LOWER LIMB INJURIES TO PASSENGER CAR OCCUPANTS

Prepared by

Fildes, B.N.
Lane, J.C.
Lenard, J.
Vulcan, A.P.
Wenzel, J.

Monash University
Accident Research Centre

CR 137

October, 1994

ISBN 0 642 51093 8

Published for the Federal Office of Road Safety, Department of Transport by the Australian Government Publishing Service

A51534 Cat. No. 94 3087 6

FEDERAL OFFICE OF ROAD SAFETY REPORT DOCUMENTATION PAGE

Report No.	Report Date	Pages	ISBN
CR 137	October 1994	44	0-642-51093-8

Title and sub-title:
Lower limb injuries to passenger car occupants

Author(s):
Fildes, B.N., Lane, J.C., Lenard, J., Vulcan, A.P. & Wenzel, J.

Performing Organisation:
Monash University Accident Research Centre
Wellington Road, Clayton, Victoria, 3168, Australia

Sponsor [Report available from]:
Federal Office of Road Safety
GPO Box 594, CANBERRA, ACT, 2601, Australia

Abstract:
Lower limb injuries occur to front seat occupants in more than one in three head-on casualty crashes A study was undertaken to determine the various types of injuries, the sources of injury inside the vehicle, and the mechanisms of injury. This information was to help guide future regulation effort aimed at reducing the frequency and severity of these injuries and to make recommendations about how these injuries might be mitigated in future vehicle design. A detailed examination was undertaken of hospitalised or killed vehicle occupants who sustained a lower limb injury in a passenger car involved in a frontal crash. The findings showed that fractures occur in 88% of crashes where someone suffers a lower limb injury. Fractures to the ankle and foot were more common than other lower limb fractures and the floor and toepan area was especially involved in these fractures. There was no apparent age or sex effects among the injured occupants. Unrestrained occupants seemed more likely to sustain a thigh fracture from contact with the instrument panel than restrained occupants. The number of fractures was directly proportional to the impact velocity and roughly half these fractures occurred at a delta-V value of 48km/h or less. The most common mechanisms of injury was compression (axial loading) of the lower leg or thigh, perpendicular loading of the knee, and crushing or twisting of the foot. There is a need for additional regulation aimed at reducing the frequency and severity of these injuries and a number of countermeasures are available.

Key Words: SAFETY, ACCIDENT, VEHICLE OCCUPANT, INJURY, TEST METHOD, LOWER LIMBS, EVALUATION, INJURY MECHANISMS

Notes:

(i) FORS reports are disseminated in the interest of information exchange.

(ii) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.

(iii) The Federal Office of Road Safety publishes four series of reports:

(a) reports generated as a result of research done within FORS are published in the OR series;

(b) reports of research conducted by other organisations on behalf of FORS are published in the CR series.

(c) reports based on analysis of FORS statistical data bases are published in the SR series;

(d) minor reports of research conducted by other organisations on behalf of FORS are published in the MR series.

Contents

Acknowledgements

The authors are indebted to the Federal Office of Road Safety, Commonwealth Department of Transport and Communications, Australia, for their sponsorship, interest and assistance with this project. Mr Keith Seyer, in particular, contributed substantially in helping develop the method, overseeing the results of the analysis and preparing the report.

The study team acknowledge the generous assistance of the three study hospitals, their co-ordinators, and their staff in providing access to patients and medical records, namely The Alfred Hospital, Box Hill Hospital and Dandenong & District Hospital. We are grateful, too, to the many patients who kindly agreed to participate in the study during their time of severe trauma. Thanks also to those at the Monash University Accident Research Centre who assisted with the data collection, especially research nurses Ms Di Holst and Ms Barbara Fox, case co-ordinator Mr David Kenny, and data analyst Mr Tri Le.

To the many crash repair shops, wrecking yards, and towing services we are eternally thankful for their valuable assistance. The RACV towing allocation service (Mr John Wardle and staff) in conjunction with VicRoads (Mr David O'Sullivan) were especially helpful in helping to locate many of the crashed vehicles.

The Victorian Police were always ready to assist either in locating the vehicles, providing details on the crash, or providing access to vehicles stored in their yards and we are extremely grateful to Mr Glare, Chief Commissioner, Mr Green, Assistant Commissioner, Traffic and Operations Support, and to the many members of the force who assisted with the study.

The Transport Accident Commission and VicRoads kindly agreed to provide their data on relevant vehicle crashes and other assistance with the study. We are grateful in particular to Mr David Attwood, Mr Bill Collins, and their staff for their assistance in making the necessary arrangements.

Executive Summary

Lower limb injuries to front seat occupants in frontal crashes are a major source of vehicle occupant trauma in this country, occurring in more than one in every three crashes where someone is either hospitalised or killed.

While not necessarily life threatening, they do cause considerable pain and suffering to the individuals involved, can require long-term treatment and rehabilitation and often result in permanent disability. They can be extremely costly to the people involved and to the community generally.

Lower Limb Study

To assist in future efforts aimed at reducing the frequency and severity of lower limb injuries, the Monash University Accident Research Centre was commissioned by the Federal Office of Road Safety to undertake a detailed examination of lower limb injuries to front seat occupants in frontal crashes involving current generation passenger cars.

The study set out to identify the range of lower limb injuries and contacts within the vehicle and to investigate the mechanisms of injury for the more serious and frequent of these injuries. The study was to make recommendations on the needs and priorities for further lower limb injury regulation and countermeasures aimed at reducing these injuries.

A literature review was initially conducted which reviewed previous research and recent developments in this area.

An analysis was then undertaken of lower limb injury cases contained in the Crashed Vehicle File at Monash University. This database comprised detailed inspections of 501 crashes that occurred in and around Melbourne involving 605 injured occupants where the occupant was either hospitalised or killed in the crash.

The injury analysis identified the most common severe lower limb injuries and their contact source within the vehicle in frontal crashes that required closer attention.

Mechanism of Injury Data

Mechanism of injury for these frequent injuries was then determined from the details of the injuries and sources of injury in the original case sheets as well as from additional details obtained from the patient files kept at the treating hospital.

An expert panel was formed consisting of a trauma surgeon, an epidemiologist, a biomechanical engineer and research staff to review each lower limb injury case in arriving at an agreed prognosis of the mechanism of injury.

Findings from the Study

There were a number of findings concerning the types and mechanisms of lower limb injuries to come from this study.

The most common severe lower limb injuries in frontal crashes are fractures (single or multiple). Fractures occur in 88% of cases where a front seat occupant is either hospitalised or killed in a frontal crash and sustains a lower limb injury.

The ***six*** most frequent lower limb fracture by contact source combinations were ankle/foot with the floor & toepan, lower leg with the floor & toepan, thigh with the instrument panel, lower leg with the instrument panel, knee with the instrument panel and knee with the steering column. The first of these was six times more likely than the last.

Current crash performance regulations only specify a maximum acceptable tolerance level for femur (thigh) loading. Moreover, there is a need for a new test dummy capable of measuring the full range of injurious forces to the lower limbs.

The average change of velocity during impact (delta-V) was slightly higher among cases where someone sustained a lower limb fracture than for all frontal crashes. Lower limb fracture cases had a higher minimum delta-V value than all injury cases.

Fifty percent of lower limb fractures occurred at 50km/h or below. The 80th percentile value was 70km/h. The number of fractures per fractured lower limb case was directly proportional to delta-V. Lower limb fractures were more common among occupants of smaller cars.

There were no marked age or sex related differences in lower limb fractures suggesting that any frailty effects due to ageing were more than offset by the level of lower limb trauma associated with frontal crashes.

There was a slight suggestion of over-involvement of unrestrained occupants among those sustaining a thigh fracture.

The three most common mechanisms of lower limb fracture include compression (axial loading) of the thigh and lower leg, perpendicular loading of the knee, and crushing or twisting of the foot. These three mechanisms (by body region) need to be emphasised in future efforts to measure and specify acceptable tolerances aimed at reducing lower limb injuries.

Foot and ankle movements of eversion and inversion and dorsiflexion were most common among foot and ankle fractures. Torsion forces were roughly equally distributed in either direction while perpendicular loading tended to be more medial than lateral.

Recommendations

There is a need for further effort aimed at reducing lower limb injuries for front seat occupants in frontal crashes. This could require additional regulation aimed at specifying a range of lower limb injury tolerance criteria.

As a pre-requisite, there is a need for test dummies sufficiently sensitive to measure the types and ranges of lower limb injuries (fractures) apparent in real world crashes.

Manufacturers, too, need to consider ways in which car design could be improved to protect these lower extremities.

Possible countermeasures for lower limb injuries include:

- more forgiving lower instrument panel designs,
- knee bars,
- removing injurious fittings in the regions likely to come into contact with lower limbs in frontal crashes,
- the use of more sturdy materials in dash boards (such as sheetmetal, rather than brittle plastics),
- innovative pedal designs to minimise the likelihood of ankle and foot fracture, and
- structural improvements in the floor and toepan regions to minimise intrusions and deformations likely to injure occupants' feet and lower legs.

1. INTRODUCTION

Lower limb injuries to front seat occupants in frontal crashes continue to be a major source of vehicle occupant trauma in terms of pain and suffering to the individuals involved and cost to both the individuals and the community. Fildes, Lane, Lenard and Vulcan (1991) demonstrated that the most frequent injury to hospitalised front seat occupants from head-on crashes was to the lower extremities. A number of countermeasures were recommended to alleviate these injuries namely knee bars and more forgiving lower instrument panel designs. These measures were all shown to be highly cost-effective (Monash University Accident Research Centre, 1992).

Apart from specifying acceptable femur loads in the US FMVSS208 and the forthcoming ADR69/00, however, there is no requirement at present anywhere in the world for vehicle manufacturers to meet lower limb injury criteria in any type of crash Regulations of this type are imperative to ensure that vehicle manufacturers pay sufficient attention to passenger car designs that will enhance lower limb protection for occupants.

Through the Federal Office of Road Safety, Australia is currently participating in the work of the European Experimental Vehicles Committee (EEVC) to develop a uniform offset frontal crash procedure. Part of this procedure will be to specify lower limb injury criteria A first step in this process is to use the criteria originally developed from the work of General Motors' researcher Bud Mertz and a fully instrumented Hybrid III dummy. However, EEVC are also developing a new generation frontal test dummy based on research underway throughout the western world. This new dummy will incorporate new leg assemblies capable of recording even more injury data.

Yet, there is very little data available on the extent of lower limb injuries, particularly the mechanisms involved in the more severe types of lower limb injuries. These data are crucial to help ensure that the new generation test dummy is sufficiently sensitive enough to measure appropriate injury types and, therefore, specify suitable test criteria to ensure real-world injury reductions.

1.1 PROJECT OBJECTIVES

The Federal Office of Road Safety recently commissioned the Monash University Accident Research Centre to undertake a study of the extent of lower limb injuries and the mechanisms or processes of lower limb injury. The objectives of this study, specified by the Federal Office of Road Safety, were to:

- identify the types of lower limb injuries (bone fractures, ligament damage, lacerations, contusions, etc) sustained by front seat occupants in frontal crashes,
- show the sources of these injuries within the vehicle (what parts of the car cause these injuries), and
- the precise mechanisms of injury (how they are caused).

The results of this study are to be used to assist the Federal Office of Road Safety in their deliberations on EEVC working parties aimed at developing a new generation crash test dummy and suitable lower limb injury criteria.

1.2 STUDY METHODOLOGY

The project design included a number of different research tasks, including a small review of Australian and overseas occupant safety literature, an analysis of detailed injury data to occupants of modern passenger cars that crash, a more thorough examination of severe lower limb injuries to determine injury mechanisms, and a project report outlining the findings from this study.

The database used in this analysis was the "Crashed Vehicle File" containing a detailed examination of 501 representative passenger car crashes (post-1982 vehicles) in and around Melbourne in which 605 vehicle occupants were hospitalised or killed. These data were collected from 1989 to 1992 using the National Accident Sampling System (NASS) and have been used in previous reports published by the Federal Office of Road Safety on frontal crashes (CR95, Fildes et al, 1991; CR100, Monash University Accident Research Centre, 1992) and more recently on side impacts (CR134, Fildes, Lane, Lenard & Vulcan, 1994).

The data analysis focussed on lower limb injuries that occurred to front seat occupants in frontal crashes and emphasised type and severity of injury, contact source, seating position, and whether the occupant was restrained or not. For each noteworthy category of lower limb injury, a set of typical (limited number) injury mechanisms were outlined. The frequency of occurrence of these mechanisms were then quantified to help prioritise future injury criteria.

2. LOWER LIMB LITERATURE REVIEW

2.1 DEFINITIONS

The lower extremity is classified into segments:

- The thigh, extending from the hip joint to the knee joint. It contains one bone, the femur, three groups of large muscles, tendons, large blood vessels and nerves.
- The leg, from knee joint to ankle joint. It contains two bones , the tibia and fibula, three groups of muscles, tendons nerves and blood vessels.
- The tibia and fibula expand at their lower ends as the malleoli, which form the upper part of the ankle joint.
- The foot, that part of the lower extremity beyond the ankle joint. It is a complex structure with seven tarsal bones (of the foot proper), five metatarsals and the bones of the toes themselves.
- The foot containing multiple joints, tendons, ligaments and a number of small muscles

The principal joints are the hip, knee and ankle.

In this account that part of the thigh containing the femur from the greater trochanter to the hip joint will be omitted. Soft tissue injury will be mostly neglected, but it is to be noted that injury to the major blood vessels, when occurring, may have a drastic effect on ultimate disability.

2.2 INCIDENCE AND IMPORTANCE

Efforts to reduce trauma in vehicle crashes have, for good reason, been directed mainly towards life threatening injuries - to the head, neck and thorax. But lower limb injuries, though seldom life-threatening, are a major cause of disability in surviving casualties from motor vehicle accidents. According to Pattimore, Ward, Thomas and Bradford (1991), a severe injury to the lower limb is often an occupant's most severe injury, so that means of mitigating these injuries would have considerable benefits.

According to Bull (1985), who analysed a large series of vehicle casualties, both those admitted to hospital and outpatients, injuries to the lower limbs are the most frequent cause of serious disability. Car crashes are a major contributor to the total of lower limb fractures from all causes. States (1986) reviews thirteen series, for different fracture types, in which the percentage derived from motor vehicle accidents (all kinds) ranges from 1.6% to 87%

States (1986) drew the conclusion that motor vehicle crashes caused:

- most pelvic fractures and hip dislocations
- three quarters of fractures of the shaft of the femur and proximal end of the tibia
- half tibial shaft fractures
- one quarter of inter-trochanteric fractures of the femur
- few heel (or calces) and femoral neck fractures.

Most ligament and articular cartilage injuries of the knee were sports injuries.

Estimates of the incidence of lower limb injuries in occupant casualties from the older literature (mostly unrestrained occupants) cited by States (1986) are: 13% (Nahum, Siegel, Hight & Brooks, 1968), 42% (Gogler, 1965) and 50% (Kihlberg, 1970).

In 1982 Huelke, O'Day and States estimated, from NCSS data, that car occupants in U.S.A. sustain 27,000 AIS 3 or 4 injuries to the lower extremity per year. These are distributed as follows: pelvis 24%, thigh 23%, knee 11%, leg 22% ankle and foot 16%. In 2520 occupants of 1074 tow-away crashes investigated by Rastogi, Wild and Duthie (1986) the incidence of lower limb injuries was 31.4% (few of the occupants were belt wearers). These authors found an incidence of 5% of fractured femurs in drivers and front seat passengers and 3% in the rear.

For occupants restrained by three-point belts, a study of Canadian car occupants with at least one injury of AIS 2 or greater (where 40% were in frontal crashes) showed that 50% had lower limb injuries (Dalmotas, 1980).

In the analysis of matched Transport Accident Commission data and police records carried out in Melbourne (Fildes et al, 1991), 17% of the injuries sustained by casualties admitted to hospital were major lower limb injuries and a further 31% were minor lower limb injuries. For frontal crashes, these percentages were 22% major and 34% minor. In the crashed vehicle study (Fildes et.al., 1991), drivers' injuries were 26% of all AIS>2 injuries, front left passengers' 13% and rear passengers' 9%. These percentages for front seat occupants, though substantial, are somewhat less than those reported by Ward, Bodiwala and Thomas (1992).

Ward, Bodiwala and Thomas (1992) examined data from the (U.K.) Cooperative Car Injury Study for restrained front seat occupants in frontal collisions. Table 2.1 shows the frequency of mean AISs for each body area.

Table 2.1
Frequency of AIS Value by Body Area
for 658 Restrained Front Seat Occupants in Frontal Collisions

	AIS value						
Body area	2	3	4	5	6	Total injured	Total with AIS over 2 (% of 658)
Head & face	257	41	8	8	-	450	314 (48)
Neck	11	11	-	-	-	99	22 (3)
Chest	167	28	7	-	-	371	202 (31)
Abdomen	21	13	5	3	-	106	42 (6)
Upper limbs	145	22	-	-	-	329	167 (25)
Lower limbs	120	94	-	-	-	460	214 (33)

Source: Ward et al (1992).

Levine (1986a) in a summary of reports of the long term outlook found that hip fractures from motor vehicle accidents (not considered in this review) often did not achieve a good result. Fractures of the shaft of the femur required six to ten months healing and eleven months before return to work. Patellar fractures generally had good results, with 94% of the injured occupants back at work after four months. Tibia and fibula fractures required up to eight months. Ankle fractures were usually faster to recovery - six to twelve weeks - and with good long term results. Fractures of the foot varied greatly depending on the bones involved. Fractures of the talus and calcaneus involving the joint caused long term disability.

According to Ward et al (1992), hip and femur fractures appear to require the greatest use of resources from the health and social services and have the worst long term prognosis, but leg, ankle and foot fractures are more frequent.

2.3 OCCUPANT VARIABLES

A number of investigators have reported on lower limb injury rates by age of occupant. Unfortunately most refer or probably refer to unrestrained occupants. Lowne (1974) found "leg" injuries in 46% of occupants aged 0-15 years compared with 66% in those aged 16 and over. Age may have been confounded with seating position as Walz, Sprenger and Niederer (1978) found little difference in the frequency of "leg injury" between child and adult rear seat occupants unbelted - both had 22%. (Pelvic injuries were more frequent with increasing age.)

The use of the age category 0 - 15 years conceals differences within the group. Ashton, Mackay and Gloyns (1974) found no leg injuries in those aged less than one year, 22% in those 1-5 and 49% in those 6-14 years. A rather similar gradient was found by Garvil (1976). The effect of restraint is shown in Table 2.2, derived from child occupants who were injured (Sturtz, 1977).

Table 2.2
Effect of Restraint on Lower Limb Injuries in Children

	Unrestrained	Restrained
upper leg	9%	5%
knee	15%	-
lower leg	15%	9%
foot	-	5%

Source: Sturtz (1977)

For children less than 10, Melvin, Stalnaker and Mohan (1978) found injuries of "extremities" in 21% of unrestrained children and 5% of restrained children in a sample of crashes investigated in depth. In another sample of tow-away crashes they found leg injuries in 13% of unrestrained and 3% of restrained children.

The interactive effects of age, occupant position and restraint use are shown in Table 2.3 (Huelke, Compton & Compton, 1991). These data are from frontal crashes collected by the National Accident Severity Study over the years 1980-1987. Restraint has a protective effect against AIS 2 and greater lower limb injuries for all age groups, but the largest effect in passengers aged 61 and over.

Table 2.3
Maximum Injury Severity by Age and Restraint Usage

	N	AIS ≥ 2	% of Total
Drivers:			
Young (16-50 years)			
Unbelted	14915	696	4.7
Belted	3720	107	2.8
Old (61+ years)			
Unbelted	1507	80	5.3
Belted	503	29	4.6
Passengers:			
Young			
Unbelted	4661	215	4.6
Belted	785	14	1.8
Old			
Unbelted	508	56	11.0
Belted	163	8	4.9

Source: Huelke et al (1991)

In a study of 1,149 non-ejected drivers, Dischinger, Cushing and Kerns (1992) found that the benefit of restraint was confined to reduction in fractures of the femur. This was true for both frontal and same-side lateral impacts.

These authors also found the incidence of lower limb injuries to be somewhat higher in the older age range (45 years and above). Moreover, females had about twice the incidence of ankle/foot injuries, and a near to significant preponderance of patella injuries by comparison with males (see Table 2.4)

Table 2.4
Incidence of Lower Extremity Injuries by Age, Sex and Type of Fracture

	Male (N=739) %	**Female (N=406) %**	**Total %**	**p**
Age:				
15-29	15.8	24.8	18.7	0.008
30-44	19.4	22.7	20.7	NS
45-59	30.8	26.5	29.0	NS
60+	20.6	25.0	22.1	NS
Specific Fracture:				
Femur	10.1	10.1	10.1	NS
Tib/fib	4.9	6.6	5.5	NS
Patella	2.6	4.7	3.3	0.06
Ankle	4.1	8.6	5.7	0.001
Tarsal	3.6	6.6	4.7	0.02

Source: Dischinger, Cushing & Kerns (1992)

2.4 VEHICLE CLASS FACTORS

A comparison between 258 injured occupants of "forward control vans", commonly used as passenger vehicles, and 3468 injured occupants of conventional cars was made by Paix, Gibson and McLean (1986), based on records of the (then) Motor Accidents Board of Victoria Van occupants in frontal crashes were more likely to have sustained a leg injury than car occupants.

Morgan, Eppinger and Hennessey (1991) found that moderate or greater foot/ankle injury was associated with lighter vehicles compared with the overall NASS vehicle population.

Table 2.5
Leg Injury Rates by Seating Position and Car Size

		Leg Injury Rate Per 100 Casualties	
		All	AIS>2
All collisions	driver	51	11
	left front	45	5
	rear	41	0
Small cars	}	49	8
Compacts	} All occupants	50	8
Large	}	51	11

Source: Fildes et al (1991)

In Table 2.5, there is no great variation in injury rates with car size. These rates are for leg injuries in general, whereas Morgan and others' observations are for ankle and foot injuries only.

2.4.1 Collision Type and Speed

The broad effect of type of collision has been noted above: lower limb injuries are predominantly incurred in frontal collisions. Dalmotas (1980), in a study of restrained occupants, found that 60% of occupants with lower limb injuries had been involved in pure frontal impacts and an uncertain additional percentage in multiple impact crashes with a frontal impact component. In side impacts, severe lower limb injuries (AIS $\geq$ 2) occurred mainly in near side (i.e., occupant side) collisions - 16.7% compared with 2.8% far side (see Table 2.6).

Table 2.6
Severe (AIS $\geq$ 2) Lower Limb Injuries in Drivers by Collision Type

Frontal only	59.7%
Multiple	18.1%
Near side	16.7%
Far side	2.8%
Other/unknown	2.8%

Source: Dalmotas (1980)

The differential effects of side and frontal impacts were noted also by Pattimore and others (1991). For restrained occupants in frontal impacts, 68% of skeletal injuries were located below the knee, while in side impacts, for occupants on the struck side (i.e , near-side), 51 % of skeletal injuries involved the pelvis.

Table 2.7
Leg Injury Rates by Type of Crash

	Frontal thigh	Frontal leg	Side thigh	Side leg
Drivers	76 (21)	62 (15)	60 (13)	33 (6)
Left front	41 (11)	57 (8)	33 (7)	33 (0)

Source: Fildes et al (1991) The rates/100 casualties are for all grades of injury and, in parenthesis, injuries >AIS2

Table 2.7 suggests that lower leg injuries are less frequent for front seat occupants in side than frontal impacts, particularly for below-the-knee injuries.

Dalmotas (1986) found that injuries of the leg/ankle/foot at the AIS 2 level occurred in collisions well below 48 km/h. Those at AIS 3 were largely confined to collisions in which there was marked intrusion of the toe pan.

It was found in this (and other) investigations that fracture of the femur tended to occur in collisions of severity well in excess of the 48 km/h barrier test. In contrast, fractures of the knee, leg , ankle or foot were observed at severities below this test condition.

Otte, von Rheinbaben and Zwipp (1992) provide details of collisions types relating to fractures of the foot (see Table 2 8).

Table 2.8
Foot Fractures by Collision Type

	Frontal	**Side left**	**Side right**	**Total**
Phalanx	16.9	4.3	7.1	13
Metatarsals	39.4	17.4	50	31.1
Tarsus	4.2	4.3	14.3	5.6
Talus	2.8	-	7.1	2.8
Calcaneum	5 6	8.7	-	5.6
Ankle joint	31.1	65.2	21.4	37
Total	**65.7**	**21.3**	**13**	**100**

Source: Otte et al (1992). % of 108 restrained drivers; side left is near, side right is far.

In the series of Rastogi and others (1986), the mean delta V for femur fractures was 42 km/h and the incidence was higher over 48 km/h. They proposed the speed-fracture relationship shown in Figure 2.1.

