

The legislation controlling footwell intrusion is shown to be insufficient to protect car occupants adequately. Car design should extend the "passenger cell" to include the footwell and lower facia areas. Legislation should test the effectiveness of design using a partial overlap test collision.

INTRODUCTION

The major objective of car accident research over the past 25 years has been to reduce the number of fatalities following car accidents. This is reflected in current legislation, which concentrates on testing for protection to head and chest. This protection does not, however, necessarily provide protection to other body regions. This becomes important when injury to those other body regions is frequent, can cause great disability, and results in large costs to the community and the victim both in terms of money and quality of life.

This paper attempts to discover where the majority of these injuries are and how they occur. Using a database detailing medical and vehicular data on many car accidents it is possible to construct a picture of how car design meets or fails to meet the secondary safety requirements of the car accident victim. This leads to a better understanding of areas of car design that might need improving. It may be that this can be brought about by changing legislation. Current European legislation will also be reviewed with this in mind.

THE DATABASE

The database used for this study consists of data from Road Traffic Accidents (RTA's) in the United Kingdom. It is compiled as part of an ongoing project funded by a United Kingdom consortium, the Co-operative Crash Injury Study. This comprises the Department of Transport, Ford Motor Company, Rover Group and Nissan UK. Skilled investigators collect specific data from the damaged vehicles. Medical data on the occupants are collected from the relevant hospitals and coroners. Information is also retrieved from police records and questionnaires sent to the victims. The identities and any personal information are kept in strictest confidence. The database currently holds information of 6245 occupants together with details of contact points within their vehicles and full details of the damage to their vehicles. Table 1 shows the occupants on the database and the impacts in which they have been involved.

Table 1 The Occupants On The Database

	Type of Impact					
Seat Position	**Frontal**	**Side**	**Rear**	**Other**	**Not Known**	**Row Total**
Front	3048	1093	256	708	25	5130 (82.2%)
Rear	583	208	41	221	36	1089 (17.5%)
Other	4	1	-	5	-	10 (0.1%)
Not known	4	-	3	6	3	16 (0.3%)
Column total	3639 (58.3%)	1302 (20.8%)	300 (4.8%)	940 (15.1%)	64 (1.0%)	6245 (100.0%)

This table shows that of the occupants on the database, 82.2% were in a front seat at impact and 58.3% were involved in a frontal impact. These two figures show that frontal impacts are the most common experienced and unsurprisingly that the majority of RTA victims are front seat occupants. When considering injury outcome, therefore, these two criteria indicate the area in which improvement to outcome would benefit the most people. Thus this study has concentrated on these occupants. The scale used on the database for coding injury is the Abbreviated Injury Scale [1].

THE PROBLEM

When considering injuries that are not potentially fatal there are a number of factors that can be used to determine the most urgent areas for improvement. These are frequency of occurrence, long term disability, length of hospitalisation, cost to provide health care and cost as a result of all or any of these. To a certain extent these factors can be inter-related. Table 2 shows the number of restrained front seat occupants with non-minor (AIS 2 or greater) injuries from a frontal impact by body region. The sample total is 658.

Table 2: Numbers Of Occupants With An Injury Of AIS 2 Or Greater By Body Region

Body Region	Frequency	% of 658 (%)
Head and Face	314	48
Neck	22	3
Chest	202	31
Abdomen	42	6
Arms	167	25
Legs	214	33

The legs are the second most common site of non-minor injury to restrained front seat occupants in a frontal impact. When all levels of injury are considered legs actually become the most frequently injured body region. Long term disability is difficult to determine because there are few sources of this information. However it may be that disability consequence is related to the length of stay in hospital. Guria [2] found a strong correlation between length of stay and disability using New Zealand data. There may be differences in the United Kingdom to this relationship due to different health care methods and resources. If, however, we suppose it to be true, a measure of length of stay for car occupants relative to their most severe injury might produce a picture of where in the body the most severely disabling injuries occur. Figure 1 shows the effect of each body region on length of stay for hospital in-patients on the database. Each point for each body region represents the number of occupants with an injury to that body region equal to their most severe injury (as determined by AIS score) expressed as a percentage of the occupants who were in-patients for the same length of time. From this it can be seen that short stay patients are very likely to have head injuries. However, as the length of stay increases it becomes more and more likely that they will have a leg injury, with long stay patients the most likely to have a leg injury. Thus it may also be said that the most disabling injuries are most likely to be leg injuries.

