HEAD AND NECK INJURIES IN ROAD ACCIDENTS

**Proceedings of a symposium held at The University of Adelaide
South Australia, 10—11 December 1985**

**NH & MRC ROAD ACCIDENT RESEARCH UNIT
THE UNIVERSITY OF ADELAIDE**

SYMPOSIUM THEME: The occurrence, mechanisms and prevention of head and neck injury due to road accidents.

INFORMATION RETRIEVAL

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KEYWORDS : accident/adult/brain/cervical vertebrae/child/conference/ crash helmet/head/injury/prevention/severity/accid, injury)/simulation/spinal column.

ABSTRACT: Head and spinal injuries are more often due to road traffic accidents than any other cause. The incidence of serious head injury is less for motorcyclists who wear helmets, than for other categories of road user. Serious closed head injury typically involves damage to blood vessels of the brain, the primary mechanisms being motion between brain and skull, and brain tissue shear; this frequently is associated with prolonged unconsciousness and coma. The development of better safety technologies requires more research. Early admission to specialised care, and comprehensive data collection facilitate treatment and assessment of injury.

The consequences of head impacts vary according to direction and magnitude of the impact force as well as the site of impact. Facial injury is reduced by the use of full-face motorcycle helmets and seat-belts. Continual revision of standards for vehicle users' helmets has improved effectiveness but more extensive anthropometric data are required for further improvement.

Pathological assessment of damage to vascular and neural tissues and correlation of the results with accident reconstruction data has improved definition of injury mechanisms. Injuries to children show age specific peculiarities and there is a need for research on subsequent educational strategies to be used. Injuries to the spinal cord constitute a major cost to the community and are affected by type of safety belt used. Simulation of movements in accidents, by mathematical modelling, is being developed as a research tool.

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The secretariat of the International Research Committee on Biokinetics of Impacts kindly gave permission for Dr Viano's paper to be reproduced herein in full. Dr Viano's paper was presented originally at the 1985 International IRCOBI Conference on the Biomechanics of Impacts.

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HEAD AND NECK INJURY IN AUSTRALIA

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ABSTRACT

Road traffic accidents in Australia cause half of all accidental deaths and two-thirds of all fatal head and spinal injuries. Their importance as a public health problem is exacerbated by the high proportion of young adults, compared with other age groups, who are killed or severely disabled by these types of accidents.

The NH&MRC Road Accident Research Unit's research on head injuries due to road traffic accidents is carried out in collaboration with the Institute of Medical and Veterinary Science, the Forensic Science Centre, the Royal Adelaide Hospital and the Adelaide Children's Hospital. It continues earlier work of the University of Adelaide's Department of Pathology which included an assessment of the benefits of safety helmets worn by motorcyclists. Aspects of the Unit's continuing long-term study of the mechanisms of damage to the brain in road traffic accidents will be presented during this Symposium.

Exchange of information and ideas at an international level is essential in any field of research and the organisation of this Symposium has been an important part of the academic work of the Unit.

1. INTRODUCTION

Accidents and adverse effects account for six or seven per cent of all deaths of males in Australia and three to four per cent of all deaths of females. Half of the deaths in these categories are due to road traffic accidents [1]. We also know that two-thirds of all fatal head and spinal injuries occur in road traffic accidents [2], hence blunt impact, rather than a penetrating wound, is the characteristic cause of head injury in Australia.

It is well known that young adults are at high risk of being killed in a road accident [1]. Consequently fatality totals, or admissions to hospital, underestimate the true magnitude of the problem. When person years of life lost is taken as the criterion road traffic accidents, and head and spinal injuries, assume a far greater importance as a public health problem relative to other causes of death. Similarly the permanent disability resulting from head and spinal injury is often both very severe and long lasting, affecting as it does individuals early in their lifespan. While the extreme degree of disability often associated with spinal injury is commonly regarded as being the most distressing outcome from non-fatal road trauma, in many ways permanent and severe brain damage is the most tragic of all disabilities. It is no exaggeration to suggest that those persons with severe brain damage are the lepers of our contemporary society.

2. RESEARCH ON HEAD INJURY

The National Health and Medical Research Council established the NH&MRC Road Accident Research Unit in 1981 to conduct research into the medical aspects of road traffic accidents. The Unit is working in two main areas: alcohol and head injury. The extent and the effectiveness of our head injury work have been enhanced by the co-operation which we have received from other organisations and individuals. In particular: the head injury laboratory which has been established at the Institute of Medical and Veterinary Science under the leadership of Dr. Peter Blumbergs, and at the suggestion of Professor Barrie Vernon-Roberts, provides neuropathology data; the State Forensic Science Centre provides access to autopsy data; Mr. Brian North, Director of Neurosurgery at the Royal Adelaide Hospital, has ensured that we have the full support and co-operation of the neurosurgical unit at that hospital; and Mr. Donald Simpson, until recently Director of Neurosurgery at the Adelaide Children's Hospital, who has demonstrated the ultimate level of co-operation by becoming a part-time member of the Unit while maintaining some clinical responsibilities.

The work of the Unit on head injury predates our establishment under the auspices of NH&MRC. In the early 1960's, Dr. Tony Ryan and I were engaged on an in-depth study of casualty accidents in the Adelaide metropolitan area under the direction of the late Professor J.S. Robertson of the Department of Pathology of this University [3]. The discussion of head injuries in the report on that study includes diagrams showing the location of impacts to the head in motorcycle accidents in relation to that part of the head which was protected by the then-fashionable 'safety helmet'. In most cases the impact was below that part of the helmet which contained the energy-absorbing liner, which in those days consisted of compressed cork.

In 1976-77, a second in-depth study was conducted in the Adelaide area. In that study we found that motorcyclists were the only category of road user for whom the head was not the most severely injured body region [4]. This was a consequence of both the protection afforded by the motorcyclist crash helmet and the high frequency of severe leg injuries sustained by motorcyclists.

Two studies have been carried out by the Unit in co-operation with the Neurosurgical Society of Australasia. The first of these dealt with the role of alcohol in cases of fatal injury to the head or spine [5]. The second dealt with the influence of distance on management and outcome of neurological injuries in South Australia [6].

Alistair Woodward and Margaret Dorsch investigated the relative frequency of head injuries in country and city areas in South Australia based on hospital discharge data assembled by the South Australian Health Commission [7]. They reported a 33 per cent higher incidence of head injury resulting in admission to hospital in the country than in the city, with more than half of the most serious cases being due to road accidents. A study demonstrating the efficacy of helmets for pedal cyclists was also carried out by Woodward and Dorsch [8].

The major activity of the Unit is a long-term study of mechanisms of damage to the brain, concentrating on fatally injured pedestrians and motorcyclists. This work will be discussed later in the symposium by Tom Gibson and Peter Blumbergs.

3. INTRODUCTION TO THE SYMPOSIUM

The National Health and Medical Research Council envisaged the Road Accident Research Unit as playing a role as an academic centre for discussion of the medical aspects of road traffic accidents.

Thus far the Unit has conducted two symposia: one on methodological aspects of the role of alcohol in road accidents in 1983 and the other on injury severity scaling in 1984 in collaboration with the Child Accident Prevention Foundation of Australia [9].

In the present symposium we have allocated a considerable proportion of the available time to discussion. This has been done in the hope that we may be able to assist some of the deliberations which are underway in other places on means of head impact protection in road accidents. I have in mind matters such as the provision of head injury protection for vehicle occupants through the Australian Design Rule system, and for motorcyclists and cyclists through the relevant Standards Association of Australia Committees on crash helmets.

It is clear that one of the major impediments to the further development of head protection measures is our inadequate understanding of the mechanisms of injury to the brain. We are therefore particularly fortunate to have Dr. David Viano with us today. It would be a bold person who would claim to have a clearer understanding of head injury mechanisms than Dr. Viano.

Before asking John Lane to introduce Dr. Viano, I should note that John is one of the grand men of the crash injury field. The usual term is 'grand old men' but even a few moments discussion with John will reveal that he can run rings around most of us in mental agility, not to mention his colourful turns of phrase. He was recently made a Member of the Order of Australia for his services to aviation medicine and road safety, but he will be remembered, dare I say, by many more people in many countries as the man who coined the term 'crashworthiness' [10].

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KEYNOTE ADDRESS

PERSPECTIVES ON HEAD INJURY RESEARCH

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ABSTRACT

A review of the current medical and engineering literature provides sufficient understanding of head injury to direct meaningful research. Serious closed head injury typically involves damage to the blood vessels of the brain. Half of the vascular injuries involve subdural hematoma including bridging vein laceration and 30 percent involve focal contusion. Vascular damage is frequently identified with cases of long-duration unconsciousness or coma following closed head injury.

Impact of the front or back of the head results primarily in vascular damage on the inferior surfaces of the frontal and temporal lobes. These are the locations where the brain rests on the skull in the cranium and are different from the speculative sites of neural damage associated with unconsciousness. However, vascular injury of the brain is a specific endpoint for research since the damage is obvious and is generally associated with severe neural damage.

The literature is filled with discussions on the mechanism of head impact injury. Impact produces three-dimensional translation and rotation of the head about its centre of gravity. Since the brain is loosely coupled to the skull by the CSF fluid interface, tethering veins, and the membranes covering the brain, abrupt acceleration of the skull generally causes the brain to lag in response. Because of the irregular bony ridges of the frontal and temporal shelves of the skull which support the brain and stiff membranes, relative motion between brain and skull at these locations has a high potential for contusion injury.

Although many mechanisms have been proposed for the injurious effects of head impact, including pressure gradients and cavitation, relative motion between brain and skull, and brain tissue shear, are implicated as the primary mechanisms of severe vascular damage in closed head impact injury. Current methods to evaluate head impact response involve an incomplete evaluation of dummy head dynamics and an inadequate analysis of the brain response during impact.

Fruitful areas of research should emphasize a more complete evaluation of three-dimensional translational and rotational motion of the dummy head during impacts associated with serious head injury. The accurate measurement of head dynamics will allow a more realistic analysis of the potential for brain injury at the known sites of primary vascular damage. The analysis procedure could rely on an advanced finite element model of the skull and brain; and, it could predict relative

motion between brain and skull, and shear strains in the brain. Although the research would emphasize vascular damage as an endpoint, it is important to develop information on the mechanisms of neural injury causing prolonged unconsciousness and coma. The mechanism of neural damage is probably not identical to that for vascular injury, and a clearer understanding of the biological factors involved in neural trauma would eventually enable meaningful biomechanics research.

Although a review of the literature points clearly to the fact that the current head injury criterion (HIC) is based on minimal data over 20 years old, the criterion has been useful for the assessment of automotive safety with anthropomorphic dummies. Yet questions remain unanswered as to whether the criterion is a sufficient procedure for the accurate prediction of the wide range in types and severities of head injury. Due to the significance of head injury as a source of critical, fatal and disabling injury in motor vehicle crashes, attention should be given to research which will evaluate current techniques and develop new procedures to evaluate head injury potential and to assess the benefits of safety technologies.

1. INCIDENCE AND SOURCES OF HEAD INJURY

Based on USA field accident data [29,31], the head is one of the most frequent body regions injured in motor vehicle crashes. It is also the most severely injured part of the body in half of the cases (Table 1). Head injury occurs with high frequency for each level of injury severity and it is a significant crash injury problem because of the death and disability it causes. When the severity and frequency of injury is considered [18,29], head injury accounts for 30 percent of the car occupant harm (Table 2). Nearly 80 per cent of the head injury harm is due to interior contacts for the primarily unrestrained USA occupants. About half of these contacts are with structural members of the interior, such as pillars, rails, windshield, side glass, and steering assembly.

Head injury is a significant societal problem and represents a major fraction of the cost of crash injuries [32]. Early estimates of the total societal burden of motor vehicle crash injuries [30] indicate a total USA cost of approximately $60 billion annually (Table 3). Considering that head injuries account for nearly 30 percent of the crash injury harm by one estimate, the cost of these injuries approaches $20 billion annually. This estimate of harm was based on a uniform cost for each severity of injury, irrespective of the cost differences for injuries of similar AIS severity (an AIS 5 brain injury has a significantly greater medical and rehabilitation cost than an AIS 5 liver injury). In a more recent estimate of motor vehicle crash harm [4], the significance of individual injuries was included, and head injuries actually approach 50 percent of the total societal burden of motor vehicle trauma.

In a majority of crashes, vehicle crush occurs with minimal deformation of the occupant compartment, but involves a combination of frontal, lateral, and rotational motions of the vehicle. Because of a distribution in vehicle dynamics, unrestrained occupants interact with

TABLE 1: Distribution of Motor Vehicle Crash Injuries. (Developed from [31], Annual Injury Projections Based on 1982 Crash Injury Data in NASS).

Body Region	Injury Severity Level			Most Severe Injury
	Minor AIS 1-2	Serious AIS 3-4	Critical AIS 5-6	
Head	2,613,000	50,000	17,000	50%
Spine	929,000	13,900	2,000	16%
Chest	350,500	36,500	16,000	3%
Abdomen	257,600	55,400	12,000	5%
Extremities	3,245,000	105,000	-	26%
Whole Body	97,000	-	-	-
Total	7,491,000	260,000	49,000	100%

TABLE 2: Car Occupant Injury Harm. (Developed from [18,19], Frequency Distribution of Contact Harm Based on 1977 to 1979 Crash Injury Data in NCSS).

Principal Contact	Head	Neck	Trunk	Extremities	All
Steering Assembly	3.1	0.4	21.3	2.0	26.9
Instrument Panel	1.9	0.4	6.0	6.4	14.6
Side Interior	0.8	0.1	9.3	2.6	13.0
Pillars-Rails	7.7	0.6	0.5	0.1	8.9
Windshield-Glass	5.5	0.2	-	0.4	6.1
Other	4.9	7.3	1.7	4.9	18.7
Interior Contacts	23.9	9.0	38.8	16.4	88.2
Exterior Contacts	5.8	1.6	3.2	1.2	11.8
Total	29.7	10.6	42.0	17.6	100.0

TABLE 3: Societal Costs of Motor Vehicle Accidents in Billions of $, for 1980. (Developed from data in [30], Annual Societal Costs of Crash Injury Based on the Average Accident Data from the 1979 to 1980 NASS).

	Uninvolved	Property Damage Only	Injury (AIS) 1	2	3	4	5	Fatality	Total
Medical Costs	-	-	0.54	0.62	0.63	0.34	1.13	0.07	3.33
Productivity Losses	-	-	0.32	0.25	0.31	0.45	0.80	12.10	14.24
Property Loss	-	16.98	2.66	0.61	0.42	0.10	0.03	0.17	20.98
Legal-Court Costs	-	0.36	1.74	0.26	0.53	0.18	0.09	0.68	3.84
Insurance Expenses	7.05	3.45	1.75	0.24	0.11	0.44	0.15	0.64	13.83
Other (EMS, Coroner, etc.)	-	0.32	0.44	0.09	0.04	0.02	0.01	0.06	0.98
	7.05	21.11	7.45	2.08	2.05	1.53	2.20	13.73	57.20

TABLE 4: Head Injury Estimates. (Developed from data in [18,29], Annual Injury Projections Based on Data from the 1977 to 1979 NCSS).

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	Total
Head Injury	1,186,900	193,400	17,400	9,000	10,900	6,400	1,424,000
Face	817,800	104,400	11,300	1,800	-	-	935,000
Brain	341,800	83,200	5,200	5,200	10,700	6,300	452,400
Brain Injury							
Concussion	341,800	83,200	5,200	2,900	4,400	500	438,000
Contusion/ Laceration	-	-	-	2,300	6,300	5,800	14,400

virtually all interior components, and head contact occurs over a broad range of velocities. Thus, the occupant's velocity and direction of interior impact and the properties of the object struck are primary factors in the subsequent impact interaction of the head. For the cases of significant intrusion or ridedown, the head contact velocity and impact mechanics are more complicated.

Concussive brain injury [29] occurs in a wide range of interior contacts (Figure 1). For minor, moderate, and severe injury, windshield contacts represent the most common source of injury. (Here AIS-76 terminology is used and ascribes cerebral concussion for varying lengths of unconsciousness including coma following head impact. Non-anatomical brain injuries in AIS-80 are ascribed on the length of unconsciousness thus limiting the severity of the term concussion to AIS 2). When the header, pillars, and instrument panel are added as sources of contact injury, these structures account for nearly three-quarters of the concussive injury occurring in motor vehicle crashes. Although there have been significant improvements in occupant protection by the introduction of the high penetration resistant windshield and energy absorbing structures, these vehicle components remain a significant source of brain injury. When critical and fatal brain injuries are considered, the pillars and header account for nearly 50 percent of the contact injury.

2. TYPES OF HEAD INJURIES AND THEIR SIGNIFICANCE

Based on the data available in the NCSS accident files [18,29], head injuries occur primarily to the face and brain, and over 400,000 occupants experience concussive injury (Table 4). Nearly 80 percent of these injuries are AIS 1 level concussions which involve confusion, dizziness and amnesia after the crash (Table 5a). AIS 1 and 2 level injuries of the brain do not involve damage apparent on a CT scan, and do not involve skull fracture or intracranial bleeding [21]. The more severe injuries of the brain involve contusion and laceration and are generally accompanied by long-duration unconsciousness (Table 5b). Severe injuries involve a significant risk of morbidity and fatality [7], and can involve skull fracture.

Independent estimates (Table 6) indicate that over 200,000 USA hospital admissions occur annually as the result of brain injury [14,18,31]. This represents approximately 16 percent of the head injured and an important fraction of the total hospital admissions for crash injuries. A majority of the cases involve confusion, amnesia and short duration unconsciousness where admission for overnight observation may be precautionary treatment before release. In the more severe cases, prolonged hospitalization and rehabilitation are required.

The available accident injury and hospital data enable only rough estimates of the frequency of head injuries; and, better data, such as from the NASS and NEISS, are needed to develop a more consistent picture of the epidemiology of head impact injury. However, the area where there is the least data is probably the most important aspect of head impact injury, the disabling effects of brain damage. Only scant information is available on the consequences, treatment and

TABLE 5: Neural Injury. (Derived from [21]).

(a)

CONFUSION

AMNESIA only with confusion

KNOCKOUT (< 15 m) only with amnesia (Lancet 1962)

UNCONSCIOUSNESS (< 1 hr) only with focal damage (Lancet 1973)

DEEP COMA (> 6 hrs) only with brainstem damage (Brain 1974)

(b)

Injury Severity	Symptom	Brain Damage	Outcome
- AIS 1	Confusion/Amnesia	Negative CT Scan	
		No Skull Fracture	Post Concussive Sequelae
Minor AIS 2	Knockout (< 15 m)	No Intracranial Bleeding	
Moderate AIS 3	Unconscious (< 1 hr)	Positive CT Scan	
		< 50% Skull Fracture	> 50% Mortality
Severe AIS 4-6	Coma (> 1 hr) - Death	Focal Contusions and Bleeding	> 35% Morbidity

TABLE 6: Significance of Head Injury. (Developed from [14,18,29,31], Annual Injury Projections Based on Data from the 1977 to 1979 NCSS, 1982, NASS, and 1980 Clinical Data).