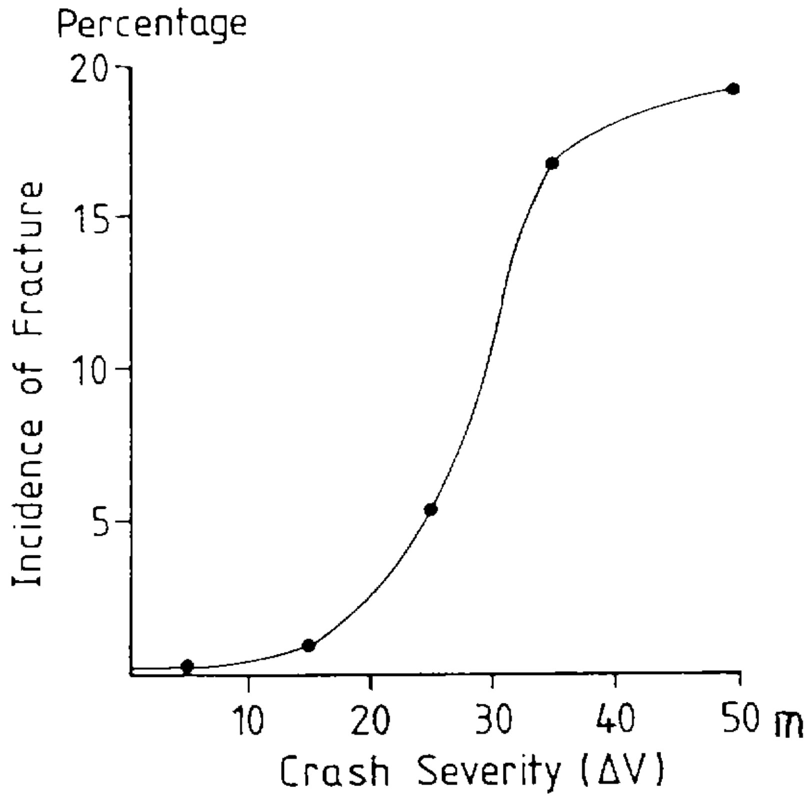


Figure 2.1 Speed-fracture relationship (Rastogi et al 1986)

2.5 INJURIES AND SOURCES

The emphasis in the literature on tissue injury is mainly on skeletal damage, though concomitant soft tissue lesions (e.g., damage to blood supply) may occasionally be the determinant of severity. The need for fixation of the affected limb and development of bony union usually determines time to recovery.

The structure of bone and its biomechanical properties are therefore basic to understanding injury mechanisms. For a summary of the anatomy of the lower limbs, reference should be made to Huelke (1986) and Levine (1986b).

2.5.1 Bone structure

Bone is a hard mineralised tissue consisting of a fibrous organic matrix (of a protein, collagen) bound by inorganic salts (mainly calcium). The long bones of the limbs are, for the most part, roughly tubular in structure, the tube consisting of hard compact bone with a core of lighter "honeycomb" of spongy bone (cancellous bone) whose mechanical properties are less well understood.

In the living subject, bone is a dynamic tissue, constantly being absorbed and rebuilt. The strength of bone is a function of its calcium content. This varies between males and females and throughout life. In adults the demolition/rebuilding process is in balance until the third or fourth decade. Loss of calcium in the elderly, particularly in post-menopausal women, is a major factor in their propensity for bone fracture (see Figures 2 2 and 2.3).

For these reasons it is simplistic to specify a standard "tolerance load" for, say, axial compressive loading of the femur. Nevertheless, a specific value is needed for design rule purposes. Much of the relevant evidence concerning the femur, tibia and patella are summarised by Nyquist (1986), from which the content of Table 2.9 is taken.

Table 2.9
Static Load to Fracture by Sex and Age

		Male	Female
Tibia:			
	bending	233-310 Nm	180-182 Nm
Femur:			
	torsion	175 Nm	136 Nm
	axial compression	7.5 kN	7.1 kN
		Age	
		20-39 years	70-79 years
Femur:			
	bending	234 Nm	184 Nm

Source: Various, collected by Nyquist (1986)

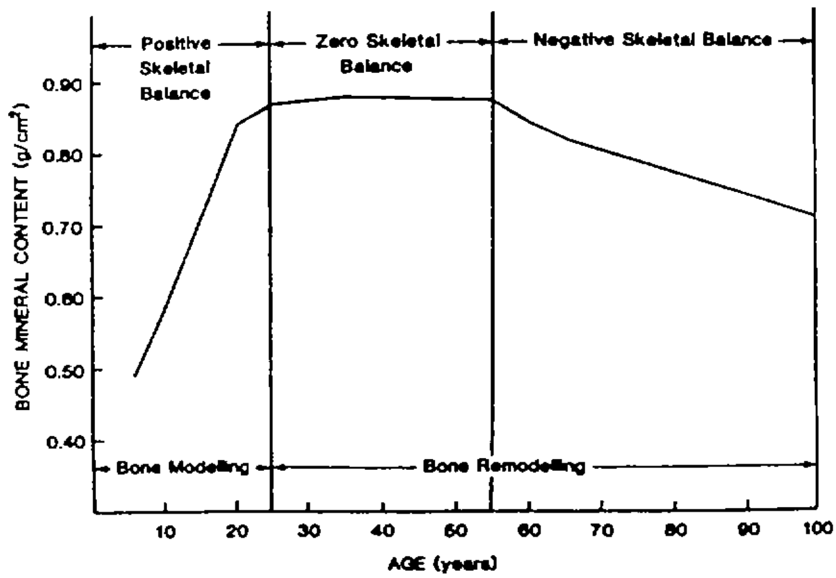
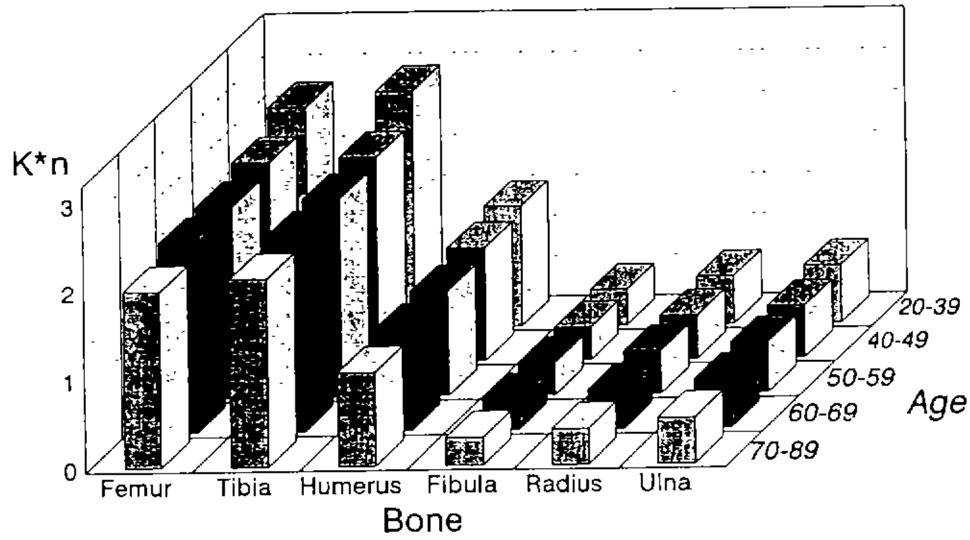


Figure 2.2 Age-related changes in bone mineral content (Kleerekoper, Fedlkamp & Goldstein, 1986)



Source: Levine (1983), based on data of Motoshima in Yamada (1970)

Figure 2.3 Changes in bone strength with ageing

There have been many investigations of the femur under dynamic loading, with both short (8-18 ms) and long (30-40 ms) loading times. Among these, the lowest axial compressive load causing fracture appears to be 4.4 kN and the highest without fracture 23.7 kN. Often, dynamic tolerance is higher than static. Rastogi and colleagues (1986) were able to estimate the load on the femur in 14 of their 39 cases of fracture of the femur. This ranged from 8 kN to 26 kN, with a mean of 18 kN.

Several complex criteria have been developed (but apparently not much used): the Fracture Injury Criterion (Viano, 1977), Knee-Thigh-Hip Injury Criterion (Nyquist, 1982) and a time dependant criterion (Lowne, 1982) Tolerance criteria for combined loads have not been attempted.

Values for dynamic loading collected by Nyquist (1982) include: for the femur in torsion 204 & 155 Nm (male); 131 & 118 Nm (female). For the femur in axial compression: 7.7 kN (male), 7.11 kN (female), 6.2 and 8.7 kN, sex unspecified. In various tests the range for no fracture was 3.67 to 11.54 kN, for one fracture in eight tests, 7.1 to 10 4 kN In tests with volunteers, dynamic axial loads of 3.6 to 4.4 kN caused only minor knee pain.

The fracture threshold for the patella depends on the loading method. With moderate padding to spread the load, the fracture level appears to exceed that of the femur. The knee joint, when impacted below the centre of rotation (with knee bent) sustained various fractures and ligament tears at an average of 5.15 kN (Viano, Culver, Haut, Melvin, Bender, Culver & Levine, 1978).

When the ankle joint was loaded in the axis of the tibia and statically, the calcaneus fractured at 3.3 to 5.5 kN (Culver, 1984).

Inversion (the foot rotated inward) and eversion were found to be the main mechanism of ankle joint injuries, at least in moderate collisions (Lestina, Kuhlmann, Keats & Alley, 1992). Dias (1979) found rupture of the deltoid ligament (the complex of ligaments on the medial (in-side) of the ankle) at 60 to 70 degrees of inversion.

The effect of dynamic loading, from below, on the ankle joint and leg, causing the foot to rotate, was studied by Begeman, Balakarishnan, Levine and King (1993). They found that peak axial loads and bending moments did not correlate with ligamentous injury, but 60 degrees of eversion is the threshold for ligamentous or malleolar injury (the normal range of motion is 27 degrees).

For fractures of the foot, there are a number of possible mechanisms. According to Otte and colleagues (1992), 10% came from jamming the foot in compression between deformable structures. Sixty-nine percent of fractured metatarsals came from supporting body loads. Most fractures of the foot were induced by deformation of the foot room.

2.5.2 Points of Contact

Generally, lower limb injuries are consequences of direct contact with interior parts of the car, either as a result of body or body part motion towards the contact point or intrusion of the contacted area towards the occupant, or both.

Regarding unrestrained occupants with severe lower limb injuries, Huelke, O'Day and States (1982) examined (U.S.) National Crash Severity Study data for 1977/1978, referring to 14,491 occupants of 8,616 tow-away crashed cars. The distribution of contact areas is shown in Table 2.10. Eleven percent of the 419 occupants with severe lower limb injuries were ejectees. Most of the injuries were incurred by drivers and front seat passengers. The back of the front seat is the contact site for most thigh, knee and leg injuries in rear occupants, who seldom sustain foot/ankle injuries.

Table 2.10
Frequency of Severe Lower Limb Injuries (AIS 3 or 4)
by Contact Points for Unrestrained Occupants

	Thigh	Knee	Leg	Ankle/foot	Unspec.	Total
Inst. panel	45	35	50	1	8	139
Floor/footwell	3	-	6	51	2	62
Side	10	2	7	3	1	13
Steer ass'y	14	4	1	-	1	20
F/seat	6	-	7	2	-	15
Exterior	2	-	4	2	1	9*
Misc	3	1	6	3	1	14
Unknown	11	5	9	6	4	35
Total	**94**	**47**	**90**	**68**	**18**	**317**

*Source: Huelke et al (1982). Pelvic injuries omitted; * all ejectees.*

For more severe injuries (AIS 2 and above) Huelke and colleagues (1991) assessed contact areas in frontal crashes from the NASS data bank, 1980-87. About 13% of occupants were restrained. Their observations, for drivers and passengers, are shown in Table 2.11.

Table 2.11
Contact Points for AIS 2 and 3 Injuries

Contact Source	Body Region Thigh %	Knee %	Leg %	Ankle/foot %
Drivers:				
Inst. panel	67	89	53	4
Steer ass'y	12	4	1	1
Side int.	10	2	3	1
Floor/footwell	3	1	37	92
Other	8	5	7	2
N=	(174)	(257)	(185)	(279)
Passengers:				
Inst. panel	84	96	76	25
Side int.	9	-	4	6
Floor/footwell	2	2	14	69
Other	5	2	6	0
N=	(56)	(50)	(78)	(71)

Source: Huelke et al (1991). Pelvic injuries omitted.

For restrained front seat surviving occupants, contact points are given by Pattimore, Ward, Thomas and Bradford (1991), derived from the database of the U.K. Cooperative Crash Injury Study, for tow-away vehicles less than six years old and with at least one injured occupant. Contact points are shown in Table 2.7. Pedals are distinguished from the rest of the footwell area.

Table 2.12
Frequency of Lower Limb Injuries
by Contact Points for Restrained Occupants

	Thigh	Knee	Leg	Ankle/foot
Inst. panel	22	11	15	3
Footwell	6	-	33	78
Pedal ass'y	2	1	23	57
Steer ass'y	4	4	3	-
Intrusion	87%	68%	78%	83%

Source: Pattimore et al (1991)

While the data for unrestrained and restrained occupants are not exactly comparable, there appears to be a sizeable reduction (from 44% to 20%) in dash (instrument panel, facia) contact in the restrained occupants. The high percentage of intrusions for all limb segment contacts in the restrained series is notable.

2.6 INJURY MECHANISMS

While there is good evidence on the biomechanical properties of bone and bony assemblies and of contact points between limb segments and car interiors, the actual mechanisms of injury, mainly fracture, are to some extent inferential.

The simplest case is that of fracture of the shaft of the femur and it is reasonable to accept States' (1986) formulation of axial loading though the knee with or without a bending moment caused by "penetration of the knee into the dash, slipping below the lower dash, or impaction of the thigh against the steering wheel or steering column...". In his series of analysed cases, the average delta Vs were 51.3 km/h for fracture by axial load alone and 60.7 km/h with a bending moment.

Patellar fractures result from load concentration on the surface of the patella. Although direct contact with an unyielding surface causes fracture at loads as low as 2.49 to 3.11 kN, load distributing padding much increases the tolerable load. Nyquist (1986) suggests that this is the more realistic loading condition. However, in a small series thoroughly investigated by States (1986), the knee impacted stiff, unyielding structures such as steering column supports and low-mounted radio equipment. Bowker (1991) recounts a case in which knee and leg fractures were found to be caused by a brake pedal bracket in only the right-hand driver variant of a particular model. The problem was caused by a modification to the facia.

Knee ligament and joint surface injuries are caused, according to States (1986), by knee impacts with the lower dash or more complex interactions between knee, dash and foot toepan and /or pedals. A particular injury, to the cruciate ligament of the knee, is caused by loading the proximal (top) end of the tibia, with the knee flexed, just below the joint (Haut, 1983; Viano, 1978).

Again, according to States (1986), tibial shaft fractures are caused by axial loading because of "knee-dash fixation" and rearward movement of the toepan coupled with torsion and/or bending movement, as in Figure 2.4.

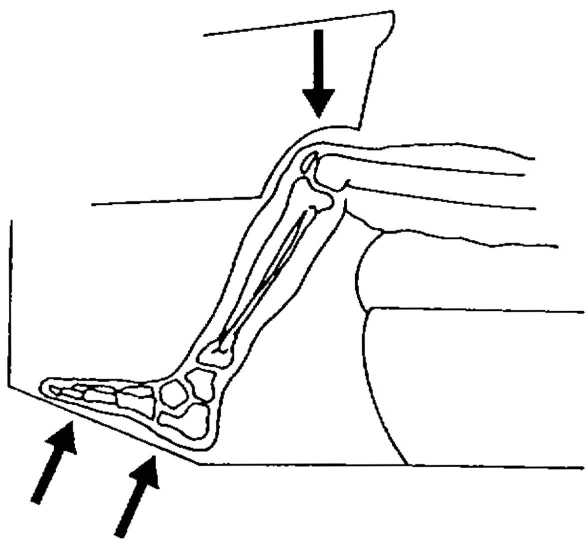


Figure 2.4 Mechanism of tibia fracture (States, 1986)

For a historical note, fracture of the talus by concentrated loading under the arch of the foot, by the rudder bar in aircraft crashes, was described as long ago as 1919 by Anderson. Injury to the ankle and foot are evidently related to the footwell and pedals, but the precise mechanisms are not all established. Begeman and Prasad (1990), in cadaver studies, showed that abrupt dorsiflexion (bending the foot upwards) past 45 degrees, without eversion, caused malleolar fractures and ligament avulsion.

Lestina and colleagues (1992), using data from tow-away crashes, found inversion or eversion of the foot to be the fracture mechanism for most injured bones (92 % of malleolar injuries). Direct vertical force was also a frequent mechanism. They did not find evidence of dorsiflexion in contrast to the experimental results of Begeman and Prasad (1990). Begeman and others (1993), using similar experimental procedures, found that malleolar fractures, stretched and torn ligaments, a tibia end fracture and a talus fracture were caused by inversion or eversion of the foot, in dynamic loading, well past the normal limits of rotation.

Using computer simulation, Pilkey, Sieveka, Crandall and Klopp (1994) found that, under conditions of driver braking there was a relation between foot position on the brake pedal and the load transmitted to the heel of the braking foot. When the heel was on or close to the toepan, the load was lower

It is possible to visualise these motions as resulting from eccentric location of the foot on a pedal at the time of loading, as the result of body inertia and/or pedal intrusion or unsymmetrical footwell intrusion.

Kruger, Heuser, Kraemer and Schmitz (1994) describe means of measuring, volumetrically, the footwell intrusion in an offset frontal crash. The intrusion is well connected with the loads on the foot. The loads on the foot varied substantially between five different subcompact cars.

2.7 CONCLUSIONS FROM THE REVIEW

1. Lower limb injuries are the source of substantial disability in surviving car occupant casualties. Often the lower limb injury is the most severe one.

2. Lower limb injuries occur predominantly, but not exclusively, in adults, in front seat occupants and in frontal crashes.

3. There are many fractures of the leg, ankle and foot (i.e., below the knee) and these tend to occur in crashes at or below barrier test speeds. For this reason it appears insufficient to rely on the femur axial compression load as the sole criterion for lower limb crash safety.

4. Injury mechanisms for thigh and knee injury appear to be well understood, but this is rather less so for ankle/foot injuries, though recent work has thrown some light on this topic.

5. Intrusion of the contacted parts of the car interior is a major consideration for all lower limb injuries.

6. Use of seat belts seems to have made some reduction in the frequency of lower limb injuries, mainly in those due to contacts with the dash. It is possible that improved restraints coming into use may make some additional reductions. However, the injury mechanisms to which unrestrained occupants are exposed must not be lost sight of, in view of the percentage of unrestrained casualties even when surveyed wearing rates are high.

3. LOWER LIMB INJURY STUDY

The project specification called for a thorough analysis of lower limb injuries to front seat occupants in frontal crashes. As well as an injury and source of injury analysis, this study included a description of "*mechanisms of injury*" not previously reported from these data. This provided a detailed understanding of lower limb injuries from contacts with the instrument panel, steering assembly and floor components. This analysis was intended to provide guidance to future occupant protection requirements covering lower limb injuries, that is, for specifying performance requirements for assessment by test dummies.

3.1 DATA COLLECTION PROCEDURE

The main source of data in this analysis was the Crashed Vehicle File described earlier. A method was developed for the detailed assessment of the extent of occupant injuries and the vehicle damage for a sample of passenger car crashes that occurred in urban and rural Victoria between 1989-1992 where at least one of the vehicle's occupants was either hospitalised or killed. This database contained details on 501 crashes and 605 hospitalised or killed occupants Of particular interest in this study were details on the 288 frontal collisions contained in this database.

As the study was primarily concerned with secondary safety aspects of the vehicle's crashworthiness performance, in-depth analysis at-the-scene was not attempted. The method has been described in previous reports (Fildes et al, 1991, 1994) but is included here again for completeness.

3.1.1 The Vehicle and Occupant Population

The population of crashed vehicles comprised post-1981 passenger cars and their derivatives (station wagons, panel vans, etc) that were involved in a road crash in Victoria where at least one occupant was severly injured and required admission to hospital. The breakdown of the sample revealed 3% of the patients required medical treatment only (additional occupants), 82% were admitted for at least one night, while 15% died either at the scene or later in hospital (details of cases where occupants died at-the-scene were kindly provided by the Coroner's office). Previous reports have demonstrated that the cases collected in this study using this strategy were roughly representative of all serious injury cases in Victoria (Monash University Accident Research Centre, 1992).

3.1.2 Procedure

The process was triggered by the admission of a vehicle occupant at one of the eight Melbourne and Metropolitan major trauma hospitals which had agreed to participate in the study. Patients were screened by a research assistant (nurse) at each hospital for the type of crash and suitability of the vehicle. These patients were then asked whether they were willing to participate in the study and signed an agreement form. Crash and patient injury details were obtained from the patient's medical record and from information obtained from the patient during an interview. Permission was also sought to inspect the crashed vehicle. For cases where the patient was severely injured, permission was sought from a member of the patient's family. (See Attachment 1 for consent and occupant injury forms.)

The crashed vehicle was subsequently located and an inspection crew dispatched to make the necessary measurements and photographs of the extent of damage. Where a second vehicle was involved, it was also located and briefly examined to complete the details required to explain the damage and to calculate the impact velocity. Each case was fully documented and coded into a computer database for subsequent analysis.

3.1.3 Calculation of Impact Velocity

Impact speed in this study was defined as the change in velocity from the moment of impact until the study vehicle separated from its impacting source (delta-V). This value was calculated using the CRASH3 program provided by the National Highway Traffic Safety Administration. It should be noted that the delta-V values computed are only estimates of impact velocity, based on the extent of deformation and are therefore subject to error from the assumptions and vehicle stiffness values used in making these calculations. American stiffness values had to be used in the calculations of delta-V for vehicles of the same size and mass, as local figures were not available. These errors could be reduced to some degree if appropriate stiffness values for Australian vehicles were to be provided by the local manufacturers.

3.1.4 Selection Criteria

The inclusion/exclusion criteria used in the study for determining the suitability of a crash are described below. Using these inclusion/exclusion criteria, roughly one in twenty-five road trauma attendances were suitable for inclusion in the study.

VEHICLE SUITABILITY: Any car or derivative with a Victorian registration number that commenced with either a "B, C or D" or a personalized plate (this effectively included all vehicles first registered during 1982 or later). Any vehicle found to be re-registered or unsuitable was subsequently excluded from the study. Four-wheel-drive vehicles of a standard car design (eg, Subaru models or Toyota Tercel) were included as suitable vehicles. However, the usual high clearance four-wheel drive vehicle configuration was not considered to be a passenger car derivative and they were excluded from this study.

CRASH SUITABILITY: It is difficult interpreting occupant protection effects for vehicles involved in multiple collisions (ie; when impacted by more than one vehicle or object, often in different crash configurations). Because of the problems in determining which impact caused which injury from which contact source, only single collisions were included. The impacted object could have been either another car, a truck, or a movable or immovable object, including roll-overs.

PATIENT SUITABILITY: Patient suitability consisted of any vehicle occupant who was admitted to one of the participating hospitals from a suitable vehicle or collision. The patient had to be defined as a recent road accident victim (TAC, MCA or other hospital coding) rather than a re-admission from a previous crash. Patients could be conscious or unconscious; fatalities and patients that subsequently died in hospital were also included. As noted earlier, details of fatalities where the patient died at the scene were provided directly by the Coroner's Office in Melbourne. In most cases it was not possible to obtain details on all occupants involved in the collision. However, where the condition and circumstances of other injured occupants could be obtained, these details were also collected. This included both adults and children. While occupants are required by law to be belted in all vehicles, a number of them nevertheless do not wear seat belts in cars. Hence, it was felt legitimate to include patients in the crashed vehicle sample who were both belted and unbelted so as not to bias the study and overlook another set of problems for a subgroup of vehicle occupants most at risk.

3.1.5 Hospital Participation Rates

Approval to approach and interview patients was obtained from the ethics committees of ***five*** major trauma hospitals in Victoria and included the Alfred Hospital (and Trauma Centre), Box Hill Hospital, Dandenong and District Hospital, Monash Medical Centre, and the Austin Hospital (Spinal Unit). In addition, another ***three*** private hospitals to whom road trauma patients from Dandenong were transferred, namely Knox Private, Dandenong Valley Private, and South Eastern District Hospitals, also agreed to participate. This approval was subject to obtaining the patient's agreement to participate, as well as ensuring confidentiality of the information collected.

On average, 100 patients were admitted each week across the eight study hospitals requiring treatment from vehicle crashes. After applying selection criteria, approximately four patients weekly were judged suitable for inclusion in the study (non-acceptable patients included pedestrians, motorcyclists, bicyclists, and non-eligible vehicles). Refusal rates in the study were extremely low (7 out of every 100 patients expressed a desire not to participate). A reducing road toll over this period meant that more cases were available at the start, than at the end, of the study

3.1.6 Patient & Vehicle Assessment

The assessment and classification of injuries sustained by road trauma patients (including injury severity judgements) requires specialised medical training and skills. Four State Registered Nurses (SRN's) were employed by MUARC during the course of this study as research assistants to undertake these duties and were extensively trained in the collection of injury data for research purposes and in making Abbreviated Injury Score (AIS) assessments of injury severity (Ozanne-Smith, 1989). A hospital proforma was developed to provide a standardised format for the collection of the patient's medical, vehicle, and crash information which was trialled and modified prior to commencement of its use in the project.

The assessment of the crashed vehicles is a critical task for accurately specifying vehicle involvement in patient injuries and similar procedures have been undertaken in several other centres in Australia and overseas. Information and discussion of inspection procedures was undertaken by the authors during overseas visits and when overseas and local experts visited MUARC (eg, Professor Murray Mackay, Dr Bob Campbell, Professor Kennerly Digges, and Mr Tom Gibson). The National Highway Traffic & Safety Administration (NHTSA) in Washington D.C. kindly provided the National Accident Sampling System's (NASS) crash inspection proforma (including training and coding manuals) as well as the computer software CRASH3 for computing Delta-V (see Attachment 2). A mechanical engineer was employed to undertake this task and given the necessary training in undertaking these inspections (see Attachment 3 for full description of inspection process). When these site data were complete, Delta-V impact velocity was calculated and the injury and vehicle damage information was coded into a computer database for subsequent analysis The engineer's assessments of injury and vehicle component interactions were compared with judgements made by the project's consultant epidemiologist, Dr J.C. Lane, and Mr Tom Gibson of the N.S.W. Road and Traffic Authority The inter-rater reliability for these judges was 70%.

