LOWER LIMB INJURIES TO CAR OCCUPANTS IN FRONTAL IMPACTS

by

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Introduction

The data bank of the Accident Unit at Birmingham University has been accumulated over a period of 8 years and consists of more than 2200 in-depth cases involving vehicle occupant injury. During this time case selection criteria appropriate to the study of both serious and fatal accidents, and accidents in which seat belts have been worn have been employed. The consequences of these several criteria are that the whole sample cannot be used to establish the frequency of particular injuries amongst the car occupant casualty population. However, those sustaining serious or fatal injury have not been systematically excluded from the sample at any stage and thus patterns and causes of injury for this group of people can be meaningfully examined.

The intention of the present study is to examine the nature of lower limb injury amongst seriously or fatally injured car occupants involved in frontal impacts. The analysis provides information for comparison with cadaver and dummy work and for consideration by those involved in legislation. Frontal impacts have been selected for study because most recent work concerned with cadaver tolerance testing or dummy injury criteria has attempted to simulate the effects of direct blows to the knee, as frequently experienced in frontals. This field sample is therefore designed to provide information directly relevant to that condition.

Structure of the Sample

The sample selected for analysis involved five models of vehicle. These were selected because relatively large numbers of examples of each were available on file and thus the number of vehicle variables, in terms of knee impact area design, was kept to a minimum consistent with having an acceptable number of cases for analysis. The makes and models of vehicles selected are described in Appendix 1.

Impacts with a direction of force between 11 and 1 o'clock have been chosen and these cases contain 181 drivers and 77 front seat passengers who received an injury of AIS 2 or more in any body area. This selection criteria based on the occupants' highest AIS score approximately corresponds with selection based on the official U.K. serious and fatal categories. Table 1 gives the sex distribution for those who did or did not suffer a lower limb fracture or dislocation by seating position. The predominance of male drivers in this sample is apparent while over half the front seat passengers were female. There was no difference in the sex distribution of those who did and did not suffer a lower limb fracture or dislocation in each front seating position. However, Table 1 does show that drivers, in this sample, experienced a higher incidence of serious lower limb injury than did front seat passengers. The restraint system usage for the two front seating positions (Table 2) does not indicate a bias of a kind which could account for the difference in frequency of fractures and dislocations apparent in Table 1.

Significance of Lower Limb Injuries

The relative importance of lower limb injuries for these 258 occupants who scored AIS 2 or more in any body area has been examined using three different injury scales, the Abbreviated Injury Scale (AIS) (1)* and two scales taken from the Comprehensive Research Injury Scales (CRIS) (2,3). The AIS sets out to be a 'threat to life' scale whilst the two scales selected from the CRIS attempt to rank injuries in terms of their 'treatment period' (TP) and the likelihood of 'permanent impairment' (PI). It was felt that the last two considerations had particular relevance to a discussion of lower limb injuries. It should be stressed that, as far as the authors are aware, the CRIS has not been used widely in published analyses and thus it does not have the general acceptance of the AIS. Remarks based on these scales are therefore somewhat tentative.

All injuries suffered by each occupant were rated on the three selected injury scales using the following body areas: head and neck, chest, abdomen, lower limbs including the pelvis, and arms. The ranking of the relative importance of injuries to the various body areas is given in Table 3. It can be seen that for this serious and fatal injury sample the AIS and permanent impairment scale of the CRIS both rate lower limb injury as second in importance to head injury for drivers. The treatment period scale of the CRIS, however, shows lower limb injury to be the most important type of injury for drivers. For passengers the lower limbs are rated as the third most important area after the head and chest by both the treatment period and permanent impairment scales of the CRIS. The AIS rates such injuries as fourth in importance only followed by injuries to the arms. These figures indicate that by any of these three considerations lower limb injuries play a significant part in driver injury but are relatively less important for passengers.