In some work to determine priorities for safety measures in car design Zeidler et al [3] used a cost scale on specific injuries calculated on administration, medical treatment, rehabilitation, social security payments, and loss of income. Using this scale they found that the mean cost of an injury to the lower limb was higher than to any other body region, being 18% higher than that of the next most costly region.

When all these factors are taken into consideration there seems to be a clear need for leg injuries to be considered when looking for ways to improve cars with respect to non-fatal injury. Having decided to look at leg injuries to vehicle occupants, the next step is to examine how these injuries occur by looking at the interaction between the vehicle and the occupant at the time of impact.

VEHICLE/OCCUPANT INTERACTION

One method of determining how injuries occur in particular configurations is to study the parts of the vehicle that the occupants contact to receive their injuries. Restraint use will have an effect on these contact areas. Tunbridge [4] demonstrated that restraint use affects injury outcome including injury to the lower limb. Since restraint use for front seat occupants became compulsory in the United Kingdom in 1983 the majority of occupants on the database have been found to be restrained. Because of these factors this study has been restricted to occupants of known restraint use.

Table 3 shows the frequency of contact areas for the leg injuries to these occupants

Table 3: Contact Areas For 2351 Leg Injuries To Restrained Front Seat Occupants In Frontal Impacts

Contact Area	% of Injuries with Contact (%)
Facia	37.6
Footwell	14.3
Pedal Assembly	12.8
Seat Belt Assembly	12.4
Steering Column Assembly	8.8
Front Door	1.3
Centre Console	1.2
Own Seat Assembly	1.5
A-Pillar	0.7
Bulkhead/Firewall	1.0
Steering Wheel Assembly	0.8
Road Wheel	0.3
Other Seat Assembly	0.2
Sill/Floor	0.2
Other Vehicle	0.2
External Object	0.0
Other Contact	1.6
Not Known	12.4

The percentage figure refers to the percentage of the 2351 injuries that were associated with that contact area. The percentages add to more than 100 because some injuries are associated with more than one area. An example might be a broken tibia due to a footwell and a facia contact. Note there appears to be a large number of restraint related injuries. This is because for this study the pelvis has been assumed as part of the legs. The great majority of these injuries are slight surface injuries of AIS score 1, and are abrasions or bruising due to contact with the restraint webbing. Slight injuries, however, are seldom responsible for disability and cost relatively little to provide care for. Table 4 shows the more common contact areas for leg injuries divided into serious and slight. The more serious injuries are coded with an AIS score of 2 or more. These injuries are mostly deep lacerations, bone fractures and dislocations. These are the injuries that cause disability and are costly to rehabilitate.

Table 4: Contact Areas For 2351 Leg Injuries By AIS Code To Restrained Front Seat Occupants In Frontal Impacts

Contact Area	% of 1895 Leg Injuries of AIS 1 (%)	% of 456 Leg Injuries of AIS 2 or more (%)
Facia	40.7	24.6
Seat Belt Assembly	15.1	1.1
Footwell	8.2	39.5
Steering Column Assembly	9.1	7.5
Pedal Assembly	10.0	24.6
Other Contacts	7.2	15.8
Not Known	13.4	8.1

This shows that almost all restraint injuries are minor, there is also a marked increase in association with the footwell and pedals area for more serious injuries and less association with the facia. The reasons for this difference are not obvious. It may be that because drivers account for 72% of the above injuries, a mechanism or environment not present for front seat passengers is having a large influence. It could be that in frontal impacts where the occupants are aware of the impending impact, the driver is bracing on the pedals at impact. It could also be that the drivers legs are restricted in a more hostile environment. The presence of the pedals and the steering column and the probable closer proximity of the occupant to the front of the passenger compartment could all contribute to a more hostile environment. Table 5 shows the differences between the contact areas associated with leg injuries of AIS 2 or more to the driver and the front seat passenger.

Table 5: Contact Areas For 456 Leg Injuries Of AIS 2 Or More By Seat Position For Restrained Front Seat Occupants In Frontal Impacts

Contact Area	% of Leg Injuries of AIS 2 or More	
	Driver (364 Total) (%)	Front Seat Passenger (92 Total) (%)
Footwell	39.8	38.0
Pedal Assembly	30.5	-
Facia	21.7	35.9
Steering Column Assembly	9.3	-
Other Contacts	15.7	21.7
Not Known	7.4	10.9

This table shows a similarity between footwell contacts for the driver and the front seat passenger. This suggests that there is no real difference between the way the two occupants interact with the footwell. This perhaps refutes the argument that there is a difference between them due to braking. There is, however, a marked difference in the frequency of facia contacts and the large number of pedal induced injuries is significant. The lower number of facia induced injuries can be explained by the large frequency of steering column induced injuries. If these are added to those of the facia the percentage equals 31.0%. If we assume that a steering column contact is equivalent to a facia contact this would suggest that there is no real difference between seating positions for this level of contact.