	NCSS/NASS	NIH
Injured	1,424,000	
Hospitalized	223,000	207,000
Fatalities	13,790	

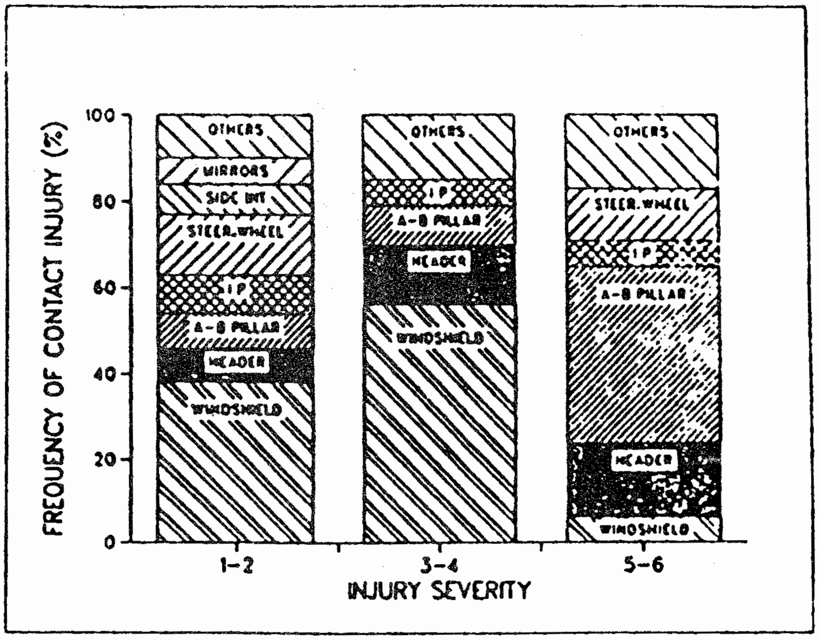

Fig. 1: Distribution of brain concussion injury, developed from data in [29], from crash injury data collected from 1977 to 1979 in the NCSS, courtesy of P. Park and T. Khalil.

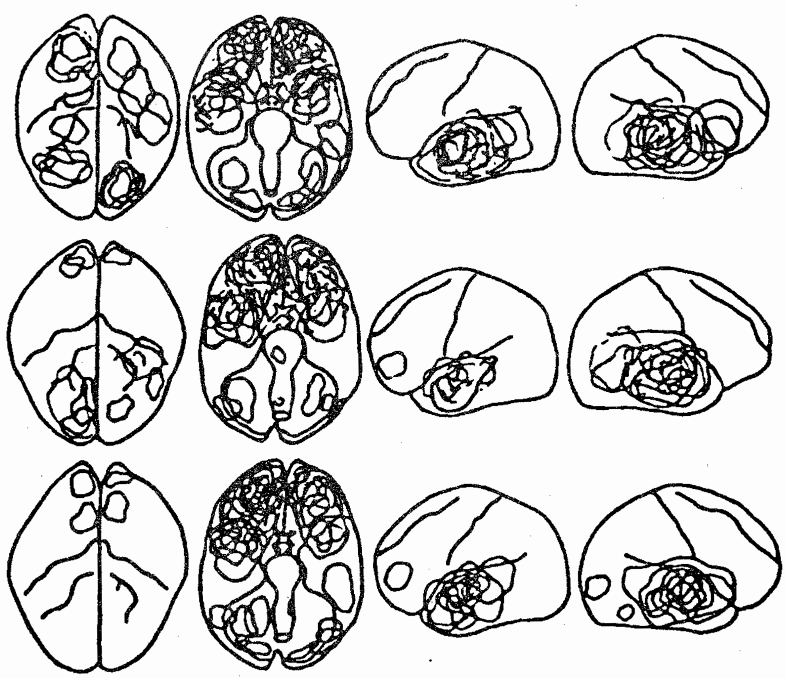

Fig. 2: Composite location of cerebral contusion based on 152 autopsies, from [8,9] with permission.

rehabilitation of the severely brain injured, and even less on the consequences of moderate head injury.

Injury disability is an important emerging problem of crash injury [26,32]. With improved medical treatment, there is better survival of the severely brain injured than would have been expected years ago. As the costs for post-traumatic care increase and the number of permanently disabled increase, more attention will focus on the disabling consequences of impact injury. In this regard, safety technologies and injury assessment tools will be needed to protect against disabling injury.

Vascular Injury Over half of the contusion injury of the brain is subdural hematoma [7,14], frequently attributable to bridging vein rupture (Table 7). Subdural hematoma has the highest risk of mortality, exceeding 60 percent of the survivors admitted to hospital. Focal injuries occur in about one-third of the cases but typically without skull fracture. In contrast, epidural hematoma frequently occurs with skull fracture. Based on autopsy evaluations of cerebral contusion [5,6,8,9,10,16,20,22], the most common sites of vascular injury are to the inferior surfaces of the frontal and temporal lobes of the brain (Figure 2). These are the locations where the brain rests on the skull in the cranium and are sites of bony ridges which may be involved in the contusion injury process. Contusion of the frontal and temporal lobes occurs whether the site of head impact is to the front or back of the head [6,8,20]. This fact implicates the geometric configuration of the brain and skull at these sites as a significant factor in the injury process.

Neural Injury Injury of nervous tissue is typically diagnosed by abnormal brain function, either loss of memory and cognitive function, or a loss of consciousness. The more significant concussive injuries involve long-duration unconsciousness and are frequently associated with severe contusion injury [21]. In the cases of moderate and minor brain injury, which is more frequent, the injury diagnosis is based on short duration unconsciousness, or confusion and amnesia (Table 5a and 5b). Although such injuries are frequently thought of as benign, follow-up of patients has identified post-concussive sequelae [28], where minor head injuries can have a significant life-altering consequence [17,25].

Although there is a low risk of mortality and a good prospect for recovery from minor head injury [25], the situation is less favorable for the moderately injured [19,24,26] (Table 8). Only 40 percent of the patients achieve good recovery. The longer-term effects of the head injury [25] are also a significant factor since many patients with minor and moderate injury experience chronic headaches and memory deficits months after the injury. Based on neuropsychological evaluations, these individuals show a deficit in comparison to a matched normal population of people. There appears to be a psychological change in these patients accompanied by loss of employment in many cases. What might be construed as a minor or moderate injury with insignificant consequences based on the AIS 2 or 3 level injury severity, is actually a more significant problem because it may involve an irreversible alteration of normal brain function. Even though AIS is a threat-to-life scale, many people interpret an injury

TABLE 7: Vascular Injury. (Developed from Data in [7,14], Frequency Distribution Based on Clinical Injury Data from 1980).

Hematoma	Frequency (%)	Mortality (%)	Skull Fracture (%)
Epidural	15	20	90
Subdural (Bridging Veins)	51	62	50
Focal	33	40	-
	100%		

TABLE 8: Head Injury Outcome. (developed from data in [7,24,25], frequency distribution based on clinical injury data from 1980).

Severity	Frequency (%)	Mortality (%)	Recovery (% Good)
Minor	70	0	75
Moderate	20	17	38
Severe	10	41	26

Followup at 3 Months

Severity	Chronic Headache (%)	Memory Deficit (%)	Neuropsycho-logical Deficit	Unemployment (%)
Minor	78	59	*	34
Moderate	93	90	***	66
Severe	na	na	na	> 75

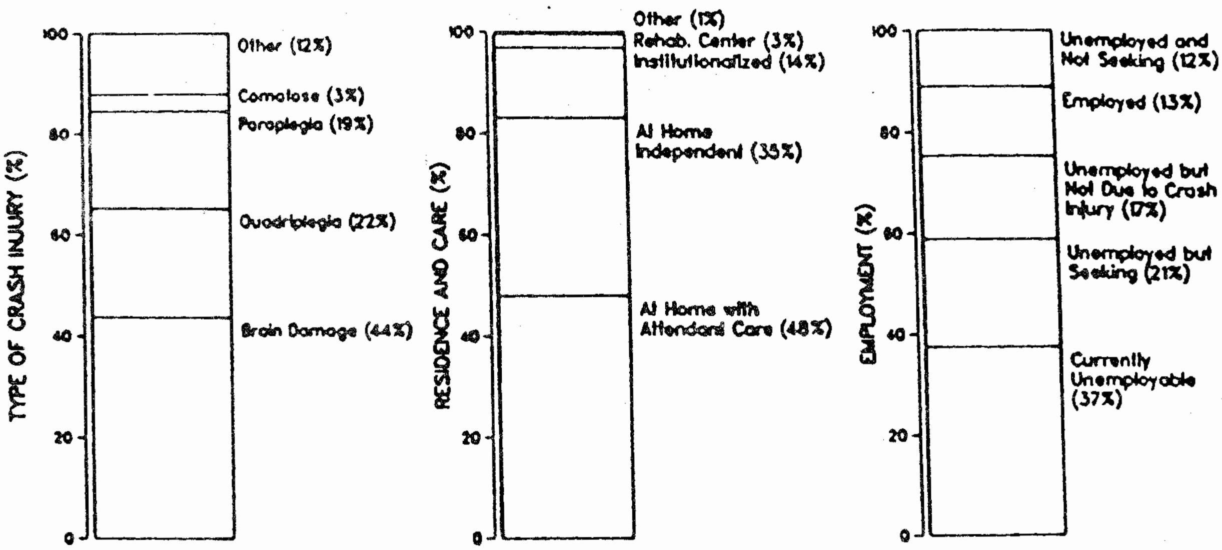

Fig. 3: Types of disabling crash injury and consequences of disability, from [32], based on crash injury followup of victims in 1978 and 1982.

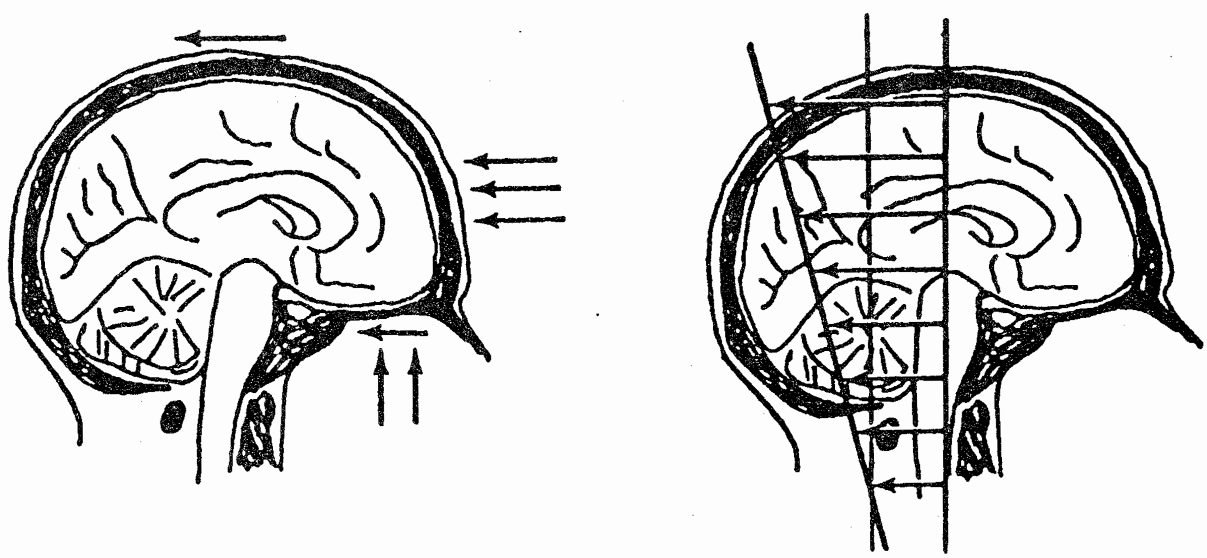

Fig. 4: Head dynamics involve translational and rotational acceleration.

severity level as a measure of potential outcome. A complementary 'well-being' scale is needed and would assess the long-term effects of crash injuries.

Recent efforts in occupant protection research have focussed primarily on technologies to reduce crash injury deaths. This has brought about significant reductions in fatality rates over the years. However protection from injury disability requires research on technologies and treatments to reduce the incidence of impairment. Many of the disabled are permanently confined to wheelchairs or limited in activity, and the severely disabled are quickly becoming a major health-care issue. The majority of injury disability is from brain and spinal cord injuries [26,32] which permanently destroy motor, sensory or cognitive function and require attendant care in nearly half of the cases (Figure 3). Only one in ten of these victims will return to gainful employment and nearly 40 percent will be unemployable for years after the injury. These individuals face an average life expectancy of 36 years with nearly a quarter living 50 years or more after the injury.

3. HEAD INJURY MECHANISMS

There is extensive literature on the possible mechanisms of head impact injury [33]. Unfortunately, the mechanisms underlying vascular and neural injury of brain tissue are complex and many of the published mechanisms are speculative. Some do not adequately account for the underlying physics of head impact. Although many papers have significantly contributed to the field of head injury mechanisms, some good papers have gone unnoticed in favor of others espousing theories that at first glance appear attractive and thus have become popular in the literature. As fundamental an issue as coup-contrecoup brain injury has become muddled and confused in the numerous papers published on the subject. The definition of a coup and contrecoup injury is not clear. The intent of this overview is not to critically review the substantial literature on mechanisms of head injury, that is a subject for a more comprehensive document, but rather this paper intends to give a perspective on the most likely mechanism underlying closed head contusive injury of the brain and on the needs for research.

The violent acceleration and motion of the skull due to impact produce deformation of brain tissues secondary to skull displacement and can result in both vascular and neural damage. The wide range of direction and location of head impact produces a complex motion of the head and complex deformations of brain tissues. Thus, impact produces a three-dimensional translation and rotation of the head about its center of gravity (Figure 4). Because the brain has inertia and is loosely coupled to the skull, its motion lags the displacement of the skull. The differential displacement causes shear between the brain and skull stretching the vessels that tether the brain [5,11,20], and strain in brain tissue [21,23,28] due to deformations from contact with bony protrusions and membranes [15].

Differential displacements due to tethering, geometric factors and pressure gradients in the brain cause a complex distortion of CNS

TABLE 9: Cadaver Head Impacts. (Developed from Data in [27]).

	Force		Acceleration	
	Peak (kN)	Duration (ms)	Translation (HIC (g))	Rotation (R/s^2 (g))
Frontal Impact				
Padded (AIS 4)	6.6	9.4	1,170 (190)	9,570 (66)
Rigid (AIS 2)	14.6	3.8	5,560 (515)	14,620 (102)
Lateral Impact				
Padded (AIS 2)	4.2	10.6	580 (140)	6,650 (46)
Rigid (AIS 5)	9.6	6.9	11,050 (530)	37,550 (260)

TABLE 10: Injury Biomechanics Research Tools

		Subject					Required
		Human	Animal	Cadaver	Dummy	Math Model	Research Team Member
	Vehicle Crush						Engineer
	Occupant Kinematics				*	**	Engineer
DEFORMATION PHYSICS Head-Pillars/Rails Torso-Steering Wheel	Impact Interactions		**	**	**	*	Engineer
INJURY TOLERANCES Skull Fracture/Brain Contusion/Aortic Rupture/ Liver Laceration	Injury Biomechanics		***	**	*		Biomechanic
FUNCTIONAL EFFECTS Brain Damage Cardiac Arrhythmia	Pathophysiology	**	**				Physiologist Physician
	Medicine	**					Physician
TREATMENT REHABILITATION							

tissue, which is accentuated at the interfaces between brain and stiff intracranial tissues and structures. Deformation of brain tissue strains the material and can result in brain laceration and contusion. Vascular injuries primarily occur on the inferior surfaces of the frontal and temporal lobes where the ridgy convolutions of the skull accentuate the potential for injury by relative motion between brain and stiffer structures [6,15,21]. This is implicated as the primary mechanism of severe vascular injury in closed head impact injury.

4. HEAD DYNAMICS

Since there is minimal risk of brain injury due to non-contact acceleration of the head [18], the accurate measurement of head dynamics during direct head impact is of primary importance. Blunt impact produces translational and rotational acceleration of the head. Because of the wide range of impact types and the lack of measurement technology, the relative significance of translation and rotation to the deformation of brain tissue has not been clarified. Clarification can be achieved only through accurate measurement of the three-dimensional dynamics of the head during severe impact.

A first step is to better understand dummy head dynamics during impacts which have a high probability of brain injury. Field investigations of head injury can provide the impact situations. Although multiple accelerometer techniques have been developed and used in dummy heads, most of the analysis techniques suffer inaccuracies in interpretating the rotational and translational acceleration during violent impacts. A technique to measure dummy head dynamics must be capable of accurately measuring translational accelerations up to 500 g and rotational accelerations up to 50,000 r/s^2 (Table 9). Head impact causing severe brain injury is a short duration event [27], particularly when hard structures such as rails and windshield glass are contacted.

A recent effort to more accurately measure the fore-and-aft (two-dimensional) rotational and translational acceleration of the dummy head has achieved success [3], even in violent impact exposures. The technique relies upon multiple linear accelerometers aligned in the midsagittal plane and a linear least-squares evaluation to determine rotational acceleration about the center of gravity of the dummy head. The advantage of this technique is that the conventional triaxial accelerometer package at the center of gravity of the dummy head is maintained for computation of HIC and comparison of results.

Acceleration of the head is only the driving force which results in deformations of brain tissue. Brain deformations cause injury. Thus, the accurate measurement of head dynamics is only the first step in a procedure to evaluate risk of brain injury. Acceleration data must be used as input to a 'post-processing' procedure to predict engineering responses, such as shear strain or tensile strain, at locations where contusion injury of the brain typically occur. One procedure may involve a finite element model (see [12] for a review of models) which closely approximates the geometric and interface conditions of brain and skull, and whose response predicts brain deformations due to translational and rotational accelerations. This procedure will

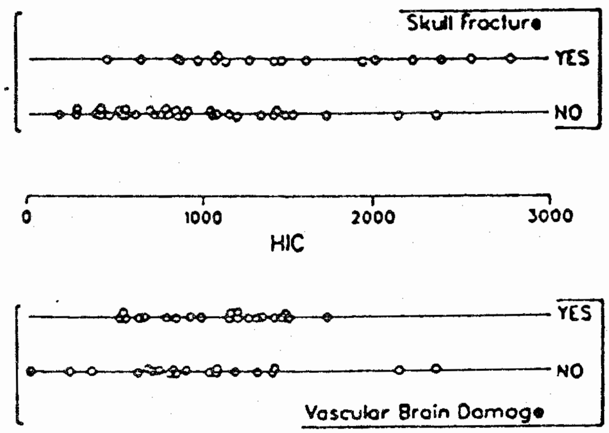

Fig. 5: Cadaver head impact data, developed from data collected by Mertz, 1983.