Locations and Sources of Serious Lower Limb Injuries

The locations of the lower limb fractures and dislocations in the sample are shown in Table 4 for unrestrained and restrained drivers and front seat passengers. It is of interest to consider what proportion of these injuries could possibly be affected by an injury criterion based on a load cell in a dummy femur. If such a load cell is considered to relate in some way to injuries

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* Numbers in parentheses refer to references at the end of the paper.

in the knee/femur/hip complex, it would be relevant to 65% of the fractures observed in the unrestrained occupants and 54% of similar injuries amongst the restrained. In both groups it is clear that, whilst injuries to the upper half of the leg are in the majority, injuries below the knee nevertheless form a substantial part of the picture.

If any type of effective control of the lower limb impact area is sought, it is important to know the distribution of knee impact sites in frontal impacts. Such knowledge, in theory, would allow structures with suitable impact characteristics to be placed in relevant parts of the vehicle. Figures 1 and 2 illustrate the position of the detected knee impact sites for all the occupants in the sample and also for those people who sustained a fracture or dislocation in the knee/femur/pelvis complex. For the purpose of this analysis, the facias of the vehicles involved have been divided horizontally into 10 cm bands. For the driver, the datum was the steering column and for the front seat passenger the datum was directly in front of the centre of the passenger seat. The driver's side has an additional category describing direct contact with the column itself. The wide distribution of knee impact sites for all occupants is evident and this spread represents a real problem if it is intended to provide controlled lower limb impact areas based on single 'whole system' impact tests. Such single condition testing seems inherently unsuited to defining the properties of what is, in practice, a widely spread impact area.

The concept of controlling knee/femur/hip injury by measuring femur compression loads presupposes that such loads are the main cause of this type of injury. The evidence available from the present sample tends to support this hypothesis with the contact marks on the vehicles suggesting in almost all cases a direct blow to the knee rather than any form of angulation being applied directly to the femur.

Effects of Speed and Intrusion

The Equivalent Test Speed (E.T.S.) distribution for the whole sample of unrestrained drivers and front seat passengers is shown in Table 5. Included in this table are the E.T.S. distributions for those sustaining fractures to the knee/femur/hip complex and anywhere below the knee. These figures indicate how the frequency of injury to both the upper and lower parts of the leg increases with rising E.T.S. Above an E.T.S. of 25 mph, 53% of the unrestrained drivers who received an AIS of 2 or more in any body area suffered a fracture or dislocation in the upper half of the leg and 29% of them sustained such an injury below the knee.

The equivalent distributions for restrained drivers and front seat passengers are shown in Table 6. Although the numbers are small, they have been included for the sake of completeness.

The occurrence of passenger compartment intrusion in the region of the knee impact area is shown in Table 7 for both restrained and unrestrained drivers. In each case the intrusion has been allocated to one of three categories based on the reduction in space between the knee impact area and the supposed normal position of the driver's knees. This categorisation was necessarily subjective but it does broadly describe the presence of no, small, or large amounts of intrusion at knee level. Included in this table is the intrusion experience for those who sustained a fracture or dislocation in the knee/femur/pelvis region. The intrusion has been rated separately for left and right legs and the fractures or dislocations referred to in the tables occurred on the same sides as the intrusion. It is of note that 13% of the legs of the unrestrained drivers in vehicles with no knee level intrusion sustained a fracture or dislocation in the knee/femur/pelvis whereas 6% of the legs of the restrained drivers suffered such injuries. The E.T.S. and age distributions for the restrained and unrestrained drivers are not significantly different and thus it is reasonable to deduce that the wearing of the belt is actually responsible for this difference in injury experience.

For belted drivers with an upper leg/pelvic fracture or dislocation in a leg not subjected to intrusion at knee level, only one case occurred at an E.T.S. below 35 mph. This is of great relevance for those considering the control of lower limb impact areas based on 'whole system' testing with belted dummies. It implies that such tests conducted on a sled or in a vehicle subjected to a distributed barrier impact at 30 mph or an angled barrier at the same speed, which frequently produce little or no intrusion, would be unlikely to examine potentially injurious knee impacts for the driver dummy in the range of vehicles in this sample. Indeed, any test which produced minimal knee level intrusion would experience the same problem. Whilst the inclusion of a femur criterion in such tests is probably still desirable, it would have little influence on the design of knee impact areas. This finding, taken together with the wide distribution of knee impact sites described in figures 1 and 2, argues strongly against the concept of single condition 'whole system' testing with belted dummies which is currently under discussion in Europe. An additional test based on a knee form impactor would seem likely to offer greater benefits in terms of the control of knee impact area design.