Examining the actual injuries sustained by each type of occupant from these contact areas reveals a similar pattern between the two. The most common injury is a femur fracture at about 34% of injuries of AIS 2 or more. Next is a patella fracture at about 11%. Although there does not appear to be a difference in the actual injury sustained, there does appear to be a slight side related difference. For drivers 36.5% of these upper leg injuries are to the left or inboard leg while 50.0% are to the right or outboard leg. For front seat passengers 51.5% are to the left or outboard leg and 42.4% are to the inboard leg. This pattern does not appear to extend into the footwell area where seat position does not appear to have an effect either on the type of lower leg injury sustained or the side of the body. For both occupants the left leg receives about 30% of these injuries while the right leg receives about 66% of them. This suggests that there is a mechanism occurring at facia level that is not duplicated at footwell level. In order to look at some of the vehicular mechanisms involved it is necessary to consider factors that might influence injury outcome. These are intrusion of the structure into the passenger cell, overlap of the front of the vehicle, impact severity and car size. Other factors that might influence injury severity are age, gender and seat position.

FACTORS INFLUENCING INJURY SEVERITY

In order to test whether intrusion has an effect on injury severity, intrusion to the area in front of each occupant was grouped into three bands of little or no intrusion, moderate intrusion, and severe intrusion. These bands were defined as 0 - 4.9cm, 5.0 - 19.9cm, and 20.0cm or greater. Tables 6 and 7 show the banding for facia and footwell respectively. They show the number of occupants, with a maximum leg injury of severity shown who experienced that amount of intrusion from that part of the vehicle. The percentage figures are that number as a percent of the total number of occupants that experienced that amount of intrusion from that part of the vehicle.

Table 6: Maximum Leg Injury Severity Of Occupant By Amount Of Intrusion At The Facia

Max Leg Injury Severity (AIS)	Amount of Intrusion (cm)		
	0.0 - 4.9	**5.0 - 19.9**	**20 +**
0 and 1	155 (90.1%)	239 (73.1%)	125 (45.0%)
2+	17 (9.9%)	88 (26.9%)	153 (55.0%)

Table 7: Maximum Leg Injury Severity Of Occupant By Amount Of Intrusion At The Footwell

Max Leg Injury Severity (AIS)	Amount of Intrusion (cm)		
	0.0 - 4.9	**5.0 - 19.9**	**20 +**
0 and 1	109 (94.0%)	340 (83.5%)	145 (42.6%)
2+	7 (6.0%)	67 (16.5%)	195 (57.4%)

A chi-squared test of Table 6 gives a chi-squared value of 108.6 with significance better that 0.01. Table 7 gives a chi-squared value of 184.2 again with significance better than 0.01. This seems to show that the chances of receiving a significant leg injury (AIS > 1) from a contact with the facia or footwell greatly increases with the amount of intrusion at those sites. However it must be remembered that intrusion is itself a product of impact energy and the amount of front end overlap.

Another method of measuring impact severity is to use the amount of crush at the front of the vehicle due to the impact. This is coded on the database on a scale of 1 to 9 according to SAE J224(b) [5]. Figure 2 shows how the proportion of leg injuries of AIS 2 and over varies with crush extent. Crush extent has been grouped by code as 0 - 2, 3 - 4, 5 - 6, 7 - 9. As expected the number of these more severe injuries increases as the crush extent increases. The numbers in brackets after the crush extent group are the total leg injuries in that group for this sample of occupants.

It is often supposed that injury severity depends on the size of car. However, it is not simple to categorise car size. The old method of using wheelbase length has become less valid as manufacturers have started putting wheels at the corners of vehicles, especially small hatchbacks, disproportionately increasing their wheelbase to the car size. In this study the mass of the vehicle has been used as an indicator of vehicle size. Again banding was used to create four groups of under 800 kg, 800 - 999 kg, 1000 - 1199 kg and 1200 kg and over. Figure 3 shows the number of injuries of AIS 2 or over sustained in each weight group of vehicle. There appears to be no clear relationship between leg injury severity and vehicle size as defined by weight of the vehicle. In the figure the numbers after the weight group are the total number of leg injuries in that group for this sample of occupants.