3.2 INJURY ANALYSIS

Independent variables of interest in the crashed vehicle study included patient characteristics, injuries sustained (including AIS severity), vehicle damage and extent of deformation, direction of principal force, severity of impact (delta-V), component and equipment failures, cabin distortion and intrusions, use of restraints, and an assessment of the source of all injuries. The use of the restraint was important for this study and the inspection method used has been shown to be an objective and accurate means of making these assessments (Cromark, Schneider & Blaisdell, 1990).

The dependent variables comprised crash and injury involvement rates per 100 vehicles or patients relative to the population of crashes investigated in the follow-up study of crashed vehicles. Interactions between injury and vehicle source were especially important comparisons in this study. Presentation of the results was confined to reporting percentage differences in involvement and rank ordering of involvement rates for injuries per body region and vehicle components.

3.2.1 Coding Injuries and Contacts

INJURIES: The National Accident Sampling System occupant injury classification system allows injuries to be coded in terms of its body region, aspect of injury, lesion, system/organ and severity (Abbreviated Injury Scale or AIS). This permits a very detailed analysis of the type of injury and what caused it. In previous analyses, injury were recoded into a limited number of body regions and other aspects were ignored. However, this lower limb analysis demanded more scrutiny of these data and a new set of parameters were required.

For lower limb injuries, there were ***four*** specific injury regions available, namely ankle-foot, knee, lower leg, and thigh. In addition, ***four*** lesion categories were of significant frequency to warrant closer attention (abrasion, contusion, fracture and laceration). Of the nine aspects of injury available, left, right, anterior and posterior were of primary interest, while ***three*** system/organs namely integumentary (skin, tissue, etc), joints and skeletal were particularly noteworthy for these injuries.

INJURY CONTACT SOURCES: The NASS source of injury classification system allows for scoring up to 82 specific vehicle components as points of contact. Again, to simplify presentation of the results for these cases, contacts were grouped into meaningful categories for lower limb injuries to front seat occupants. These categories included the steering wheel and column, instrument panel, glove compartment, side panel, A-pillar, floor and toe pan, foor controls, parking brake, ground and exterior, and add-on equipment. These categories were determined from a frequency printout of all relevant contacts with a view towards arriving at meaningful groupings of components.

3.2.2 Details of Lower Limb Injuries

The final data base comprised details on 501 vehicles and 605 patients from crashes that occurred in Victoria between the 1st April 1989 and the 31st July 1992. For the purposes of this study, a subset of frontal crashes was selected, yielding 288 frontal crashes and 394 injured occupants This subset was further refined to select only frontal crashes in which any occupants sustained lower limb injuries. This selection yielded 243 frontal crashes and 280 occupants with lower limb injuries. Thus, a substantial proportion (71%) of occupants injured in frontal crashes sustained injuries to the lower limbs. The breakdown of lower limb injured occupants by type of frontal crash showed that 23% of occupants were injured in full frontals, 29% in offset frontals and 48% in oblique frontals.

REGION OF INJURY: Table 3.1 shows the region of injury by frontal crash configuration. Knees were the most common areas injured among the lower limbs accounting for one-third of all injuries to these regions. There were significant differences in the type of injuries sustained in frontal crash configurations: knees were particularly over-represented in full frontals, ankle/ foot in offset crashes, and the thigh in oblique crashes (χ^2=29.7, p<.005). Oblique crashes resulted in more injuries generally than other types of frontals.

TYPE OF INJURY: Table 3.2 shows the breakdown of injury types by frontal crash configuration. Fractures accounted for more than one-quarter of all injuries sustained in these crashes and a somewhat surprising 88% of occupants sustained a lower limb fracture of some sort. Fractures and lacerations were more common in offset crashes, abrasions in full frontals and obliques, and contusions in oblique angled front crashes (χ^2=11.8, p<.10).

INJURY SEVERITY: Table 3.3 shows the breakdown of injury severity by frontal crash configuration. Of particular interest, 60% of these injuries were classified as minor (AIS 1) and only 15% were serious or severe injuries (AIS 3 or more). There were no significant differences in injury severity across the three different frontal crash types (χ^2=2.7, p>.10).

Table 3.1
Region of Injury by Frontal Crash Configuration

Region of Lower Limb Injury	Full frontal *n=61, p=70*		Offset *n=74,p=85*		Oblique *n=108. p=125*		Total *n=243, p=280*	
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)
Ankle/foot	50	(71)	84	(99)	88	(70)	222	(79)
Lower leg	55	(79)	71	(84)	124	(99)	250	(89)
Knee	91	(130)	94	(111)	126	(100)	311	(111)
Thigh	19	(27)	44	(52)	95	(76)	158	(56)
Total	**215**		**293**		**433**		**941**	

NB: *Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient)*
n=the number of crashed vehicles in which someone sustained a lower limb injury of any severity, p=number of injured occupants. Percentages = no. of injuries/no. of injured occupants.

Table 3.2
Type of Injury by Frontal Crash Configuration

Region of Lower Limb Injury	Full frontal *n=61, p=70*		Offset *n=74,p=85*		Oblique *n=108, p=125*		Total *n=243, p=280*	
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)
Abrasion	46	(66)	44	(52)	83	(66)	173	(62)
Contusion	50	(71)	91	(107)	147	(118)	288	(103)
Fracture	52	(74)	87	(102)	110	(88)	249	(88)
Laceration	46	(66)	58	(68)	72	(58)	176	(63)
Total	**194**		**280**		**412**		**886**	

NB: *Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient).*
n = no. of crashed vehicles in which someone sustained a lower limb injury of any severity;
p = no. of injured occupants. Percentages = no. of injuries/no. of injured occupants.

Table 3.3
Severity of Injury by Frontal Crash Configuration

Lower Limb Injury Severity	Full frontal *n=61, p=70*		Offset *n=74,p=85*		Oblique *n=108, p=125*		Total *n=243, p=280*	
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)
Minor (AIS 1)	128	(183)	170	(200)	275	(220)	573	(205)
Moderate (AIS 2)	58	(83)	79	(93)	99	(79)	236	(84)
Serious (AIS 3)	32	(46)	47	(55)	72	(58)	151	(54)
Severe (AIS 4)	nil	(0)	1	(1)	nil	(0)	1	(0.5)
Total	**218**		**297**		**412**		**886**	

NB: *Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient).*
n = no. of crashed vehicles in which someone sustained a lower limb injury of any severity;
p = no. of injured occupants. Percentages = no. of injuries/no. of injured occupants.

Table 3.4
Type of Injury by Region of Injury in Frontal Crashes

Lower Limb Lesion	Ankle *n=103, p=115*		Leg *n=109, p=129*		Knee *n=145, p=160*		Thigh *n=85, p=95*		Total
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)	
Abrasion	11	(10)	59	(46)	78	(49)	17	(18)	165
Contusion	81	(70)	59	(46)	80	(50)	59	(62)	279
Fracture	96	(83)	81	(63)	31	(19)	57	(60)	265
Laceration	13	(11)	45	(35)	96	(60)	19	(20)	173
Total	**201**		**244**		**285**		**152**		**882**

NB: Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient).
n = no. of crashed vehicles in which someone sustained a lower limb injury of any severity;
p = no of injured occupants Percentages = no. of injuries/no. of injured occupants

TYPE OF INJURY AND REGION: The combination of type of injury and region was of particular interest in this analysis. Table 3.4 shows the distribution of lower limb injuries by injury lesion across all frontal crashes. The six most common injury/lesions were

- fractures to the ankle/foot (83%),
- contusions to the ankle/foot (70%),
- fractures to the lower leg (63%),
- contusion to the thigh (62%),
- fracture to the thigh (60%), and
- lacerations to the knee (60%).

For moderate or serious injuries only (AIS 2 or above), fractures to the ankle/foot, lower leg and thigh all rated rather high and warrant closer attention

SYSTEM/ORGANS: The three system/organs that were noteworthy among lower limbs are broken down by frontal crash type and are shown in Table 3 5. Two-thirds of all injuries were integumentary (of skin, tissue, etc), more than a quarter were skeletal, while only 6% involved the knee or ankle joints. Injuries to the joints appeared to be a particular problem (ie; more over-represented) in full frontal crashes ($\chi2=9.0$, $p=.05$).

3.2.3 Source of Lower Limb Injury

As noted earlier, the various sources of lower limb injuries were grouped into 12 categories based on their frequency of occurence and interest The breakdown of contact source by frontal crash type is shown in Table 3.6.

Table 3.5
System/Organ by Frontal Crash Configuration

Lower Limb System/Organ	Full frontal n=61, p=70		Offset n=74.p=85		Oblique n=108, p=125		Total n=243, p=280	
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)
Integumentary	137	(195)	193	(227)	304	(243)	634	(226)
Joints	21	(30)	16	(19)	18	(14)	55	(20)
Skeletal	60	(65)	85	(75)	122	(65)	267	(95)
Total	**218**		**294**		**444**		**956**	

NB: *Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient).*
n = no. of crashed vehicles in which someone sustained a lower limb injury of any severity;
p = no. of injured occupants. Percentages = no. of injuries/no. of injured occupants.

Table 3.6
Injury Source by Frontal Crash Configuration

Lower Limb Injury Source	Full frontal n=61, p=70		Offset n=74,p=85		Oblique n=108, p=125		Total n=243, p=280	
	FREQ	(%)	FREQ	(%)	FREQ	(%)	FREQ	(%)
Steering wheel	4	(6)	4	(5)	8	(6)	16	(6)
Steering Column	12	(17)	12	(14)	18	(14)	42	(15)
Instrument Panel	106	(151)	131	(154)	185	(148)	422	(151)
Glove Compartment	6	(9)	5	(6)	2	(2)	13	(5)
Side Panel	0		7	(8)	35	(28)	42	(15)
A-Pillar	0		2	(2)	6	(5)	8	(3)
Floor & Toe Pan	480	(69)	91	(107)	95	(76)	234	(84)
Foot Controls	5	(7)	5	(6)	11	(9)	21	(8)
Parking Brake	1	(1)	0		4	(3)	5	(2)
Ground & Exterior	7	(7)	6	(7)	15	(12)	28	(10)
Other/Unknown	0		0		14	(11)	14	(5)
Total	**189**		**263**		**393**		**926**	

NB: *Multiple injuries were allowed in this analysis to ensure that all injuries were recorded. This means that the total number of injuries was more than the total number of patients (average of 3.4 injuries per patient).*
n = no. of crashed vehicles in which someone sustained a lower limb injury of any severity;

Table 3.7
Body Region/Contact Source Analysis for All and Severe (AIS > 2) Lower Limb Injuries for 243 Front Seat Occupants in Frontal Crashes

BODY REGION / CONTACT SOURCE	Ankle/Foot	Lower Leg	Knee	Thigh	TOTAL
Steering Wheel			1	6	7
				(2)	(2)
Steering Column		1	15	1	17
		(1)	(2)	(1)	(4)
Instrument panel		56	85	33	174
		(5)	(5)	(16)	(26)
Glove Compartment		4	1	1	6
Side Panel	1	5		11	17
		(1)		(4)	(5)
A-Pillar		1		2	3
		(1)		(1)	(2)
Floor & Toe Pan	71	23	1	2	97
	(9)	(14)			(23)
Foot Controls	8	1			9
Parking Brake			2		2
Ground & Exterior	5	2	2	2	11
	(1)				(1)
Add-On Equipment		1			1
Other/unknown		2	1	4	7
TOTAL	85	96	108	62	351
	(10)	(22)	(7)	(24)	(63)

Top row figures are the injury/source contact rates per 100 injured occupants for all injuries Those in PARENTHESIS are the rates per 100 occupants for severe injuries (AIS>2). Multiple injuries are included where separate injury sources were involved

Table 3.8
Body Region/Contact Source Analysis for Lower Limb Fractures for 243 Front Seat Occupants in Frontal Crashes

CONTACT SOURCE \ BODY REGION	Ankle/Foot	Lower Leg	Knee	Thigh	TOTAL
Steering Wheel			1	6 (2)	7 (2)
Steering Column		1 (1)	15 (2)	1 (1)	17 (4)
Instrument panel		56 (5)	85 (5)	33 (16)	174 (26)
Glove Compartment		4	1	1	6
Side Panel	1	5 (1)		11 (4)	17 (5)
A-Pillar		1 (1)		2 (1)	3 (2)
Floor & Toe Pan	71 (9)	23 (14)	1	2	97 (23)
Foot Controls	8	1			9
Parking Brake			2		2
Ground & Exterior	5 (1)	2	2	2	11 (1)
Add-On Equipment		1			1
Other/unknown		2	1	4	7
TOTAL	85 (10)	96 (22)	108 (7)	62 (24)	351 (63)

Top row figures are the injury/source contact rates per 100 injured occupants for all injuries. Those in PARENTHESIS are the rates per 100 occupants for severe injuries (AIS>2) Multiple injuries are included where separate injury sources were involved

TYPE OF INJURY BY SOURCE: Table 3.7 shows the injury by source analysis for lower limb injuries sustained by front seat occupants in frontal crashes for all and severe (AIS>2) injuries. For all injuries, the six most important injury/source combinations included:

- knee with the instrument panel (88%),
- ankle/foot with floor and toe pan (64%),
- lower leg with instrument panel (55%),
- thigh with instrument panel (30%), and
- lower leg with floor and toe pan (21%), and
- knee with steering column (15%).

For severe (AIS>2) injuries only, the most noteworthy combinations were:

- thigh with the instrument panel (16%),
- lower leg with the floor and toe pan (14%),
- ankle/foot with the floor and toe pan (9%),
- lower leg with the instrument panel (5%), and
- knee with the instrument panel (5%).

Table 3.8 further shows the injury and source analysis for only ***fractures*** to the lower limbs where the most noteworthy combinations were:

- ankle/foot with the floor and toe pan (38%),
- lower leg with the floor and toe pan (19%),
- thigh with the instrument panel (16%),
- lower leg with the instrument panel (9%),
- knee with the instrument panel (6%), and
- knee with the steering column (6%)

3.2.4 Injury & Source Summary

These results show that injuries to the lower limbs can occur from impacts involving full frontals, offset frontals and oblique frontal crash types While many of these injuries are relatively minor involving skin and soft tissue injury, a sizable proportion did involve more serious injury to the skeleton and joints Fractures to the lower limbs were particularly noted involving contacts with the floor and toe pan and the instrument panel. The most common injury-source combinations for fractures that should be emphasised when determining mechanisms of injury were

ankle/foot with the floor and toe pan
lower leg with the floor and toe pan
thigh with the instrument panel
lower leg with the instrument panel
knee with the instrument panel
knee with the steering column

3.3 MECHANISM OF LOWER LIMB FRACTURES

The data collection procedure did not include a routine mechanism of injury assessment. However, Wenzel (1992) had previously developed such an assessment from a re-analysis of a restricted set of these cases in determining the mechanism of seatbelt injuries from a previous study. This procedure required a more detailed examination of the case details contained in the original files and supplementing these data with additional information obtained from the hospital records. Of particular interest were the X-ray photographs, radiologists' reports, surgical notes and incidental details recorded in the patient's medical file. This information was then sufficient to arrive at meaningful and useful judgements of the mechanism of lower limb fracture. A similar process to that used by Wenzel (1992) was adopted in this study.

3.3.1 Mechanism of Injury Categories

Conducting mechanism of injury analysis can be an unweildy task if not focussed on a limited but sufficent number of restricted mechanism categories. The following categories of mechanisms and direction of injury were adopted in this study and each significant injury was ascribed ***three*** possible mechanisms.

CODE	MECHANISM	DIRECTION
01	Axial compression	nil
02	Axial tension	nil
03	Perpendicular loading	medial/lateral
04	Torsion	+ve/-ve (c'wise/antic'wise)
05	Shearing	nil
06	Crushing	nil
11	Leg twist (looking down)	+ve/-ve (c'wise/antic'wise)
12	Foot twist (towards toes)	+ve/-ve (inversion/eversion)
13	Ankle twist (thru' foot)	+ve/-ve (planaflexion/dorsiflexion)

A summary format of lower limb injury was developed for each case which required a detailed assessment of the likely injury forces from which up to three mechanisms of injury could be ascribed. A sample summary sheet format is included as Attachment 4 to this report.

3.3.2 Procedure

The six most common lower limb injury-source combinations listed earlier were the basis for mechanism of injury assessment. The relevant case numbers containing these injuries were extracted from the database and the original treating hospital was approached requesting approval to obtain this extra information. Ethics committee approval was subsequently provided by the Alfred, Box Hill and Dandenong and District Hospitals for the study which constituted the bulk of these cases. There were a number of fatal cases where the occupant had also sustained fractures to the lower limbs, although rarely the cause of death. As the same degree of detailed information was not usually available on lower limb injury for these cases, they were subsequently excluded from this analysis.

Armed with the original case details, the researchers visited the treating hospital and extracted the necessary additional mechanism of injury information. X-rays were sought when available and photographed although in most cases, the radiologists' and surgeons' summaries were sufficient for these purposes. Hospital case notes provide a rich source of information for determining the mechanism of lower limb injury (some cases, however, were clearly more definitive than others). A summary package was compiled for each lower limb injury case and these can be found in a supplementary volume to this report.

The final stage in the process was to assess the mechanism of injury for each case. An expert panel was formed for this process containing a biomechanical engineer, an epidemiologist, a trauma surgeon, and members of the crashed vehicle file research team. Each case was presented and discussed until a consensus view was reached about the mechanism of injury Towards the latter stage, cases were initially ascribed mechanism of injury by the research team and then circulated to the expert panel for confirmation or subsequent discussion In all cases, the final judgements were unanimously agreed to by the panel

3.3.3 Mechanism of Injury Results

There were 156 eligible lower limb fracture cases in the database, although some cases contained more than one fracture and occasionally, more than one injury-source combination. Overall, 63% of the eligible cases were re-examined for mechanism of injury assessment and this varied from 47% for lower leg by instrument panel fractures to 79% knee by steering column injuries. Reasons for non-examination were predominantly fatal cases. Approximately 10 cases seemed to yield a complete and relatively stable pattern of results for each particular injury-source combination.

The mechanism of injury findings are shown in Table 3.9 The most common mechanism was compression, followed by perpendicular loading, crushing and foot twisting These frequencies were very much dependent upon the particular injury-source fracture combination. For fractures of the lower leg and thigh, compression was an even more predominant mechanism of injury, occurring in roughly two-thirds of these cases. Perpendicular loading was more commonly associated with knee injuries from contacts with the instrument panel and steering column while crushing and foot twisting was most frequent among fractures to the ankle and foot from contacts with the floor and toepan.

3.3.4 Direction of Fracture Mechanism

The direction of the force leading to a lower limb fracture (where relevant) was also recorded and analysed. As noted earlier, it was not always possible (or meaningful) to have a direction of force assessment for each mechanism (ie; compression was direction neutral) The direction of injury mechanism results are listed in Table 3.10. These findings are reported for each of the ***six*** major injury-source fracture combinations of special interest in this analysis There was no point in summarising these findings for all fractures as the results would be meaningless

Table 3.9
Mechanism of Lower Limb Fracture for Front Seat Occupants (N=99)

INJURY SOURCE	ankle/foot floor/toepan	lower leg floor/toepan	thigh inst. panel	lower leg inst. panel	knee inst. panel	knee steering	*TOTAL*
compression	31%	62%	62%	60%	20%	17%	***42%***
tension							
perp. loading	5%	24%	24%	30%	80%	83%	***25%***
torsion		5%	4%				***1%***
shearing	7%	5%					***4%***
crushing	31%						***13%***
leg twist		5%					***1%***
foot twist	25%		10%	10%			***13%***
ankle twist	2%						***1%***

Table 3.10
Direction Findings for Lower Limb Fractures

Ankle/Foot Fractures from Floor and Toepan

70%	not applicable		
27%	12 - foot twist	eversion (-ve)	40%
		inversion (+ve)	60%
3%	13 - ankle twist	dorsiflexion	100%
		plantarflexion	0%

Lower Leg from Floor and Toepan

66%	not applicable		
24%	03 - perpendicular loading	lateral	0%
		medial	100%
10%	04 - torsion	positive	50%
		negative	50%

Thigh from Instrument Panel

65%	not applicable		
21%	03 - perpendicular loading	lateral	33%
		medial	67%
14%	04 - torsion	positive	75%
		negative	25%

Lower Leg from Instrument Panel

60%	not applicable		
30%	03 - perpendicular loading	lateral	0%
		medial	100%
10%	04 - torsion	positive	0%
		negative	100%

Knee from Instrument Panel

100%	not applicable

Knee from Steering Wheel

92%	not applicable		
8%	03 - perpendicular loading	lateral	100%
		medial	0%

3.3.5 Implications for Instrumentation

These findings can be interpreted in terms of the instrumenting needs for crash test dummies able to record these injuries. The most common mechanisms identified in this study were compression and perpendicular loading for the thigh, lower leg and knee, and crushing and foot twisting for the ankle and foot. Instrumentation options to record these injuries comprise strain gauges on the femur, lower leg and the foot, and load cells on the knee and foot. A deformable foot might be another option for measuring foot crush. Strain gauges on the ankle would also permit measurement of twisting and shearing of the ankle/foot as well as supplementing other injurious foot measurements.

While instrumenting dummies is an important first step to minimising lower limb fractures, ultimately, performance criteria for lower limb dummy instrumentation will also be required for regulation aimed at reducing these serious and disabling injuries. This study, however, was only able to specify recording mechanisms from real world data and thus more detailed biomechanical experimentation is still required to determine acceptable performance levels increased for occupant protection.

3.4 OTHER ASPECTS OF LOWER LIMB INJURIES

While the main focus of this study was on lower limb injuries and their mechanisms, several other vehicle and crash related factors were highlighted in the literature review that were likely to be of interest in this study too The final analaysis, therefore, compared the characteristics of this sub-set of lower limb fracture injuries with similar characteristics from all frontal crashes. It should be remembered that lower limb fractures occurred in roughly one-third of the frontal crashes observed in this study. While differences between those who did and did not sustain a lower leg injury might seem more relevant for this comparison, this was not attempted because of the multiple number of injuries sustained by these people and the likely biases that this lower limb separation procedure might introduce. Thus, any differences found here would be expected to be conservative

3.4.1 Estimated Impact Velocity

The estimated delta-V distribution of the lower limb fracture sample was compared with the overall frontal distribution in Table 3 11

Table 3.11
Delta-V Distributions for All Frontal Injuries and Those Involving Fractured Lower Limbs

Distribution	All Injuries	Lower Limb Fractures
Modal value	42 - 48 km/h	55 - 60 km/h
Mean delta-V	53 km/h	56 km/h
Standard deviation	22 7 km/h	23.5 km/h
Minimum value	9 km/h	19 km/h
Maximum value	100+ km/h	100+ km/h

The mean delta-V and modal value was slightly higher for the lower limb fracture group than the total all injury sample, although there was very little difference in their respective standard deviations. Moreover, the minimum delta-V estimate was 10 km/h greater for the lower limb injury sub-group, confirming these fractures do tend to happen at more severe impact speeds.