For the legs of unrestrained drivers with knee level intrusion, 50% sustained a fracture or dislocation to the upper half of the leg or the pelvis. Restrained drivers' legs with knee level intrusion also suffered a higher incidence of fracture than their counterparts with no intrusion, fractures in the intrusion cases occurring in 21% of legs. However, intrusion at knee level and E.T.S. were found to be strongly associated and thus the individual effect of these two variables for the intrusion cases cannot be clearly demonstrated.

The intrusion experience in each side of the footwell has been assessed in a similar way to that used for knee level intrusion. In this instance, the space between the footwell and the front of the seat was divided into three zones. No or insignificant intrusion catered for footwell intrusion of less than 5 cm. Intrusion in excess of this was categorised as small with less than 50% of the space used up, and large, with more than half this space gone. This system again allowed intrusion, in the footwell in this instance, to be described in broad terms. The results obtained for both belted and unbelted drivers are shown in Table 8. This table also illustrates the footwell intrusion experience for those who sustained a fracture below the knee. In 7% of the legs of belted drivers and 5% of the legs of unbelted drivers with no intrusion in the footwell, a fracture occurred below the knee. For those with some degree of intrusion, 25% of the legs of unrestrained drivers received such injuries, compared with 31% of the legs of restrained drivers. If all levels of intrusion are considered together, 12% of the legs of the unrestrained drivers suffered a fracture or dislocation below the knee as against 16% of the legs of the restrained drivers. Again there was a very highly significant association betweeen high E.T.S. values and large amounts of footwell intrusion and thus the individual contribution of each could not be clearly demonstrated. However, the E.T.S. distributions for the belted and unbelted drivers at all intrusion levels were significantly different at the 5% level of confidence, with the belted drivers generally being exposed to the higher energy impacts. Given this difference together with the association between E.T.S. and footwell intrusion, it is not possible to determine whether belt use in itself offered any additional protection against fractures or dislocations below the knee.

The numbers of front seat passengers available in this sample are not sufficiently large to allow a similar comparison of intrusion and belt use for these occupants. However, the data is presented in tables 9 and 10 for completeness.

Comparisons between Field Study and Cadaver Tests

Comparison of the results of the present study with those from other field studies which specifically examine lower limb injuries is difficult as other authors (4,5) have in general included impacts other than frontal impacts or have also included all severities of injury and all seating positions. However, comparison between this study and published work on cadaver tests is valid since care has been taken in this study to produce a field sample in which loading conditions are as close as possible to those experienced by cadavers in recent test work.

The types of tests and patterns of upper leg and pelvic injuries for cadavers are summarised in Table 11. The predominance of patella fractures and condylar and supracondylar femur fractures are apparent and the almost total absence of hip injury following impacts on the knee is notable. In this field study, the principle injuries to the upper half of the leg were fractures to the femoral shaft, fractures to the pelvis and hip followed by patella fractures (Table 12). It is of note that the frequent cruciate ligament injuries described in one of the most recent papers on cadaver work (11) have not been reported in the present field study. Whilst such injuries may be under-reported amongst real accident victims, and especially amongst the fatalities, their apparent total absence is significant.

The apparent difference in injury pattern between the accident sample and the cadaver data should be carefully considered if tolerance levels are being established based solely on cadaver results.

Few cadaver tests have attempted to simulate injury mechanisms experienced by car occupants with respect to below the knee loading. In the present study, 67% of fractures to the tibia and fibula were associated with footwell intrusion while 74% of fractures and dislocations of the foot and ankle were accompanied by such intrusion. In general, there was an absence of well-defined contact points associated with serious below the knee injuries, tending to indicate that loads transmitted via the pedals and footwell play a significant role in the generation of such injuries.