Age is a factor that might be thought to influence injury outcome. By banding age of the occupant into nine groups, the worst injury to the leg region for each occupant can be used to measure leg injury severity for each age group. Figure 4 shows the severity of leg injury for each age group. There does not appear to be any clear change in severity of leg injury with age of group although under 15's tend to show a slightly higher susceptibility to injury. In this figure the numbers in brackets after the ageband indicate the total occupants in that age group who fall into the previously defined category of restrained front seat occupants in a frontal impact who received a leg injury.

The gender of the occupant is another factor that could possibly influence injury outcome. Figure 5 shows the severity of the most severe leg injury for each gender. This does not appear to indicate a difference between the sexes as far as leg injury in a frontal impact is concerned. Again the numbers in brackets after each gender indicate the total occupants in the same previously defined sample.

Although, as seen above, seat position appears to have an affect on the contacts made by the occupant and the type of leg injury received, it does not appear to have a significant effect on injury severity. Table 8 shows the differences between them for the most severe leg injury received by each occupant.

Table 8: Occupant Severity Of Leg Injuries By Seat Position

Leg Injury Severity (AIS)	Drivers (708) (%)	Front Seat Passengers (284) (%)
1	70.9	77.8
2	14.5	10.9
3	14.3	11.3
4	0.3	-

When tested, this did not show a statistically significant difference although there is perhaps a tendency for drivers to be more severely injured.

LEGISLATION

A number of legislative regulations are relevant to the types of impact and injury discussed in this study. These are represented by the Economic Commission for Europe (ECE) of the United Nations Organisation (UNO) regulations [6,7,8,9]. These are regulations 12, 16, 21 and 33 and relate to steering systems, restraint systems, interior fittings, and structural behaviour in a head on collision respectively. Regulation 12 which concerns "the protection of the driver against the steering mechanism in the event of an impact" specifies the amount of movement that the steering wheel and topmost part of the steering column are allowed after a frontal impact barrier test at 48.3 km/h (30 mph). Although this movement will, due to vehicle construction, be directly related to the amount of intrusion at the facia and footwell, the regulation does not address movement of the steering column at lower points which are likely to directly contact the legs. As far as construction of the system is concerned, the regulation specifies hardness and sharpness of parts that are possible to be contacted by a head form on a manikin in the driver's seat. This relates solely to the steering wheel and the very top of the column and does not relate to other potential body contacts.

Regulation 21 relating to the structure of interior fittings concentrates on areas that can be contacted by a head form on a test manikin. As far as the facia and related shelving and fittings are concerned it details hardness and sharpness of these and their supports but does not concern itself with unrelated bracketry behind these structures that might be contacted as a result of these frangible structures breaking. The regulation does not regulate for any part below the horizontal plane at the `H' point and specifically excludes the pedals and their immediate pivotal mechanism.

Regulation 33 specifies the structural behaviour of the internal parts of the vehicle after a frontal barrier collision at 48.3 km/h. It states that the horizontal distance between the rearmost part of the facia and the 'R' point should be greater than 450 mm and the horizontal distance between the rearmost part of the footwell and the 'R' point should be greater than 650 mm. This regulation also makes the general statement that "After the test, no rigid component in the passenger compartment shall constitute a risk of serious injury to the vehicle's occupants". Apart from requiring a subjective judgement this test does not take account of the occupant vehicle interaction that often exposes those rigid components that are likely to cause serious injury. This is because the test is performed without a manikin.

Regulation 16 relates to restraint systems. In this it specifies that during a dynamic sled test similar in deceleration to a 48.3 km/h barrier test, a manikin should move forward by between 80mm and 200mm at pelvic level. This means that in a 48.3km/h impact if the occupant moves forward by the mean value of 140 mm and the facia moves rearward as specified by regulation 33, there is a space of 310 mm in which to fit the knee to hip, assuming that the seat is in the rearmost position. For the 50th percentile male this knee to hip distance is about 490mm. It is not surprising perhaps, when we see this, that there are so many leg injuries in frontal impacts on the database.

It is well known that manufacturers subject their vehicles to many more tests and much stricter tests than these. However, if the legislative requirements are so minimal, there will inevitably be a reduced incentive for manufacturers to design cars to provide safety in these areas. We have seen from the database the importance of intrusion on injury severity, the effect of front-end overlap, and how hostile the pedals seem to be. It seems that legislation does not go far enough to ensure that manufacturers provide sufficient protection. Stricter requirements for footwell and facia intrusion are necessary. Pedals and their attachment need to be less hostile. Offset barrier tests are required with fully instrumented manikins included.