The percent of fractured limb cases was also compared with the change of velocity on impact (delta-V), shown in Figure 3.1. This cumulative plot shows that 50% of these cases had a delta-V value of approximately 50km/h or less and 80%, a delta-V of 70km/h or less. The relationship between delta-V and the number of fractures per fractured lower limb case was further examined in Figure 3 2. This shows that the number of lower limb fractures per case is positively correlated with impact velocity (the faster the impact velocity, the higher the likelihood of multiple lower limb fractures to these front seat occupants)

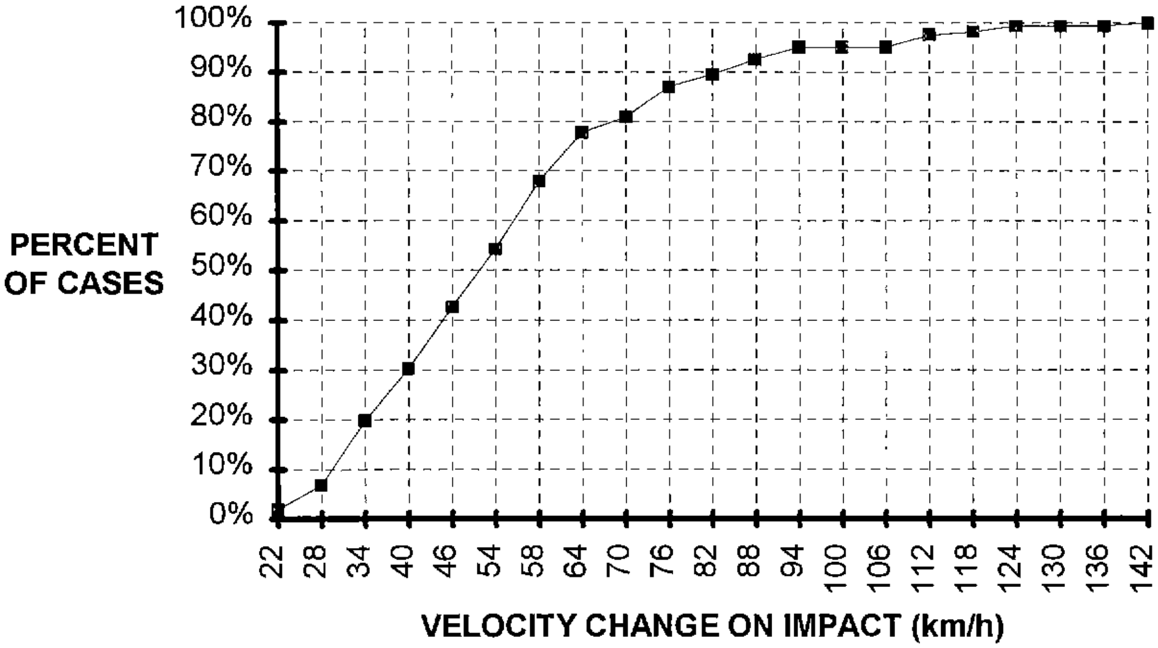


Figure 3.1 Cumulative percentage of lower limb injury cases by delta-V

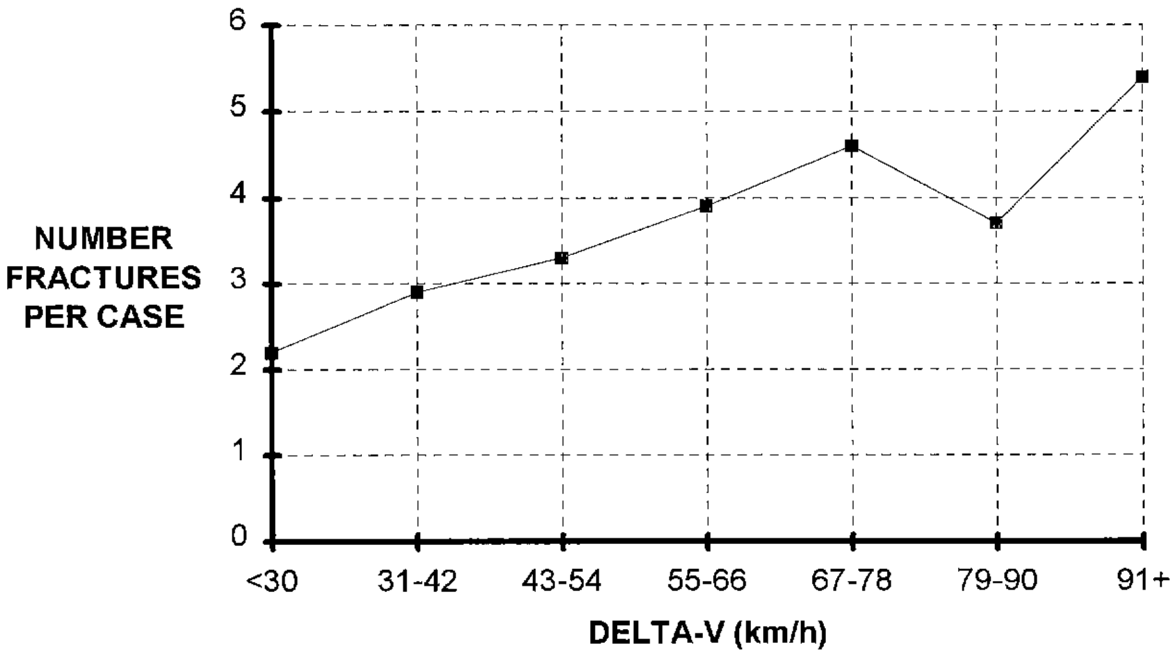


Figure 3.2 Relationship between delta-V and the number of fractures for each fractured lower limb case

3.4.2 Effect of Vehicle Size

The effect of the size of the occupant's vehicle was compared for the sample of lower limb fractures and the total frontal injured population and is shown in Table 3 12 below. The likelihood of a lower limb fracture compared to all frontal crash injuries was clearly much greater for occupants in very small and compact cars.

Table 3.12
Size of the Occupant's Vehicle in Frontal Crashes for All Injuries and Lower Limb Fractures

Vehicle Size	All Injuries	Lower Limb Fractures
Mini (<750kg)	5%	9%
Small (750-1000kg)	25%	23%
Compact (1001-1250kg)	40%	59%
Intermediate (1251-1500 kg)	28%	8%
Large (>1500 kg)	2%	1%

3.4.3 Occupant Characteristics

The age and sex distribution of the lower limb fracture group compared to all injured in frontal crashes is illustrated in Table 3.13. While there was a slightly greater tendency for females to sustain a lower limb fracture compared to all injuries, there were no clear differences for any age group between lower limb fractures and all injuries. While this might seem a little surprising given the general frailty of ageing, it is clear that any predisposition to lower limb fracture is somewhat irrelevant for front seat occupants in relatively severe frontal crashes.

Table 3.13
Age and Sex of the Occupant Sustaining All Injuries and Lower Limb Fractures in Frontal Crashes

Occupant	All Injuries	Lower Limb Fractures
Sex:		
Male	46%	40%
Female	54%	60%
Age:		
<17 years	8%	3%
17-25 years	27%	30%
26-55 years	47%	48%
56-75 years	15%	16%
>75 years	3%	3%

3.4.4 Lower Limb Fractures & Seat Belt Use

Lower limb fractures for restrained occupants are shown in Table 3.14. Seat belt wearing rates for those sustaining a lower limb fracture were lower than in frontal crashes in general, suggesting that unrestrained occupants are more susceptible to lower limb fracture. This was especially so for fractures of the thigh.

Table 3.14
Lower Limb Fractures by Seat Belt Use for Front Seat Occupants

Restrained occupants in all frontal crashes	83%
Restrained occupants where a lower limb injury was sustained	78%
Restrained occupants by ankle-foot fracture	82%
Restrained occupants by lower leg fracture	82%
Restrained occupants by knee fracture	80%
Restrained occupants by thigh fracture	74%

4. DISCUSSION AND CONCLUSIONS

This study set out to examine the pattern of lower limb injuries to occupants of cars involved in frontal crashes and the mechanisms of injury for the more severe ones. This was to illustrate the types of lower limb injuries sustained by occupants of modern passenger cars in head-on collisions and to give guidance to future efforts aimed at reducing these disabling, painful and costly injuries. There are a number of aspects of the results presented in the previous Chapter that need to be discussed.

4.1 THE IMPORTANCE OF LOWER LIMB INJURIES

The literature review clearly demonstrates that lower limb injuries are of major concern today in vehicle crashes on the road. While not necessarily life threatening, these injuries are of substantial frequency in road crashes, they do cause considerable pain and suffering to the individuals involved, some lower limb injuries have a propensity to on-going disability after recovery, and they can be extremely costly to society in terms of treatment, rehabilitation and loss of earning compensation costs.

States (1986) reported that the most common cause of lower limb injury in society was from car crashes and that fractures were especially noteworthy. To date, current frontal crash performance regulations which set acceptable lower limb injury criteria, such as the US standard FMVSS 208 and the Australian ADR 69, concentrate only on specifying a femur load requirement. The results of this study clearly demonstrate that there are many other types of lower limb injury of equal or greater incidence and severity that are not considered by current crash performance standards. In particular, fractures to the ankle, foot, lower legs and knees do not receive any consideration by present standards yet are frequent injuries in crashes of relatively modest severity.

Current efforts to address lower limb injury by the development of a more sensitive test dummy and the specification of a more comprehensive set of lower limb injury criteria are clearly warranted by the findings reported here.

4.2 LOWER LIMB INJURIES

4.2.1 Types of Injuries

The majority of lower limb injuries sustained by front seat occupants in frontal crashes of most concern were fractures to the thigh, knee, lower leg or foot. These injuries occurred in 88% of the cases examined where the occupant was hospitalised or killed. This relatively high rate of involvement probably reflects the injury entrance criterion, although it might also reflect a high likelihood of sustaining severe injury for occupants who injure their lower limbs in these relatively severe head-on collisions. The reasons why a more severe outcome was found for oblique crashes is not clear as it was expected that offsets would have resulted in the most severe outcomes. This might simply reflect anomalies in the way the three different crash configurations were coded and analysed in this study, rather than any substantive finding.

Fractures to the ankle/foot and lower leg were between one and a half and two times as frequent as thigh fractures in this sample of frontal crashes. Skeletal injury occurred in 65% of these crashes where an occupant was either hospitalised or killed. Severe injury (AIS 3) was judged in roughly one-third of all these lower limb injuries, in spite of the fact that over 80% of all occupants sustaining a lower limb injury were properly restrained during their crash. There were no marked age or sex effects in these findings which suggests that any frailty effects are more than offset by a high likelihood of severe outcome.

There is some divergence in these results with overseas findings, mainly those from the United States of America. Huelke, O'Day and States (1982) reported a much higher incidence of thigh than other lower limb fractures in frontal collisions than what was found here However, these were mainly among unrestrained occupants and from a an earlier generation of vehicles. In a more recent UK study, Pattimore, Ward, Thomas and Bradford (1991) reported similar proportions of skeletal injuries and injuries below the knee for restrained occupants in crashes as were found here. Dalmotas (1980) also reported a higher propensity for knee, leg, ankle and foot fractures in Canadian crashes around the regulation test speed of 48 km/h for barrier crash performance assessment

It is likely, therefore, that the results reported in this study are typical of the findings expected from a highly restrained motoring population. The fact that there are a sizeable number of these severe lower limb injuries at crash speeds at or below regulation levels shows there is considerable scope still for further occupant protection improvement.

4.2.2 The Relationship with Impact Speed

The distribution of delta-V values among these lower limb injury cases was 3 km/h higher than in all frontals involving front seat passengers. In addition, there were no lower limb fractures reported below 19 km/h. These findings suggests that lower limb injury (especially lower limb fractures) are more frequent at higher impact speeds There was a strong positive relationship observed between the number of fractures sustained by each occupant and the impact speed of the vehicle. A speed-incidence relationship was reported by Rastogi and colleagues (1986) for the incidence of fracture, but the positive correlation between impact speed and **number** of lower limb fractures per occupant has not been reported elsewhere.

The relationship reported in the previous Chapter between lower limb fracture injury and delta-V showed that an impact speed of 48 km/h or less (as specified in the new ADR 69/00) accounted for approximately 50% of the front seat occupant lower limb fractures observed in this sample of real world frontal crashes. Seventy to eighty percent of fractures had a delta-V of 60 to 70 km/h and below. The likelihood of a lower limb fracture by impact velocity was not computed here but could be in terms of increased risk for restrained and unrestrained occupants. A 48 km/h impact speed requirement in a frontal crash test, therefore, would seem to be an adequate level for specifying lower limb injury tolerances, although a higher impact speed would clearly be a more rigorous criterion.

4.2.3 Injury Sources

Sources of lower limb injury to occupants in frontal crashes mainly comprised the instrument panel, floor and toepan and the steering column. The side panel, too, was a frequent source of injury in oblique frontal crashes. Foot controls were only involved in 10% of the injuries described here, although it was difficult to assess the role of pedals in lower limb injuries retrospectively. It had been hoped to examine the relation between fracture and intrusion or deformation but this proved to be too difficult to achieve. Besides, it would have been only of marginal benefit as most of the cases observed in the attachment case summary volume clearly show that these injuries almost always involved intrusion of some kind.

The injury by contact source results were again most illuminating and revealed 6 injury-source fracture combinations common in these crashes. Ankle/foot fractures from contact with the floor and toepan were most common and twice as frequent as the next injury-source combination (lower leg with the floor and toepan). Thigh fractures from the instrument panel (the interaction most likely covered by current standards) was third most common, but less than half as frequent as the foremost combination. Interestingly, the studies by Huelke et al (1982) and Pattimore et al (1991) also reported that ankle and foot injuries from contacts with the floor was the most frequent lower limb injury event in their separate studies of essentially unrestrained and restrained occupants.

The incidence levels of the latter UK study were closer to those found here, especially when combining ankle/foot injuries from the floor and the pedals. This was to be expected given similar levels of restraint wearing and current generation vehicles As noted above, it was difficult in this study to assign pedal as a source of injury after the event as it was not always clear that the occupant (driver) had his or her foot on the pedals at the time of collision and, in many instances, they could not recall their precise foot position at the time of the collision. It was more meaningful to examine the incidence of the pedals as a source of injury from the mechanism of injury analysis where a more detailed examination of each of the cases was undertaken, involving both inspection details and medical and surgical reports on the injury and its causes. This is discussed further in the next section of this report.

4.3 MECHANISMS OF LOWER LIMB INJURY

As well as identifying the type and sources of lower limb injuries inside the vehicle, this study set out to examine the mechanisms of lower limb fractures during the crash. To facilitate this, each lower limb injury case had to be re-examined using the full set of data available in each occupant's medical file, radiology reports and x-rays and a panel of medical, biomechanical and research experts to arrive at a consensus view about injury processes. A similar study had been conducted previously by Wenzel (1992) and his procedure was adopted and expanded upon in this study. Mechanism of injury assessments were confined to the six most common injury by contact source interactions to emphasise priority injury causations.

The most common mechanism of lower limb fracture was clearly compression and this was particularly evident in lower leg and thigh fractures. Perpendicular loading of the lower limb skeleton occurred in roughly one-quarter of these cases but was the major mechanism in all knee fractures. Crushing and twisting of the foot caused fracture on between 25 and 30% of these cases and many of these involved multiple fractures of these complicated boney structures These three mechanisms should be highest priority for future efforts aimed at reducing lower limb fractures for front seat occupants in frontal crashes.

States (1986) reported that "axial loading" or compression forces resulting from knee contact with the dash and floor intrusions resulted in tibial shaft fracture. The results observed here show that this type of fracture was relatively frequent. However, FMVSS 208 (and the new ADR 69/00) only specify maximum compressive loads of the femur. This mechanism was only the third most common form of lower limb fracture and, clearly, reveals a need for at least an additional tibia load criterion.

It should be stressed that fractures of the ankle and foot from contact with the floor and toepan were ***the*** most common lower limb fracture observed in this study. Yet, there appear to have been very few previous investigations of these injuries and their mechanisms from the literature uncovered during this review. Lestina and his colleagues in 1992 did report that both inversion and eversion as well as dorsiflexion of the foot were common fracture mechanisms in these extreme lower limb injuries. The results found in this study seem to confirm these findings. In addition, they point to the complex nature of these fractures and the need for instruments sensitive to a range of foot and ankle movements as a pre-requisite for future lower limb injury prevention.

As well as more sensitive dummies capable of measuring these foot and ankle injuries, an injury criterion too is clearly needed to specify acceptable levels of loading to these regions. As many of these injuries were associated with floor and toepan intrusions, it would be expected that these additional criteria would ultimately lead to design improvements of the floor and toepan area to reduce the number and extent of these intrusions and deformations. Studies, such as those reported by Viano (1977), Lowne (1982) and Nyquist (1986), would be sufficient for providing the biomechanical data for setting these tolerance criteria.

4.3.1 The Role of the Pedals

One of the most vexing aspects of this study was the inability to specify accurately the role of the foot pedals in causing fractures to the ankle and foot for drivers involved in frontal crashes. This was because of the retrospective nature of these investigations, and the fact that occupants were often out of their cars when rescuers arrived at the scene, furthermore, most occupants could not recall with any degree of accuracy the precise circumstances that existed at the time of collision because of the overwhelming influence of road crashes on memory. Yet, the pedals would seem to be a potential source of considerable lower limb trauma for drivers in these frontal crashes.

These data showed that foot controls were associated with only 8% of lower limb injuries (12% of drivers' lower limb injuries, not reported here) and mainly involving injury to the ankle or feet. For the reasons expressed above, it is likely that these figures are conservative. There are two aspects of these findings that are relevant for lower limb injury prevention First, it raises a need for additional effort aimed at reducing the ankle-foot injury potential of these foot controls. How this might be achieved is unclear at this time but innovative solutions would be necessary to reduce the likelihood of these painful, crippling and expensive injuries. Some form of break-away pedal design or possibly a more substantive pedal design might be required, ensuring of course that they do not interfere with normal driving operations. A more radical suggestion might be to replace some or all foot pedals with stork controls, although this needs to consider vehicle control implications and injury trade-offs.

The second aspect of pedals and lower limb injury relates to the need (choice) for future regulations to specify driver dummy positions for the lower limbs and feet in test configuration. If driver dummies were to be required to have their feet located on the pedals, it raises questions of validity (whether it should be one or two feet and which feet as there are many situations where drivers brake and/or accelerate into a crash). Moreover, having the feet attached to the pedals would have implications for the types of injuries sustained and acceptable tolerance levels. This issue clearly requires further consideration in developing additional lower limb injury dummy abilities and acceptable tolerance criteria.

4.4 CONCLUSIONS

A number of conclusions can be drawn from the findings of this study of lower limb injuries to front seat occupants involved in frontal crashes.

1. Lower limb injuries occur to front seat occupants in more than one in every three frontal crashes where someone is either hospitalised or killed. Fractures occur in 88% of these injuries and are the most common severe outcome. Oblique frontal impacts usually resulted in more lower limb injuries including fractures than either full or offset frontal collisions.

2. While not necessarily life threatening, they do cause considerable pain and suffering to the people who sustain them, have a propensity for permanent disability and long-term rehabilitation, and can be extremely costly to the individuals and to society in general.

3. Current frontal crash regulations such as FMVSS208 and the proposed ADR69/00 only specify acceptable levels of femur loads.

4. The six most frequent lower limb fracture by contact source combinations were ankle/foot with the floor & toepan, lower leg with the floor & toepan, thigh with the instrument panel, lower leg with the instrument panel, knee with the instrument panel and knee with the steering column. The first of these, however, was six times more likely than the last

5. Average delta-V was slightly higher among lower limb fractures than for all frontal crashes with a higher minimum threshold value. Fifty percent of lower limb fractures occurred at 48km/h or below. The 80th percentile value was 70km/h. The number of fractures per fractured lower limb case was directly proportional to delta-V Lower limb fractures were more common among occupants of smaller cars

6. There were no apparent age or sex related differences in lower limb fractures suggesting that any frailty effects were more than offset by the level of lower limb trauma associated with frontal crashes. There was a slight suggestion of an over-representation of unrestrained occupants among those sustaining a thigh fracture

7. The three most common mechanisms of lower limb fracture include compression (axial loading) of the thigh and lower leg, perpendicular loading of the knee, and crushing or twisting of the foot. These three mechanisms (by body region) need to be emphasised in future efforts to measure and specify acceptable tolerances aimed at reducing lower limb injuries

8. Foot and ankle movements of eversion and inversion and dorsiflexion were most common among foot and ankle fractures. Torsion forces were roughly equally distributed in either direction while perpendicular loading tended to be more medial than lateral.

4.5 RECOMMENDATIONS

There is considerable evidence of the need for further attention to reducing lower limb injuries for front seat occupants involved in frontal crashes. As a pre-requisite, there is a need for additional lower limb protection in current or proposed crash performance standards. This will require the development of dummies sufficiently sensitive to measure the types and ranges of lower limb injuries (fractures) apparent in real world crashes. In addition, there is a need to specify acceptable tolerance criteria to ensure reduction in the numbers and severity of these injuries.

Manufacturers, too, need to consider ways in which car design could be improved to protect these lower extremities. Possible countermeasures might include more forgiving lower instrument panel designs, knee bars, and removing injurious fittings in the regions likely to come into contact with lower limbs in frontal crashes. The use of more sturdy materials in dash boards (sheetmetal rather than brittle plastics) would also alleviate severe lacerations from impact with these regions. Innovative pedal designs to minimise the likelihood of ankle and foot fracture would seem warranted. Structural improvements in the floor and toepan regions to minimise intrusions and deformations likely to injury occupants feet and lower legs would also be of benefit

REFERENCES

Anderson, H.G. (1919). *The Medical and Surgical Aspects of Aviation*, London: Oxford University Press.

Ashton, S.J., Mackay, G.M. & Gloyns, P.F. (1974). 'Trauma to children as car occupants'. *Proceedings of International Meeting on Biomechanics of Trauma in Children*, Lyon, France, IRCOBI.

Begeman, P.C. & Prasad, P. (1990). 'Human ankle impact response in dorsiflexion'. *34th Stapp Car Crash Conference Proceedings*, Orlando, Florida, Nov 4-7, 1990, P-236, 39-53, Technical Paper No. 902308. Warrendale, PA, Society of Automotive Engineers.

Begeman, P., Balakrishnan, P., Levine, R.S. & King, A. (1993). 'Dynamic human ankle response to inversion and eversion'. *37th Stapp Car Crash Conference Proceedings*, Nov 7-8, San Antonio, TX, P-269, 83-93, Technical Paper No 933115. Warrendale, PA, Society of Automotive Engineers.

Bowker, A. (1991). 'The use of crash injury research data by vehicle inspectorate to identify secondary safety concerns', *13th International Technical Conference on Experimental Safety Vehicles*, Paris, Paper 91-S1-W-17.

Bull, J P. (1985). 'Disabilities caused by road traffic accidents and their relation to severity scores'. *Acc. Anal & Prev., 17*, 387-397.

Cromark, J R , Schneider, D. & Blaisdell, D. (1990). 'Occupant kinematics and belt markings in crash tests with unrestrained and partially restrained test dummies'. *Proceedings of the 34th annual conferece of the Association for the Advancement of Automotive Medicine*, pp.203-225.

Culver, C C (1984). Lower leg axial force studies; exploratory tests using excised cadaver legs. Unpublished report, Biomedical Science Department, General Motors Research Laboratories (cited by Nyquist, 1986).

Dalmotas, D.J (1980). 'Mechanisms of injury to vehicle occupants restrained by three-point seat belts'. *24th Stapp Car Crash Conference Proceedings*, Technical Paper No.801311, pp.439-457. Warrendale, PA: Society of Automotive Engineers.

Dias, L.S. (1979). 'The lateral ankle sprain: An experimental study' *J. Trauma*, 19, 266-269.

Dischinger, P , Cusning, B & Kerns,T. (1992). 'Lower extremity fractures in motor vehicle collisions: Influence of direction of impact and seatbelt use' *Proceedings of the 36th Annual Conference of the Association for the Advancement of Automotive Medicine*, 319-325.

Fildes, B.N., Lane, J.C., Lenard, J. & Vulcan, A P (1991). *Passenger cars and occupant injury*, Report CR 95, Monash University Accident Research Centre. Canberra: Federal Office of Road Safety.

Fildes, B.N., Lane, J.C., Lenard, J. & Vulcan, A.P (1994). *Passenger cars and occupant injury: Side impact crashes*, Report CR 134, Monash University Accident Research Centre Canberra: Federal Office of Road Safety.

Garvil, G. (1976). Children in injury level accidents. *Proceedings of the 20th Annual Conference of the Association for the Advancement of Automotive Medicine*.

Gogler, G. (1965). *Road accidents.* Chirugica Documenta Geigy, Geigy (UK) Ltd, Manchester, 100-103.

Haut, R.C. (1983). 'The influence of superficial tissue on response of the primate knee to traumatic posterior tibial drawer', *J. Biomechanics,* 16, 465-472,

Huelke, D.F. (1986) 'Anatomy of the lower extremity - an overview' . *Symposium on the Biomechanics and Medical Aspects of Lower Limb Injuries,* Technical Paper 861921, 1-22. Society of Automotive Engineers, Warrendale, PA.

Huelke, D.F., Compton, T.W., & Compton, C.P. (1991). *Lower extremity injuries in frontal crashes: Injuries, locations, AIS and contacts.* SAE Technical Paper 910811. Warrendale, PA: Society of Automotive Engineers.

Huelke, D.F., O'Day, J. & States, J.D. (1982). 'Lower extremity injuries in automobile crashes', *Acc Anal. and Prev, 14,* 95-106.

Kihlberg, J.K. (1970). 'Multiplicity of injuries in automobile accidents'. In E.S Gurdjian (Ed), *Impact Injury & Crash Protection,* (Chapter 1). Springfield, IL.

Kleerekoper, M., Feldkamp, L.A & Goldstein, S.A.(1986). 'The effect of aging on the skeleton - implications for changes in tolerance'. *Symposium on the Biomechanics and Medical Aspects of Lower Limb Injuries,* Technical Paper No. 861926, pp.91-96. Warrendale, PA: Society of Automotive Engineers.

Kruger, H.J., Heuser, G., Kraemer, B. & Schmitz, A. (1994). 'Footloads and footwell intrusion in an offset frontal crash'. Paper No. 94 S4 O 03, *14th International Technical Conference on the Enhanced Safety of Vehicles,* Munich, Germany.

Lestina, D.C., Kuhlmann, T.P., Keats, T.E. & Alley, R.M. (1992). 'Mechanisms of fracture in ankle and foot injuries to drivers in motor vehicle crashes'. *36th Stapp Car Crash Conference Proceedings,* Technical Paper No 922515, 59-87. Warrendale, PA: Society of Automotive Engineers.

Levine, R.S. (1986a). 'A review of the long-term effects of selected lower limb injuries'. *Symposium on the Biomechanics and Medical Aspects of Lower Limb Injuries,* Technical Paper 860501, pp.143-159. .Warrendale, PA.: Society of Automotive Engineers

Levine, R.S. (1986b). 'An introduction to lower limb injuries'. *Symposium on Biomechanics and Medical Aspects of Lower Limb Injuries,* Technical.Paper 861922, pp.23-31 Warrendale, PA.: Society of Automotive Engineers

Levine, R.S. (1993). 'Injury to the extremities', in A.M. Nahum & J.W. Melvin (eds), *Accidental Injury Biomechanics & Prevention.* New York: Springer-Verlag.