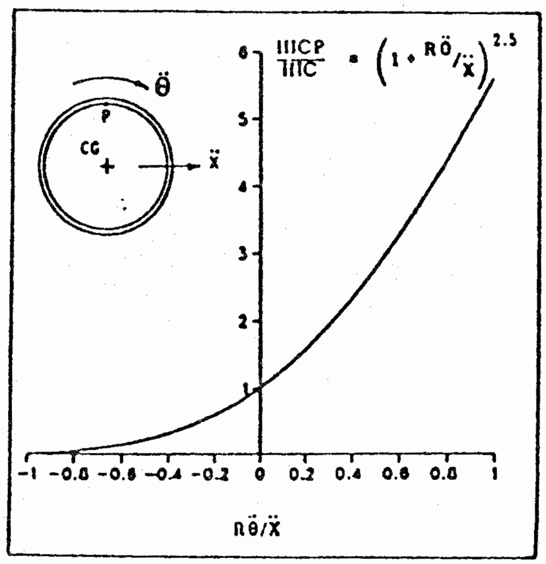

Fig. 6: HIC is not a unique measure of the severity of head acceleration (from [13] with permission).

require a tolerance criterion for tissue damage but would provide a more global assessment of brain injury risk.

The current head injury assessment technology and criterion use a stiff dummy skull covered by an elastic skin, measure a single point acceleration at the head center of gravity, and use a weighting function based on the resultant acceleration to assess the severity of head impact and potential for brain injury. However, the current weighting function (HIC) is not a decisive correlate with vascular damage observed in cadaver experiments (Figure 5). The criterion is also not a precise predictor of skull fracture. One difficulty of correlating injury with HIC may be due to the single point evaluation of risk. The HIC at the interface between brain and skull can be very different from the HIC at the center of gravity [13], depending on the relative magnitude of the rotational acceleration (Figure 6). It is important to recognize that impact experiments show significant rotational accelerations and the site of injury is typically not at the head center of gravity.

5. INJURY BIOMECHANICS

Because of the high frequency and potential significance of neural damage to central nervous tissues, the study of concussion is an important research topic. However, there is scant information on the basic biological mechanisms of neural trauma, and it may not be an immediate response. Neural trauma is a progressive injury which takes time for the pathophysiology to reach a permanent endpoint. Even though unconsciousness is a diagnosable symptom, it may mask a sequence of biological processes that may actually account for the ultimate severity of brain damage.

In the experimental setting it is difficult to localize and observe neural injury except with histology [1,2,28] and anaesthesia is a compounding factor. Because of the infancy of neural trauma research, basic study is needed using well-controlled experimental models, and the research teams must include neural scientists, biomechanics and physiologists, to investigate the response of CNS tissues to trauma (Table 10). In the longer term, neural trauma research will link up with other studies that have advanced our understanding of the biomechanics of vascular brain injuries.

At this time, the most obvious and important objective for brain injury research is to understand the injury biomechanics associated with vascular brain damage. Injury causing long-duration unconsciousness is generally accompanied by contusion injury, and the contusion is easy to localize and diagnose. Thus, experimental research may use vascular injury as an endpoint to assess the significance of translational and rotational accelerations of the skull, of relative motion between brain and skull, and of deformations of brain tissues.

Although it is likely that the mechanism of neural injury is different from that of vascular injury, the development of knowledge on head dynamics causing brain contusion should provide a better engineering criterion to assess safety technologies. Head injury tolerance research would also benefit from study of skull and facial fracture where the emphasis should be on the biomechanics of injury. Eventually, the head injury criterion must adequately address brain injuries causing functional damage, impairment of cognition, changes in personality and behavior, and altered physical and occupational function. However, our knowledge of the basic mechanisms of neural damage is not complete enough at this time to consider biomechanics studies on closed head neural tolerances. Disability caused by brain damage will be an important problem of the future but progress on reducing head injuries is most likely if the biomechanics of severe brain contusion is clarified first, and new technologies developed and used to evaluate safety technologies.

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DISCUSSION OF DR. VIANO'S PAPER

Dr. A.J. Woodward: Can you comment on the clear differences between men and women shown in your slide concerning the effect of alcohol on risk of disabling injury for a given impact?

Dr. D. Viano: I can only state that there are known differences between men and women. It is largely obscured by cases of post-menopausal women with leg injuries of a minor to moderate severity. Bone injuries are more prevalent in post-menopausal women. With the more severe injuries I am not aware of a clear distinction in risk but somebody else may have more specific information.

Dr. M. Wigan: Have you yet got to a point where finite element models of the brain and linkages have started to be useful rather than indicative?

Dr. D. Viano: No, it is an extremely challenging problem, involving a large displacement both geometric and material and the codes are gradually becoming sophisticated enough to deal with it. We honestly look at it as a research question. The investigators involved are planning to do something with this, but I view it as one of the high-risk elements of our research.

Mr. S. MacLean: You made a comparison of the different causes of death and then oriented it by looking at the lost days of productivity. Did the committee with which you were involved also look at such a comparison in terms of the cost of treatment and rehabilitation? Might a different picture then emerge as a result of the fact that diseases which lead to death may require much more expensive treatment? Would motor accidents then be less significant in the picture which you had?

Dr. D. Viano: There is an attempt made by the Committee to have rehabilitation represented on our National Academy of Science Committee. The most frustrating aspect of my whole year and a half on (that Committee) was how little information there was in the U.S. on rehabilitation. You can't even determine how many people are out there. They 'go to the winds' when they are released from the hospital and information is only anecdotal. One of the conclusions was that we have very poor information on the rehabilitation side. Those that represented rehabilitation professed only that we want to integrate into the different facilities all that we already know. They barely spoke about doing more research and what needed to be done. So it's a good question but, at least in the U.S., we don't have that data.

Mr. S. MacLean: In fact, in part you answer the question in a subsequent table in terms of lost work days which could be some sort of surrogate for that measure.

Dr. D. Viano: Well it's a very general national-based study and has a lot of problems but it's the best that we have on the pure trauma-related problems.

Dr. P. Vulcan: Regarding the improved experimental techniques over the last two decades, is any of the research work which has been done likely to lead you to the conclusion that there is any difference in the fundamental principle that, for a given velocity of impact and a given force distribution, the longer the deceleration distance or the longer the deceleration time, the lower the probability of head injury.

Dr. D. Viano: I'll say it's really complicated, much more than just stopping distance for the following reason. I can play a trick with the technologies that I have where, with the same value of HIC computed by the traditional measures, the dummy can be hit in different places with different results; for example it can be hit so that the head translates back and rotates in such a way that the measurements at the centre of gravity of the dummy head almost come out to zero. So you have a very low HIC with an impact so hard that I know you wouldn't expect it. It is a very complicated dynamics problem, it's not just the stopping distance of a point, it's related to the dynamics of the motion over the stopping distance. So in the very general sense, the longer the stopping distance, the more gradual the deceleration. But the motion of the body during that stopping distance is very critical also.

Dr. M. Williams: Could you give some information about implications of your results with regard to protective helmet design, and particularly the influence of angular acceleration.

Dr. D. Viano: The mini sled procedure is being developed by Bell Helmets in California but it's not yet available for testing helmets. I have no practical experience using this technique. We are just starting to try it with boxing protective gear and that's just to help out our U.S. Olympic Boxing Committee.

Mr. J. Corner: Your placement of accelerometers within the dummy head is intriguing. Presumably, you measure rotation by accurately placing the five accelerometers in each of the three directions. I'm intrigued as to why you placed them around the centre of gravity rather than having perhaps two or three triaxial accelerometers placed well apart. Did you experiment with that? Also, when you use a dummy head on a dummy neck you are very dependent on the dynamics of the artificial neck. Does that worry you at all?

Dr. D. Viano: In answer to your first question - we analysed all of the available multi-accelerometer packages that have been published in the literature. Generally they are exterior to the head though there are a few that have been put inside the dummy head. But we have designed the system and evaluated it so it would take the most severe impact, and that could be a blast impact which is a very high frequency, a very sharp spike. None of the published procedures would work for very high dynamic loadings. We used this procedure to move the line of accelerometers maximally away from the centre of gravity, to optimize the ability to produce good information about rotational and translational acceleration. We've hit the dummy head as hard as we could and the system tracks accurately, so we are comfortable that our approach is much better than what was available from previous publications. We know accurately where the seismic mass is. It is not just knowing where the accelerometer is, you need to know precisely where the seismic mass is and with that kind of knowledge it is quite interesting to know that triaxes that are normally in the dummy head are not at the centre of gravity. Some of them are as much as a centimetre away from the centre of gravity. So, as the head goes through strange motions, we actually can produce the centre of gravity accelerations and the HIC and we can compare it against the package readings. There are some major differences depending on where the head is struck.

As for your second question, I accept all the deficiencies of the Hybrid III dummy because I think it's going to be accepted as the state of art dummy in the next 15 years. And I'd just like to know what that dummy is doing in terms of head and neck loadings. As Jac Wisman's improved neck comes along I'd be happy to put it under a test headform because clearly the neck and the thoracic spine in the dummy are not really good simulants of us; the biggest problem of the thoracic spine is that there is no flexibility at all. So as we get better dummies I think this technology will be applied.

SPINAL CORD INJURY - DEVELOPMENT OF A DATA COLLECTION SYSTEM

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(Presented by Dr. D.C. Burke)

ABSTRACT

A sophisticated system of data collection on all new patients admitted to the Spinal Injuries Unit of the Austin Hospital has been developed since 1978, using computer storage. The technique used is described and some of the results of the data collection on 352 consecutive admissions between 1st July, 1978 and 31st December, 1982 are discussed.

The data analysed includes epidemiological information, such as age, sex, locality of residence, cause of trauma, locality of injury and delay between injury and admission to the Unit. Other data is presented on associated injuries, type of skeletal injury and neurological lesions. The outcome of treatment in the Unit is discussed under placement on discharge, spinal stability, neurological results, urinary results, results of physical rehabilitation, and duration of hospitalisation. The implications and usefulness of this data collection are discussed.

1. INTRODUCTION

Australia is an almost ideal country for the development of a data collection system on spinal cord injuries, as the vast majority of these injuries are treated in a relatively small number of specialised spinal cord injury centres in the capital cities of each State.

A comprehensive data collection system, using computer technology, has been developed in the Spinal Injuries Unit of the Austin Hospital in conjunction with La Trobe University. Very detailed data has been collected on all new admissions to the Unit since 1st July, 1978. This paper reports an analysis of some of the data collected on 352 consecutive admissions to the Unit between 1st July, 1978 and 31st December, 1982. This work has been reported in more detail recently in the Australian and New Zealand Journal of Surgery [1,2]. The study has been supported by the Royal Australasian College of Surgeons Road Trauma Committee, and La Trobe University, and the authors acknowledge with thanks the support received.

2. METHOD

The original data collection form developed in 1978 and analysed manually after the first 12 months, was significantly modified to change to computer storage in 1979 and with subsequent experience of the use of the system. The data collection form contains 308 variables, grouped into 6 main headings, ranging from personal details regarding the patient at admission, through clinical information on admission, to outcomes of treatment on discharge from the patient's first admission. The collection of data has continued to the present, but this report is based on an analysis of 352 consecutive admissions in the first four and half years between 1st July 1978 and 31st December, 1982. The data is collected by one of the two senior doctors on the Spinal Unit and then transferred to computer cards on the La Trobe University DEC 10 mainframe computer by the third author. The forms are filled in at the hospital on admission and on discharge of the patient. No record of the patient's name, address or hospital number is transferred to the computer, to preserve anonymity and all patients are informed of the data collection form and its use and assured of anonymity. The total time involved in the collection of data at the hospital is of the order of 1 hour per patient admission.

Regular 6 monthly analyses of the data are made as a self audit of the Unit's performance, and other requests for data retrieval and analysis of information are made from time to time as required for the preparation of hospital reports, and for specific analyses or requests for information from outside the hospital. The data contained in this report was analysed in June 1983 with respect to initial information recorded on admission and further analysed some months later following the final discharge from hospital of all the patients admitted in the 5 year period.

3. RESULTS

3.1 Epidemiological Information

Of the 352 new admissions to the Unit, 325 (92.3 percent) sustained spinal cord injuries from a variety of trauma, and only 27 (7.7 percent) sustained spinal paralysis from non-traumatic causes. The highest number of annual admissions was 96 in 1982.

The study includes all spinal cord injuries occurring over the four and a half years in the States of Victoria and Tasmania. A small number of patients are also admitted from other States, particularly from southern New South Wales, as this is geographically closer to Melbourne than Sydney.

Age and sex of the 352 patients is illustrated in Table 1.

It will be noted that the majority of the patients are under the age of 40 years, with a peak between 17 and 20 years, and the males out number females by 78 percent to 22 percent.

Table 2 shows that the majority of patients lived in Victoria, and that the proportion in relation to those living in Tasmania was approximately relative to the populations of the two States. Interestingly, only 55 percent of the patients lived in capital cities compared with country areas, this being quite out of proportion to the much larger numbers of people who live in capital cities in Australia, and suggests that country people are more at risk from spinal cord injury.

TABLE 1: Age and sex of all admissions 1.7.78 - 31.12.82

Age	Male	Female	Total
0-16	16	12	28
17-20	62	16	78
21-25	57	7	64
26-29	33	9	42
30-39	47	11	58
40-49	21	7	28
50-59	14	8	22
60 & over	24	8	32

TABLE 2: Locality and state of residence (all patients)

State	Capital City	Country Town	Rural	Total
Victoria	173 (60.3%)	97 (33.8%)	17 (5.9%)	287
Tasmania	13 (30.2%)	20 (46.5%)	10 (23.3%)	43
Other	8 (36.4%)	10 (65.5%)	4 (18.2%)	22
TOTAL	194 (55.1%)	127 (36.1%)	31 (8.8%)	352

TABLE 3: Cause of Trauma

Cause	Number (Percentage)
Road Accident	169 (52.0%)
Sporting	52 (16.0%)
Occupational	34 (10.5%)
Farming	6 (1.8%)
Domestic	40 (12.0%)
Other	25 (7.7%)
TOTAL	325 (Male 256 (78.8%) Female 69 (21.2%)

In this study, the major cause of spinal cord injuries was road accidents, followed by much smaller numbers of sporting accidents, occupational accidents and others, including domestic accidents (see Table 3). Of the sporting injuries, the vast majority are from diving into shallow water.

3.1.1 Road trauma

Because road trauma is such a major cause of spinal cord injuries in Australia, a more detailed analysis of this group has been made. Table 4 shows where the accidents have occurred. The proportion of Victorians to Tasmanians is approximately the same as the proportions for residence, but the site of the accident is much more heavily biased towards country regions than the place of residence. It will be obvious from these figures that the commonest cause of spinal cord injury in Victoria and Tasmania is from road accidents occurring in the country. Although country people were disproportionately represented in the total population of admissions, it will also be apparent that both country and city people are at risk from road accidents in the country. This is not surprising in view of the long stretches of roads between towns and cities in Australia, roads which are often of poor quality, and result from high speed accidents in which a vehicle runs off the road and either overturns and/or hits a fixed immovable object such as a tree. This was found to be a far more common cause of injury than collision with another vehicle.

TABLE 4: Locality of road trauma

Capital City		56 (33.1%)
Country Town		38 (22.5%)
Rural		75 (44.4%)
Victoria	133 (78.7%)	
Tasmania	19 (11.3%)	
Other	17 (10.1%)	

Of those injured in motor vehicle accidents (excluding pedestrians, motorcycles and bicycles), 66 percent had not been ejected from the vehicle, 45 percent were wearing a seat belt, and 23 percent were not wearing a belt which was installed in the vehicle. This confirms an earlier study by one of the authors [3] that failure to wear a seat belt is a major contributing factor in the causation of a spinal cord injury in motor vehicle accidents, and that the injury occurs more frequently from being thrown around inside the vehicle rather than from it.

36 percent of the drivers of vehicles admitted to consumption of alcohol prior to the accident. Only a very small number admitted to consumption of drugs prior to the accident. These figures are almost certainly an understatement, and it would have been interesting to have compared the actual blood alcohol levels of these people with their statements. This information is available, as samples for

blood alcohol are required by law in Victoria to be collected after an accident, but an attempt to cross analyse this information by seeking the blood alcohol levels from the appropriate authority was unsuccessful.

3.2 Clinical Data on Admission

3.2.1 Delay in admission

Table 5 illustrates the delay between injury and admission to the Spinal Injuries Unit. 45.5 percent were admitted within 6 hours of injury, 75 percent within 24 hours. Admission of Victorian patients was more rapid than those from Tasmania, but this is explained by the fact that Tasmanian patients have to be transported by air, between 300 and 500 km across the sea, to reach Melbourne. Nevertheless, 54 percent of Tasmanian patients were admitted within 24 hours.

TABLE 5: Delay between injury and admission of all patients with traumatic lesions, 1.7.78 - 31.12.82

Delay	Victoria	Tasmania	All Patients
Less than 6 hours	54.1%	2.4%	45.5%
6-12 hours	17.5%	26.8%	19.3%
12-24 hours	7.8%	24.4%	10.5%
24-48 hours	5.9%	14.6%	7.0%
2-7 days	5.6%	17.1%	7.5%
1-6 weeks	7.0%	4.9%	6.6%
More than 6 weeks	2.2%	9.8%	3.3%

3.2.2 Associated injuries

A high proportion of patients were admitted with associated injuries in addition to the spinal cord injury (see Table 6). The commonest single other injury was a head injury, followed by thoracic injuries and significant skin lacerations. A significant number of patients also had fractures of other vertebrae than at the level of spinal cord injury. Not surprisingly, road trauma resulted in a much higher incidence of associated injuries than other causes of injury; that is, 77 percent of road trauma cases, compared with about 42 percent for all other causes.