Conclusions

For this sample of seriously or fatally injured car occupants involved in frontal impacts it has been found that:-

1. Drivers suffer fractures or dislocations in the lower limbs more frequently than front seat passengers. In terms of the 'treatment period'

scale from the CRIS, injuries to the lower limbs were ranked ahead of those to all other body areas, for drivers. The AIS and 'permanent impairment' scale of the CRIS ranked drivers' lower limb injuries second only to head injuries.

2. For unrestrained occupants, 65% of the lower limb fractures and dislocations occurred in the knee/femur/pelvic complex. For restrained occupants the equivalent figure was 54%. In both groups it is clear that, whilst injuries to the upper half of the leg are the most frequent, injuries below the knee form a substantial part of the picture.

3. Knee impact sites are widely spread across the facia, suggesting that single 'whole system' tests may be inherently unsuitable for controlling the impact properties of these areas. An additional test based on a knee form impactor would seem likely to offer greater benefits.

4. In general, injuries to the knee/femur/pelvis complex were associated with loading on the knees rather than angulation applied directly to the femur.

5. The use of seat belts halved the incidence of fractures in the upper half of the legs for drivers. Only one restrained driver in this sample sustained a fracture in the upper half of the leg without knee level intrusion below an E.T.S. of 35 mph. This finding has implications for 'whole system' testing using restrained dummies in crash test configurations which produce little or no intrusion.

6. Patterns of injury reported in recent cadaver work investigating injuries following direct loading on the knee are different from those found in this study of real accidents. This difference may have serious implications for the tolerance levels based on such cadaver experiments.

References

1. AMERICAN ASSOCIATION OF AUTOMOTIVE MEDICINE. The Abbreviated Injury Scale (1976 Revision) AAAM, Morton Grove, Illinois - 1976.

2. STATES, J.D., The Abbreviated and Comprehensive Research Injury Scales. Proceedings of the 13th Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 282-294, SAE paper no. 690810. December 1969.

3. STATES J.D., FENNER Jr. H.A., FLAMBOE E.E., NELSON W.D., HAMES L.N. Field Application and Research Development of the Abbreviated Injury Scale. Proceedings of the 15th Stapp Car Crash Conference, Society of Automotive Engineering Inc., pp. 710-738, SAE paper no. 710873. November 1971.

4. GRATTAN E. and HOBBS J.A. Mechanisms of Serious Lower Limb Injuries to Motor Vehicle Occupants. Road Research Laboratory, Ministry of Transport. R.R.L. Report LR 201. 1968.

5. NAHUM A.M., SIEGEL A.W., HIGHT P.V., BROOKS S.H. Lower Extremity Injuries of Front Seat Occupants. Society of Automotive Engineers Inc., SAE paper no. 680483. May 1968.

6. PATRICK L.M., KROELL C.K., MERTZ H.J. Forces on the Human Body in Simulated Crashes. Proceedings of the 9th Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 237-259. October 1965.

7. PATRICK L.M., MERTZ H.J., KROELL C.K. Cadaver Knee Chest and Head Impact Loads. Proceedings of the 11th Stapp Car Crash Conference, Society of Automotive Engineers Inc., SAE paper no. 670913. October 1967.

8. POWELL W.R., ADVANI S.H., CLARK R.N., OJALA S.J., HOLT D.J. Investigation of Femur Response to Longitudinal Impact. Proceedings of the 18th Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 539-556, SAE paper no. 741190. December 1974.

9. POWELL W.R., OJALA S.J., ADVANI S.H., MARTIN R.B. Cadaver Femur Responses to Longitudinal Impacts. Proceedings of the 19th Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 561-579, SAE paper no. 751160. November 1975.

10. MELVIN J.W., STALNAKER R.L., ALEM N.M., BENSON J.B., MOHAN D. Impact Response and Tolerance of the Lower Extremities. Proceedings of the 19th Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 543-559, SAE paper no. 751159. November 1975.