CONCLUSIONS

Although leg injuries are not life threatening in nature there appears to be a need to look at ways of preventing them by better car design. This need is suggested by considerations of frequency of occurrence, cost to the community and cost to the victim. The areas of car design where improvement would bring about the most beneficial effect are the facia, the footwell, the steering system and the pedal assembly. It seems that intrusion and front-end overlap of the impact have a large influence on the outcome of leg injury severity. The differences experienced by drivers and their front seat passengers indicate different mechanisms occur at facia level and footwell level. The steering system and the pedals are an obvious reason for some of these differences. They are large contributors to the numbers of non-minor driver leg injuries (AIS of 2 or more).

At facia level there is a greater tendency for the outboard leg of the occupant to suffer injury. However, at footwell level, there is a greater tendency for the off-side leg regardless of seating position to suffer injury. This difference is hard to explain without more detailed data. It may be that the centre of the facia has less tendency to intrude than the footwell, the footwell being more influenced by engine movement, and that the footwell reflects the greater number of off-side to off-side offset frontals that occur.

Other conclusions that can be made are that car size, seat position, gender and age of the restrained occupant do not appear to affect the severity of leg injuries received in a frontal impact. However, intrusion, front end overlap,and impact severity whether measured by ETS or crush extent all have a major effect on the severity of leg injury received. Impact severity and front end overlap cannot be controlled, but although they have an effect on the intrusion they are not the only factors. The strength of the passenger cell, particularly the footwell area is the other major factor. This part of the vehicle needs strengthening. At the moment the amount of space left to the occupant after an impact can be all too small and with the close proximity of hostile components such as pedals, brackets and the steering column injury is inevitable.

Proper design can improve this situation relatively easily. We might expect legislation to encourage this to come about. However it appears that current legislation is well short of what is required. Tighter control on layout, aggressiveness and hardness of components including the pedals is required. There also needs to be more realistic testing including offset frontal barrier tests and an instrumented manikin. Ultimately, however the test is performed, the amount of intrusion allowed must be reduced.

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Figure 1. Importance Of Injury Site With Respect To Length Of Stay In Hospital