3.2.3 Skeletal injury

Classification of skeletal injury was by a modified form of the classification described by Holdsworth [4]. Table 7 lists the numbers of different skeletal injuries comparing cervical with non-cervical levels of injury. Cervical lesions slightly outnumbered non-cervical. The commonest type of injury was a simple crush fracture of the body of a vertebra, followed by bilateral intervertebral joint dislocations. 60 patients were described as multiple, indicating that

TABLE 6: Associated injuries (All trauma)

Injury	Total
Head Injury	83 (25.5%)
Thoracic Injury	75 (23.1%)
Skin Lacerations	61 (18.8%)
Long Bone Fracture(s)	43 (13.2%)
Other Vertebrae Fracture	34 (10.5%)
Pelvic Injury	17 (5.2%)
Other	95 (29.2%)
No Associated Injury	129 (39.7%)*

* (Road Trauma 23.1%
Other Trauma 57.7%)

either more than one vertebra was involved at the level of injury, or that they had multiple types of injuries such as crush fracture plus unilateral dislocation of a postero-intervertebral joint.

TABLE 7: Classification of skeletal injuries by level (Trauma Cases Only)

	Cervical	Non Cervical	Total
Crush fracture	40	61	101
Unilateral Dislocation	12	7	19
Bilateral Dislocation	28	7	35
Other fracture	8	8	16
Other fracture/dislocation	4	24	28
Hyperextension	22	0	22
Forward Subluxation	13	0	13
Multiple injuries	33	27	60
No bony injury	8	16	24
Gun shot wound	1	4	5
Stab wound	1	1	2
TOTAL	170	155	325

3.2.4 Neurological lesion

The level and type of neurological lesion is shown in Table 8. Cervical injuries slightly outnumbered non-cervical injuries, as seen with skeletal injury, and the commonest neurological levels of injury were between C4 and C5 in the cervical spine and T11 and L1 in the thoraco-lumbar area. Incomplete injuries slightly outnumbered complete injuries and this is very apparent with the cervical group, whilst the reverse applied in the thoracic and lumbar injuries, where complete lesions were in the majority.

TABLE 8: Neurological lesion on admission (Trauma Only)

	Complete	Incomplete	Total
C1-C3	10	23	33
C4-C5	46	56	102
C6-C8	17	16	33
All Cervical	73 (46.8%)	95 (54.1%)	168 (51.8%)
T1-T6	37	9	46
T7-T10	11	8	19
T11-L1	27	40	67
L2-S1	8	11	19
No Neurological deficit	0	6	6
All Non-Cervical	83 (53.2%)	74 (43.8%)	157 (48.3%)
TOTAL	156 (48.0%)	169 (52.0%)	325 (100.0%)

3.3 Outcomes of treatment

Of the 352 new admissions between 1.7.78 and 31.12.82, 262 were considered to be normal discharges. This was defined as traumatic cases only and excluded those who died whilst in hospital, those transferred to other hospitals and cases of hysterical paralysis where it was not clear whether they should be considered as post traumatic or non traumatic. Of these 262 patients, 224 (86 percent) were discharged to their normal domicile, i.e. a house or flat, 23 (8.8 percent) were discharged to a hostel, the majority temporarily as a halfway house prior to discharge home, and 15 (5.7 percent) to an institution, such as a nursing home or quadriplegic centre. The proportion of those requiring institutional care has been shown progressively to decrease annually as independent living and attendant care schemes have been progressively developed as an alternative to institutional care.

3.3.1 Spinal stability

The treatment of the spinal fracture or dislocation was predominantly conservative. Nonsurgical treatment included the application of head tongs for cervical traction, and closed reduction of spinal dislocations under anaesthesia. 92.7 percent were managed non surgically. The most frequent indication for surgery was patients with multiple lesions and those with unilateral or bilateral dislocations of the spine. Surgical procedures included open reduction and internal fixation, and spinal fusion. Of the 35 patients who required primary surgical procedures, 22 were those with injuries of the thoracic and lumbar spine.

Spinal stability was judged on extension and flexion X-Rays taken 3 to 4 months after admission, irrespective of the method of management. It was defined as lack of abnormal mobility at the injured segment. Persistent spinal deformity was not taken as evidence of instability. 89 percent were judged to be stable, 3 percent as unstable, and in 7 percent of cases spinal stability was not finalised at discharge. Of the 9 patients judged to be unstable and requiring delayed surgical stabilisation, 4 were patients with multiple fractures. Only one of the 101 patients with a crush fracture of a vertebral body was found to be unstable.

3.3.2 Neurological end results

Table 9 depicts the neurological sequelae, utilizing the system described by Frankel et al [5]. Neurological lesion is classified in 5 categories from complete loss of function below the level of injury to no neurological deficit, and compares neurology on admission with that on discharge. The numbers in the diagonal running obliquely downwards from left to right (AA, BB, CC, DD and EE) refer to those whose neurology did not change. Those above it improved from one category to another and those below deteriorated neurologically.

TABLE 9: Neurological end results (262 normal discharges - Trauma Only)

		Neurology on Discharge					
		A	B	C	D	E	Totals
Neurology on Admission	A	98	17	4	6	2	127
	B	5	14	6	10	4	39
	C	1	0	9	14	1	25
	D	0	0	1	41	19	61
	E	0	0	0	0	10	10
		104	31	20	71	36	262

A - Complete lesion
B - Incomplete lesion - sensory sparing
C - Incomplete lesion - motor useless sparing
D - Incomplete lesion - motor useful sparing
E - Normal

In summary, 66 percent remained unchanged, 31 percent improved, and 2.7 percent worsened. Analysing the neurological outcomes in another way, 23 percent of those initially complete became incomplete, and of those initially incomplete 40 percent improved and 5 percent deteriorated. It must be said that the surprisingly high percentage of those assessed as initially complete who improved might suggest an inadequate examination on admission to the unit, either due to the inability of the patient to fully co-operate so soon after a major injury, or the inability of the examiner to detect subtle evidence of an incomplete injury, perhaps due to fatigue, particularly in the early hours of the morning.

3.3.3 Mortality

13 (3.7 percent) of patients died during the first admission. Seven of these died of respiratory failure (all cervical injuries), 3 from

pulmonary embolus, one from a cardiovascular cause, one from severe abdominal injuries, and one from a severe head injury.

The death rate from pulmonary embolus is low. All admissions to the spinal injuries unit receive a prophylactic programme for venous thrombosis, consisting of low dose Heparin and continuous electrical calf stimulation for 10 days initially, followed by full anti-coagulation over the period of recumbancy.

3.3.4 Urinary tract outcome

Urinary tract management is by a short period of indwelling catheter over the first week or so, until the patient's general condition and metabolic imbalances have stabilised, followed by a programme of intermittent catheterisation. This is to try and avoid accidental over-distention of the bladder in the immediate post traumatic period. The frequency of catheterisation is progressively decreased as bladder training proceeds and the patient regains an ability to empty the bladder, either reflexly, or through crede and/or abdominal straining.

Table 10 summarises the results, with nearly 70 percent of the patients leaving hospital catheter free; that is, with a balanced neurogenic bladder. A higher proportion of females were discharged with indwelling catheters than males, not surprising in view of the difficulties in controlling incontinence in these patients. A small proportion were discharged on self intermittent catheterisation, but this proportion has been progressively increasing in recent years as the technique has become more acceptable and better known.

<u>TABLE 10</u>: Urinary tract outcome

Catheter free	69.1% (Male 69.7%, Female 67.9%)
Indwelling catheter	14.9% (Male 12.0%, Female 26.4%)
Intermittent catheterisation	Balance

Table 11 summarises the urinary results with respect to infection. Nearly 80 percent were discharged from hospital with sterile urine, the outcome being better for males than females, reflecting the lower proportion requiring some form of catheterisation on discharge.

The results are not as good as those reported by Pearman [6] from the Perth Spinal Unit.

3.3.5 Physical independence

The outcome of the rehabilitation programme was assessed with respect to ability to dress, transfer in and out of bed, on and off toilet and shower, in and out of a car, and with respect to functional walking.

TABLE 11: Urinary infection on discharge (Normal Discharges - Trauma)

	Sterile	Infected
Male	165 (78.9%)	44 (21.1%)
Female	39 (73.6%)	14 (26.4%)
TOTAL	204 (77.9%)	58 (22.1%)

This is summarised in Table 12, which includes data for patients at different disability levels.

While 63 percent of the patients were able to walk to some extent at discharge, only 39 percent of these were at a functional level and 24 percent for exercise only. One half of the complete paraplegics, but of course no complete tetraplegics, were able to walk.

77 percent of patients were able to dress themselves independently by discharge (95 percent of complete paraplegics and 27 percent of complete tetraplegics), 11 percent were able to dress with some assistance, and 12 percent were fully dependent.

TABLE 12: Physical independence of normal non-transient discharges (% Fully Independent)

Para/Tetra Status	Dressing	Transfer to Bed	Transfer to Toilet or Shower	Transfer to Car	Functional Walking
Complete Paraplegic	95	94	92	94	18
Paraplegic B.C.	96	96	96	96	46
Paraplegic D.E.	90	98	95	98	71
Complete Tetraplegic	27	30	22	25	0
Tetraplegic B.C.	29	33	29	29	0
Tetraplegic D.E.	87	87	87	87	70
All Normal Discharge	77	79	75	77	39

79 percent of the patients were able to transfer in and out bed independently, 75 percent were able to accomplish toilet and shower transfers independently, and 77 percent were able to transfer in and out of a car.

By discharge from hospital, 40 percent of complete tetraplegics were able to drive a motor car fitted with hand controls. Driving instruction by a professional instructor, using hand controls where necessary, was available as part of the rehabilitation programme. Figures for other categories of disability are not presented because a significant proportion of the patients were disqualified from driving by age or suspension of licence, and a significant number of other patients were not assessed for driving as their disability was too slight to warrant testing.

3.3.6 Average duration of hospitalisation

The duration of hospitalisation is summarised in Table 13. Not surprisingly, complete and nearly complete tetraplegics required the longest periods of hospitalisation and very incomplete paraplegics the least. The average survival period of those who died was 43 days.

Patients injured as a result of road traffic accidents required a longer average hospitalisation than those from other causes, presumably because of the higher proportion of associated injuries complicating their medical condition and the rehabilitation process.

TABLE 13: Average Duration of Hospitalisation, for all 352 admissions

By Lesion	Days	By Cause	Days
Complete Paraplegics	188	Road Traffic	178
Paraplegics B,C	150	Occupational	131
Paraplegics D,E	113	Sporting	157
Complete Tetraplegics	282	Domestic	124
Tetraplegics B,C	230	Assault	176
Tetraplegics D,E	127		
Less than 2 weeks stay	4	Non Trauma	126
Died	43	Overall	159

4. CONCLUSIONS AND SUMMARY

The data collection system described has already proved of great value. Perhaps its main function has been to develop a sophisticated system of baseline data about the outcome of patients treated in a specialised spinal injuries unit, which should prove very useful in the future to compare methods of treatment, either in the same centre, or with other centres using different methods of treatment. It is to be hoped that this system will be able to be adopted by other spinal units in Australia in the future so that controlled studies of different treatment methods can be conducted. The system has also proven to be invaluable to staff of the unit as a self audit of its performance, for example to be able to closely monitor the incidence of various complications of spinal paralysis, such as outcomes of urinary tract management, length of stay in hospital, and the results of the rehabilitation programme. Information has also been able to be made rapidly available to various outside bodies requiring information about spinal cord injuries and this should prove useful in monitoring the incidence of injuries, particularly with prevention in mind.

The system developed so far has been confined to the first admission to hospital. Clearly, it will need to be extended to follow up of patients after discharge from the unit, and this is planned as the next stage of the study.

Analysis of this large series of patients treated at the Austin Hospital has supported the basically conservative approach of treatment to the spinal injury, supplemented by surgery in selected cases, has vindicated the unit's management of the neurogenic bladder (though there is room for improvement), and has justified the relatively high cost of treatment of these injuries through the low mortality rate and the high proportion of healthy, independent disabled people able to return to the community.

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DISCUSSION OF DR. BURKE'S PAPER

Dr. P. Last: This is a model that the other spinal injury units most certainly should follow and I hope they will. However, the International Classification of Impairments, Disabilities and Handicaps, the ICIDH, is of great value in assessing outcome. We have been using it at Julia Farr Centre now for more than two years and are very happy with it; it is very reliable and stable in terms of impairment assessment. With disabilities, the functional results of impairment, there is a fluctuation in performance from day to day and there is a fluctuation in the value judgement of the individual observers. In our particular setting, assessing handicap has not proved useful, whereas in your setting it would be absolutely crucial. I would like to publicise the ICIDH and I urge that it be added as an additional component in your assessment and recording process, if you don't already do that.

Dr. D. Burke: The reason we haven't used it is that our system was developed before the ICIDH was available, and it is too complicated for our purpose. It requires a mainframe computer to analyse all the data and we've kept our method as simple as possible because we have to rely on therapists and patients to tell us whether they can do or can not do, or whether they require assistance and so on. Ours is very much a functional assessment of the patient, defined as: can you do it completely independently, or do you require assistance of any sort at all, or are you completely dependent? 1, 2, 3 - very simple!

Mr. D. Simpson: Your figures for early admission to your unit are very creditable, notably for the first six hours. How did you do this? Was it by a good organizational system, bypassing other hospitals? Also, how worthwhile is it in view of your conservative attitude towards acute management of spinal injuries? Do you see yourselves as having gained very much from the percentage of early admissions which is certainly much better than other States in Australia are reporting?

Dr. D. Burke: The system developed through aggressive practices of David Cheshire, my predecessor, who persuaded doctors throughout the States of Victoria and Tasmania to send on patients immediately. And now it is the accepted thing in the two States that immediately a spinal injury is diagnosed or suspected it is sent to the spinal unit. That is helped by cooperation from the ambulance services, particularly the air ambulance services.

We have not analysed the value of this as yet. We have the information to separate out the early admissions from the late admissions and see whether there have been any improved results as far as spinal stability or spinal cord recovery is concerned. Also, it would be very useful to compare our results with those for similar-timed admissions reported by John Yeo in Sydney who uses hyperbaric oxygen. The potential for this work is only just being realised. We have established a system and a set of baseline data and now we are going to start using it sensibly and usefully.

Dr. G. Trinca: To add to those comments: the system with ambulance services, in Melbourne anyway, is that if there is any suspicion of a spinal cord injury, patients are not taken from ambulance when they attend a hospital other than a spinal unit. Patients are examined in the ambulance and if there is any suspicion of spinal cord injury they are transferred to the Spinal Unit at the Austin Hospital. That saves some delay. The only time when the patient is removed, and only after medical inspection, is if there is a need for stabilization of other serious multiple injuries before transferral.

Dr. D. Burke: There are other parts to it. The patient is taken directly to the Spinal Unit, not through the Casualty Department of the Austin Hospital. Consequently, the handling of the patient is all done by experienced spinal unit staff, under my supervision and my deputy's supervision. With our own orderlies handling patients there is no inexpert handling of the patients from the moment that they arrive at the Austin Hospital. Whether that matters or not I don't know; that needs to be tested as well.

Dr. G. Trinca: If a spinal injury is suspected, then they will take them and that's a very important thing. There is no objection to even a suspicion.

Dr. H. Pang: Just a brief point on rugby union. Last year the Federal Minister for Sport gave the University of Wollongong a substantial grant to enable them to undertake an investigation to show that the main injuries are caused by scrums which collapse.

Dr. D. Burke: I did at one stage gather information from all the other spinal units in Australia plus the two in New Zealand, plus one in Cape Town, South Africa and wrote a paper which I submitted to the Australian Medical Journal. It was rejected as being uninteresting to them. But it clearly showed a very much higher incidence of spinal cord injuries from rugby football as compared to Australian rules football.

Dr. P. Last: How many of your high-level quads are ventilator dependent and do you have any of those at home on that basis?

Dr. D. Burke: Within my time, which goes up to mid 1982, the answer is none. Since then there have been a few. That may be due to a change in speed of admission to hospital, or perhaps it's a change in attitude of the current medical director as compared to myself.

Mr. G. Noonan: Does your data base have any indication of the factors in a road crash that may lead to spinal cord injury?

Dr. D. Burke: The data simply indicate position in the car, seatbelt wearing and what sort of accident it was, run off the road, collision and so on. Current research by one of my recent registrars, Dr. Joe Toscano, is accumulating much more detailed information, physical, psychological and historical, from a wide variety of observations and witnesses. He hopes to find out if there is any deterioration neurologically between the accident and admission to the Austin Hospital, by interviewing people who saw that patient along the way. Now that is of course subject to all sorts of errors but there are indications of some very interesting results.

BIOMECHANICS AND SEQUELAE OF IMPACTS TO THE MID AND LOWER FACIAL REGION IN RELATION TO THE ROAD ACCIDENT SITUATION

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ABSTRACT

The sequelae following any impact to the mandible depend on the position of the mandible at the time of impact, whether closure occurred as a result of the impact and the magnitude and direction of the impact force. If the mandible is struck by sufficient impact force from below, a variable amount of this force is transmitted to the skull and brain, either directly through the temporomandibular joints, or indirectly in a vertical direction through the teeth and mid-facial skeleton. Resultant force transmission causes different acceleration effects to the brain. Direct transmission usually causes a predominance of linear acceleration effects, while indirect transmission usually causes a predominance of rotational acceleration effects. Frontal impacts to the maxilla, by comparison, will cause mainly linear acceleration effects. Generally, more force transmission occurs following mandibular impact compared to an equivalent impact to the maxilla, as fracturing occurs at lower force levels in the maxilla resulting in some energy absorption. The sequelae following maxillary and mandibular impacts may cause serious cerebral injuries by acceleration effects.

1. INTRODUCTION

Trauma to the face occurs commonly in the road accident situation. In motor vehicle accidents injury to the facial region is frequent, comprising about one-third of all injuries sustained [1,2]. Such injuries are usually caused by impact against the windscreen, steering wheel or instrument panel [1,2]. The use of seat belts has reduced the frequency of all types of facial injury by over a quarter and the frequency of the most severe types of facial injuries by about two-thirds [1,2]. In a motor vehicle accident, the type and extent of facial injury sustained depends, inter alia, on the crash configuration, the use of seat belts, the area of face contacted and the magnitude and direction of the forces involved [1,3,4]. In a recent study of facial fractures in Australia, it was found that road accidents were the commonest single cause, comprising 32 percent, but significantly were responsible for 97.5 percent of the most severe mid-facial injuries [5]. The ratio of occurrence of mid-facial to mandibular fractures sustained in road accidents is approximately 1 to 0.7; the commonest maxillary fracture seen is mainly the Le Fort II type, and that for the mandible is a fractured condyle [2]. Also the most frequently occurring other injury associated with mid and lower facial fractures is concussion or other types of closed head injury [2]. An increase in the incidence of facial fractures sustained by rear seat passengers has been noticed in recent years and is thought to be due to the head colliding with fixed head restraints on the front seats [6]. Finally, in motorcycle accidents, it is estimated that about 40 percent of injuries occur to the facial region, which are most commonly associated with wearing an open-face helmet [7].