Lowne, R.W. (1974). 'Injuries to children involved in road accidents'. *Proceedings of International Meeting on the Biomechanics of Trauma in Children.* Lyon, France: IRCOBI.

Lowne, R.W. (1982). *A revised upper leg injury criterion,* Working Paper No 42, Crowthorne, Transport and Road Research Laboratory. Document ISO/TC22/SC12/WG6 No 109, International Standards Organisation, (cited by Nyquist, 1986).

Melvin, J.W., Stalnaker, R.L. & Mohan, D. (1978). 'Protection of child occupants in automobile crashes'. *22nd Stapp Car Crash Conference Proceedings,* pp.673-695 Warrendale, PA: Society of Automotive Engineers.

Monash University Accident Research Centre (1992). *Feasibility of occupant protection measures* Report CR 100, Monash University Accident Research Centre. Canberra: Federal Office of Road Safety.

Morgan, R.M., Eppinger, R.H. & Hennessey, B.C. (1991) 'Ankle joint injury mechanism for adults in frontal automotive impact'. *35th Stapp Car Crash Conference Proceedings*, Technical Paper 912902, pp.189-198 Warrendale, PA: Society of Automotive Engineers.

Nahum, A.M. & Melvin, J.H. (1993). *Accidental injury: Biomechanics and prevention.* New York: Springer-Verlag

Nahum, A.M., Siegel, A.W., Hight, P.V. & Brooks, S.H. (1968). *Lower extremity injuries of front seat occupants.* SAE Technical Paper No 680483,. (cited by States, 1986).

Nyquist, G.W. (1982). *A pulse shape dependent knee-thigh-hip injury criterion for use with the Part 572 dummy.* Document ISO/TC22/SC12/WG6, No 117, International Standards Organisation, (Cited by Nyquist, 1986).

Nyquist, G.W. (1986). 'Injury tolerance characteristics of the adult human lower extremities under static and dynamic loading'. *Symposium on Biomechanics and Medical Aspects of Lower Limb Injuries*, Technical Paper 861925, pp.79-90. Warrendale PA Society of Automotive Engineers

Otte, D., Von Rheinbaben, H. & Zwipp, H. (1992). 'Biomechanics of injuries to the foot and ankle joint of car drivers and improvements for an optimal car floor development'. *36th Stapp Car Crash Conference Proceedings*, Technical Paper No 922514, pp.43-68. Warrendale, PA: Society of Automotive Engineers.

Ozanne-Smith, J. (1989). Evaluation of the effects of the Alfred Hospital Trauma Centre: Inter-rater reliability. Unpublished MPH Dissertation, Monash University Department of Social and Preventative Medicine, Melbourne, Australia.

Paix, B.R., Gibson, T.J., Mclean, A.J. & Woodward A., (1986). 'Severity of injury in road crashes: A comparison of injured occupants of forward control vehicles and conventional passenger cars' *Med. J. Aust., 145,* 433-436

Pattimore ,D., Ward, E., Thomas, P. & Bradford, M. (1991). 'The nature and cause of lower limb injuries in car crashes'. *35th Stapp Car Crash Conference Proceedings,* Technical Paper No. 912901, pp.177-187. Warrendale, PA: Society of Automotive Engineers.

Pilkey, W.D., Sieveka, E.M., Crandall, J.R. & Klopp, G. (1994). 'The influences of foot placement and vehicular intrusion on occupant lower limb injury in full-frontal and frontal-offset crashes' Paper No. 94 S4 W31, *14th International Technical Conference on the Enhanced Safety of Vehicles*, Munich, Germany

Rastogi, S., Wild, B.R. & Duthie, R.B. (1986). 'Biomechanical aspects of femoral fractures in automobile accidents', *J. Bone & Joint Surg., Series B, 68,* 760-766.

States, J.D. (1986). 'Adult occupant injuries of the lower limb'. *Symposium on Biomechanics and Medical Aspects of Lower Limb Injuries,* Technical Paper No. 861927, pp.97-113. Warrendale, PA Society of Automotive Engineers

Sturtz, G. (1977). 'Traumatic and cost mainpoints of injury model and cause of injury concerning unrestraint and restraint child car occupants and agressivity and cost of injuries by vehicle front shapes and elements in real pedestrian accidents'. *21st Stapp Car Crash Conference Proceedings*, pp1093- Warrendale, PA,: Society of Automotive Engineers.

Viano, D.C. (1977). 'Considerations for a femur injury criterion'. *21st Stapp Car Crash Conference Proceedings*, Technical Paper 770925, pp.445-473. Warrendale, PA: Society of Automotive Engineers.

Viano, D.C., Culver, C.C., Haut, R.C., Melvin, J.W., Bender, M., Culver, R.H. & Levine, R.S. (1978). 'Bolster impacts to the knee and tibia of human cadavers and an anthromorphic dummy'. *22nd Stapp Car Crash Conference Proceedings*, Technical Paper No 780996, pp.403-428. Warrendale, PA: Society of Automotive Engineers.

Walz, F.H., Sprenger, H.J., & Niederer, P.F. (1978). 'Severely and fatally injured rear seat car passengers (OAIS > 1) in Switzerland during 1976'. *Proceedings of the 22nd Annual Conference of the American Association for Automotive Medicine*, pp.129-140.

Ward, E.G., Bodiwala, G.G., & Thomas, P.D. (1992). 'The importance of lower limb injuries in car crashes when cost and disability are considered'. *Accid. Anal. & Prev. 24*, 613-620.

Wenzel, J. (1992). Seat belt associated fractures of the sternum. Unpublished paper presented at the 4th International Conference on Emergency Medicine, Washington.

Yamada, H. (1970). *Strength of biological materials*. Baltimore: Williams & Wilkins.

Attachment 1

Consent and Occupant Injury Forms

M O N A S H U N I V E R S I T Y

ACCIDENT RESEARCH CENTRE
Director: Dr A. P. Vulcan

AUSTRALIA

Dear ______________________,

Thank you for talking to us recently and agreeing to help us in our vehicle safety research. The Accident Research Centre at Monash University is currently engaged in a study of how vehicles perform in accidents. This work is aimed at making our vehicles and roads safer for all Australians.

This work requires us to examine vehicles involved in road crashes to determine how various parts of the vehicle behave in real accidents and compare these findings with the sorts of injuries people like yourself have suffered as a result of the crash.

To do this, we need your co-operation. We would like to talk to you about the crash you were recently involved in and any injuries you may have sustained from the crash. We would also like to see if you can recall which parts of the vehicle caused your injuries.

If you were treated in a hospital after the crash, we would also like to look at your medical record file at this hospital.

The information we collect is for **research purposes only** and will be treated in strictest confidence. We do not intend discussing any aspect of our findings with either the police, your insurance company or any other party to the crash. We may need to inspect any other vehicle involved in the collision as well but only for the purpose of examining the damage sustained in the crash. We will not seek to participate in any legal action over the crash.

At the end of our investigations, we will condense all the individual cases of information we have seen into an anonymous set of data without names and addresses. Hence, your confidentiality is further safeguarded here. At the end of our research, our report will highlight aspects of car design that require further safety improvements.

We have enclosed a consent form for you to sign, agreeing to you participating in this important study and, where appropriate, authorising us to obtain details about your injuries from the hospital where you were treated. Please sign and date this form if you are willing to participate in the study. Our nurse, Sister Nicole O'Meara will contact you shortly to talk to you about the crash.

I hope you have made a swift recovery from your injuries and that you have fully recovered from the effects of the accident.

Yours sincerely,

Peter Vulcan

Professor Peter Vulcan,
Director.

Should you have any complaint concerning the manner in which this research project is conducted, please do not hesitate to inform the researchers in person or you may prefer to contact the Standing Committee on Ethics in Research on Humans, University Secretariat, Monash University.

CLAYTON, VICTORIA, 3168 AUSTRALIA TELEX: AA32691 FAX: (61) (3) 565 4363 TELEPHONE: (03) 565 4371 IDD: +61 3 565 4371

Dear ____________________

CONSENT TO BE INTERVIEWED

I have read through and understand this letter and I HEREBY CONSENT to officers of the Monash University Accident Research Centre interviewing me about the circumstances of the collision I was recently involved in and consulting my hospital records if appropriate.

Signature ____

Please print full name ____________________________________

Dated this __________ day of ________________ 19

Treating Hospital ____

Treating Doctor ____

(Doctor's Address) _______________________________________

___________________________________Telephone______________

Would you please sign this form and return it to the Monash University Accident Research Centre as soon as possible. Thank you for your co-operation with this important research.

Should you have any complaint concerning the manner in which this research project is conducted, please do not hesitate to inform the researchers in person or you may prefer to contact the Standing Committee on Ethics in Research on Humans, University Secretariat, Monash University.

OCCUPANT PROTECTION PROJECT

MEDICAL REPORT FORM

Reg. No.	Case No.

Date of interview
Date of birth

OCCUPANT DETAILS	
Name	
Address	
Telephone	UR/Coroner No

CRASH DETAILS	
Location	
Date	Time
Police Station	Officer
Ambulance Type	Case No.

OTHER VEHICLE	
Make/Model	
Owner/Driver	
Address	
Telephone	Reg. No.
Passenger name Telephone number	
Treating hospital or GP	

Monash University Accident Research Centre

MEDICAL REPORT FORM

Case No.

ACCIDENT CIRCUMSTANCES	
Vehicle Make/Model	
Seat Position	Seatbelt Use
Description	
Evasive Action (steering, braking)	
Vehicle-A Speed (pre-impact, impact)	
Vehicle-B Speed	Driving Experience
Weather	Light
Trailer	*Heavy luggage/cargo*
Fuel Level	*Fuel Spillage*
Fire	*Windows Open*
Trapped	
Ejected	
Exit from Vehicle	

Monash University Accident Research Centre

MEDICAL REPORT FORM

INJURY DESCRIPTION	
Injury	Source
Bruises	
Abrasions	
Lacerations (sutures required)	
Fractures	
Loss of consciousness	
Relevant Prior Injuries	
Treatment Level	Duration of Treatment

MEDICAL REPORT FORM

OCCUPANT DETAILS	
Age	Sex *Pregnant*
Height	Weight

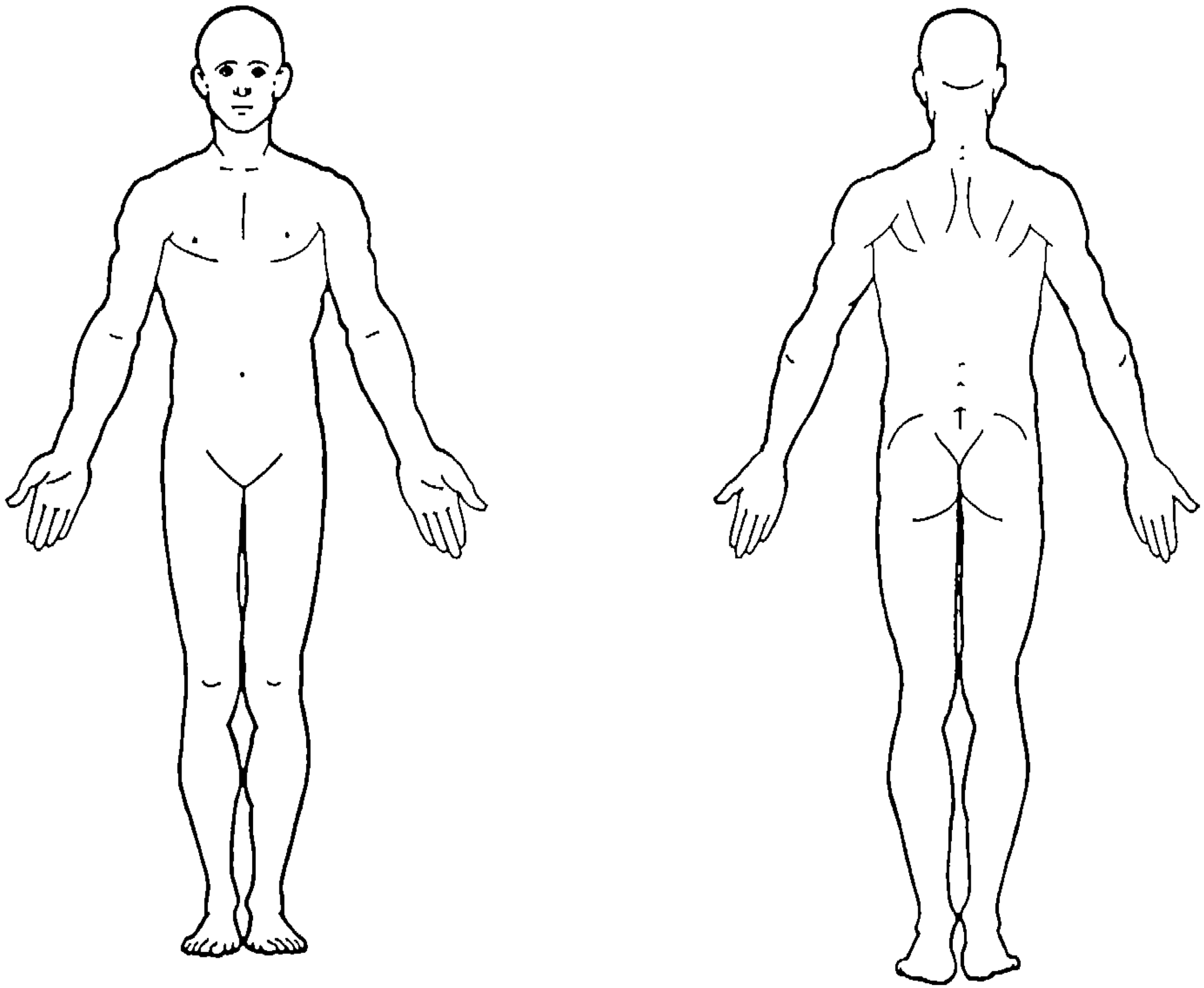
OTHER OCCUPANTS

MEDICAL REPORT FORM

FINAL INJURY CODING		
AIS Code	NASS Code	Description

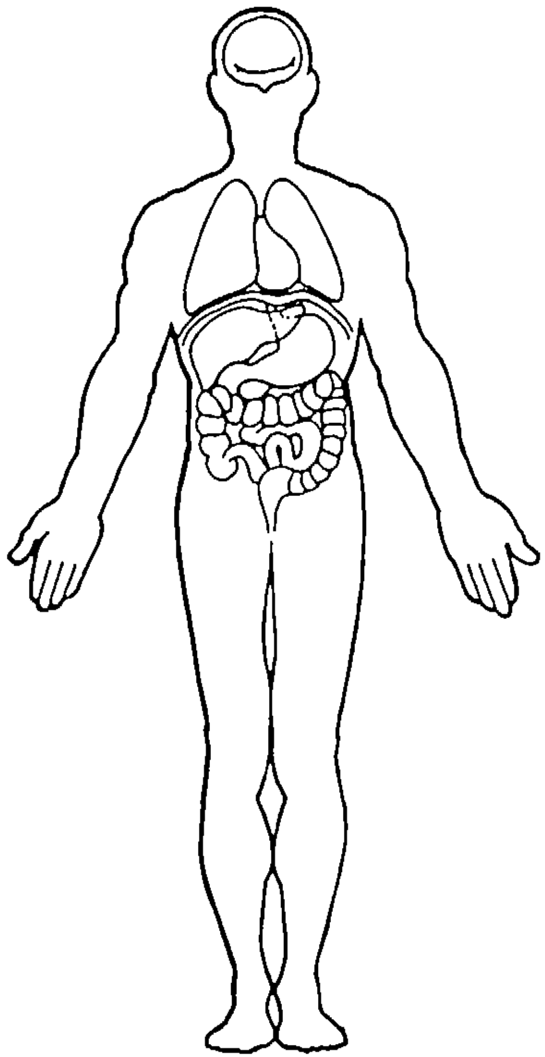
OFFICIAL INJURY DATA—SOFT TISSUE INJURIES

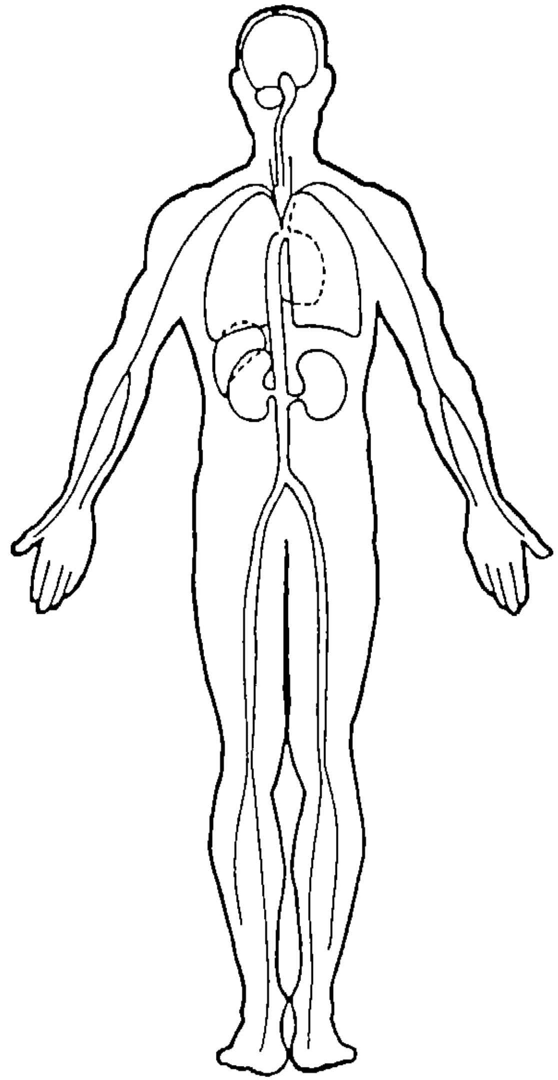
Indicate the *Location, Lesion, Detail* (size, depth, fracture type, head injury clinical signs and neurological deficits), and *Source* of all injuries indicated by official sources (or from PAR or other unofficial sources if medical records and interviewee data are unavailable.)



OFFICIAL INJURY DATA—INTERNAL INJURIES

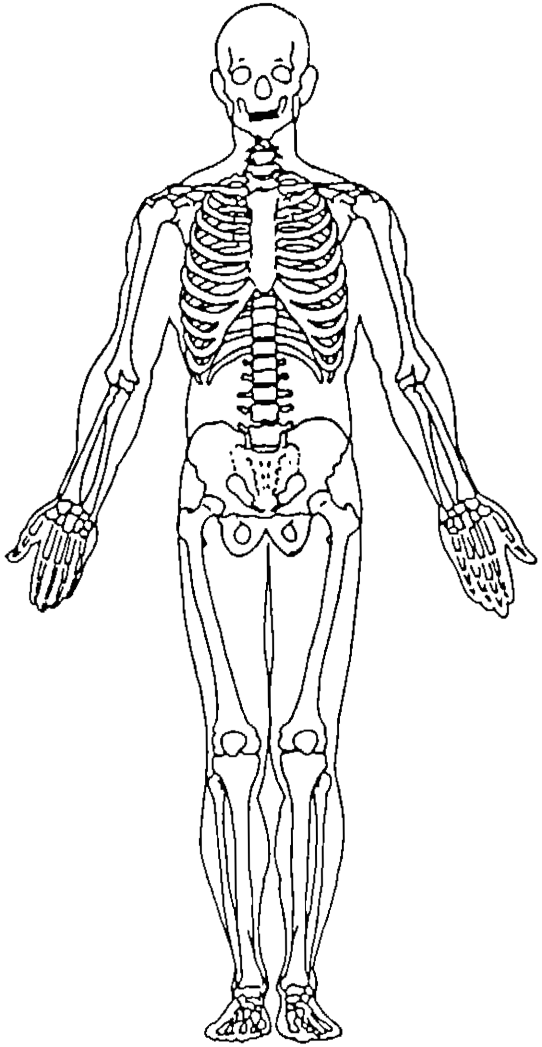
Indicate the *Location, Lesion, Detail* (size, depth, fracture type, head injury clinical signs and neurological deficits), and *Source* of all Injuries Indicated by official sources (or from PAR or other unofficial sources if medical records and interviewee data are unavailable.)

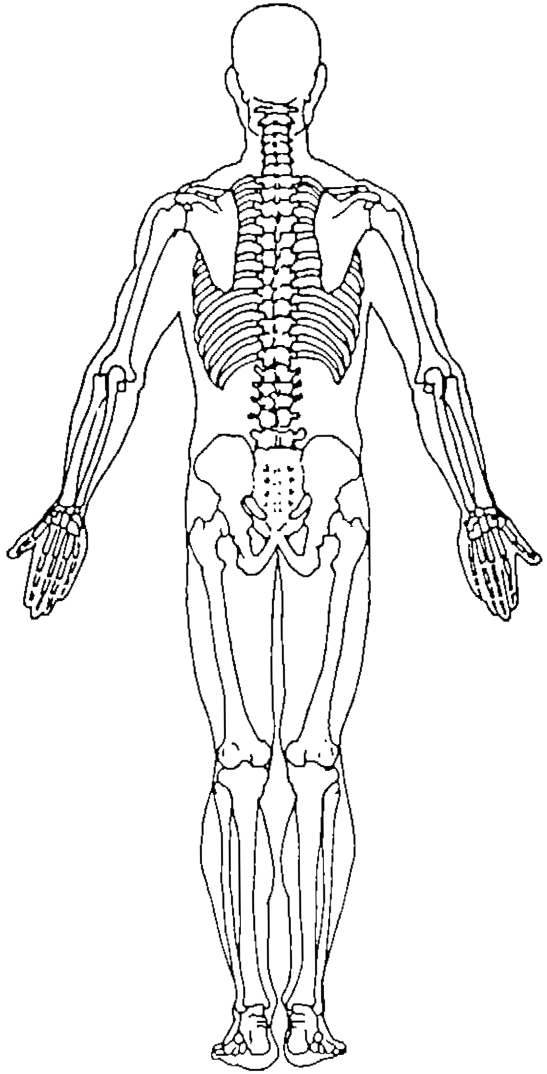




OFFICIAL INJURY DATA—SKELETAL INJURIES

Indicate the *Location, Lesion, Detail* (size, depth, fracture type, head injury clinical signs and neurological deficits), and *Source* of all injuries indicated by official sources (or from PAR or other unofficial sources if medical records and interviewee data are unavailable.)





Monash University Accident Research Centre

OCCUPANT INJURY FORM

CASE NUMBER ____________ PATIENT'S NAME ______________________________

HOSPITAL NUMBER ________________ UR NUMBER ________________________

INJURY DATA

Record below the *actual injuries sustained* by this occupant that were identified from the official and unofficial data sources. Remember not to double count an injury just because it was identified from two different sources. If greater than twenty injuries have been documented, encode the balance on the Occupant Injury Supplement.

		O.I.C. – A.I.S.								
	Source of Injury Data	Body Region	Aspect	Lesion	System Organ	A.I.S. Severity	Injury Source	Injury Source Confidence Level	Direct/ Indirect Injury	Occupant Area Intrusion No.
1st	5. ___	6. ___	7. ___	8. ___	9. ___	10. ___	11. ___ ___	12. ___	13. ___	14. ___ ___
2nd	15. ___	16. ___	17. ___	18. ___	19. ___	20. ___	21. ___ ___	22. ___	23. ___	24. ___ ___
3rd	25. ___	26. ___	27. ___	28. ___	29. ___	30. ___	31. ___ ___	32. ___	33. ___	34. ___ ___
4th	35. ___	36. ___	37. ___	38. ___	39. ___	40. ___	41. ___ ___	42. ___	43. ___	44. ___ ___
5th	45. ___	46. ___	47. ___	48. ___	49. ___	50. ___	51. ___ ___	52. ___	53. ___	54. ___ ___
6th	55. ___	56. ___	57. ___	58. ___	59. ___	60. ___	61. ___ ___	62. ___	63. ___	64. ___ ___
7th	65. ___	66. ___	67. ___	68. ___	69. ___	70. ___	71. ___ ___	72. ___	73. ___	74. ___ ___
8th	75. ___	76. ___	77. ___	78. ___	79. ___	80. ___	81. ___ ___	82. ___	83. ___	84. ___ ___
9th	85. ___	86. ___	87. ___	88. ___	89. ___	90. ___	91. ___ ___	92. ___	93. ___	94. ___ ___
10th	95. ___	96. ___	97. ___	98. ___	99. ___	100. ___	101. ___ ___	102. ___	103. ___	104. ___ ___
11th	105. ___	106___	107___	108. ___	109___	110. ___	111. ___ ___	112. ___	113. ___	114. ___ ___
12th	115. ___	116___	117___	118. ___	119___	120. ___	121. ___ ___	122. ___	123. ___	124. ___ ___
13th	125. ___	126___	127___	128. ___	129___	130. ___	131. ___ ___	132. ___	133. ___	134. ___ ___
14th	135. ___	136___	137___	138. ___	139___	140. ___	141. ___ ___	142. ___	143 ___	144. ___ ___
15th	145. ___	146___	147___	148. ___	149.___	150. ___	151. ___ ___	152. ___	153. ___	154. ___ ___
16th	155. ___	156___	157___	158. ___	159.___	160. ___	161. ___ ___	162. ___	163. ___	164. ___ ___
17th	165. ___	166___	167___	168. ___	169.___	170. ___	171. ___ ___	172. ___	173. ___	174. ___ ___
18th	175. ___	176___	177___	178. ___	179___	180. ___	181. ___ ___	182. ___	183. ___	184. ___ ___
19th	185. ___	186___	187___	188. ___	189___	190. ___	191. ___ ___	192. ___	193. ___	194. ___ ___
20th	195. ___	196___	197___	198. ___	199___	200. ___	201. ___ ___	202. ___	203. ___	204. ___ ___

Derived with appreciation from the National Accident Sampling System, National Highway & Safety Administration, US Department of Transportation.