11. VIANO D.C., CULVER C.C., HAUT R.C., MELVIN J.W., BENDER M., CULVER R.H., LEVINE R.S. Bolster Impacts to the Knee and Tibia of Human Cadavers and an Anthropomorphic Dummy. Proceedings of 22nd Stapp Car Crash Conference, Society of Automotive Engineers Inc., pp. 401-428, SAE paper no. 780896. October 1978.

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Table 1. Occupant sex by seating positions and presence of serious lower limb injury.

	Drivers		Front Seat Passengers		Total
	Lower limb fracture or dislocation		Lower limb fracture or dislocation		
	Yes	No	Yes	No	
Male	76	88	9	24	197
Female	6	11	10	34	61
Total	82	99	19	58	258

Table 2. Seat belt use by seating positions.

	Seat belt used		
	Yes	No	Total
Driver	47	134	181
FSP	19	58	77
Total	66	192	258

Table 3. Ranking of body areas by AIS, TP and PI for drivers and front seat passengers.

Rank	AIS		TP		PI	
	Driver	FSP	Driver	FSP	Driver	FSP
1	head 49%	head 62%	legs 50%	head 60%	head 51%	head 60%
2	legs 30%	chest 31%	head 36%	chest 26%	legs 41%	chest 34%
3	chest 28%	abdomen 13%	chest 22%	legs 22%	chest 35%	legs 18%
4	arms 13%	legs 12%	arms 20%	arms 13%	arms 25%	arms 12%
5	abdomen 11%	arms 8%	abdomen 0%	abdomen 0%	abdomen 9%	abdomen 8%

The percentages represent the frequency with which each body area has the highest or equal highest value of the scale in question.

Table 4. Locations of lower limb fractures and dislocations for restrained and unrestrained front seat occupants.

a) Unrestrained

Region in which fracture occurred	Drivers			Front Seat Passengers			Total
	Left leg	Right leg	Total	Left leg	Right leg	Total	
Hip and pelvis	11	15	26	5	3	8	34
Femur	7	22	29	2	3	5	34
Knee	4	8	12	0	0	0	12
Tibia and fibula	5	8	13	3	2	5	18
Foot and ankle	3	20	23	1	1	2	25

b) Restrained *

Region in which fracture occurred	Drivers*			Front seat Passengers			Total
	Left leg	Right leg	Total	Left leg	Right leg	Total	
Hip and pelvis	1	2	3	1	3	4	7
Femur	0	6	6	3	2	5	11
Knee	0	3	3	0	0	0	3
Tibia and fibula	3	3	6	0	0	0	6
Foot and ankle	1	8	9	0	3	3	12

* Note: In one case, a lap belt was used. In all other cases three point belts were worn.

Table 5. Location of lower limb fractures or dislocations by ETS for unrestrained drivers and front seat passengers.

a) Unrestrained drivers

	E.T.S. (mph)								
	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
No. of drivers	1	4	14	20	31	14	18	5	2
With upper N leg fracture %	0 0	1 25%	2 14%	2 10%	12 39%	8 57%	11 61%	4 80%	2 100%
With lower N leg fracture %	0 0	0 0	0 0	5 25%	10 32%	2 14%	5 28%	2 40%	1 50%

b) Unrestrained front seat passengers

	E.T.S. (mph)								
	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
No. of FSPs	1	5	6	10	8	7	10	0	0
With upper N leg fracture %	0 0	0 0	0 0	2 20%	1 12%	2 29%	3 30%	- -	- -
With lower N leg fracture %	0 0	0 0	1 16%	0 0	1 12%	1 14%	3 30%	- -	- -

Table 6. Location of lower limb fractures or dislocations by E.T.S. for restrained drivers and front seat passengers.