Impact forces to the face may cause two main types of injury:

i) Injuries at the site of impact, such as soft tissue injury and fractures of the underlying bone. Such fractures may extend beyond the site of impact along lines of bone weakness.

   These impact injuries can be reduced by increasing external protection to the area of impact as, for example, with the use of protective full-face helmets by motorcyclists; further reduction of the magnitude of injury is gained by use of energy-absorbing lining in helmets [8].

ii) Additionally, acceleration of the head may occur and result in focal or diffuse types of cerebral injury. Acceleration of the head can be reduced by body restraint using a seat belt, but is virtually unaffected by the wearing of a helmet [8]. It is possible that, because of the increased mass when wearing a helmet, acceleration effects could actually be increased [9].

The acceleration effects are especially related to the site of impact on the face and the magnitude and direction of the impacting force. If the direction of the impacting force passes through the centre of gravity of the head and causes the head to move in a straight line, linear acceleration occurs. This is exemplified in boxing with the straight punch to the face [10]. Where the direction is at right angles to the axis of linear acceleration, rotational acceleration occurs. This is exemplified in boxing with the uppercut punch [10]. Usually the impact axis does not correspond exactly to either directional axis and combined acceleration effects are caused. Also multiple impacts frequently occur in the road accident situation.

It is known that the effects of either type of acceleration of the head cause different injury patterns in the brain and it is believed that rotational acceleration is the most injurious because of the amount of shear stress it induces in the brain [10].

The ability of the head to move freely affects the outcome of an impact to the facial region. Nahum et al [11] showed that by using a restrained head model the magnitude of the impact force was increased by about a third above that for a freely mobile head model. Gurdjian [12] supported these concepts and added that with a restrained head there was an increased severity of direct impact injuries, while with the unrestrained head the severity of acceleration injuries was increased.

2. TOLERANCE OF FACIAL TISSUES

The soft tissues of the face lessen the force of impact by a considerable amount, estimated at about one-quarter [11]. This is due to energy absorption with increased duration and distribution of the impact [12,13]. This protective quality is related to plastic and elastic qualities of the tissues. However, the soft tissues are thin over the chin and lower surface of the mandible and less force reduction occurs with impacts to this area [14]. The midface basically consists of cavities with reinforced vertical buttresses, i.e. the nasomaxillary, zygomatic and pterygomaxillary buttresses [15]. These buttresses transmit loads to the cranial base, and the skeletal architecture is especially resistant to vertical forces [15]. However, because of the thinness of the maxillary bones, there is little resistance to frontal impacts and when these occur, fracturing occurs early [1,15].

The mandible, by comparison, has a dense cancellous structure and structurally it resembles a rigid U-shaped arch with hinge joints at either end. It is reinforced in the region of the mental prominence and along the lower border. There is also a strong internal buttress, the main mandibular buttress, which extends from the mental prominence to the condyle head on either side. Therefore the mandible is much more resistant to frontal impacts, than is the maxilla. Also, because of the shape of the mandible, any dynamic forces applied to it are distributed throughout its length, as occurs in any solid arch structure [16]. Finally, the mandible is generally more liable than the maxilla to sustain injury, because it is more prominent and therefore more exposed to impacts [13].

Tests of the facial bones for tolerance to fracture show that a considerable range exists, depending especially on actual impact site and direction of the impact [16]. Nahum [13] showed that the range of tolerance of the mandible to frontal impact was much higher than that for lateral impacts, while the maxilla had a relatively low fracture tolerance level (see Figure 1). It should be understood that forces of 1000 lbs are easily generated in medium speed motor vehicle crashes when the head impacts on, for example, the windscreen if a seat belt is not being worn [13]. However, no testing has been done yet to define the fracture tolerance of the maxilla and mandible to vertical impacts delivered to the inferior surface of the mandible, which is a common impact direction.

3. FORCE TRANSMISSION FOLLOWING FACIAL IMPACT

If a force is applied to a bone and fracture occurs, some of the force is absorbed in creating the fracture [13]. Maxillo-cranial force transmission occurs to a limited extent following frontal impact, due to the low fracture tolerance of the maxilla. However, impacts to the mandible can be transferred to the maxilla through the occlusion when the mandible is struck from below. As mentioned previously, the mid-face is structured to withstand high magnitude forces in this direction. Such forces may cause rotational acceleration of the skull.

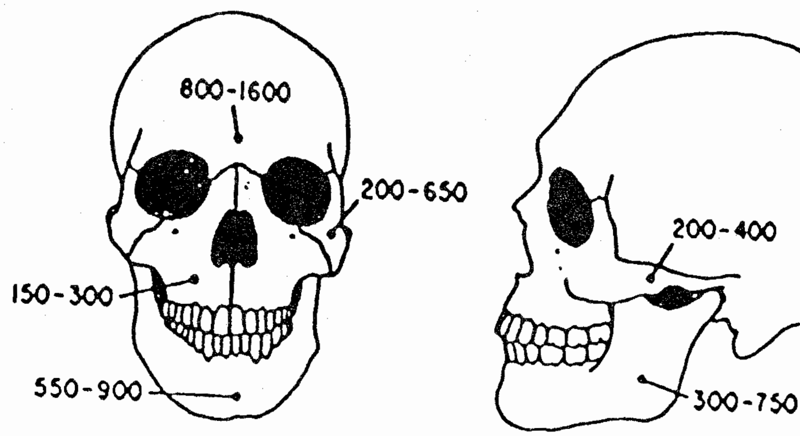

Fig. 1: Fracture tolerance levels of facial bones (lbs.) [13]

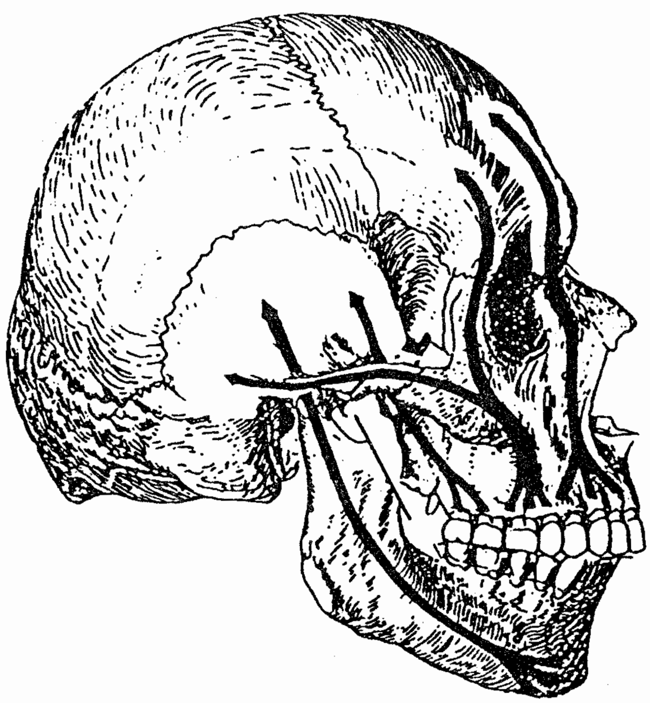

Fig. 2: Force transmission following mandibular impact, from either in front or below.

Mandibulo-cranial force transmission occurs only following impacts which are delivered in an upwards direction to the front or side of the mandible. Impacts from directly in front to the chin point are dissipated to a variable degree with forced opening of the mandible and by the soft tissues of the front of the neck [11]. Similarly, horizontal impacts to the lateral aspect of the mandible are dissipated to a variable degree by sidewards movement of the mandible.

However, impacts from below to the front or side of the mandible will cause closure of the jaws, if they are not already closed and by this action, force is transferred to the skull through the temporo-mandibular joints causing mainly linear acceleration effects, or through the occlusion and midfacial buttresses causing mainly rotational acceleration effects. Depending on the actual direction of force, there will be varying components of either type of acceleration produced (see Figure 2).

4. PREVIOUS EXPERIMENTAL RESEARCH ON MANDIBULO-CRANIAL FORCE TRANSMISSION

In 1967 Hickey et al [17] used an impact-producing mechanism (linear impactor) to deliver a controlled force from a given distance to the inferior border of the chin of a cadaver. Changes in intra-cranial pressure were measured by means of a fluid-filled system after a hole was drilled through the skull and a plastic tube inserted just inside the skull. The plastic tube and available space inside the skull were filled with normal saline solution and the tube was connected to a pressure transducer. An indication of bone deformation was obtained in the temporal region where a strain gauge was cemented to the bone. An accelerometer was placed at the point of impact on the chin.

Intracranial pressure and skull deformation were measured following impacts to the mandible with the teeth closed, first without and then with a mouthguard in place. There was less increase of intracranial pressure when the mouthguard was in place, and bone deformation was also decreased moderately when compared to the non-mouthguard situation.

The application of these findings was important to Sports Medicine, but may also be utilised particularly in improved protection for the motorcyclist.

5. PROTECTIVE HELMETS

Use of a full-face motorcycle helmet provides facial protection in addition to skull protection, by force distribution and energy absorption [4,7]. Cannell et al [7] recently showed the superiority of the full-face helmet compared to the open-face helmet in motorcycle accidents; persons wearing full-face helmets sustained considerably less facial injuries of all types. It had been shown previously that the great majority of head impacts occurred to the facial region. However this part of the helmet is not subjected to impact tolerance testing. At present there is strong pressure to repeal motorcycle helmet regulations, as has occurred in the USA [4].

Finally, currently available bicycle helmets are primarily designed for skull protection; no specific enquiry of facial injuries sustained by cyclists has been made but it is known that the incidence is quite high [4].

6. SEAT BELTS

With an unrestrained driver in a head on collision, the greater the force of impact the more likely is the head to be propelled forwards and to collide with the windscreen. In accidents of less impact force, the head will tend to collide with the steering wheel or instrument panel [12].

With a rigid seat belt, head movement still occurs following a head-on collision, but is reduced compared to the unrestrained situation, and the face is much less likely to strike anything. However, if impact forces are sufficiently great, the lower part of the face may strike the steering wheel rim. Studies have shown that inertia-activated seat belts do not prevent facial injuries as completely as rigid seat belts because facial impact often occurs before the system is activated [4].

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DISCUSSION OF DR. CHAPMAN'S PAPER

We apologise for the fact that, due to a technical fault, a record of this discussion was not made.

BICYCLE HELMET DESIGN TO AUSTRALIAN STANDARDS

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ABSTRACT

The Australian Standard for bicycle helmets is AS 2063.1: Lightweight Protective Helmets. When released in 1977, it was one of the first Standards to address the needs of bicycle riders. Its requirements were so stringent that it was not until 1982 that a helmet could be approved by the Standards Association as conforming to the Standard. The Standard is only design restrictive in that it requires a hard shell, a means of absorbing an impact and a retention system.
All other requirements are performance requirements and the appropriate tests are fully specified.

1. CURRENT AUSTRALIAN STANDARDS

The current Australian Standard for cyclists' helmets is AS 2063, Part 1 - 1982 [1] which was first published in 1977. It is a generic Standard, covering lightweight protective helmets for use in pedal cycling, horse riding and other similar activities requiring similar protection.

As a result of recent public pressure, the Standards Association of Australia (SAA) is in the process of developing a Standard specifically for pedal cycle riders. This will be known as Australian Standard AS 2063 Part 2. The Standard was recently released as a draft Standard for public comment as DR 85321 [2]. It is expected that it will be released as a Standard early in 1986. It calls up the requirements of AS 2063 Part 1 with a further requirement of helmet retention system stability.

2. DESIGN REQUIREMENTS

The requirements of AS 2063 Part 1 that are design restrictive are few and are covered by clauses 4.1, 4.1.2, 4.2, 4.3, 4.4., namely:

> "4.1.1. Components. The helmet shall consist of:
>
> (a) a hard shell;
> (b) a means of absorbing impact energy; and
> (c) a retention system.
>
> All components of this protective system shall be permanently attached to one another.

4.1.2. Attachment of Components. The helmet shall have no internal projections likely to cause injury to the wearer in the event of an accident nor shall any component be fitted to the helmet in such a way that it is likely to cause injury to the wearer in the event of any accident.

4.2 Retention System. The retention system shall be constructed so that when properly fastened the helmet cannot be readily dislodged from its normal position on the wearer's head under impact conditions.

The design of the retention system shall be such that no component is detachable from the components attached to the helmet, e.g. a component linking the two halves of the system.

4.3 External Projections. Rigid projections outside the shell shall be limited to those required for essential accessories and shall not protrude more than 5mm.

4.4 Ventilation Openings. The helmet may have any number of ventilation openings, provided that the projected area normal to the headform surface does not excess 400 mm^2 for the largest of such openings. It shall not be possible to pass a rod 20 mm in diameter through any of the openings."

Clause 4.1.1. requires three basic components, namely:

the hard shell;
the aborbing layer; and
the retention system.

The hard shell is required to protect the rider from abrasion such as may be received from sliding across the pavement, but more importantly, to spread the impact so that it may be absorbed by a greater area of the impact attenuation medium. Clause 4.6 of the Standard requires the manufacturer to give due consideration to the material used for this outer shell and the materials used currently in approved helmets are:

Polyester/fibreglass laminate
A.B.S.
P.B.T. (Valox)

Other materials that may also be suitable include:

Polycarbonate

These materials are chosen after considering their ultra violet ray properties, their resistance to various substances with which they may come into contact during their life, and ageing properties, in addition to the mechanical properties.

The impact absorbing layer is almost always expanded polystyrene foam. One approved helmet has a cradle system similar to industrial safety helmets. The polystyrene foam is of varying density and thickness to achieve the energy absorbing characteristics required. As with most engineering problems, a trade off is required to achieve the specification. Too thick an absorbing layer will result in too bulky a helmet; too thin a layer of dense foam will result in too low a safety margin as well as manufacturing difficulties.

Work by Gale and Mills [3] and others indicate that polystyrene foam is an almost ideal medium in that it readily absorbs energy and has little rebound. At high strain rates (such as experienced in accidents) it is an almost ideal medium. Densities currently used by Australian manufacturers are in the range of 50-65 grams/litre in the dry condition.

The retention system places such a high load requirement on the straps that simple fastening systems such as velcro and press studs are not able to meet the requirements. As will be seen under the performance requirements, these levels are very high. This area of the Standard does not address the stability of the retention system and it is to this area that the proposed AS 2063, Part 2 addresses itself.

The external projection and ventilation requirements are straightforward and require only simple measurements. Ventilation requirements are currently the subject of much discussion within the SAA's Committees. However, it is considered that much work needs to be done before this area is defined in more detail, and may be defined by the market place rather than by the Standard.

3. PERFORMANCE REQUIREMENTS

AS 2063, Part 1, defines four tests that must be passed and these are covered in Clauses 6.2, 6.3, 6.4, 6.5, namely:

"6.2 Impact Energy Attenuation

6.2.1 Test Sites. The helmet shall be tested at four sites above the test line defined in AS 2512.1, Clause 3.12, none of which shall be within one-sixth of the maximum helmet circumference of any other test site or within 5 mm of a ventilation opening where these are provided.

6.2.2 Requirement. When the helmet is tested in accordance with AS 2512.3 using a flat anvil only and a free-fall height of 1500 (+30-5) mm, the headform acceleration shall not exceed -

(a) 400 g peak;
(b) 200 g for a cumulative duration of 3.0 ms; and
(c) 150 g for a cumulative duration of 6.0 ms.

None of the protective components shall become detached under test impact.

6.3 Resistance to Penetration

6.3.1 Test sites. The helmet shall be tested at a minimum of two test sites above the test line defined in AS 2512.1, Clause 3.12, none of which shall be a fastener or other rigid projection or within 5 mm of a ventilation opening where these are provided. Impact points shall be at least 75 mm apart and at least 75 mm from the centres of any impacts applied during the tests specified in Clause 6.2.

6.3.2 Requirement. When the helmet is tested in accordance with AS 2512.4 using a fall height of 1000 ± 15 mm, the striker shall not contact the surface of the test headform.

6.4 Retention System Test.

When the retention system of each helmet is subjected to a preliminary force of 225 ± 5 N applied for 30 s and then an additional force of 500 ± 5 N applied for 120 s in accordance with AS 2512.5, the retention system or its attachments shall not separate, and the elongation between the preliminary load condition and the test load shall not exceed 25 mm.

Where the retention system consists of components which can be independently fastened without securing the complete assembly, each such component shall independently comply with the requirements of this Clause.

6.5 Horizontal Peripheral Vision Clearance.

When measured at the basic plane in accordance with AS 2512.6, the peripheral vision clearance of the helmet shall be not less than 105 degrees on each side of the mid-sagittal plane. In addition the brow opening of the helmet shall be at least 25 mm above all points in the basic plane that are within the specified angle of peripheral vision clearance."

The performance requirements of AS 2063 Part 1 were such at the time of its release in 1977 that there was no helmet that could be approved to the Standard. It was not until 1982 that the Guardian helmet could be approved, closely followed by the Stackhat. Both of these are Australian made helmets. Subsequently, several imported helmets have been approved by the SAA to carry their certification mark. It is significant that some highly respected helmets available cannot meet the Australian requirements, although they surpass the requirements of their country of origin. These helmets includes such names as Bell, Hanna Pro, MSR and OGK.

4. DISCUSSION ON PERFORMANCE REQUIREMENTS

4.1 Impact energy attenuation

The Impact Energy Attenuation (Clause 6.2) is perhaps the most critical, because it measures the helmet's ability to absorb the impact by the cyclist. This was recognised recently in the Transafe Report of the House of Representatives Standing Committee on Road Safety [4]: on the issue of pedal cyclists' helmets, it was recommended that:

"(a) the Attorney General declare AS 2063.2 as a Product Safety Standard under the Trade Practices Act as soon as practicable following the finalisation of the long term revision of the Standard.

(b) until the Product Safety Standard above can be declared, the Attorney General declare unsafe those bicycle helmets which do not meet the impact energy attenuation requirements of the current AS 2063.1.

(c) bona fide toy helmets be permanently labelled that the helmet is a toy only and should not be used for safety purposes.

When compared with the motorcycle helmet requirements, that test level is somewhat lower, reflecting the lower impact energy levels that are likely to occur. These test levels must be achieved with a much lower helmet mass as the wearer is exerting considerable energy in propelling him- or her-self along. If compared with overseas Standards, such as the American ANSI Z90.1, the test level required by the Australian Standard is much higher. The drop height for Australia is 1.5 m and for America is 1.0 m.