SOURCE OF INJURY DATA

OFFICIAL

(1) Autopsy records with or without hospital medical records
(2) Hospital medical records other than emergency room (eg. discharge summary)
(3) Emergency room records only (including associated X-rays or other lab reports)
(4) Private physician, walk-in or emergency clinic

UNOFFICIAL

(5) Lay coroner report
(6) E.M.S. personnel
(7) Interviewee
(8) Other source (specify):
(9) Police

INJURY SOURCE

FRONT

(01) Windshield
(02) Mirror
(03) Sunvisor
(04) Steering wheel rim
(05) Steering wheel hub/spoke
(06) Steering wheel (combination of codes 04 and 05)
(07) Steering column, transmission selector lever, other attachment
(08) Add-on equipment (e.g., CB, tape deck, air conditioner)
(09) Left instrument panel and below
(10) Center instrument panel and below
(11) Right instrument panel and below
(12) Glove compartment door
(13) Knee bolster
(14) Windshield including one or more of the following: front header, A-pillar, instrument panel, mirror, or steering assembly (driver side only)
(15) Windshield including one or more of the following: front header, A-pillar, instrument panel, or mirror (passenger side only)
(16) Other front object (specify):

LEFT SIDE

(20) Left side interior surface, excluding hardware or armrests
(21) Left side hardware or armrest
(22) Left A pillar
(23) Left B pillar
(24) Other left pillar (specify):
(25) Left side window glass or frame
(26) Left side window glass including one or more of the following: frame, window sill, A-pillar, B-pillar, or roof side rail
(27) Other left side object (specify):

RIGHT SIDE

(30) Right side interior surface, excluding hardware or armrests
(31) Right side hardware or armrest
(32) Right A pillar
(33) Right B pillar
(34) Other right pillar (specify):
(35) Right side window glass or frame
(36) Right side window glass including one or more of the following: frame, window sill, A-pillar, B-pillar, roof side rail
(37) Other right side object (specify):

INTERIOR

(40) Seat, back support
(41) Belt restraint webbing/buckle
(42) Belt restraint B-pillar attachment point
(43) Other restraint system component (specify):
(44) Head restraint system
(45) Air cushion
(46) Other occupants (specify):
(47) Interior loose objects
(48) Child safety seat (specify)
(49) Other interior object (specify).

ROOF

(50) Front header
(51) Rear header
(52) Roof left side rail
(53) Roof right side rail
(54) Roof or convertible top

FLOOR

(56) Floor including toe pan
(57) Floor or console mounted transmission lever, including console
(58) Parking brake handle
(59) Foot controls including parking brake

REAR

(60) Backlight (rear window)
(61) Backlight storage rack, door, etc.
(62) Other rear object (specify):

EXTERIOR OF OCCUPANT'S VEHICLE

(65) Hood
(66) Outside hardware (e.g., outside mirror, antenna)
(67) Other exterior surface or tires (specify):
(68) Unknown exterior objects

EXTERIOR OF OTHER MOTOR VEHICLE

(70) Front bumper
(71) Hood edge
(72) Other front of vehicle (specify):
(73) Hood
(74) Hood ornament
(75) Windshield, roof rail, A-pillar
(76) Side surface
(77) Side mirrors
(78) Other side protrusions (specify):
(79) Rear surface
(80) Undercarriage
(81) Tires and wheels
(82) Other exterior of other motor vehicle (specify):
(83) Unknown exterior of other motor vehicle

OTHER VEHICLE OR OBJECT IN THE ENVIRONMENT

(84) Ground
(85) Other vehicle or object (specify)
(86) Unknown vehicle or object

NONCONTACT INJURY

(90) Fire in vehicle
(91) Flying glass
(92) Other noncontact injury source (specify)
(97) Injured, unknown source

INJURY SOURCE CONFIDENCE LEVEL

(1) Certain
(2) Probable
(3) Possible
(9) Unknown

DIRECT/INDIRECT INJURY

(1) Direct contact injury
(2) Indirect contact injury
(3) Noncontact injury
(7) Injured, unknown source

OCCUPANT INJURY CLASSIFICATION

O.I.C. Body Region

(M) Abdomen
(Q) Ankle–foot
(A) Arm (upper)
(B) Back–thoracolumbar spine
(C) Chest
(E) Elbow
(F) Face
(R) Forearm
(H) Head–skull
(U) Injured, unknown region
(K) Knee
(L) Leg (lower)
(Y) Lower limb(s) (whole or unknown part)
(N) Neck–cervical spine
(P) Pelvic–hip
(S) Shoulder
(T) Thigh
(X) Upper limb(s) (whole or unknown part)
(O) Whole body
(W) Wrist–hand

Aspect of Injury

(A) Anterior–front
(C) Central
(I) Inferior–lower
(U) Injured, unknown aspect
(L) Left
(P) Posterior–back
(R) Right
(S) Superior–upper
(W) Whole region

Lesion

(A) Abrasion
(M) Amputation
(V) Avulsion
(B) Burn
(K) Concussion
(C) Contusion
(N) Crush
(G) Detachment, separation
(D) Dislocation
(F) Fracture
(Z) Fracture and dislocation
(U) Injured, unknown lesion
(L) Laceration
(O) Other
(P) Perforation, puncture
(R) Rupture
(S) Sprain
(T) Strain
(E) Total severance, transection

System/Organ

(W) All systems in region
(A) Arteries–veins
(B) Brain
(D) Digestive
(E) Ears
(O) Eye
(H) Heart
(U) Injured, unknown system
(I) Integumentary
(J) Joints
(K) Kidneys
(L) Liver
(M) Muscles
(N) Nervous system
(P) Pulmonary–lungs
(R) Respiratory
(S) Skeletal
(C) Spinal cord
(Q) Spleen
(T) Thyroid, other endocrine gland
(G) Urogenital
(V) Vertebrae

Abbreviated Injury Scale

(1) Minor injury
(2) Moderate injury
(3) Serious injury
(4) Severe injury
(5) Critical injury
(6) Maximum (untreatable)
(7) Injured, unknown severity

Attachment 2

The (NASS) Vehicle Inspection and Crash 3 Forms

US Department of Transportation
National Highway Traffic Safety Administration

GENERAL VEHICLE FORM

NATIONAL ACCIDENT SAMPLING SYSTEM
CRASHWORTHINESS DATA SYSTEM

1. Primary Sampling Unit Number ___ ___

2. Case Number—Stratum ___ ___ ___ ___

3. Vehicle Number ___ ___

VEHICLE IDENTIFICATION

4. Vehicle Model Year ___ ___
   Code the last two digits of the model year
   (99) Unknown

5. Vehicle Make (specify): ___ ___

   ____

   Applicable codes are found in your NASS CDS Data Collection, Coding, and Editing Manual.
   (99) Unknown

6. Vehicle Model (specify): ___ ___ ___

   ____

   Applicable codes are found in your NASS CDS Data Collection, Coding, and Editing Manual.
   (999) Unknown

7. Body Type ___ ___
   Note: Applicable codes are found on the back of this page.

8. Vehicle Identification Number

   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___

   Left justify; Slash zeros and letter Z (Ø and Ƶ)
   No VIN—Code all zeros
   Unknown—Code all nine's

OFFICIAL RECORDS

9. Police Reported Vehicle Disposition ___
   (0) Not towed due to vehicle damage
   (1) Towed due to vehicle damage
   (9) Unknown

10. Police Reported Travel Speed ___ ___

    Code to the nearest mph (NOTE: 00 means less than 0.5 mph)
    (97) 96.5 mph and above
    (99) Unknown

11. Police Reported Alcohol or Drug Presence ___
    (0) Neither alcohol nor drugs present
    (1) Yes (alcohol present)
    (2) Yes (drugs present)
    (3) Yes (alcohol and drugs present)
    (4) Yes (alcohol or drugs present—specifics unknown)
    (7) Not reported
    (8) No driver present
    (9) Unknown

12. Alcohol Test Result for Driver ___ ___
    Code actual value (decimal implied before first digit—0.xx)
    (95) Test refused
    (96) None given
    (97) AC test performed, results unknown
    (98) No driver present
    (99) Unknown

    Source ____________________

ACCIDENT RELATED

13. Speed Limit ___ ___
    (00) No statutory limit
    Code posted or statutory speed limit
    (99) Unknown

14. Attempted Avoidance Maneuver ___ ___
    (00) No impact
    (01) No avoidance actions
    (02) Braking (no lockup)
    (03) Braking (lockup)
    (04) Braking (lockup unknown)
    (05) Releasing brakes
    (06) Steering left
    (07) Steering right
    (08) Braking and steering left
    (09) Braking and steering right
    (10) Accelerating
    (11) Accelerating and steering left
    (12) Accelerating and steering right
    (98) Other action (specify):

    ____

    (99) Unknown

15. Accident Type ___ ___
    Applicable codes may be found on the back of page two of this field form
    (00) No impact
    Code the number of the diagram that best describes the accident circumstance
    (98) Other accident type (specify):

    ____

    (99) Unknown

****** STOP HERE IF GV07 DOES NOT EQUAL 01-49 ******

HS Form 435
1/88

OCCUPANT RELATED

16. Driver Presence in Vehicle __
    (0) Driver not present
    (1) Driver present
    (9) Unknown

17. Number of Occupants This Vehicle __ __
    (00-96) Code actual number of occupants for this vehicle
    (97) 97 or more
    (99) Unknown

18. Number of Occupant Forms Submitted __ __

VEHICLE WEIGHT ITEMS

19. Vehicle Curb Weight __ __, __ 0 0
    ____Code weight to nearest 100 pounds.
    (000) Less than 50 pounds
    (135) 13,500 lbs or more
    (999) Unknown

    Source: ____________________

20. Vehicle Cargo Weight __ __ 0 0
    ____Code weight to nearest 100 pounds.
    (00) Less than 50 pounds
    (97) 9,650 lbs or more
    (99) Unknown

RECONSTRUCTION DATA

21. Towed Trailing Unit __
    (0) No towed unit
    (1) Yes—towed trailing unit
    (9) Unknown

22. Documentation of Trajectory Data for This Vehicle __
    (0) No
    (1) Yes

23. Post Collision Condition of Tree or Pole (for Highest Delta V) __
    (0) Not collision (for highest delta V) with tree or pole
    (1) Not damaged
    (2) Cracked/sheared
    (3) Tilted <45 degrees
    (4) Tilted ≥45 degrees
    (5) Uprooted tree
    (6) Separated pole from base
    (7) Pole replaced
    (8) Other (specify): ____________________
    (9) Unknown

24. Rollover __
    (0) No rollover (no overturning)

    Rollover (primarily about the longitudinal axis)
    (1) Rollover, 1 quarter turn only
    (2) Rollover, 2 quarter turns
    (3) Rollover, 3 quarter turns
    (4) Rollover, 4 or more quarter turns (specify): ____________________

    (5) Rollover—end-over-end (i.e., primarily about the lateral axis)
    (9) Rollover (overturn), details unknown

OVERRIDE/UNDERRIDE (THIS VEHICLE)

25. Front Override/Underride (this vehicle) __

26. Rear Override/Underride (this vehicle) __

    (0) No override/underride, or not an end-to-end impact

    Override (see specific CDC)
    (1) 1st CDC
    (2) 2nd CDC
    (3) Other not automated CDC (specify): ____________________

    Underride (see specific CDC)
    (4) 1st CDC
    (5) 2nd CDC
    (6) Other not automated CDC (specify) ____________________

    (7) Medium/heavy truck override
    (9) Unknown

HEADING ANGLE AT IMPACT FOR HIGHEST DELTA V

Values: (000)-(359) Code actual value
(997) Noncollision
(998) Impact with object
(999) Unknown

27. Heading Angle for This Vehicle __ __ __

28. Heading Angle for Other Vehicle __ __ __

29. Basis for Total Delta V (Highest) ___

Delta V Calculated
(1) CRASH program—damage only routine
(2) CRASH program—damage and trajectory routine
(3) Missing vehicle algorithm

Delta V Not Calculated
(4) At least one vehicle (which may be this vehicle) is beyond the scope of an acceptable reconstruction program, regardless of collision conditions.

(5) All vehicles within scope (CDC applicable) of CRASH program but one of the collision conditions is beyond the scope of the CRASH program or other acceptable reconstruction techniques, regardless of adequacy of damage data.

(6) All vehicle and collision conditions are within scope of one of the acceptable reconstruction programs, but there is insufficient data available.

COMPUTER GENERATED DELTA V

Secondary Highest

30. Total Delta V ___ ___

___ Nearest mph ___

(NOTE: 00 means less than 0.5 mph)
(97) 96.5 mph and above
(99) Unknown

31. Longitudinal Component of Delta V ± ___ ___

___ Nearest mph ___

(NOTE: __00 means greater than −0.5 and less than +0.5 mph)
(±97) ±96.5 mph and above
(__ 99) Unknown

Secondary Highest

32. Lateral Component of Delta V ± ___ ___

___ Nearest mph ___

(NOTE: __00 means greater than −0.5 and less than +0.5 mph)
(±97) ±96.5 mph and above
(__ 99) Unknown

33. Energy Absorption ___ ___ ___, ___ 0 0

___ Nearest 100 foot-lbs ___

(NOTE: 0000 means less than 50 Foot-Lbs)
(9997) 999,650 foot-lbs or more
(9999) Unknown

34. Confidence in Reconstruction Program Results (for Highest Delta V) ___
(0) No reconstruction
(1) Collision fits model—results appear reasonable
(2) Collision fits model—results appear high
(3) Collision fits model—results appear low
(4) Borderline reconstruction—results appear reasonable

35. Type of Vehicle Inspection ___
(0) No Inspection
(1) Complete inspection
(2) Partial inspection (specify):

____

*** STOP HERE IF THE CDS APPLICABLE ***
VEHICLE WAS NOT INSPECTED

U.S. Department of Transportation
National Highway Traffic Safety Administration

EXTERIOR VEHICLE FORM

NATIONAL ACCIDENT SAMPLING SYSTEM
CRASHWORTHINESS DATA SYSTEM

1. Primary Sampling Unit Number __ __

2. Case Number—Stratum __ __ __ __

3. Vehicle Number __ __

VEHICLE IDENTIFICATION

VIN. __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ __ Model Year ______

Vehicle Make (specify): ______ Vehicle Model (specify): ______

LOCATOR

Locate the end of the damage with respect to the vehicle longitudinal center line or bumper corner for end impacts or an undamaged axle for side impacts.

Specific Impact No.	Location of Direct Damage	Location of Field L

CRUSH PROFILE

NOTES: Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, etc.) and label adjustments (e.g., free space).

Measure and document on the vehicle diagram the location of maximum crush.

Measure C1 to C6 from driver to passenger side in front or rear impacts and rear to front in side impacts.

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following. bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

Use as many lines/columns as necessary to describe each damage profile.

Specific Impact Number	Plane of C-Measurements	Direct Damage		Field L	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width (CDC)	Max Crush								

HS Form 435A
1/88

National Accident Sampling System—Crashworthiness Data System: Exterior Vehicle Form

VEHICLE DAMAGE SKETCH

TIRE–WHEEL DAMAGE

a. Rotation physically restricted / b. Tire deflated

	a. Rotation physically restricted	b. Tire deflated
RF	___	___
LF	___	___
RR	___	___
LR	___	___

(1) Yes (2) No (8) NA (9) Unk.

TYPE OF TRANSMISSION

☐ Manual ☐ Automatic

ORIGINAL SPECIFICATIONS

Wheelbase	________
Overall Length	________
Maximum Width	________
Curb Weight	________
Average Track	________
Front Overhang	________
Rear Overhang	________
Engine Size: cyl./ displ.	________
Undeformed End Width	________

WHEEL STEER ANGLES

(For locked front wheels or displaced rear axles only)

RF ± ___ ___ °

LF ± ___ ___ °

RR ± ___ ___ °

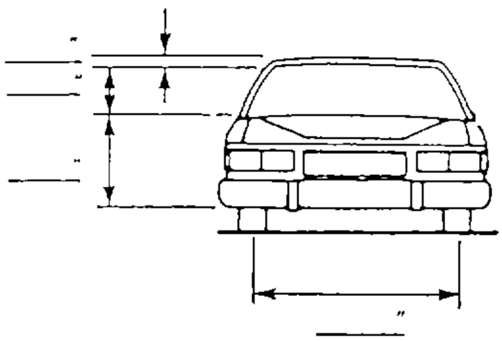
LR ± ___ ___ °

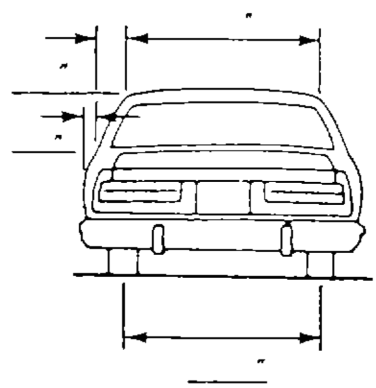
Within ±5 degrees

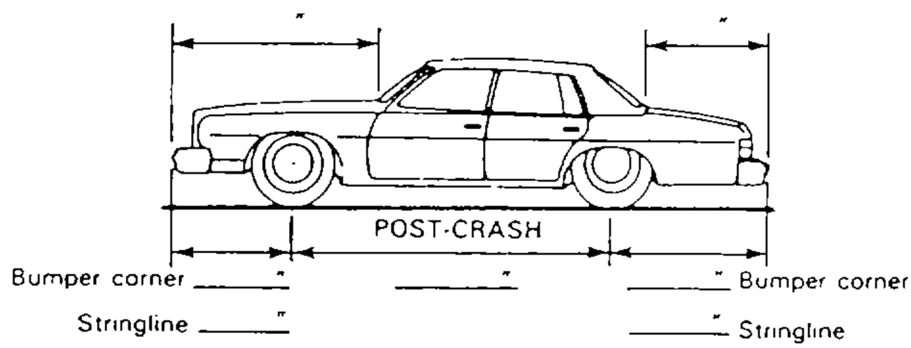
DRIVE WHEELS

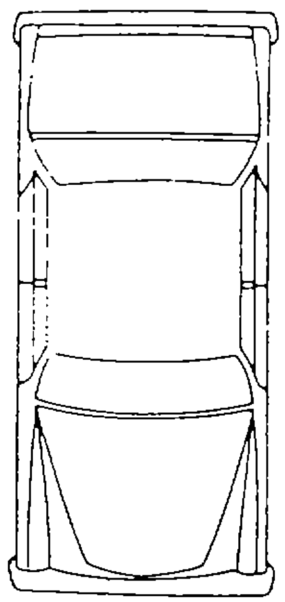
☐ FWD ☐ RWD ☐ 4WD

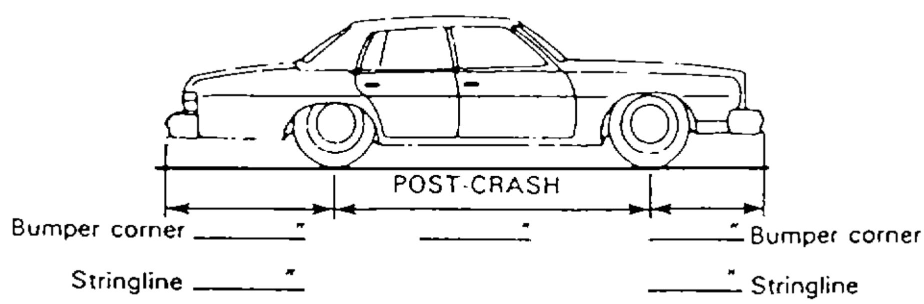
Approximate Cargo Weight ________











NOTES: Sketch new perimeter and cross hatch direct damage and single hatch induced damage on all views. Annotate observations which might be useful in reconstructing the accident (e.g., grass in tire bead, direction of striations, scuff on sidewall, etc.). If pulling trailer, sketch type of trailer and damage received on the back of this page.

Annotate any damage caused by extrication such as component removal by torching, prying, or hydraulic shears

CDC WORKSHEET

CODES FOR OBJECT CONTACTED

01-30—Vehicle Number

Noncollision
- (31) Overturn—rollover
- (32) Fire or explosion
- (33) Jackknife
- (34) Other intraunit damage (specify): ____________
- (35) Noncollision injury
- (38) Other noncollision (specify): ____________
- (39) Noncollision—details unknown

Collision with Fixed Object
- (41) Tree (≤4 inches in diameter)
- (42) Tree (>4 inches in diameter)
- (43) Shrubbery or bush
- (44) Embankment
- (45) Breakaway pole or post (any diameter)

Nonbreakaway Pole or Post
- (50) Pole or post (≤4 inches in diameter)
- (51) Pole or post (>4 but ≤12 inches in diameter)
- (52) Pole or post (>12 inches in diameter)
- (53) Pole or post (diameter unknown)
- (54) Concrete traffic barrier
- (55) Impact attenuator
- (56) Other traffic barrier (specify): ____________
- (57) Fence
- (58) Wall
- (59) Building
- (60) Ditch or Culvert
- (61) Ground
- (62) Fire hydrant
- (63) Curb
- (64) Bridge
- (68) Other fixed object (specify): ____________
- (69) Unknown fixed object

Collision With Nonfixed Object
- (71) Motor vehicle not in transport
- (72) Pedestrian
- (73) Cyclist or cycle
- (74) Other nonmotorist or conveyance (specify): ____________
- (75) Vehicle occupant
- (76) Animal
- (77) Train
- (78) Trailer, disconnected in transport
- (88) Other nonfixed object (specify): ____________
- (89) Unknown nonfixed object
- (98) Other event (specify): ____________
- (99) Unknown event or object

DEFORMATION CLASSIFICATION BY EVENT NUMBER

Accident Event Sequence Number	Object Contacted	(1) (2) Direction of Force (degrees)	Incremental Value of Shift	(3) Deformation Location	(4) Specific Longitudinal or Lateral Location	(5) Specific Vertical or Lateral Location	(6) Type of Damage Distribution	(7) Deformation Extent
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __
__ __	__ __	__ __ __	__ __	__	__	__	__	__ __

COLLISION DEFORMATION CLASSIFICATION

HIGHEST DELTA "V"

Accident Event Sequence Number	Object Contacted	(1) (2) Direction of Force	(3) Deformation Location	(4) Specific Longitudinal or Lateral Location	(5) Specific Vertical or Lateral Location	(6) Type of Damage Distribution	(7) Deformation Extent
4. __ __	5. __ __	6. __ __	7. __	8. __	9. __	10. __	11. __ __

Second Highest Delta "V"

12. __ __	13. __ __	14. __ __	15. __	16. __	17. __	18. __	19. __ __

CRUSH PROFILE

(The crush profile for the damage described in the CDC(s) above should be documented in the appropriate space below. ALL MEASUREMENTS ARE IN INCHES.)

HIGHEST DELTA "V"

20. L	21. C1	C2	C3	C4	C5	C6	22. ± D
__ __ __	__ __	__ __	__ __	__ __	__ __	__ __	± __ __ __ __

Second Highest Delta "V"

23. L	24. C1	C2	C3	C4	C5	C6	25. ± D
__ __ __	__ __	__ __	__ __	__ __	__ __	__ __	± __ __ __ __

26. Are CDCs Documented but Not Coded on The Automated File __
(0) No
(1) Yes

27. Researcher's Assessment of Vehicle Disposition __
(0) Not towed due to vehicle damage
(1) Towed due to vehicle damage
(9) Unknown

28. Original Wheelbase __ __ __.__
____Code to the nearest tenth of an inch
(9999) Unknown

*****STOP HERE IF THE CDS APPLICABLE*****
VEHICLE WAS NOT TOWED (I.E., GV09 = 0 OR 9)

U.S. Department of Transportation
National Highway Traffic Safety Administration

INTERIOR VEHICLE FORM

NATIONAL ACCIDENT SAMPLING SYSTEM
CRASHWORTHINESS DATA SYSTEM

1. Primary Sampling Unit Number __ __
2. Case Number—Stratum __ __ __ __
3. Vehicle Number __ __

INTEGRITY

4. Passenger Compartment Integrity __ __

(00) No integrity loss

Yes, Integrity Was Lost Through
(01) Windshield
(02) Door (side)
(03) Door/hatch (rear)
(04) Roof
(05) Roof glass
(06) Side window
(07) Rear window
(08) Roof and roof glass
(09) Windshield and door (side)
(10) Windshield and roof
(11) Side and rear window
(98) Other combination of above (specify):

____

(99) Unknown

Door, Tailgate Or Hatch Opening

5. LF __ 6. RF __ 7. LR __ 8. RR __ 9. TG/H __

(0) No door/gate/hatch
(1) Door/gate/hatch remained closed and operational
(2) Door/gate/hatch came open during collision
(3) Door/gate/hatch jammed shut
(8) Other (specify):

____

(9) Unknown

Damage/Failure Associated with Door, Tailgate or Hatch Opening in Collision: If IV05-IV09 ≠ 2, Then Code 0.