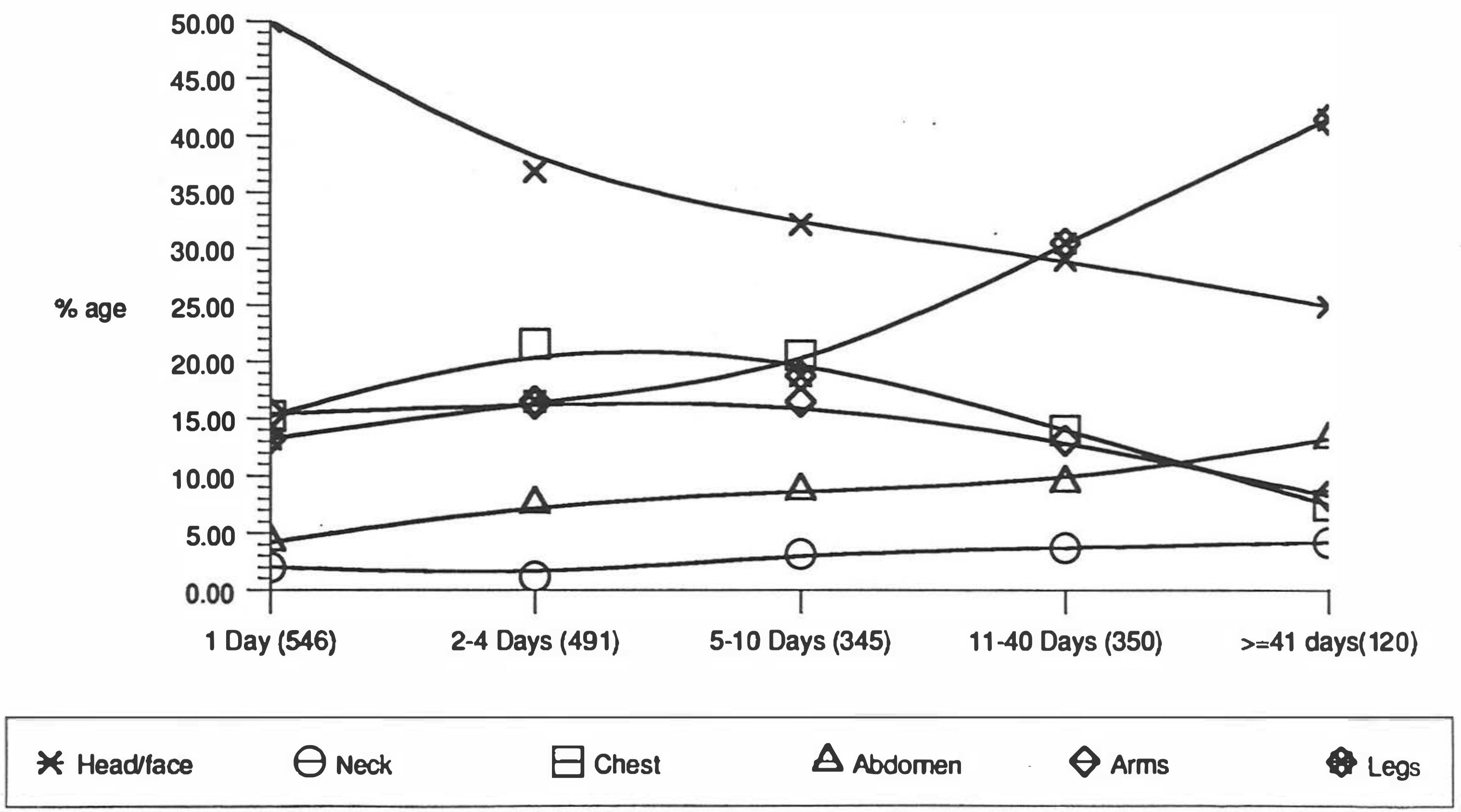

Figure 2. Distribution Of Leg Injuries Of AIS 2+ Over Crush Extent Groups For Restrained FSO's In Frontal Impacts