a) Restrained drivers

	E.T.S. (mph)							
	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
No. of drivers	0	7	6	9	3	11	0	1
With upper leg fracture N	-	0	1	0	1	5	-	0
%	-	0	17%	0	33%	45%	-	0
With lower leg fracture N	-	1	0	3	0	4	-	1
%	-	14%	0	33%	0	36%	-	100%

b) Restrained front seat passengers

	E.T.S. (mph)							
	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
No. of FSPs	1	3	3	1	1	4	1	1
With upper leg fracture N	0	0	0	0	0	0	1	0
%	0	0	0	0	0	0	100%	0
With lower leg fracture N	0	0	1	1	0	1	0	0
%	0	0	33%	100%	0	25%	0	0

Table 7. Incidence of knee level intrusion for drivers with and without associated lower limb fractures and dislocations.

a) Unrestrained drivers

		Amount of intrusion				
		Left Leg			Right Leg	
	None	Small	Large	None	Small	Large
No. of legs	107	14	13	97	13	24
Upper leg fractures N %	14 13%	3 21%	5 38%	13 13%	9 69%	15 62%

b) Restrained drivers

		Amount of intrusion				
		Left Leg			Right Leg	
	None	Small	Large	None	Small	Large
No. of legs	34	7	6	31	4	12
Upper leg fractures N %	1 3%	0 0	0 0	3 10%	2 50%	5 42%

Table 8. Incidence of footwell intrusion for drivers with and without associated fractures and dislocations.

a) Unrestrained drivers

		Amount of Intrusion				
		Left Leg			Right Leg	
	None	Small	Large	None	Small	Large
No. of legs	95	23	15	76	28	29
Lower leg fractures N %	2 2%	2 9%	4 27%	7 9%	6 21%	12 41%

b) Restrained drivers

		Amount of intrusion				
		Left Leg			Right Leg	
	None	Small	Large	None	Small	Large
No. of legs	34	10	3	25	13	9
Lower leg fractures N %	2 6%	1 10%	1 33%	2 8%	5 38%	4 44%

Table 9. Incidence of knee level intrusion for front seat passengers with and without associated fractures and dislocations.

a) Unrestrained front seat passengers

		Amount of intrusion					
		Left Leg			Right Leg		
		None	Small	Large	None	Small	Large
No. of legs		52	3	3	52	3	3
Upper leg fractures	N %	6 12%	0 0	1 33%	4 8%	0 0	1 33%

b) Restrained front seat passengers

		Amount of intrusion					
		Left Leg			Right Leg		
		None	Small	Large	None	Small	Large
No. of legs		15	1	3	14	2	3
Upper leg fractures	N %	2 13%	0 0	2 67%	0 0	1 50%	2 67%

Table 10. Incidence of footwell intrusion for front seat passengers with and without associated fractures and dislocations.

a) Unrestrained front seat passengers

		Amount of intrusion					
		Left Leg			Right Leg		
		None	Small	Large	None	Small	Large
No. of legs		41	14	3	46	11	1
Lower leg fractures	N %	2 5%	1 7%	1 33%	0 0	3 27%	0 0

b) Restrained front seat passengers

		Amount of intrusion					
		Left Leg			Right Leg		
		None	Small	Large	None	Small	Large
No. of legs		14	3	2	14	2	3
Lower legs fractures	N %	0 0	0 0	0 0	2 14%	0 0	1 33%

Table 11. Summary of cadaver knee impact tests.