10. LF __ 11. RF __ 12. LR __ 13. RR __ 14. TG/H __

(0) No door/gate/hatch or door not opened

Door, Tailgate, or Hatch Came Open During Collision
(1) Door operational (no damage)
(2) Latch/striker failure due to damage
(3) Hinge failure due to damage
(4) Door structure failure due to damage
(5) Door support (i.e., pillar, sill, roof side rail, etc.) failure due to damage
(6) Latch/striker and hinge failure due to damage
(8) Other failure (specify):

____

(9) Unknown

GLAZING

Glazing Damage from Impact Forces

15. WS __ 16. LF __ 17. RF __ 18. LR __ 19. RR __
20. BL __ 21. Roof __ 22. Other __

(0) No glazing damage from impact forces
(2) Glazing in place and cracked from impact forces
(3) Glazing in place and holed from impact forces
(4) Glazing out-of-place (cracked or not) and not holed from impact forces
(5) Glazing out-of-place and holed from impact forces
(6) Glazing disintegrated from impact forces
(7) Glazing removed prior to accident
(8) No glazing
(9) Unknown if damaged

Glazing Damage from Occupant Contact

23. WS __ 24. LF __ 25. RF __ 26. LR __ 27. RR __
28. BL __ 29. Roof __ 30. Other __

(0) No occupant contact to glazing or no glazing
(1) Glazing contacted by occupant but no glazing damage
(2) Glazing in place and cracked by occupant contact
(3) Glazing in place and holed by occupant contact
(4) Glazing out-of-place (cracked or not) by occupant contact and not holed by occupant contact
(5) Glazing out-of-place by occupant contact and holed by occupant contact
(6) Glazing disintegrated by occupant contact
(9) Unknown if contacted by occupant

If No Glazing Damage *And* No Occupant Contact or No Glazing, Then Code IV 31 Through IV 46 As 0

Type of Window/Windshield Glazing

31. WS __ 32. LF __ 33. RF __ 34. LR __ 35. RR __
36. BL __ 37. Roof __ 38. Other __

(0) No glazing contact and no damage, or no glazing
(1) AS-1 – Laminated
(2) AS-2 – Tempered
(3) AS-3 – Tempered-tinted
(4) AS-14 – Glass/Plastic
(8) Other (specify)

____

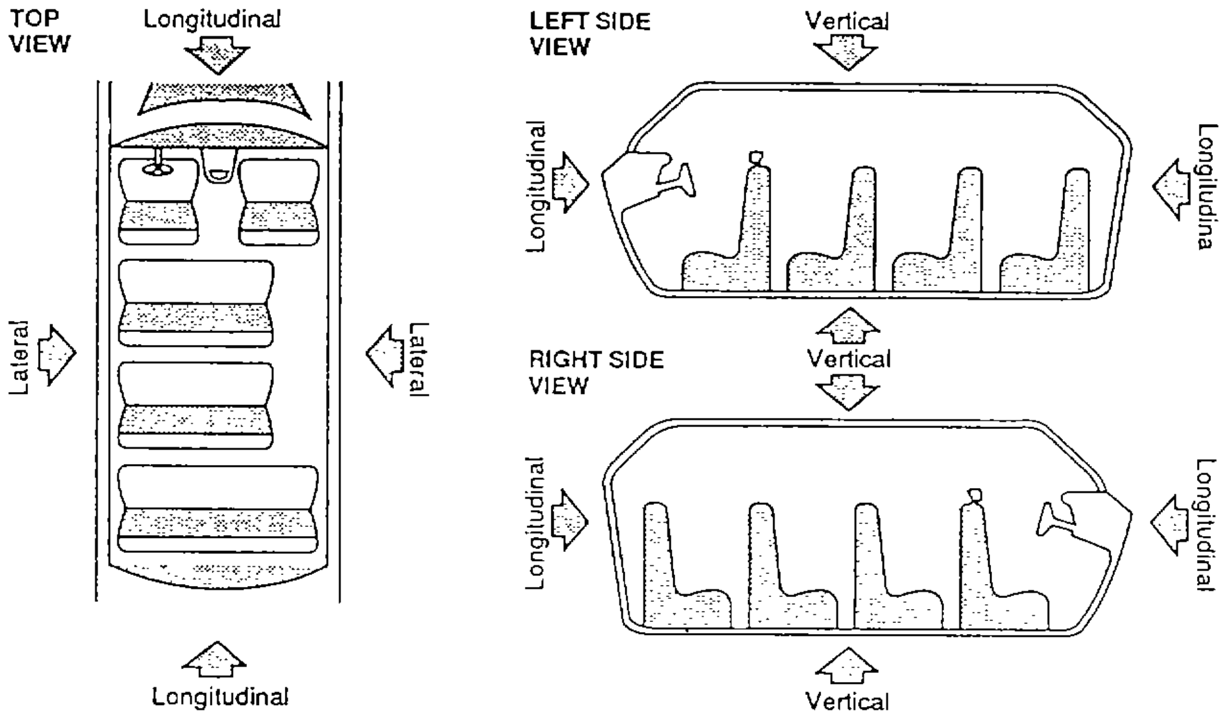
(9) Unknown

Window Precrash Glazing Status

39. WS __ 40. LF __ 41. RF __ 42. LR __ 43. RR __
44. BL __ 45. Roof __ 46. Other __

(0) No glazing contact and no damage, or no glazing
(1) Fixed
(2) Closed
(3) Partially opened
(4) Fully opened
(9) Unknown

INTRUSION WORK SHEET



INTRUDED COMPONENT	LOCATION OF INTRUSION	DOMINANT CRUSH DIRECTION	COMPARISON VALUE	–	INTRUDED VALUE	=	INTRUSION
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	
				–		=	

OCCUPANT AREA INTRUSION

Note: If no intrusions, leave variables IV 47-IV 86 blank.

	Location of Intrusion	Intruding Component	Magnitude of Intrusion	Dominant Crush Direction
1st	47.____	48.____	49.___	50.___
2nd	51.____	52.____	53.___	54.___
3rd	55.____	56.____	57.___	58.___
4th	59.____	60.____	61.___	62.___
5th	63.____	64.____	65.___	66.___
6th	67.____	68.____	69.___	70.___
7th	71.____	72.____	73.___	74.___
8th	75.____	76.____	77.___	78.___
9th	79.____	80.____	81.___	82.___
10th	83.____	84.____	85.___	86.___

LOCATION OF INTRUSION

Front Seat
- (11) Left
- (12) Middle
- (13) Right

Second Seat
- (21) Left
- (22) Middle
- (23) Right

Third Seat
- (31) Left
- (32) Middle
- (33) Right

Fourth Seat
- (41) Left
- (42) Middle
- (43) Right

(98) Other enclosed area (specify):

____

(99) Unknown

INTRUDING COMPONENT

Interior Components
- (01) Steering assembly
- (02) Instrument panel left
- (03) Instrument panel center
- (04) Instrument panel right
- (05) Toe pan
- (06) A-pillar
- (07) B-pillar
- (08) C-pillar
- (09) D-pillar
- (10) Door panel
- (11) Side panel/kickpanel
- (12) Roof (or convertible top)
- (13) Roof side rail
- (14) Windshield
- (15) Windshield header
- (16) Window frame
- (17) Floor pan
- (18) Backlight header
- (19) Front seat back
- (20) Second seat back
- (21) Third seat back
- (22) Fourth seat back
- (23) Fifth seat back
- (24) Seat cushion
- (25) Back panel or door surface
- (26) Other interior component (specify):

____

Exterior Components
- (30) Hood
- (31) Outside surface of vehicle (specify):

____

- (32) Other exterior object in the environment (specify): ____________
- (33) Unknown exterior object
- (98) Intrusion of unlisted component(s) (specify): ____________
- (99) Unknown

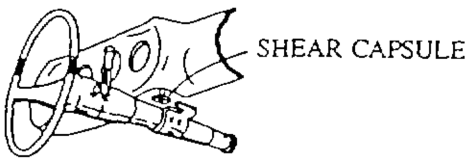
MAGNITUDE OF INTRUSION
- (1) ≥ 1 inch but < 3 inches
- (2) ≥ 3 inches but < 6 inches
- (3) ≥ 6 inches but < 12 inches
- (4) ≥ 12 inches but < 18 inches
- (5) ≥ 18 inches but < 24 inches
- (6) ≥ 24 inches
- (9) Unknown

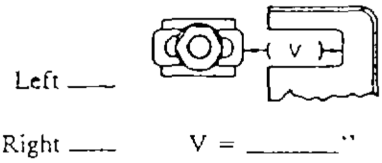
DOMINANT CRUSH DIRECTION
- (1) Vertical
- (2) Longitudinal
- (3) Lateral
- (9) Unknown

STEERING COLUMN WORKING DIAGRAMS

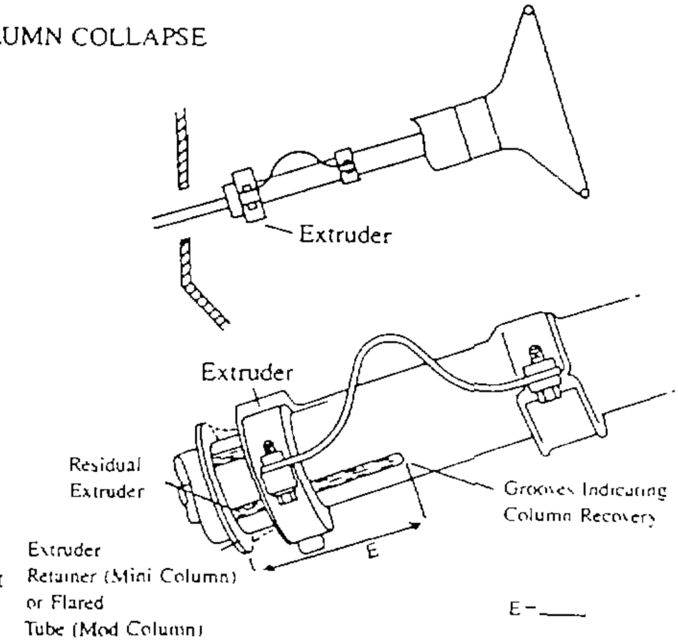
STEERING COLUMN COLLAPSE

Steering Column Shear Module Movement



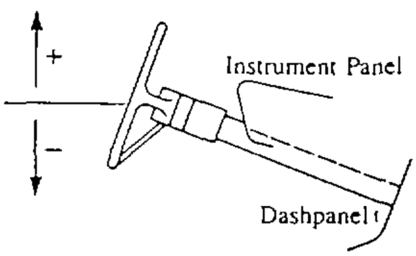


Direction and Magnitude of Steering Column Movement

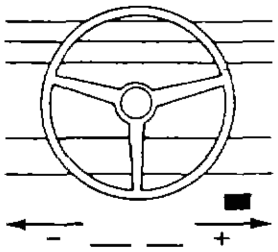


STEERING COLUMN MOVEMENT

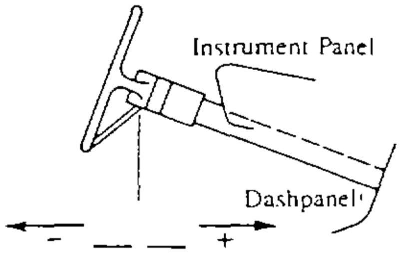
Vertical Movement



Lateral Movement



Longitudinal Movement



	COMPARISON VALUE	–	DAMAGED VALUE	=	MOVEMENT
VERTICAL		–		=	
LATERAL		–		=	
LONGITUDINAL		–		=	

STEERING RIM/SPOKE DEFORMATION

COMPARISON VALUE	–	DAMAGED VALUE	=	DEFORMATION
	–		=	
	–		=	

STEERING COLUMN

87. Steering Column Type ___
    (1) Fixed column
    (2) Tilt column
    (3) Telescoping column
    (4) Tilt and telescoping column
    (8) Other column type (specify):

    ____

    (9) Unknown

88. Steering Column Collapse Due to Occupant Loading ___ ___
    _____ Code actual measured movement to the nearest inch. See coding manual for measurement technique(s).
    (00) No movement, compression, or collapse
    (01-49) Actual measured value
    (50) 50 inches or greater

    Estimated movement from observation
    (81) Less than 1 inch
    (82) ≥ 1 inch but < 2 inches
    (83) ≥ 2 inches but < 4 inches
    (84) ≥ 4 inches but < 6 inches
    (85) ≥ 6 inches but < 8 inches
    (86) Greater than or equal to 8 inches

    (97) Apparent movement, value undetermined or cannot be measured or estimated
    (98) Nonspecified type column
    (99) Unknown

Direction And Magnitude of Steering Column Movement

89. Vertical Movement ± ___ ___ ___

90. Lateral Movement ± ___ ___ ___

91. Longitudinal Movement ± ___ ___ ___
    Code the actual measured movement to the nearest inch. See Coding Manual for measurement technique(s)
    (−00) No Steering column movement
    (±01 − ±49) Actual measured value
    (±50) 50 inches or greater

    Estimated movement from observation
    (±81) ≥ 1 inch but < 3 inches
    (±82) ≥ 3 inches but < 6 inches
    (±83) ≥ 6 inches but < 12 inches
    (±84) ≥ 12 inches

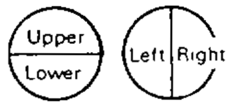
    (__97) Apparent movement > 1 inch but cannot be measured or estimated
    (__99) Unknown

92. Steering Rim/Spoke Deformation ___
    _____ Code actual measured deformation to the nearest inch.
    (0) No steering rim deformation
    (1-5) Actual measured value
    (6) 6 inches or more
    (8) Observed deformation cannot be measured
    (9) Unknown

93. Location of Steering Rim/Spoke Deformation ___ ___
    (00) No steering rim deformation

    Quarter Sections
    (01) Section A
    (02) Section B
    (03) Section C
    (04) Section D

    Half Sections
    (05) Upper half of rim/spoke
    (06) Lower half of rim/spoke
    (07) Left half of rim/spoke
    (08) Right half of rim/spoke



    (09) Complete steering wheel collapse
    (10) Undetermined location
    (99) Unknown

INSTRUMENT PANEL

94. Odometer Reading ___ ___ ___,000
    _______ miles—Code mileage to the nearest 1,000 miles
    (000) No odometer
    (001) Less than 1,500 miles
    (300) 299,500 miles or more
    (999) Unknown

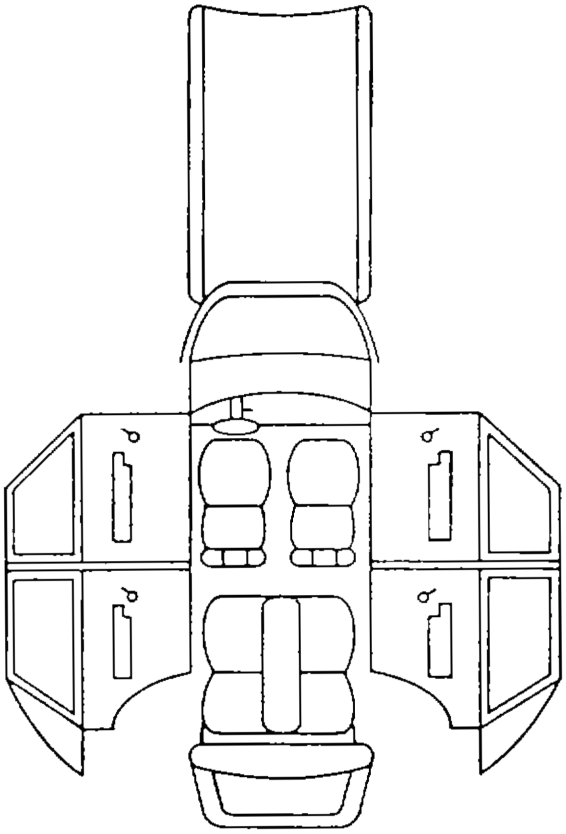
    Source:______________________

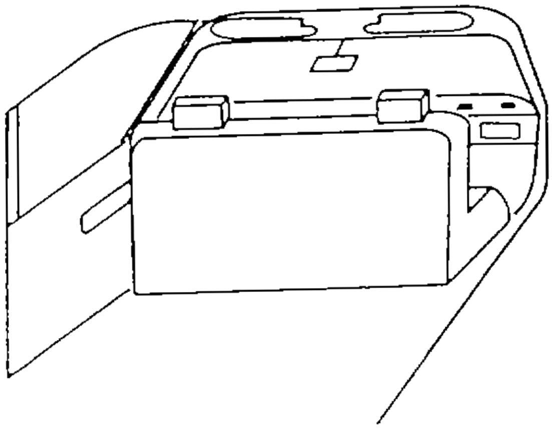
95. Instrument Panel Damage from Occupant Contact ___
    (0) No
    (1) Yes
    (9) Unknown

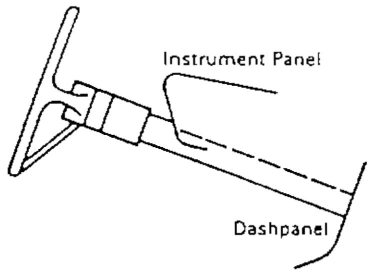
96. Knee Bolsters Deformed from Occupant Contact ___
    (0) No
    (1) Yes
    (8) Not present
    (9) Unknown

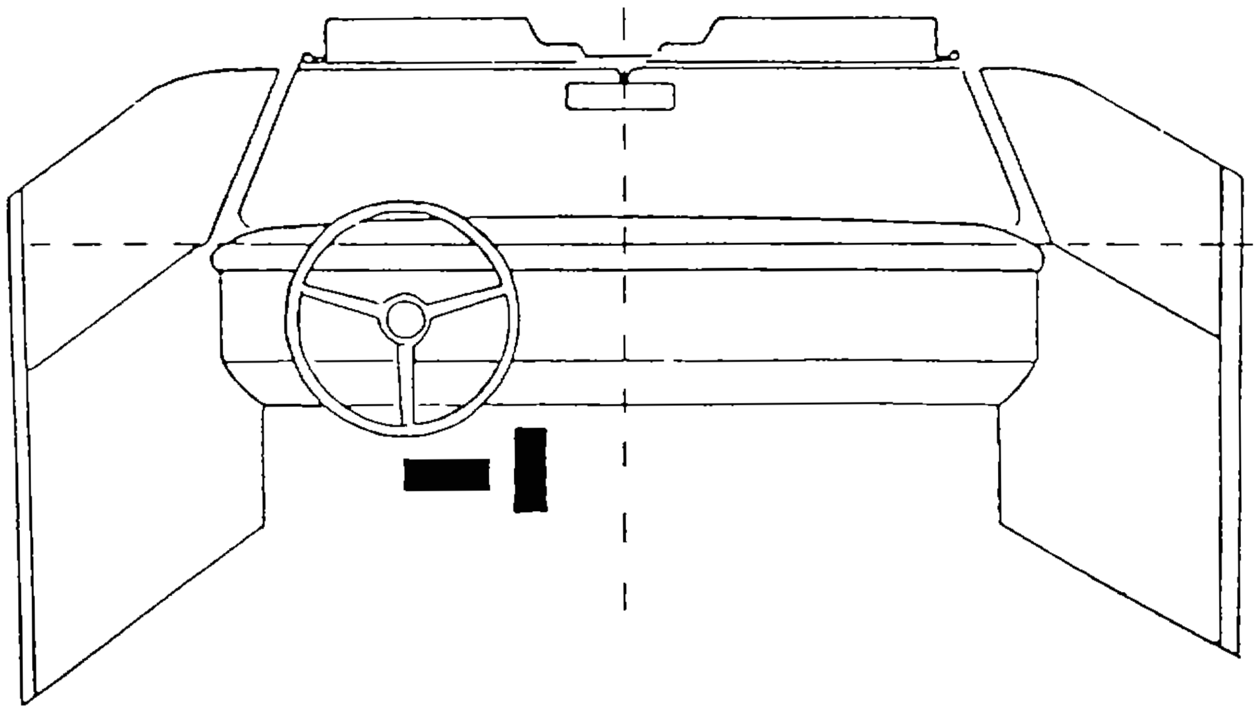
97. Did Glove Compartment Door Open During Collision(s) ___
    (0) No
    (1) Yes
    (8) Not present
    (9) Unknown

VEHICLE INTERIOR SKETCHES









National Accident Sampling System – Crashworthiness Data System. Interior Vehicle Form

POINTS OF OCCUPANT CONTACT

Contact	Interior Component Contacted	Occupant No. If Known	Body Region If Known	Supporting Physical Evidence	Confidence Level of Contact Point
A					
B					
C					
D					
E					
F					
G					
H					
I					
J					
K					
L					
M					
N					

CODES FOR INTERIOR COMPONENTS

FRONT
- (01) Windshield
- (02) Mirror
- (03) Sunvisor
- (04) Steering wheel rim
- (05) Steering wheel hub/spoke
- (06) Steering wheel (combination of codes 04 and 05)
- (07) Steering column, transmission selector lever, other attachment
- (08) Add on equipment (e.g., CB, tape deck, air conditioner)
- (09) Left instrument panel and below
- (10) Center instrument panel and below
- (11) Right instrument panel and below
- (12) Glove compartment door
- (13) Knee bolster
- (14) Windshield including one or more of the following, front header, A-pillar, instrument panel, mirror,or steering assembly (driver side only)
- (15) Windshield including one or more of the following: front header, A-pillar, instrument panel, or mirror (passenger side only)
- (16) Other front object (specify): ____________

LEFT SIDE
- (20) Left side interior surface, excluding hardware or armrests
- (21) Left side hardware or armrest
- (22) Left A pillar
- (23) Left B pillar
- (24) Other left pillar (specify): ____________
- (25) Left side window glass or frame
- (26) Left side window glass including one or more of the following: frame, window sill, A-pillar, B-pillar, or roof side rail
- (27) Other left side object (specify) ____________

RIGHT SIDE
- (30) Right side interior surface, excluding hardware or armrests
- (31) Right side hardware or armrest
- (32) Right A pillar
- (33) Right B pillar
- (34) Other right pillar (specify): ____________
- (35) Right side window glass or frame
- (36) Right side window glass including one or more of the following frame, window sill, A-pillar, B-pillar, or roof side rail
- (37) Other right side object (specify) ____________

INTERIOR
- (40) Seat, back support
- (41) Belt restraint webbing/buckle
- (42) Belt restraint B-pillar attachment point
- (43) Other restraint system component (specify): ____________
- (44) Head restraint system
- (45) Air cushion
- (46) Other occupants (specify): ____________
- (47) Interior loose objects
- (48) Child safety seat (specify): ____________
- (49) Other interior object (specify): ____________

ROOF
- (50) Front header
- (51) Rear header
- (52) Roof left side rail
- (53) Roof right side rail
- (54) Roof or convertible top

FLOOR
- (56) Floor including toe pan
- (57) Floor or console mounted transmission lever, including console
- (58) Parking brake handle
- (59) *Foot controls including parking brake

REAR
- (60) Backlight (rear window)
- (61) Backlight storage rack, door, etc.
- (62) Other rear object (specify): ____________

CONFIDENCE LEVEL OF CONTACT POINT
- (1) Certain
- (2) Probable
- (3) Possible
- (4) Unknown

AUTOMATIC RESTRAINTS

NOTES: Encode the data for each applicable front seat position. The attributes for the variables may be found below. Restraint systems should be assessed during the vehicle inspection then coded on the Occupant Assessment Form.

		Left	Center	Right
F I R S T	Availability			
	Function			
	Failure			

Automatic (Passive) Restraint System Availability

(0) Not equipped/not available
(1) Airbag
(2) Airbag disconnected (specify): ______________________
(3) Airbag not reinstalled
(4) 2 point automatic belts
(5) 3 point automatic belts
(6) Automatic belts destroyed or rendered inoperative
(9) Unknown

Automatic (Passive) Restraint Function

(0) Not equipped/not available

Automatic Belt
(1) Automatic belt in use
(2) Automatic belt not in use
(3) Automatic belt use unknown

Air Bag
(4) Airbag deployed during accident
(5) Airbag deployed inadvertently just prior to accident
(6) Deployed, accident sequence undetermined
(7) Nondeployed
(8) Unknown if deployed
(9) Unknown

Did Automatic (Passive) Restraint Fail

(0) Not equipped/not available
(1) No
(2) Yes (specify): ______________________
(9) Unknown

MANUAL RESTRAINTS

NOTES: Encode the applicable data for **each seat position** in the vehicle. The attributes for the variables may be found below. Restraint systems should be assessed during the vehicle inspection then coded on the Occupant Assessment Form.

If a child safety seat is present, encode the data on the back of this page.

If the vehicle has automatic *restraints available, encode the appropriate* data on the back of the previous page.

		Left	Center	Right
FIRST	Availability			
	Use			
	Failure Modes			
SECOND	Availability			
	Use			
	Failure Modes			
THIRD	Availability			
	Use			
	Failure Modes			
OTHER	Availability			
	Use			
	Failure Modes			

Manual (Active) Belt System Availability

(0) Not available
(1) Belt removed/destroyed
(2) Shoulder belt
(3) Lap belt
(4) Lap and shoulder belt
(5) Belt available – type unknown
(8) Other belt (specify):

____

(9) Unknown

Manual (Active) Belt System Use

(00) None used, not available, or belt removed/destroyed
(01) Inoperative (specify):

____

(02) Shoulder belt
(03) Lap belt
(04) Lap and shoulder belt
(05) Belt used – *type unknown*

____

(08) Other belt used (specify):

____

(12) Shoulder belt used with child safety seat
(13) Lap belt used with child safety seat
(14) Lap and shoulder belt used with child safety seat
(15) Belt used with child safety seat – type unknown
(18) Other belt used with child safety seat (specify):

____

(99) Unknown if belt used

Manual (Active) Belt Failure Modes During Accident

(0) No manual belt used or not available
(1) No manual belt failure(s)
(2) Manual belt failure(s) (encode all that apply above)
[A] Torn webbing (stretched webbing not included)
[B] Broken buckle or latchplate
[C] Upper anchorage separated
[D] *Other achorage separated (specify):*

____

[E] Broken retractor
[F] Other manual belt failure (specify):

____

(9) *Unknown*

CHILD SAFETY SEAT FIELD ASSESSMENT

When a child safety seat is present enter the occupant's number in the first row and complete the column below the occupant's number using the codes listed below. Complete a column for each child safety seat present.