Test requirements for Australia are that the deceleration shall not exceed 400 g, shall not be at 200 g for more than 3.0 ms, and shall not be at 150 g for more than 6.0 ms. This is illustrated in Fig. 1. When a helmet has satisfactory impact attenuation properties the energy pulse is similar to Fig. 2. If insufficient absorbing media is present the pulse may appear as Fig. 3.

As the amount of energy is constant the area under the curve will remain constant so the pulse which represents a failure will be high and narrow when compared with a satisfactory result. Compressible foams used for comfort liners and as the only liner in some unsatisfactory helmets will initially compress at very low test levels and then will act as a solid media giving little or no energy impact attenuation.

A material that does not remain deformed after an impact but reverts to its original shape will submit the head to an equivalent of a secondary impact.

4.2 Penetration resistance

The penetration resistance is to my knowledge a unique test for bicycle helmets. Other Standards use a hemispherical anvil with an energy attenuation. For the Australian requirement a striker which consists of a cone of an included angle of 60 degrees, a point radius of 0.5 mm and a mass of 3 kg is dropped from a height of 1.0 m onto the helmet. This test was initially for the motorcycle helmet to test the quality of the fibreglass laminate used. It was not to my belief intended to represent any particular object that a cyclist may strike in an accident situation. The continued retention of the test is being considered by the SAA's Committee on pedal cyclists' helmets.

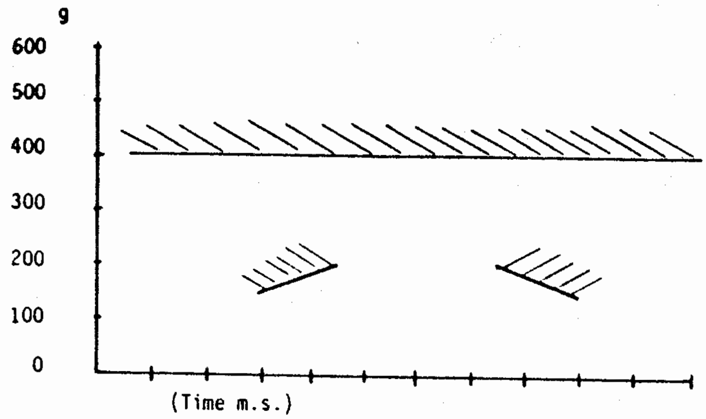

Fig. 1: Limits of deceleration permitted

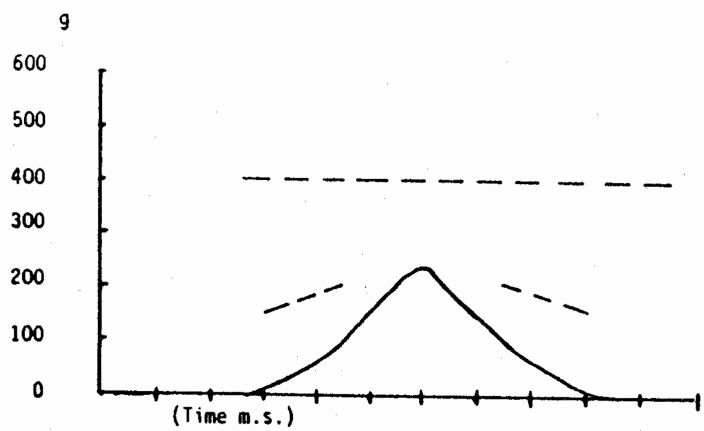

Fig. 2: An acceptable deceleration curve

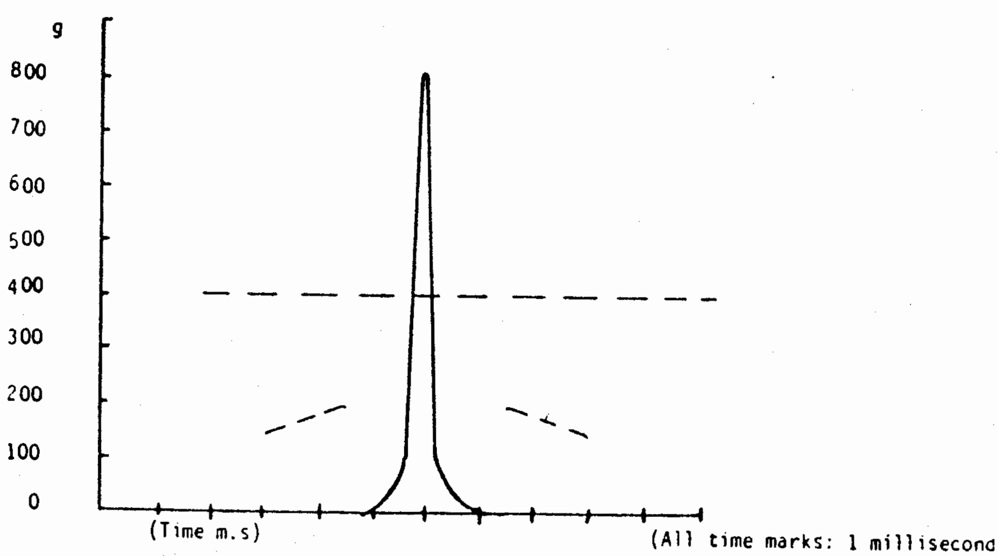

Fig. 3: An unacceptable deceleration curve

4.3 Retention system test

This test is primarily a test of the strength of the retention system and its attachment to the helmet. A helmet strap is loaded with 225 N. The extension of the strap is noted and the load increased to 500 N. After 120 s the extension is not permitted to exceed 25 mm. As will be noted these test loads are rather high and therefore will preclude the use of such fixings as small plastic clips and velcro type tapes.

4.4 Horizontal peripheral vision clearance

A helmet that is so designed that it obstructs vision is in itself a safety hazard and this is simply a measurement test to ensure that vision is not restricted.

5. FUTURE DIRECTIONS

AS 2063.1 had a deficiency that recently came to light in the area of helmet stability on the head. This problem was addressed in the draft Standard DR 85321. A helmet is placed on a 150 headform conforming to 150 DIS 6220 Type A or J which has the chin area slightly modified to more accurately represent the bony structure of the jaw.

The SAA will be further considering the requirements of pedal cyclists and will review the requirements of:

- (a) penetration resistance;
- (b) ventiliation; and
- (c) helmet stability,

with the hope of presenting an even safer helmet for pedal cyclists.

6. CONCLUSION

It must be recognised that a helmet cannot protect a cyclist from all eventualities; however it can offer a significant measure of protection. The work of Dorsch indicates that a cyclist has 19 times more protection when wearing a hard shell helmet than with no helmet, which is a significantly increased level of protection. Australian Standard AS 2063.1 provides a hard shell helmet that offers this level of protection and is, I believe, one of the most stringent requirements specified.

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DISCUSSION OF MR. HAND'S PAPER

Dr. H. Pang: You mentioned the ventilation test only in passing. From a manufacturer's point of view could you offer us an opinion as to what difference a new ventilation standard would have on your process?

Mr. I. Hand: The ventilation requirement is something that will be defined in the marketplace. Obviously helmet ventilation requirements are different in the Northern Territory compared to Tasmania, and it is my belief that a standard cannot possibly specify at a reasonable cost a test that would be acceptable throughout Australia.

Mr. R. Niven: Are Australian manufacturers looking at costs, particularly for young children who fast outgrow a helmet of very small size. Also, what is your view of the statement "any helmet is better than none at all"?

Mr. I. Hand: We are conscious of cost. Competition in the marketplace to some degree will govern costs. AS 2063.1 is entirely a voluntary standard. As a manufacturing entity, we believe that it is worth our while to manufacture to that standard but we do address the question of cost the whole time and endeavour to keep the cost as low as possible. In relation to a young child it is my personal belief (and I emphasise personal belief) that a child less than seven should not be riding a two-wheeled push bike anyway and we seek to address that portion of the market up. There are other requirements and some protection for very young children may be beneficial, say in the case where they are carried by mother on a pushbike, in which a much lighter mass with a lower overall mechanical requirement could be quite helpful.

I do not subscribe to the view that a poor helmet is better than none. I think the classic answer is you put a $10 helmet on a $10 head, and a $40 helmet on a priceless head.

Mr. A. Whittle: In view of what Dr. Chapman said this morning, at some stage in the future will some steps be taken to redesign the helmet to prevent facial injuries?

Mr. I. Hand: This is a question of the requirements in the market place. There is nothing to prevent us from designing one now apart from the economics involved. To tool up to put a helmet in the marketplace would cost approximately $200,000 and that money must be spent before any return comes in. From a cyclist's point of view, some form of facial protection is likely to cause problems in terms of ventilation in that the cyclist is expending great amounts of energy and needs air for cooling. If the need is shown and the requirement is there in the marketplace, we would certainly be looking at it.

Mr. D. Simpson: Returning to the issue of a helmet for children under the age of seven: because a lot of children under seven do, in fact, ride bicycles, could Mr. Hand comment on the proposal that such a helmet should be purely a firm liner helmet like the Lil' Bell Shell for example, without a hard shell. What sort of protection would that give and what sort of a reduction in costs would it give?

Mr. I. Hand: On the protection side of it, it would certainly offer impact protection providing the head is not being scraped over the bitumen. If the head was being scraped over the bitumen then the polystyrene foam would be very rapidly worn away and offer no protection. On the question of cost, I think there would be a significant reduction but I couldn't be precise at present.

Mr. G. Rodsted: Considering the small size of the Australian market, the high costs of tooling up to make the product, and the cost benefits of wearing helmets, do you believe that the government should provide support for manufacturers in initial tooling up, design and development programs?

Mr. I. Hand: I believe that the government should - and that there are some mechanisms available such as project grants. Through the results of the House of Representatives' Committee the government obviously has become very aware of the benefits to be had by helmet wearing and I think that manufacturers and potential manufacturers should be encouraged in that area.

Ms. C. Boughton: Regarding the penetration test and the drop test onto a steel plate, what are your own views about how this reflects the real world situation that the helmet has to meet?

Mr. I. Hand: I believe that the energy impact attenuation requirements are excellent and that any helmet manufactured should meet those requirements. I have no qualms about that and there may be some argument, which I wouldn't be against, to go to an even higher level of drop to represent perhaps a further height fall off the top of a bicycle. I have no qualms with the current height for energy impact attentuation. I believe that further work needs to be done in the area of penetration resistance because this does not represent the real world; however I understand it was originally devised as a quality control test for fibreglass laminates.

Dr. P. Last: A quick comment on the real world - one often sees school children riding to school with helmets on but the straps not done up. I appreciate that addition of velcro, at present optional, would add to the cost but nevertheless I suspect that a helmet held on by velcro is better than a helmet not held on at all.

Mr. I. Hand: Unfortunately if we are going to make a helmet to the Standard we cannot use the velcro-type fastener because it simply cannot withstand the load required by the Standard as it is currently.

Dr. P. Last: I appreciate that. My point was, though, that if you could put it on in addition, that's a simple thing to do.

Mr. I. Hand: It's always possible. The Standards Committee at this point in time is investigating the question of the retention test and I think that will be the appropriate forum.

Dr. P. Tamblyn: I would like to support Dr. Last's comment about helmets not being done up. I have observed in fatal motorcycle accidents that quite a proportion of the helmets actually come off during the impact and that the straps are found undone. It is not really possible to know whether they were ever done up in the first place or whether they were done up and the buckles failed. If they were not done up in the first place, I guess it's because the buckles are too difficult to do up. I think there should be an effective buckling system that can be operated one-handed.

Mr. I. Hand: The Standards Committee should question whether that retention test load is in fact too high - 500 newtons (about 125 pounds) is a very heavy load that a retention system must pass. There is no point in manufacturing a helmet that doesn't conform to that Standard in all respects because then we are not able to offer to the cycling public a helmet assured of maintaining a certain level of protection.

Mr. G. Rodsted: There is a very real danger, with the Standard being enhanced all the time as it is at the moment, of making the helmet out of the range of purchasing power of the average consumer?

Mr. I. Hand: I think that's fair comment. Any improvement to the Standard almost always will cost somewhere along the line. There are very few improvements I have seen that in actual fact will cost less money in the end product.

AUSTRALIAN HELMET STANDARDS AND THEIR ENFORCEMENT

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Vehicle Users' Helmets

ABSTRACT

Since 1975, Australian helmet and visor standards have progressively moved from an advisory to a mandatory role for vehicle users' helmets, with bicycle helmets now beginning to follow a similar path. The 1975-85 developments in the AS 1698, AS 1609 and AS 2630 standards are traced, and the changes in the emphasis in the uses made of the Standards discussed. The convergence of visor and motor vehicle helmet standards have been the precursors to a rising need to make the Standards revision process more responsive, better informed technically and adaptive to the now rapidly changing product designs, and to consider the best methods for ensuring similar capabilities for the mandating Authorities. The minority role that Australian manufacturing industry presently plays in all types of vehicle users' helmets places considerable emphasis on FMVSS, ECE and EEC standards processes, in addition to the traditional role of the ISO. Anthropometric survey data is now needed for the Australian population to further several varieties of helmet test requirements, and there is a demonstrated need for a higher and continuing level of Federal technical research support for this key mandated national Standard.

1. INTRODUCTION

Helmet standards in Australia followed BSI for some time, moving to the FMVSS-influenced AS 1698 Standard in the late 1970's. This shift had little significance until the advent of universal mandation of the Standard, following the recommendations to that effect by the Federal House of Representatives Standing Committee on Road Safety [1]. The small number of local Australian manufacturers of either bicycle or motor vehicle helmets places a strong reliance on external markets for supplies, and a consequential importance on coordination with overseas Standards. The influence of mandation has been substantial in most countries, and the regulatory responses have differed.

The continuing brisk rate of change in helmet designs (and the secondary safety and other functions now being added as a marketing result of the legal enforcement of vehicle users' helmets) requires continuing technical input from within Australia to maintain the Standard as an effective and consumer-endorsed measure. The factual basis for this updating is wanting in infrastructure, partly due to a perception that administrative action has terminated the need for continuing investment in both technical manpower and up to date Australian-specific information within Australia. Without these, the credible operation of the Standard is at risk.

2. THE AUSTRALIAN STANDARDS

The relevant Australian Standards to this discussion are as follows:

(a) AS 1698 ... Vehicle Users' Helmets [2]

(b) AS 2063.x ... General Purpose Helmets [3] (with subsidiary Standards appearing (.x))

(c) AS 1609 ... Automotive Eye Protection [4]

(d) AS 2512.x ... Helmet Test Procedures (with several subsidiary Standards (.x)) [5]

The relationships between these different Standards are straightforward. AS 1698 calls up AS 1609 and the several different helmet test procedure standards AS 2512.x (where .x refers to the series of separate subsections dealing with retention, headforms, penetration etc). AS 2063 also calls up 2512.x, and thus the AS 2512.x Standards require cooperation between at least these two committees, and others in the helmet area are also involved. These two helmet Standards share the testing procedures and headforms, but at different levels of performance. The splitting of the test procedures from the helmet Standards themselves was an initiative taken after the House of Representatives Standing Committee on Road Safety Report on Motorcycle and Bicycle Safety [1], but the intent of this process has apparently not quite been followed through, with the development of a separate Draft retention testing specification under 2063.2, rather than as a jointly agreed additional 2512.x Draft.

One further link between Standards that is worth noting is the link between AS 1609 and the AS 1607 Standard for sunglass lenses, which provides links between permissible levels of tinting, and the physical materials which can comply.

The current position in terms of legal mandation is as follows:

AS 1698 ..... helmets marked to this Standard are mandated for all motorcycle riders operating in a public place in all States and Territories. All of the State and National car, go-kart and motorcycle competition authorising bodies require helmets to meet this Standard, although some have additional requirements. AS 1698 calls up AS 1609 and AS 2512.x, so that these Standards too have mandated effect. The Federal Attorney General's Department has legislated for the AS 1698 mark to be a mandated requirement for all (motor) vehicle users' helmet sales and imports.

AS 1609 ..... automotive eye protection supplied with the helmet at the point of sale must comply with this Standard. If the goods are NOT sold with the helmet, then an AS 1609 mark is not required at the point of sale.

AS 2063 ..... general purpose helmets are not mandated for use by cyclists or other types of user, but the Australian Autocycle Union was originally prepared to accept this marking for "events where speed is not a determining factor", and this appears in the national regulations handbook (the General Competition Regulations) for the years immediately after the AS 2063 was set up.

3. RESPONSIBILITIES FOR HELMET STANDARDS ENFORCEMENT

The now complete take-up of the AS 1698 Standard by State and Federal bodies has brought the State Departments of Consumer Affairs and the Trade Practices Commission (now the Attorney General's Department) into the enforcement network. The calling up of the specific issue and amendment to the AS 1698 Standard into Federal law is not automatic, and at one point there was a three year delay between the issue of an Amendment and the calling up of the mandated Standard to incorporate it.

The conventional enforcement of helmet usage is the province of the Police in all States. The requirement is to ensure that the helmets in use in public places bear the AS 1698 Mark: some States have usage exemption provisions, but if a helmet is used it must comply with AS 1698 and be marked as such.

Bicycle helmets are following along behind a similar legislative path, but rather more slowly. The AS 2063 Standard was asked to cover perhaps too wide a range of client organisations and users, and, while attaining a reasonable level of impact attenuation and access to the continuing batch sampling quality control procedures of SAA, several major groups of AS 2063 users are now moving to obtain associated Standards, calling up AS 2063 and adding specialised requirements to it to produce AS 2063.2, for example. The recently completed Draft mentioned earlier in connection with AS 2512.x (DR 85322) gives initial form to this proposal for bicycle users; covering ventilation, retention system effectiveness and marking.

The voluntary levels of usage of bicycle helmets are rising, but are not yet at a point where any Government has felt able to move to mandating their use. When this point arrives, the enforcement issues will be significant, as the majority of bicycle riders are minors, and it is only recently that substantive attention has been devoted by Australian Police Forces to bicycle law enforcement.

The AS 2063 Standard is, however, being steadily promoted for mandated use by various organised groups of horse and pony riders, where the mandation of their use in competition is being pressed for by significant numbers of clubs.

The different levels of enforcement in effect for helmets are therefore as follows:

(a) Customs Imports and Point of Sale - AS 1698, AS 1609

(b) State Road Traffic Regulations - AS 1698, AS 1609

(c) Competition Authorising Bodies - AS 2063, AS 1698, AS 1609

(d) Standards called by the above - AS 2512, AS 1067 [6], AS 1337 [7].

There can be conflicts in interpretation between these different levels and types of body, and these have indeed arisen.