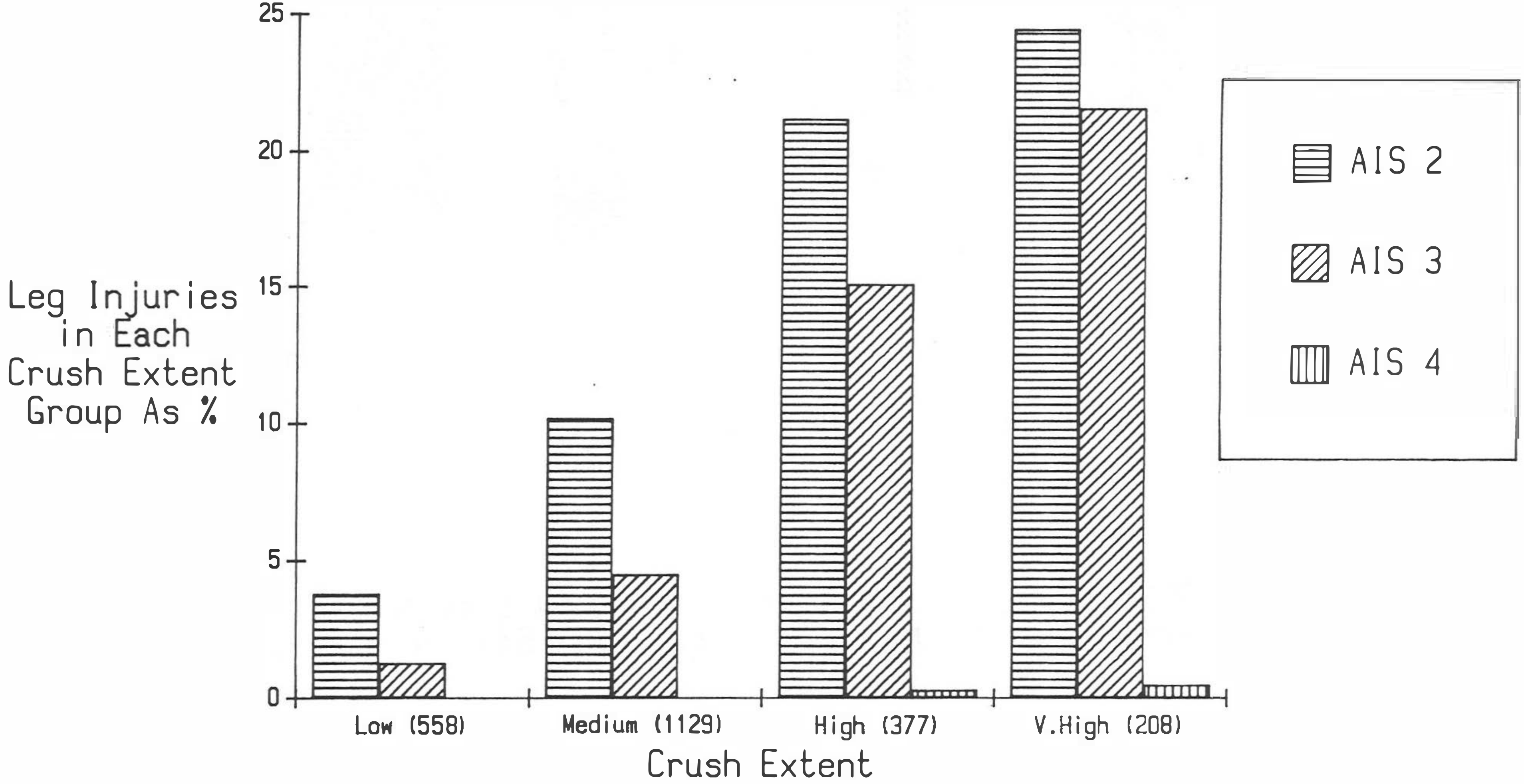

Figure 3. Leg Injuries Of AIS 2 And Over In Each Weight Group As % for Restrained FSO's In Frontal Impacts