Occupant Number						
1. Type of Child Safety Seat						
2. Child Safety Seat Orientation						
3. Child Safety Seat Harness Usage						
4. Child Safety Seat Shield Usage						
5. Child Safety Seat Tether Usage						
6. Child Safety Seat Make/Model	Specify Below for Each Child Safety Seat					

1. Type of Child Safety Seat

(0) No child safety seat
(1) Infant seat
(2) Toddler seat
(3) Convertible seat
(4) Booster seat
(7) Other type child safety seat (specify):

____

(8) Unknown child safety seat type
(9) Unknown if child safety seat used

2. Child Safety Seat Orientation

(00) No child safety seat

Designed for Rear Facing for This Age/Weight
(01) Rear facing
(02) Forward facing
(03) Other orientation (specify):

____

(04) Unknown orientation

Designed for Forward Facing for This Age/Weight
(11) Rear facing
(12) Forward facing
(18) Other orientation (specify):

____

(19) Unknown orientation

Unknown Design or Orientation for This Age/Weight, or Unknown Age/Weight
(21) Rear facing
(22) Forward facing
(28) Other orientation (specify):

____

(29) Unknown orientation

(99) Unknown if child safety seat used

3. Child Safety Seat Harness Usage

4. Child Safety Seat Shield Usage

5. Child Safety Seat Tether Usage

Note: Options Below Are Used for Variables 3-5

(00) No child safety seat

Not Designed with Harness/Shield/Tether
(01) After market harness/shield/tether added, not used
(02) After market harness/shield/tether used
(03) Child safety seat used, but no after market harness/shield/tether added
(09) Unknown if harness/shield/tether added or used

Designed with Harness/Shield/Tether
(11) Harness/shield/tether not used
(12) Harness/shield/tether used
(19) Unknown if harness/shield/tether used

Unknown if Designed with Harness/Shield/Tether
(21) Harness/shield/tether not used
(22) Harness/shield/tether used
(29) Unknown if harness/shield/tether used

(99) Unknown if child safety seat used

6. Child Safety Seat Make/Model
(Specify make/model and occupant number)

____

____

____

____

HEAD RESTRAINTS/SEAT EVALUATION

NOTES: Encode the applicable data for **each seat position** in the vehicle. The attributes for these variables may be found at the bottom of the page. Head restraint type/damage and seat type/performance should be assessed during the vehicle inspection then coded on the Occupant Assessment Form.

		Left	Center	Right
FIRST	Head Restraint Type/Damage			
	Seat Type			
	Seat Performance			
SECOND	Head Restraint Type/Damage			
	Seat Type			
	Seat Performance			
THIRD	Head Restraint Type/Damage			
	Seat Type			
	Seat Performance			
OTHER	Head Restraint Type/Damage			
	Seat Type			
	Seat Performance			

Head Restraint Type/Damage by Occupant at This Occupant Position

(0) No head restraints
(1) Integral – no damage
(2) Integral – damaged during accident
(3) Adjustable – no damage
(4) Adjustable – damaged during accident
(5) Add-on – no damage
(6) Add-on – damaged during accident
(8) Other (specify): ____________
(9) Unknown

Seat Type (This Occupant Position)

(00) Occupant not seated or no seat
(01) Bucket
(02) Bucket with folding back
(03) Bench
(04) Bench with separate back cushions
(05) Bench with folding back(s)
(06) Split bench with separate back cushions
(07) Split bench with folding back(s)
(08) Pedestal (i.e., van type)
(09) Other seat type (specify): ____________
(99) Unknown

Seat Performance (This Occupant Position)

(0) Occupant not seated or no seat
(1) No seat performance failure(s)

(2) Seat performance failure(s)
(Encode all that apply)

[A] Seat adjusters failed
[B] Seat back folding locks failed
[C] Seat tracks failed
[D] Seat anchors failed
[E] Deformed by impact of passenger from rear
[F] Deformed by impact of passenger from front
[G] Deformed by own inertial forces
[H] Deformed by passenger compartment intrusion (specify):
____
____
____

[I] Other (specify): ____________
____

(9) Unknown

DESCRIBE ANY INDICATION OF ABNORMAL OCCUPANT POSTURE (I.E. UNUSUAL OCCUPANT CONTACT PATTERN)

____
____
____

EJECTION/ENTRAPMENT DATA

Complete the following if the researcher has any indications that an occupant was either ejected from or entrapped in the vehicle. Code the appropriate data on the Occupant Assessment Form.

EJECTION No [ ] Yes [ ]

Describe indications of ejection and body parts involved in partial ejection(s):

Occupant Number						
Ejection						
Ejection Area						
Ejection Medium						
Medium Status						

Ejection
- (1) Complete ejection
- (2) Partial ejection
- (3) Ejection, unknown degree
- (9) Unknown

Ejection Area
- (1) Windshield
- (2) Left front
- (3) Right front
- (4) Left rear
- (5) Right rear
- (6) Rear
- (7) Roof
- (8) Other area (e.g., back of pickup, etc.) (specify):
- (9) Unknown

Ejection Medium
- (1) Door/hatch/tailgate
- (2) Nonfixed roof structure
- (3) Fixed glazing
- (4) Nonfixed glazing (specify):
- (5) Integral structure
- (8) Other medium (specify):
- (9) Unknown

Medium Status (Immediately Prior to Impact)
- (1) Open
- (2) Closed
- (3) Integral structure
- (9) Unknown

ENTRAPMENT No [ ] Yes [ ]

Describe entrapment mechanism:

Component(s):

(Note in vehicle interior diagram)

US Department of Transportation
National Highway Traffic Safety Administration

NATIONAL ACCIDENT SAMPLING SYSTEM
CRASHWORTHINESS DATA SYSTEM

CRASHPC PROGRAM SUMMARY

Identifying Title

___ ___	___ ___ ___ ___	___ ___	___ ___ ___ ___ ___ ___
Primary Sampling Unit	Case No.—Stratum	Accident Event Sequence No.	Date (mm dd yy)

CRASHPC Vehicle Identification

	Year	Make	Model	NASS Veh. No.
Vehicle 1	______	______	______	______
Vehicle 2	______	______	______	______

GENERAL INFORMATION

VEHICLE 1

Size ___

Weight ______ + ______ + ______ = ___ ___ ___ ___
Curb Occupant(s) Cargo

CDC ___ ___ ___ ___ ___ ___ ___

PDOF ___ ___ ___

Stiffness ___

VEHICLE 2

Size ___

Weight ______ + ______ + ______ = ___ ___ ___ ___
Curb Occupant(s) Cargo

CDC ___ ___ ___ ___ ___ ___ ___

PDOF ___ ___ ___

Stiffness ___

SCENE INFORMATION

Rest and Impact Positions [ ] No, *Go To Damage Information* [ ] Yes

VEHICLE 1

Rest Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Impact Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Slip Angle ___ ___ ___

VEHICLE 2

Rest Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Impact Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Slip Angle ___ ___ ___

VEHICLE MOTION

Sustained Contact [ ] No [ ] Yes

VEHICLE 1

Skidding [ ] No [ ] Yes
Skidding Stop Before Rest [ ] No [ ] Yes
End-of-Skidding Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Curved Path [ ] No [ ] Yes
Point on Path
X ___ ___ ___ . ___ Y ___ ___ ___ . ___

Rotation Direction [ ] None [ ] CW [ ]CCW
Rotation > 360° [ ] No [ ] Yes

VEHICLE 2

Skidding [ ] No [ ] Yes
Skidding Stop Before Rest [ ] No [ ] Yes
End-of-Skidding Position
- X ___ ___ ___ . ___
- Y ___ ___ ___ . ___
- PSI ___ ___ ___ . ___

Curved Path [ ] No [ ] Yes
Point on Path
X ___ ___ ___ . ___ Y ___ ___ ___ . ___

Rotation Direction [ ] None [ ] CW [ ]CCW
Rotation > 360° [ ] No [ ] Yes

FRICTION INFORMATION

Coefficient of Friction . ___ ___ ___

Rolling Resistance Option ___

Vehicle 1 Rolling Resistance

LF ___ . ___ ___ RF ___ . ___ ___

LR ___ . ___ ___ RR ___ . ___ ___

Vehicle 2 Rolling Resistance

LF ___ . ___ ___ RF ___ . ___ ___

LR ___ . ___ ___ RR ___ . ___ ___

TRAJECTORY INFORMATION

Trajectory Data [ ] No [ ] Yes

If No, Go To Damage Information

Vehicle 1 Steer Angles

LF ___ ___ ___ RF ___ ___ ___

LR ___ ___ ___ RR ___ ___ ___

Vehicle 2 Steer Angles

LF ___ ___ ___ RF ___ ___ ___

LR ___ ___ ___ RR ___ ___ ___

Terrain Boundary [ ] No [ ] Yes

First Point

X ___ ___ ___ . ___ Y ___ ___ ___ . ___

Second Point

X ___ ___ ___ . ___ Y ___ ___ ___ . ___

Secondary Friction Coefficient . ___ ___ ___

DAMAGE INFORMATION

	VEHICLE 1		VEHICLE 2
Damage Length	___ ___ ___ . ___ ___	Damage Length	___ ___ ___ . ___ ___
Crush Depths	C1 ___ ___ . ___ ___	Crush Depths	C1 ___ ___ . ___ ___
	C2 ___ ___ . ___ ___		C2 ___ ___ . ___ ___
	C3 ___ ___ . ___ ___		C3 ___ ___ . ___ ___
	C4 ___ ___ . ___ ___		C4 ___ ___ . ___ ___
	C5 ___ ___ . ___ ___		C5 ___ ___ . ___ ___
	C6 ___ ___ . ___ ___		C6 ___ ___ . ___ ___
Damage Offset	± ___ ___ ___ . ___ ___	Damage Offset	± ___ ___ ___ . ___ ___

IF THIS COMMON IMPACT WAS WITH A MOTOR VEHICLE *NOT IN TRANSPORT*, FILL IN THE INFORMATION BELOW.

Model Year: ______________________

Make: ______________________

Model: ______________________

VIN: ______________________

The Weight, CDC, Scene Data and Damage Information for this vehicle should be recorded above.

Complete and ATTACH the appropriate vehicle damage sketch and dimensions to the Form.

29. Basis for Total Delta V (Highest) ___

Delta V Calculated
(1) CRASH program—damage only routine
(2) CRASH program—damage and trajectory routine
(3) Missing vehicle algorithm

Delta V Not Calculated
(4) At least one vehicle (which may be this vehicle) is beyond the scope of an acceptable reconstruction program, regardless of collision conditions.

(5) All vehicles within scope (CDC applicable) of CRASH program but one of the collision conditions is beyond the scope of the CRASH program or other acceptable reconstruction techniques, regardless of adequacy of damage data.

(6) All vehicle and collision conditions are within scope of one of the acceptable reconstruction programs, but there is insufficient data available.

COMPUTER GENERATED DELTA V

Secondary Highest

30. Total Delta V ___ ___

___ Nearest mph ___

(NOTE: 00 means less than 0.5 mph)
(97) 96.5 mph and above
(99) Unknown

31. Longitudinal Component of Delta V ± ___ ___

___ Nearest mph ___

(NOTE: __00 means greater than −0.5 and less than +0.5 mph)
(±97) ±96.5 mph and above
(__ 99) Unknown

Secondary Highest

32. Lateral Component of Delta V ± ___ ___

___ Nearest mph ___

(NOTE: __00 means greater than −0.5 and less than +0.5 mph)
(±97) ±96.5 mph and above
(__ 99) Unknown

33. Energy Absorption ___ ___ ___, ___ 0 0

___ Nearest 100 foot-lbs ___

(NOTE: 0000 means less than 50 Foot-Lbs)
(9997) 999,650 foot-lbs or more
(9999) Unknown

34. Confidence in Reconstruction Program Results (for Highest Delta V) ___
(0) No reconstruction
(1) Collision fits model—results appear reasonable
(2) Collision fits model—results appear high
(3) Collision fits model—results appear low
(4) Borderline reconstruction—results appear reasonable

35. Type of Vehicle Inspection ___
(0) No Inspection
(1) Complete inspection
(2) Partial inspection (specify): ______________________

*** STOP HERE IF THE CDS APPLICABLE ***
VEHICLE WAS NOT INSPECTED

Attachment 3

Details of Inspection Procedure

INSPECTION PROCEDURE FOR CRASHED VEHICLES

The inspection procedure for crashed vehicles divides naturally into six stages: (1) fully identifying and specifying the damaged vehicle, (2) describing the exterior body damage, (3) describing the interior (passenger compartment) damage, (4) reconstructing the injury mechanism, (5) compiling a photographic record, and (6) establishing a computer database for analysis.

1. IDENTIFICATION

The vehicle type is specified (a) by reference to its external badges, number plates, compliance plate, manufacturer's plate, emission control label, chassis number and registration label and (b) by direct observation of the car body, engine, undercarriage and interior.

2. EXTERIOR DAMAGE

Observations on the state of the doors and windows are generally routine. The two main types of glass (laminated and toughened) shatter differently, the fracture pattern thereby enabling identification. The setting of a broken side-window at impact (open or closed) is indicated by glass fragments left around the window frame and by the location of the winder mechanism within the door. Laminated glass normally reveals by its fracture pattern whether it was broken by deformation of its frame or by point contact (eg. a head or hand); in the case of toughened glass it is sometimes necessary to search for hair or skin fragments around the window frame, or other forensic evidence, to help assign the cause of damage.

The main aims of the remaining external damage observations are to record (a) the direction and area of application of the impact force and (b) the change in shape ('crush') of the crashed vehicle, especially as would be seen from overhead.

The region of direct contact, such as metal-to-metal contact between two cars, is usually indicated by the extent of crush, by sharp changes of shape of metallic components, by the relatively fine-grained texture of surface damage (eg. to sheet metal panels), and similar considerations.

The direction of the force applied to the vehicle during impact is often reflected in the residual deformation of structural components within the region of direct contact. In the case of an offset frontal, for example, the front corner making metal-to-metal contact with the other car may be crushed (a) directly back, or (b) back and into the engine compartment, or (c) back and to the outside of the original body line. Similarly, in the case of a side collision centred on the passenger compartment, the B-pillar may be pushed directly across the car, or across the car with a component of deformation to either the front or the back. This type of observation provides a physical basis for the assignment of the impact force direction to the clockface (ie. to the nearest 30 deg.). Scratch lines, the overall shape of body crush and various other discernible features may also be useful, however this assessment always requires an element of judgment and an awareness of numerous complexities.

The change in shape from original of the crashed vehicle is sketched and measured. The sketches are made over diagrams of a generic sedan viewed from its four sides and overhead. These sketches routinely include the vehicle's post-crash shape, the area of direct contact and direction of force, sheet metal buckling, secondary impacts, car body bowing, parts of the vehicle cut, damaged or removed after the crash, scratch lines, and notes relevant to the crash sequence or to the interpretation of the photographic record.

The crash damage measurements are intended in part to provide input to the CRASH3 program for calculating DELTA-V - the vehicle's change of velocity during impact (NHTSA 1986). This influences the measurement procedure and format in which the data is recorded. A typical case might run as follows:-

The car has suffered frontal damage. A horizontal 2m pole supported on two uprights is aligned with the undamaged rear bumper to serve as a zero reference line. A 5m measuring tape is laid on the ground alongside the car extending from the rear bumper line to (beyond) the front bumper. Readings are then taken of the rear axle-line, front axle-line and the front bumper corner. The original position of the front bumper is also marked off on the ground at this stage, this specification length having been determined from reference texts carried on site. Since the damage is severe, readings are also taken of the A, B and C pillars, the dashboard corner and the steering wheel hub in order to help subsequent estimates of interior damage and injury mechanisms. All the measurements on each side are taken without moving the tape, making it a one-person operation and minimizing measurement uncertainty.

The three-piece frame is then moved from the rear of the car to the original front bumper position, to serve now as a zero reference line for front-end crush. The crush profile is recorded by six measurements taken at equal distances (left to right) along the deformed surface of the car (i.e. crush is measured at six points along the car that were equally spaced before the accident). The crush profile is completed by recording the width of the overall damage field and of the direct contact sub-field, and by locating these fields within the damaged side - in this case the front end of the car. These measures again refer to pre-crash or original lengths. For example, if the front-end has been reduced to 80% of its original width and wholly damaged as a result of wrapping around a pole, the damage field is recorded as the original width. Sometimes this means that reference has to be made to similar undamaged cars, to an undamaged section of the same car, or to original specifications.

Finally, the damage is coded according to the Collision Deformation Classification (SAE J224 MAR80).

The procedure for a side collision varies slightly from the frontal case. The zero reference line for the measurement of crush is generally directly marked off by string or a 2m pole placed across the field of damage and aligned at its ends to undamaged sections of the car surface. For example, a damaged vehicle that had taken impact to its left doors might have its crush profile taken relative to a string attached or aligned to the left side A and C pillars. This method largely avoids the incorporation of the body structure 'bowing' into the crush profile.

The case of a rollover or of other non-two-dimensional impact cannot be analysed by the CRASH3 model, so measurements are made as the case dictates, with the aim of having as accurate passenger compartment intrusion information as possible.

3. INTERIOR DAMAGE

A main aim of the internal damage observations is to record the change of shape and intrusions into the passenger compartment. Sketches are drawn over printed diagrams of various views of a generic passenger compartment. These sketches routinely include (i) outlines of the vehicle's internal shape at mid, lower and upper sections, (ii) identification of intruding components and the magnitude and direction of the extent of intrusion, (iii) steering wheel movement, (iv) components cut, damaged or removed after impact, and (v) notes on items of special interest or importance. Intrusion magnitudes (and other movements) are usually estimated on site, using a tape measure, by either judging original positions or by comparing measurements with a similar undamaged car or an undamaged section of the same car.

Special attention is given during the internal damage inspection to the steering assembly, seats and seat belts. Beyond a routine description of these components (tilt column, bucket seats, retractable belts etc.) the seats and seat belts are checked for mechanical or performance failure, and both the movement of the steering column relative to its mount at the dashboard and the deformation of the steering wheel rim are measured.

One important task is to ascertain whether the seatbelts in the car were in use during the accident. A belt system that has been loaded can leave a variety of signs:

- The surfaces of the tongue (latchplate) touching the webbing often appear to be scratched or abraded in a manner never occurring by normal wear and tear. This sign varies from being barely discernible under magnification to being grossly visible at a cursory glance.
- Similar damage may be observed on the D-ring typically mounted on the upper B-pillar.
- The webbing which in use lies in the vicinity of the D-ring or tongue may be marked by scummy deposits, by discolouration, by a change in surface texture and reflectivity due to fibre flattening or abrasion, or by fibre damage as if by the generation of surface heat.
- The interior trim down the B-pillar may be fractured or dislodged by the tightening and straightening of the webbing directed from the D-ring to the retractor.
- Other components may be damaged by loading of the seat belt system, including the latch and surrounding parts, and the webbing and surrounding parts in the vicinity of the lower outboard anchor.
- Blood and glass fragments or similar may be present over the full length of the webbing (or over only that part of the webbing that is exposed while fully retracted).

Occasionally useful circumstantial evidence is available, for example, the webbing may have beencut during rescue, indicating that the rescue team found it in use.

Sometimes the crash forces on a belt system are not sufficient to leave any discernible signs. In practice this means that it is generally easier to prove (by inspection) that a belt was worn than to prove that it was not.

4. INJURY MECHANISM

The final part of the vehicle inspection involves reconstructing how the occupant's injuries occurred.

Normal practice is to obtain the injury details before conducting the inspection. This gives focus to the examination, enabling maximum confidence in the reconstruction to be built up in minimum time. The signs of occupant contact can be extremely subtle and the mechanisms of injury can be elusive or complex - it helps to know whether one is searching for the explanation of a broken nose or of a broken ankle!

As an initial working assumption, the direction of the occupant's inertial movement relative to the vehicle during the accident sequence may be assumed to be opposite to the direction of the applied impact force. Given the occupant's seating position and likelihood of seat belt use, this suggests where to look for signs of contact; in the case of a left side impact, for example, one searches initially to the left of the injured occupant. A simple aid to gaining some feel for the situation is to sit in the same position as the patient - if possible with the seat belt tensioned by the body to its position at full load.

Signs of occupant contact vary greatly: clothing fibres, strands of hair and flakes of skin can be found on the contacted components; movement, damage or deformation of components around the car interior may be plainly due to forces originating from within the car and acting oppositely to the direction of the impact force; intrusion may be so great as to make contact inevitable; component surfaces may be smeared, brushed, discoloured or abraded by the contact.

Notes on the signs of occupant contact are recorded over diagrams of a generic vehicle interior, with the emphasis heavily on injury-causing contacts. A judgment of confidence level is also assigned to each suggested contact point.

In the absence of specific evidence, a degree of inference can be involved in the assignment of injury-causing contact points. For example, an unbelted driver might be known to have hit his head on the windscreen and his knees on the lower dash; his bilateral rib fractures are then plausibly attributed to steering wheel contact, even though no forensic evidence or rim deformation is apparent. This type of judgment, to a greater or lesser degree, runs through the reconstruction of how some injuries occur.

One situation of particular difficulty and frequency is the case of a belted driver suffering sternum or rib fractures. It is not always easy to distinguish seat belt pressure from steering wheel contact as the injuring force. Routine procedure in this case, if possible, is to line up the belt webbing into its position of full load (as described above) and to measure the distance from the sternum to the steering wheel hub. If appropriate, placing one's knees into a shattered lower dashboard and stretching one's head toward a point of known contact gives some impression of the likelihood of steering wheel contact, always bearing in mind the probable role of webbing stretch, elastic rebound of the steering assembly, occupant's height and weight, and various other considerations. It may be most plausible, in this and several other common situations, to attribute the injury to a combination of forces.

There are normally more injuries that injury-causing contact points. It saves time at inspection to have already grouped the injuries according to their likely common cause. The broken nose, cut lip, chipped tooth and fractured jaw, for example, probably arose in the same way. These injury groups are transcribed from the hospital report onto a page bearing several views of the human body; explanatory notes on the origin and application of forces on the body likely to have generated these injuries are then made as part of the inspection process.

5. PHOTOGRAPHIC RECORD

After the field notes are completed, around twenty to thirty photographs are taken of the crashed vehicle. An unexceptional case has a rough balance between interior and exterior shots - unusual or interesting features naturally draw special attention.

6. COMPUTER RECORD

Much of the information gathered from the patient interview, injury description and vehicle inspection is converted to (mostly) numeric code, generating about 650-1000 characters on computer for each occupant (depending on the number of injuries). Information such as name, address and registration number are specifically not included to protect confidentiality. The code is mostly derived from the NASS format (NHTSA 1989).

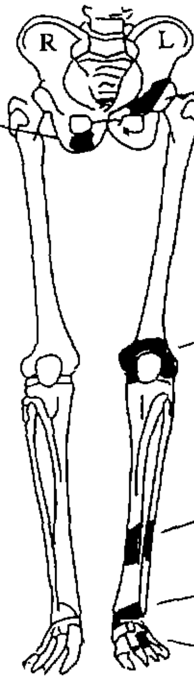
The CRASH3 program is used to compute impact velocity from residual crush measurements. Statistical analysis is undertaken on SPSS software.

Attachment 4

Lower Limb Injury Summary Sheet

CASE D102-1 FRONT PASSENGER

Lower Limb Injuries



Notes

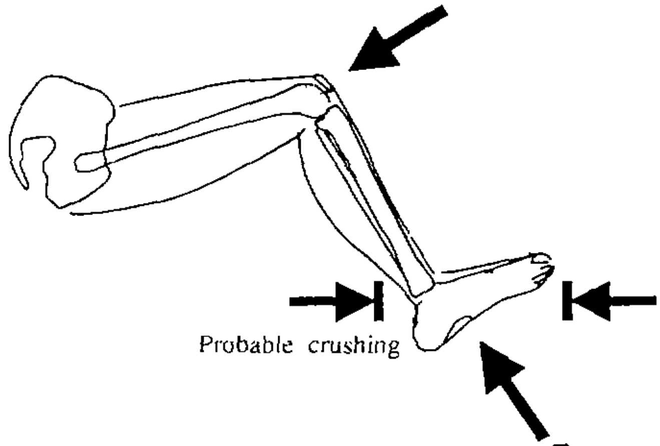
Ambulance report stated that patient's door was pushed in substantially and that patient was trapped with legs pushed towards transmission tunnel.

Toepan, dash and firewall intruded to front of seat cushion presenting a vertical wall of metal to the lower limbs.

Thigh injury is from heavy knee contact against the dash and firewall. The pelvic fractures probably resulted primarily from forces transmitted through the thigh although direct contact with the door may have contributed.

Foot fractures are consistent with the application of static crushing forces, the exact nature of which is unclear. The left foot was probably jammed between toepan metal and the seat base.

Tibia and fibula shaft fractures could have resulted either from a dynamic compressive force on the leg by contacts at the knee and foot or else by crushing forces after deformation of the toepan.



Mechanism of Injury	Possible Instrumentation
Compression of thigh (knee loading)	Strain gauge on femur/ Knee load cell
Compression of lower leg	Strain gauge on lower leg
Crushing of foot	Load cells on foot/ Deformable foot