Authors	Ref.	Cadaver Type	Nature of Loading	Most Frequent Mode of Injury
Patrick, Kroell & Mertz	6	Embalmed cadavers, seated and unrestrained	Padded target impingement sled test	Supracondylar fractures of the femur and comminuted fractures of the patella, at loads varying from 1500 to 3850 lbs.
Patrick, Mertz & Kroell	7	Embalmed cadavers as described above	As above	No fractures observed at forces up to 1970 lbs.
Powell et al	8	Embalmed cadavers, seated with 90^0 flexed lower leg	Gravity activated impact pendulum with a rigid striker head, applied to one flexed knee at a time.	The majority of fractures involved the femoral condyles or patella. Mean fracture load 10.49kN (2360 lbs).
Powell et al	9	Embalmed cadavers, seated with lower leg flexed to 90^0	Impact pendulum as described above	Condylar and supracondylar fractures of the femur. Patella fractures. Average fracture load was 9.7 kN
Powell et al	9	Fresh cadavers, seated with lower leg flexed to 90^0	As above	Patella fractures Average fracture load was 11.2 kN (2500 lbs.)
Melvin et al	10	Fresh cadavers, seated with lower leg flexed to 90^0	Padded striking mass, actuated to constant velocity before knee impact	All fractures were in the distal 1/3 and supracondylar regions of the femur, and in the patella. Loads varied from 15.6 kN to 19.6 kN.
Viano et al	11	Fresh cadavers, seated, with upper body restrained	3 locations impacted with a 55.9 kg bolster covered mass at 6.0 m/s. 1. Tibia impact of a 90^0 flexed lower leg 2. Knee impact with lower leg flexed to 90^0 3. Knee-tibia impact against knee complex of 45^0 flexed lower leg using a tapered bolster.	1. All females showed comminuted fractures of the tibia and fibula. Average peak contact load 5.15 kN. Males showed tears and avulsions of posterior cruciate ligament. 2. Avulsion of posterior cruciate ligament from tibial plateau. Several females showed fractures of femoral condyles or patella. Average peak contact load 7.02 kN. 3. No apparent injury as leg under-rode bolster. Average peak force 3.66 kN.

Table 12: The pattern of lower limb injuries.

Type of Injury *	Number of fractures and dislocations
HIP AND PELVIS	
Fractures of the pelvis (not including the acetabulum)	24
Dislocations or fracture dislocations of the hip	15
Fractures of the acetabulum	4
FEMUR	
Trochanteric fractures	1
Fractures within the shaft	25
Femoral fracture, precise nature not known	15
Condylar or supracondylar fractures	3
Fractures involving the knee joint	4
KNEE	
Patella fractures	13
Dislocations of the patella	1
Fracture/dislocation of the knee	1
LOWER LEG	
Fracture extending into knee joint	3
Simple fracture of tibia and/or fibula	17
Compound fracture of tibia and/or fibula	3
Comminuted fracture of tibia and/or fibula	4
Simple fracture of tibia and fibula at lower end	2
Comminuted fracture of tibia and fibula at lower end	2
Fracture of lower leg, precise details not known	1
FOOT AND ANKLE	
Malleolar fractures	14
Displaced Potts fracture	1
Ligament avulsion	1
Fractures and/or dislocations of tarsals	19
Fracture or dislocation of metatarsal	3
Fractures of phalanges	1
Fractured or dislocated bone in foot (precise details not known)	5

*Injury descriptions are not mutually exclusive within each region of the lower limb.

FIGURE 1: POSITION OF KNOWN DRIVER LEG CONTACTS.