4. THE EFFECTS OF THE LOCATION OF RESPONSIBILITY FOR THE STANDARD

One of the major differences between Australia and other countries is the lack of a direct Federal role in the support, maintenance and development of these Standards.

The Federal bodies with responsibilities for the mandation and exercise of the Standard are all in the Consumer Protection field, in Point of Sale and Import areas. These types of Departments have rarely had the resources or the skilled manpower to work with the Standard and test for compliance independently. Their role is a different one, and they have no funds or facilities for their own independent testing for compliance with the certification and performance aspects of Standards with which they are concerned.

This highlights the significance of the choice made by Australia to maintain motor vehicle helmets as SAA Standards, enforced by consumer and user legislation alone.

The European Economic Community (EEC) has a series of motor vehicle Standards which include motorcycle helmets (as ECE Regulation 22). These Regulations are developed in close association with the UN Economic Commission for Europe (ECE), through Working Party 29 on vehicle regulations. Australia is a signatory to this Commission, and in general has a published policy of progressively moving from the FMVSS (US) wellspring to the ECE WP29 resource: this policy is being followed through in the drafting of the new form of the Australian Design Rules, although helmets are still being excluded from this process, and the enforcement and compliance mechanisms in Australia may well not follow the ECE/EEC patterns.

The other major source from which Australia has drawn the basis for vehicle-related Standards is the USA. Helmets in the USA are regulated under a Federal Motor Vehicle Safety Standard (FMVSS 218). This started life as an endorsement of the ANSI Z90.1-1971 Standard, which is enforced as part of the FMVSS system, and is subject to the same strictures and self-certification procedures.

In both cases the helmet is regarded in - and the enforcement system is geared to respond to - a Governmental Vehicle Regulation framework, with the testing, certification and technical backup that comes with this choice of mechanism. In the US case the enforcement mechanisms used also include the withholding of Federal road funding as an additional lever on State legislatures.

There are other benefits in having a system of this type: the regular publishing of performance data from helmet testing (see, for example, Liu [8]), and the steady flow of technical research funding to maintain the technical basis for the Standard. On the other side of the ledger, the very different mechanisms employed to update and to review the ANSI and FMVSS standards have led to a large gap between the two official US sources of standards specification, as the FMVSS process has proved to be slow to respond to changes.

The third option is provided by the Snell Foundation, which issues its own Standards [9] and endorses (rather than certifies) compliance of the helmet design to this Standard. Snell has always had the avowed aim of raising the impact resistance standards, rather than maintaining a standard for the broad market or, indeed, underpinning the quality control on a continuous batch sampling basis. Snell's aim is to push the leading edge of the impact protection capabilities of helmets, with implicit emphasis on racing car application needs, in recognition of the original participation of Peter Snell in this part of motor sport.

As a result of this approach, the Snell endorsement has high user credibility, and indeed is an ancilliary to the requirements of CAMS in Australia. Nevertheless, the batch sample quality control, and the field follow up procedures of the more formally-based SAA, FMVSS and EEC Standards are in general not available to the Snell mark. It is ironic that (generally uninformed and less than entirely accurate) controversy over the AS 1698 mark has led in some cases to a greater reliance by competition users on the legally weakly enforced Snell Foundation endorsement. This emphasises the need for continuing up-to-date user and technical information to be produced and released to maintain the credibility of the helmet Standard and its mandated enforcement.

It must be realised that the general span of a user's active involvement in motorcycling is usually considerably less than the five years from about 17 to 22, at the start of their road driving career. This places a special responsibility on road safety and legal enforcement and education bodies to keep up with this narrow age span cohort of the population.

The choice of SAA as the basic framework for helmet Standards setting, revision, certification and batch endorsement has the benefit of faster and more responsive reaction to changes in the market place and to technical change than the Federally-based Vehicle Design Regulation systems: this might surprise some people, but the record shows that this is generally the case. There are improvements required in the Standards mechanism to make the system work better.

A relevant and effective SAA Standards Review Board which covered the automotive and consumer aspects of this and related consumer Standards could help to reduce delays due to controversy over changes: better continuing research support from government would have the dual effect of improving the quality of the continuing technical input into the Committee, and abbreviating the delays in obtaining technical testing and investigative support on the issues as they arise.

5. SPECIFIC ISSUES WITH THE AUSTRALIAN HELMET STANDARDS

As a result of the difficulties in obtaining access to continuing testing and investigative support for the Standard, SAA recently produced a list of technical issues of concern to the Standard, and forwarded it to the appropriate national bodies.

The issues covered included retention of the helmet on the head in the case of an accident; treatment of attachments and projections; ventillation and cyclist issues; and monitoring performance in the field.

5.1 Retention of the helmet on the head in the case of an accident

The effects of having common factors across a range of helmet Standards are to increase the need for closer links between the committees concerned, and also to broaden the base of such communications. One example is the development of a draft for a new AS 2512.x as a result of helmet fitment problems with pedal cycle users of helmets approved to AS 2063, yet regarded as unsafe by the user groups. This was due to lack of user confidence in the ability of some of these helmets to be retained on the heads of a sizable fraction of the population in the case of an accident, due to the ease with which certain helmets could be statically pulled off some types of head shapes.

Essentially the problem was - and is - one of the appropriate shape of headform below the baseplanes defined in the Standards. This requires a headform to be adopted which defines both a chin position and a length of jaw abutment, in addition to some choice of rear cranial protrusion beyond the rear line of the neck.

This requirement is also one shared by the Vehicle Users' Helmet Committee: some suggestions were made by witnesses to the 1977 HORSCORS Enquiry [1] that some open face motorcycle helmets were prone to separating from the head, yet the chinstrap remained connected. A small study had been done by UNISEARCH at the University of NSW, for the Auto Cycle Union of NSW, which suggested that there could indeed be a problem, as their static tests seemed to show that certain combinations of human heads and particular helmets could be dislodged by rotation by a static force. Results from several studies are reported by Stocker and Loffelholtz [10] to show that in West German motorcycle accidents the helmet became dislodged from the head in between 2 and 14 percent of cases.

Clearly the best way of dealing with this problem is to set up a suitable headform, and a static force laboratory dislodgement test. The barrier to this was - and really still is - the lack of an acceptable standard headform defined for the head sections below the test plane defined in the Standards. The necessary anthropometric work for this task has not yet been carried out for a representative Australian population: most similar requirements for anthropometry in Australia tend to draw from the US measurements carried out some ten years or more ago.

The same requirements (for anthropometry for the head and neck) also arise for jaw and facial protection testing. Currently the Snell Foundation have adopted a static lateral crush force test procedure to try to ensure a reasonable degree of structural integrity for the jaw area of motorcycle and car helmets.

Sarrailhe [11] has suggested that considerably more development in this direction would be a constructive move for testing to move to improve the association between laboratory and field helmet safety performance. AFNOR (the French Standards Association) adopted a jaw/neck extension to their test headforms, but even the French manufacturers have found this to be less than satisfactory as a basis for retention or jaw area impact testing methods (Herbsmann, 1984 pers. comm.).

One recent suggestion made for correcting this situation in Australia is to employ the NMR scanner results, as a by product of routine investigations carried out in hospitals. The NMR scanners involved have not yet reached Australia, but the prospect of taking multiple cross sections on various orientations for a good sample of heads in this effective and nonintrusive manner is extremely promising. Using a low resolution binary scanning mode, such sections could be taken very quickly (when compared with the fine detail sought in most medical applications of the technique).

To save on the use made of limited medical facility time, the data could then be stored on magnetic tape. It is now quite feasible and economic to use image processing techniques offline to produce the skull outlines in various planes in digital form, and interpolate the connecting shapes using splines. This method would then permit a direct statistical assembly of the shapes at different levels, and facilitate the production of headform specifications and numerically controlled cutting machinery tapes to produce them.

This would be particularly useful to match the current headforms with Australian anthropometry, and to set up a suitable 'small' or 'child' headform or headforms. The need for such a 'child' headform has long been recognised and indeed more than one might prove to be required for many purposes. The substantial use made of bicycles by children is a further pressure in this direction, although bicycle helmets tend to cover the bare minimum of the area required by the test area defined in the Standard concerned.

It is still the case that in the USA only the C (medium) headform is required to meet the FMVSS 218 testing procedures, and a current proposal [12] to extend the requirement to other headform sizes has not yet been resolved [13].

The identification of nose and chin shapes and positioning criteria would go far towards making a full face impact protection test possible, and towards correcting the present unsatisfactory position with helmet retention testing for all type of vehicle users' helmets.

The problems of adapting and improving the Standard in the area of retention include the present inability to cope with helmets that have no retention strap and clip around the neck and chin of the user. Bell (USA) and GPA (France) both offer such helmets, and these offer a fresh solution to the possible problem of helmets coming off particular types of heads in accidents even when the retention straps were in proper use.

5.2 Treatment of attachments and projections

Once a helmet can be assumed to be a normal part of the motorcycle/ rider combination as a result of mandated use, then the addition of secondary safety issues becomes both a political and a practical matter. Wigan [14] considered some of the optical and physical interactions and the relationships with car-based Design Rules and Standards, but the trend to an integrated helmet entity has moved a long way since 1979 (the date of [14]). The recent French work to assess the actual protection offered by the visor/maxillary protection zone of helmet nexus is a welcome development [15]. It is important to note that the team involved drew upon finite element modelling, biomechanical cadaver testing, and helmet design refinements requiring both inputs. This multidisciplinary cooperation is typical of effective modern engineering, and it has unfortunately been a rare sight in helmet safety in Australia to see marshalled in this way, the medical, mathematical, biomechanical and test procedure skills that are available. It is encouraging that this is now also becoming a reality in Queensland, at the Institute of Technology, as well as in Adelaide, at the NH&MRC Road Accident Research Unit.

Perhaps the best current examples are the use of intercom equipment, and the integration of visor and helmet as a single entity. In both cases the attachment provisions become a matter of concern, as the traditional view has been that such devices are 'extras', and the helmet will normally be used without them.

This is no longer a sound principle to use, and visors, ventilation and communication provisions are now being made as a integral part of helmets. The facial protection role of visors is now becoming a fairly reliable addition to the helmet shell itself, but it is still the case that the test line for the shell impact tests extends only over a limited part of the shell, and has nothing to say about the regions where either visors or facial protection extensions of the shell are provided.

Optional sections of the current ISO Draft Helmet Standard [16] makes some provison for this, but needs to be extended, tested and approved by a wider community before it is likely to be endorsed. It is, however, certainly in advance of the present AS 1698 in this regard.

The result of the slow pace of adaption to this altered situation is a strongly polarised debate on the 'projections' produced by the attachment (or even the bare attachment foundations) of visors etc. This has led recently to a High Court ruling that the interpretation of the AS Standard is the province of the SAA and not of third parties calling up the Standard for mandation purposes.

Nevertheless, the availability of an objective performance test for the likely potential of a 'projection' for angular momentum or rotational energy transfer to the rider is clearly the appropriate route to follow. The subjective variations in interpretation in some certification aspects of helmets have proved that such tests must be developed. One of the problems is the lack of statistically significant field evidence for the objective safety risk induced by any specific height or nature of 'projection'.

This point alone is sufficient to demonstrate the requirement for a continuing technical input into maintaining availability of Australian expertise in the helmet area to the SAA Committees and in reaction to the test and field requirements such as these, where a new test is required. The BSI have a form of such test under development, but the manner of its application and the adoption of a specific procedure is still some way away. It is no longer appropriate for Australians to have to await the results of overseas work in this way [17], now that the AS 1698/AS 1609 Standards are mandated requirements for import, sale and use.

While the issue of 'projections' has been difficult to resolve, the next issue is how best to treat helmets and visors as a single testing entity: a point only touched upon in the simply legal difficulties surrounding the 'projections' definitions in the current Standard. At the same time, one result of the High Court judgement is to place greater pressure on Standards drafting to avoid any possible subjective phrasings and, where possible, to use performance tests instead. In many areas (such as fire retardation requirements, for example) this could lead to significant cost increases in Standards testing, for no equivalent gain.

This issue will increase the need for a continuing research and test development role to maintain and update the Standard. Building on the French work [15] to handle the overall performance of the visor/mounting/helmet shell and maxillary area as a unified protection system will require a considerable improvement in the level of testing support - and indeed in the ability and willingness of the AS Committee Member Organisations to invest the necessary efforts to overcome the current essentially legal barriers to improving the levels of assured safety to riders and drivers.

5.3 Ventilation and cyclist issues

One of the new requirements for helmets is to provide adequate ventilation. This is a side effect of the increasing levels of use both by cyclists and by motorcyclists in competition and in hot and humid areas. The major pressure for adequate Standards accommodation of this need is currently coming from bicycle riders and from motocross motorcycle riders, due to their substantial exertion levels, and the role of transpiration from the head in the maintainence of body temperature. In the past such riders would have chosen whether or not they would use a closed helmet at all (although the motorcyclists have required helmet use for such competition for a very long time indeed, the informal farm, trail and country off-road riders have long exercised their choice in usage).

The requirements for adequate ventilation entries and exits tend to conflict with current specifications of projections and contraflexures of the external shell. Bicycle helmets have had discontinuities in the shell surface above the test plane, and certainly newer developments have tended to have introduced drastic contraflexures (dips and hollows) in a continuous shell in the search for user acceptability [18]. Once again, this is French work, and forces reconsideration of the present criteria for 'projections' and 'contraflexure'. An underlying concern that rotational forces may be induced at unacceptable levels by 'projections' cannot be employed indefinitely as grounds for failing to face up to the user needs for protection with effective ventilation and facial protection assurance.

5.4 Monitoring performance in the field

One of the perennial problems with helmet Standards is the difficulty in obtaining field data on which to base the case for changes in the Standard. This is exacerbated by the lack of an effective means of reporting and monitoring either the performance against the SAA tests of helmets in the field, or the performance of helmets in the field in accidents. One-off studies simply cannot fulfill this continuing feedback role. A recommendation to this effect formed part of the HORSCORS Report (op.cit.), but has yet to achieve more than a single year of initial work, carried out in 1984 specifically as a one-year study by the Queensland Institute of Technology with funding assistance from the Federal Office of Road Safety.

The continuing problems of SAA Standards with respect to notification of faults and monitoring of field performance in the automotive and vehicle area have been rehearsed previously by this author [19] and will not be repeated here: better systems are certainly needed to support mandated Standards.

6. SUMMARY

Australian helmet Standards are currently in need of adjustment in both the form of the Standard itself and the manner in which the Standard is employed and enforced; these changes rest largely on better continuing governmental technical support for the Standard (and the Standards generating process). The initial moves by the Federal Office of Road Safety are to be welcomed as providing the first year of such an essential continuing underpinning of this key road safety Standard. It is to be hoped that advances in facial protection, helmet retention, ventilation and other aspects of modern helmets can now be addressed with such a continuing source of technical input and current testing knowledge and equipment committed specifically to safeguarding the key two-wheeled vehicle accident amelioration measure: the vehicle users' helmet.

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DISCUSSION OF DR. WIGAN'S PAPER

Mr. M. Holloway: The helmet's virtual sole function used to be protection of the brain. Nowadays it is implicated in protection of eyesight, of the jaw and of the face. Could you give us any idea of what priorities we should give to these various aspects of helmet design?

Dr. M. Wigan: It's quantifiably the case that the grounds for mandating helmets are in the reduction of severe injuries and there is an additional small quantum, a very definite one, to be gained in having coverage of the face, but there are other issues involved there as well. In fact it is the marketplace that has spoken in the increase in the use of full-face helmets. It is the users who want them - not exclusively, and many people have both. However, as a result of that and of increased and more sophisticated demands for ventilation and communication, the helmet is now part of the vehicle. In fact it's now defacto a vehicle design standard. So a manufacturer or a provider of an ancillary facility can expect a helmet to be available on the vehicle. Consequently communication facilities are now the sort of thing the police want, need and have to have. Facial protection that actually has good ventilation as well is something that users know is needed. In fact fitting decent goggles was always a problem and getting them to stay fitting was even worse. The difficulty at the moment is that we don't have a mechanism for reacting fast enough within the committee structure, because of the lack of evidence coming forward, to be able to accommodate all our essentially market-driven requirements, given that the helmet is mandated to be there. In fact, for that reason, we've had cases over the last two or three years where the Standard actually stopped a number of things that would have been desirable from happening. The priority should be to face facts and say: we now have a head protection entity, let us test this head protection entity. If you want to have facial protection and jaw protection, let us know please, as it's our responsibility to ensure that a helmet works in an accident. Let us please ensure that this section is also covered by quality assurance. The sorts of tests that need to be done and the sorts of things we need to embrace within the Standard, are precisely the things on which work is now being undertaken in Australia. So the priorities are clear, to protect the brain. But we must remember we've now gone back to join the rest of the major part of the world and said it's part of the vehicle and therefore people wish to attach things to it. Let us find a way of doing the same thing.

Mr. D. Simpson: Now that jaw protection is widely used, ambulance officers are receiving training on how to extract the head from the helmet. There was a good deal of concern about injuries to the neck in doing so. Do you have any data on how real that concern is?

Dr. M. Wigan: Frankly no. But one of the first things that was done when full-face helmets became widely used was the issuing of an extremely good series of clear diagrams which actually worked to assist people in competition and sporting events to be able to remove helmets sensibly. I think this is one of those cases where we need to ensure that the information is a normal part of emergency workers' knowledge. I might add that the first enclosure type helmets weren't very good that way and were a real concern to many people. The more recent designs overcome that problem and are a positive advance. So: we really should make sure that people do know how to remove a helmet; and we should make certain that better methods of retention can be accommodated.

Dr. H. Pang: I refer to the need for anthropometric data on skulls. Now is it that the ISO international standard is different from the Australian data that we can hope we'll get one day, or is it that the international methodology, the actual measurements, are not adequate and we need to do better?

Dr. M. Wigan: The actual measurements adopted in the French Standard are not acceptable to most of the French. It's pretty widely recognized that it isn't quite satisfactory. Also the shapes are different; the difficulty is actually getting the objective measures. We need to have specifications for precise application in testing. For example, say we have a crushability standard, what distance? If we have an impact standard, against what? If we have a retention standard, which shape? We know that if we take 20 heads and put on 20 helmets of the open face variety, some will probably slip off. We don't even have the anthropometric data to enable us to determine what is a reasonable test bench head that will avoid that problem with our type of population. In fact we are not even sure what the distribution is, in our population.

Dr. P. Tamblyn: I've looked at a number of helmets belonging to cyclists and motorcyclists who have been in crashes and they tend to be well covered with all sorts of adhesive stickers that say Z90 and Snell and various BSI numbers. How does the purchaser know that the helmet they buy really has passed those tests or whether they've just been stuck on by an enthusiastic manufacturer?