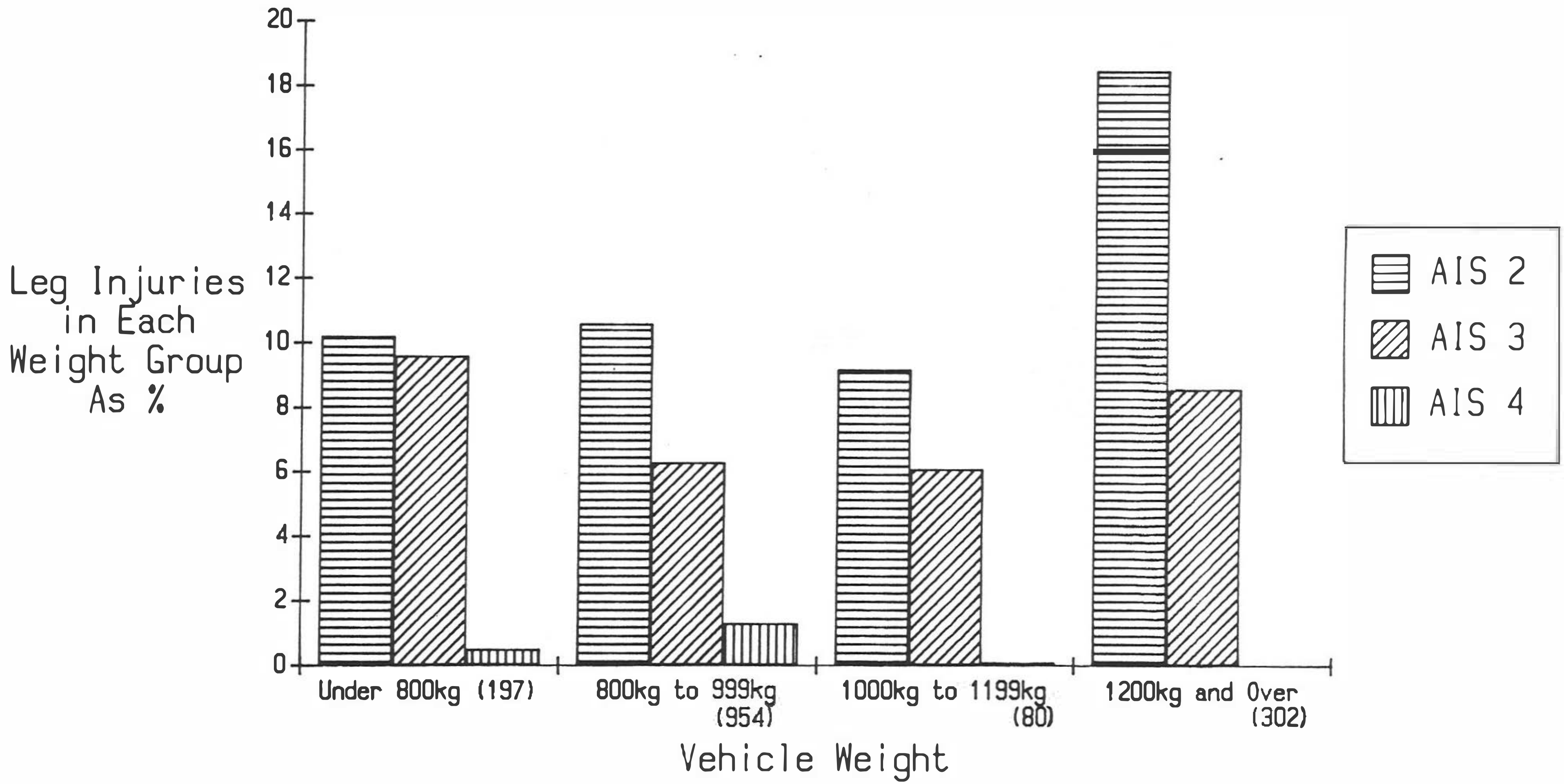

Figure 4. Restrained FSO's With Maximum Leg Injury Of AIS 2 Or Over Against Age

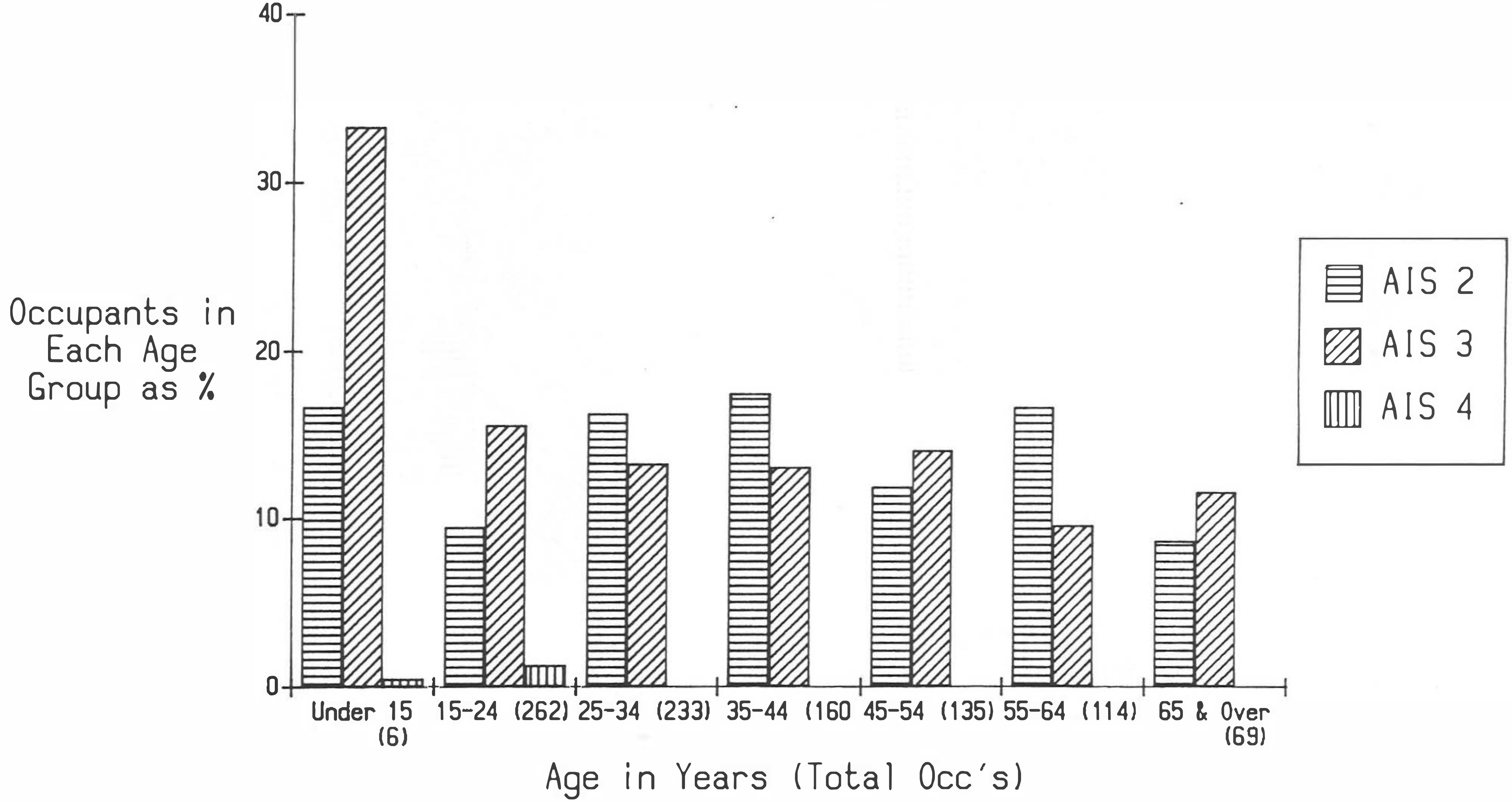

Figure 5. Restrained FSO's With Maximum AIS Of 2 Or Over In Frontal Impacts