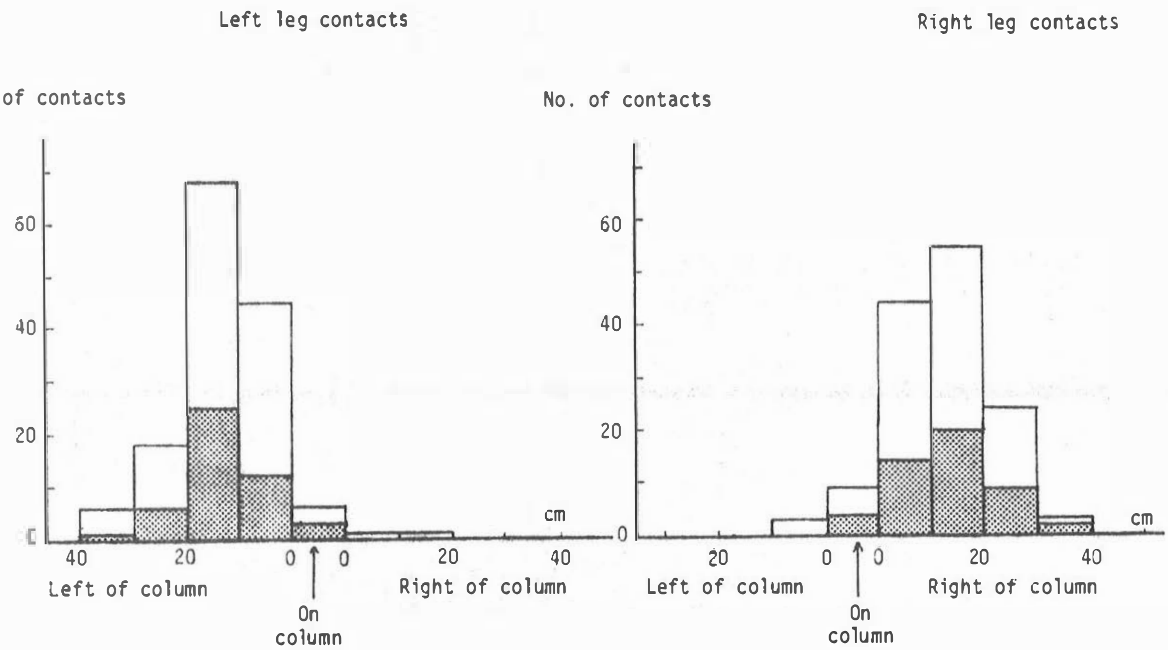
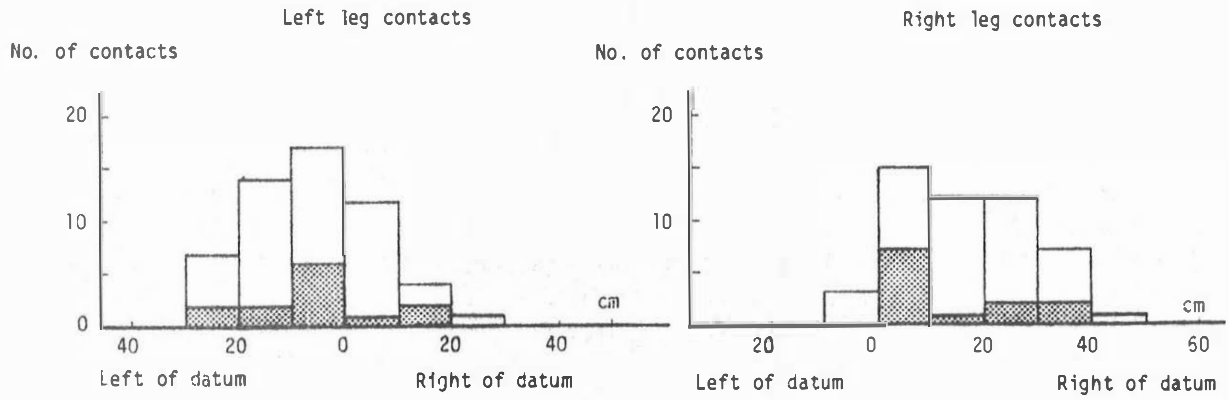
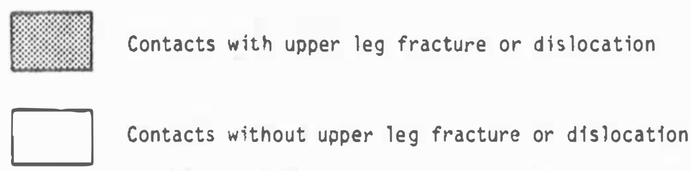


FIGURE 2: POSITION OF KNOWN PASSENGER LEG CONTACTS.





Appendix 1. Vehicle makes and models.

Manufacturer	Model	No. of Cars	No. of Drivers	No. of Front Seat Passengers	Total No. of Occupants
Ford	Cortina	67	55	27	82
Ford	Escort	52	47	18	65
BL	Marina	37	34	11	45
Chrysler	Avenger	32	29	13	42
Vauxhall *	HC Viva	18	12	7	19
Vauxhall *	Firenza	3	3	0	3
Vauxhall *	Magnum	1	1	1	2
	Totals	210	181	77	258

Note: Only occupants with a highest AIS of 2 or more are included in this analysis.

* In this analysis the three Vauxhall models have been considered together.