Dr. M. Wigan: That's exactly the question that I wish more people using helmets would ask. Z90.1, is used in this country with zero enforcement. If it's a Snell sticker, it basically means nothing - except the manufacturer would be very upset if they had a genuine Snell certification removed. The only mark which you can, and have to, trust is the SAA sticker. It is a federal offence to put the sticker on, or claim compliance with that Standard if that is not the case. And in fact one of the small increases, costs which have had to be borne by all parties, was to put on helmets that metallized high-quality sticker which seems to be lasting quite a few years, to ensure that that evidence remains on them - it is after all the only basis on which even the police can check for wearing of a valid helmet. In practical terms, if there is a BSI sticker that has been validly applied, you have very similar assurance but you have no legal backing here to that assurance. AS 1609 and 2063 are continuously monitored and are the only ones that are.

CURRENT STATUS OF INTERNATIONAL STANDARDS ON HELMETS

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ABSTRACT

This paper examines the composition of current standards for protective head wear for vehicular users. In particular the roles of current performance requirements including test procedures and criteria are evaluated. Development of new test procedures and their proposed introduction into international standards is discussed. Consideration is also given to the existing standards for facial and eye protectors. Finally the shortcomings of existing standards are documented and recommendations made for their improvement.

The full text of this paper is not available.

DISCUSSION OF MS. PEDDER'S PAPER

Dr. M. Wigan: As Chairman of the SAA Committee I should say that the Australian Standards Association has agreed on our recommendations to combine the AS 1609 and AS 1698 standards progressively. That's been a standing recommendation. I'm glad to hear you agree. Another point is that AS 1609 is called up by AS 1698 which means that a penetration test is effectively within the Standard. And lastly I think it would be unreasonable not to acknowledge Peter Snell's posthumous contribution. Flame protection is crucial to the car competition world.

Mr. G. Rodsted: Regarding the problems with committees: of great concern to me is the conflict within the committee structure, the different viewpoints between manufacturing and consumer interests and also the lack of medical representation. Do you think that there is any alternative way of handling the situation to come to a better result, because we are getting strong views expressed and it is the weight of numbers which pushes to a conclusion?

Ms. J. Pedder: There is no immediate solution. I would like to support very strongly the inclusion of the manufacturing interests in the committee and I think they have a very vital role, but so does consumer representation. Having sat on many committees where what you say has been true, I think maybe we can limit the number of representatives from groups which may be interested but who in fact may not have the specific expertise in looking at head protection. They have got considerable expertise in industrial design and in knowledge about new materials and also obviously have got to keep the rest of us on it making sure we don't suddenly create a large white elephant that nobody can make. But there should be some restriction on the number of manufacturing interests.

Mr. G. Rodsted: Manufacturing interests are not our problem. We have 35 on one committee and 24 on another and I think the manufacturing interests are about 3, but consumer representation is different.

SUMMARY OF DISCUSSION SESSION A

Promotion of helmet usage in Victoria

To begin the discussion session, Dr. Peter Vulcan made a short presentation on the effectiveness of the Road Traffic Authority of Victoria campaign to promote the wearing of bicycle helmets. This campaign started in 1983, initially using the 'BIKE-ED' unit in primary schools, and then through various multimedia publicity campaigns, including the 'Use your head, use a helmet' promotion. A bulk purchase scheme sold 1000 helmets at cost price through the schools. As a result of pressure from the helmet distributors this was changed to a discount arrangement between the schools and their local retailers. The final step was to introduce a $10 rebate on the purchase price of a new helmet and this scheme resulted in 38,000 claims.

The bicycle helmet usage rate for adult commuters has risen from about 27 per cent in 1983 to 42 per cent two years later. For primary school students the usage rate has risen from 4 per cent to 38 per cent and the secondary student usage rate from 1 to 2 per cent to 15 per cent. The injury claims to the Motor Accidents Board were obtained and these cover all cyclists hospitalised or killed in Victoria over the period. When a 12 month moving total, to cut down seasonal fluctuation, is considered for the 12 months up to June 1982 and this is compared to the 12 months up to June 1985, a 21 per cent reduction is apparent for recorded head injuries. In the same period there was a 12 per cent increase in other injuries. For the Melbourne metropolitan area, which has somewhat higher wearing rates, the results are even more striking.

While discussion about refinements to the Standards is necessary, it is important to remember that helmets complying with the existing Standards are extremely effective in reducing head injury.

Whiplash injuries to car occupants

The focus of the discussion then shifted onto whiplash injuries to the neck of car occupants as a result of rear impacts. There was general agreement that the requirement for head restraints in cars (ADR 22A) was not as effective as was hoped when it was introduced. More research is required as to the exact mechanism of injury causation, whether it is the jerk (the rate of change of acceleration) of the impact or some other factor which is important, before effective countermeasures can be designed.

Motorcycle helmets

The discussion returned to helmet design. A description was given of the BSI requirement for a solvent wipe before carrying out the impact and retention tests. This requirement, which has also been adopted by the SAA, has led to a change in the polycarbonate material used in some helmet shells. This material, which is susceptible to brittle failures with mistreatment and exposure to ultra violet, is no longer used.

The effect of the added mass of a helmet on neck injury is still causing some concern. Experience in the U.S.A. has not shown any increase in neck injury. The study carried out by Dr. John Yeo, which included all spinal injuries treated at the Royal North Shore Hospital in Sydney from 1973 to 1978, showed that there was a reduced chance of quadriplegia with a full face helmet as opposed to an open face helmet. This study also showed that there was statistically a significantly greater risk of clavicle fracture with a full face helmet. Presumably this would be due to the transmission of the force of impact through the helmet directly to the clavicle. A question was asked as to the distribution of usage of the helmet type with motorcycle size having some effect in these studies. However full face helmets are a dominant part of the market and there does not appear to be any correlation between helmet type and motorcycle size and type - moped riders often wear full face helmets. Basal skull fractures are often seen in fatal motorcycle accidents, but this population is usually very severely injured with multiple possible causes of death. A study carried out at the Traffic Authority Research Unit (TARU) in New South Wales on the motorcycle fatalities which occurred in 1984 showed that, although a 95 per cent helmet usage rate was observed in the general motorcycle population, some 20 per cent of fatalities were not wearing helmets at the time of the accident.

It was questioned whether using a helmet impaired hearing and thus might lead to increased involvement in accidents. Although helmets, especially poorly fitting ones, generate some wind noise, this is not necessarily worse than the wind noise generated by the head of an unhelmeted rider. The amount of sound attenuation that did occur was not in a critical frequency range and was insignificant in comparison with other sources of noise, including the mechanical noise of the motorcycle. A study on this has been carried out by Professor Aldman in Sweden.

Reference was made to Adams and his risk compensation theory and whether this was significant for pedal cyclists.

Some concern was also expressed about helmets saving lives but leaving some survivors with permanent brain damage. The accident statistics are hard to analyse in this respect, but there is no evidence to suggest more severe injury than with no helmet. The wearing of a helmet appears to change the severity threshold at which injury will occur. More concentration on the study of survivors of accidents might help to answer this concern. Whether helmets should be optimised for maximum protection in moderate or more severe impacts is not resolvable at present.

Helmet usage in sport

As well as promoting helmets for pedal cycling there is a need to encourage greater use of helmets designed to AS 2063, the general purpose helmet Standard, in sport. To make the use of proper helmets more acceptable in sporting groups such as pony clubs, more promotion and encouragement is required. In these cases it is often possible to enforce usage by minors.

NEUROPATHOLOGICAL ASPECTS OF HEAD INJURY

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ABSTRACT

The NH&MRC Road Accident Research Unit is engaged currently in a detailed descriptive neuropathological study of the many types and combinations of lesions that occur in the brains of fatal head injuries sustained in road traffic accidents.

Mechanisms of injury production are investigated by the correlation of accident reconstruction data with the pathological findings.

Some of the more common types of brain injury are briefly described with particular attention given to diffuse axonal injury and patterns of vascular damage.

1. BRAIN LESIONS

Traumatic brain lesions may be classified as primary, which include contact lesions and lesions distant from the impact site, and secondary, which are due to hypoxaemia, ischaemia and raised intra-cranial pressure (see Figure 1).

1.1 Primary lesions

1.1.1 Contact lesions are the direct result of trauma to the tissues and manifest themselves structurally in a limited (focal) area. These impact lesions include extradural haematomas usually due to direct traumatic damage to the middle meningeal artery, acute subdural haematomas related to underlying contusions and/or lacerations, some types of cortical contusions, 'burst lobes', direct lacerations and contusions of the cranial nerves and brainstem and direct lacerations of major intracranial vessels (dural sinuses, arteries and veins).

1.1.2 Lesions distant from the impact site are believed to be the result of translational and/or rotational forces and are often diffusely distributed throughout the brain. In particular, diffuse axonal injury (DAI) and the type of acute subdural haematoma (ASDH) related to physical disruption of subdural bridging vessels may result from angular acceleration forces alone [2].

1.1.3 Types of impact injury

(a) Diffuse axonal injury (DAI)

This widespread damage to axons in the white matter of the brain, was originally defined by Strich [3] in 1956 and subsequently expanded by Adams and coworkers [4,5,6].

IMPACT

ROTATIONAL
(ANGULAR ACCELERATION)

Lesions distant from Impact due to angular acceleration (Non-contact).

1. Diffuse brain injury
   - Diffuse Axonal Injury (DAI)
   - Diffuse Vascular Injury (DVI)
     - spectrum from microhaemorrhage to large intracerebral haematomas
2. Acute subdural haematomas related to physical disruption of subdural bridging vessels
3. Contusions related to movement of brain over bony surfaces e.g. typical inferior frontal and temporal lobe contusions

Primary Impact (Contact) Phenomena.
Focal Injuries

1. Scalp laceration
2. Skull fracture
3. Extradural haematoma
4. Acute subdural haematoma related to underlying contusion/laceration
5. Laceration/contusion cranial nerves
6. Laceration major intracranial vessels
7. Some types of cortical contusions e.g. coup or fracture contusion
8. 'Burst' lobe

Lesions distant from impact site (remote contact). Focal Injuries

1. Vault and basilar skull fractures
2. Contrecoup contusion
3. Spectrum of vascular injury
   a) microhaemorrhage
   b) intracerebral haemorrhage

Secondary Brain Damage

1. Hypoxic brain damage
2. Brain swelling and oedema

Fig. 1: Types of head injury related to mechanisms (Modified after Gennarelli [1]).

Strich [3] described diffuse degeneration of the cerebral white matter in a series of patients with severe post traumatic dementia and since her original observations the same pathological process has been described by others as 'shearing injury' [7,8], 'diffuse damage of immediate impact type' [4] and 'diffuse white matter shearing injury' [9].

Strich [3,7] concluded that the axonal damage was produced by mechanical forces at the moment of impact.

The concept of DAI as a form of immediate trauma has not remained unchallenged and some workers maintain that it arises as a secondary event due to hypoxic damage, post traumatic oedema or to secondary compression of the brainstem as a result of tentorial herniation [10,11].

A major advance in this field has occurred since Gennarelli and his group [2] have shown that similar clinical and structural changes can be produced experimentally in subhuman primates using non-impact controlled angular acceleration of the head without there being any increase in intracranial pressure or hypoxaemia.

Hume Adams et al. [6] reported a detailed neuropathological analysis of 45 cases and defined the characteristic features of DAI as:

i) focal lesions in the corpus callosum and dorsolateral quadrant (or quadrants) of the rostral brainstem adjacent to the superior cerebellar peduncles;

ii) evidence of diffuse damage to axons.

Patients who sustain severe DAI are unconscious from the moment of impact, do not experience a lucid interval, and remain unconscious, vegetative or at least severely disabled until death. Their clinical state has been referred to in the past as primary brainstem injury, but although there is damage to the brainstem in DAI, it is always accompanied by evidence of diffuse brain damage [4].

Diffuse damage to axons can only be detected microscopically in appropriately stained tissue: it takes the form of axonal retraction balls (RB's) in short survivors (days), microglial stars in cases of intermediate survival (several days to weeks), or evidence of degeneration of fibre tracts in the white matter in patients who survive for many weeks or months.

(b) Patterns of Vascular Damage

Vascular damage may take the form of traumatic intracranial haemorrhage, contusions, or diffuse vascular injury.

Traumatic intracranial haemorrhage is distinguished as four major categories:

i) extradural haematoma where blood accumulates between the calvarium and the dura mater;

ii) subdural haematoma where haemorrhage occurs into the space between the dura and the arachnoid;

iii) subarachnoid haemorrhage where bleeding occurs in the space between the arachnoid and the pia mater; and

iv) intraparenchymal haematoma including 'burst' lobes [5] where bleeding occurs into the substance of the brain.

Of these, subarachnoid haemorrhage is by far the most common in patients who sustain closed head trauma but, in itself, is rarely lethal [12].

Contusions, which are bruises of the neural parenchyma, usually involve the crown of a gyrus and are wedge-shaped with the apex extending into the neural parenchyma [13]. They consist of extravasations of erythrocytes (micro haemorrhages) about small damaged vessels within the neural parenchyma. The resulting disruption of the blood brain barrier produces vasogenic oedema and ischaemia. Thus contusions are composite lesions consisting of varying degrees of vascular and neural injury and exhibit a wide spectrum of histologic abnormality. Serial CT scanning shows that they are dynamic lesions showing a progressive evolution in time.

Diffuse Vascular Injury (multiple small haemorrhages) may occur in any part of the brain but is seen typically in the white matter of the anterior frontal and temporal lobes, the central grey matter around the third ventricle and the periaqueductal regions of the brainstem. These injuries have been referred to as primary brainstem haemorrhages by Tomlinson [14] who considered that they were an expression of damage to the brain tissues incompatible with life. This pattern of vascular damage is seen most frequently in patients who die very soon after head injury ('instantaneous' group of fatal head injuries).

1.2 Secondary brain damage

This is the result of dynamic changes within the brain initiated by either focal or diffuse brain injury and is usually hypoxic/ischaemic in nature.

All of these lesions may occur singly or, more commonly, in various combinations, in any given patient.

2. NEUROHISTOLOGICAL METHODS

As diffuse axonal injury and hypoxic and ischaemic damage can be assessed adequately only by microscopic examination, any comprehensive investigation of neurotrauma must include a detailed neurohistological analysis [4,5]. To aid our assessment of microscopic lesions we have developed a method for producing whole brain sections embedded in paraffin wax by the modification of existing techniques. The study of whole brain sections facilitates the recognition of the many different types of lesion and their topographic distribution. The anatomical location of lesions is of vital importance in the understanding of the clinical dysfunction that they produce. The same

SERIOUS ACCIDENT

Hospital

Fatal

Autopsy

Detailed Examination of the Brain Injuries

Detailed Review of the Accident

Improved Understanding of the Mechanisms of Brain Injury in Motor Vehicle Accidents

Non-Fatal

In Depth Accident Investigation

- Site
- Vehicles
- Witnesses

Simulation of the Injury Causing Events (if possible)

Fig. 2: Schematic diagram of the investigation of fatal head injury victims

lesion in different areas of the brain will result in different neurological abnormalities.

All brains are fixed in concentrated formalin for a minimum period of two weeks prior to dissection. After transection of the midbrain, the cerebral hemispheres are cut into 1 cm thick slices in the coronal plane. Similar slices are made of each cerebellar hemisphere in a vertical plane parallel to the vermis. All macroscopic abnormalities are recorded photographically. A total of ten blocks of the cerebrum (left and right hemispheres) are embedded in paraffin wax; sections are stained by Nissl's method for neurones using cresyl violet, by Weils' technique for myelin, haemtoxylin and eosin (as routine stains) and by various other techniques as appropriate. The brainstem is sliced into 9 blocks; one block each of upper midbrain, lower midbrain, upper pons, mid pons, mid medulla and lower medulla are embedded in paraffin wax and the sections stained with haematoxylin and eosin, cresyl violet, Weil and Palmgren techniques for axons. Representative blocks of anterior, middle and posterior corpus callosum are handled in a similar fashion.

3. CORRELATION OF RESULTS

All microscopic and macroscopic abnormalities are charted on a series of line diagrams of the cerebral hemispheres, brainstem and cerebellum. Evidence of raised intracranial pressure during life is assessed by using the criteria of Adams et al [15] and the severity of contusional damage is estimated by determining the contusion index [16].

It is important that this information on the patterns of brain damage is not studied in isolation. It is interpreted in the context of a comprehensive study of the type and pattern of injuries sustained by the remainder of the body and in particular the soft tissues and bones of the head. All this information is then correlated with the accident reconstruction data including, in suitable cases, mathematical modelling techniques (see Figure 2).

We believe that it is this type of accident reconstruction-clinicopathological correlative approach that will help define the injury mechanisms associated with the individual types of brain damage.

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DISCUSSION OF DR. BLUMBERGS'S PAPER

We apologise for the fact that, due to a technical fault, a record of this discussion was not made.

ACUTE SUBDURAL HAEMATOMA - PATHOLOGY AND MECHANISMS

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ABSTRACT

A review of 63 cases of acute subdural haematoma (ASDH) is presented and the pathology, mechanism and correlation of the two are discussed. On the basis of operative findings the cases were divided into those due to venous bleeding, arterial bleeding, contusion/laceration and those in which no active bleeding was seen. The results of an anatomical study of the subdural bridging structures are also discussed.

Portions of the work have been submitted for publication elsewhere.

1. INTRODUCTION

Acute subdural haematomas (ASDH) are generally defined as solid clots in the subdural space that produce symptoms within three days of onset [1]. They represent a major cause of mortality and morbidity following road trauma [2]. Over a two and a half year period up to January, 1985, there were 63 cases of ASDH admitted to the Royal Adelaide Hospital (RAH).

In 27 percent there was no antecedent trauma with the underlying causes being aneurysm or arteriovenous malformation (AVM), anticoagulants, neoplasm and spontaneous haemorrhages. The mortality in this group was 41 percent.

This paper will concentrate on the traumatic cases which constitute the remaining 73 percent. The overall breakdown of our traumatic cases is shown in Table 1.

TABLE 1: Traumatic acute subdural haematoma

	Fall	Pedestrian	Assault	MVA	Other	Total
Died	6	10	1	2	2	21
Survived	10	3	6	6	0	25
TOTAL	16	13	7	8	2	46

There were 46 cases with a mortality of 46 percent. Only 10 patients made a good recovery and a further six had a mild disability, leaving 30 either dead or significantly disabled.

2. PATHOLOGY

The possible sites for bleeding in closed head injury are from bridging veins, cortical arteries and contusion/laceration of the cerebral substance [3]. Penetrating injuries, such as gunshot wounds, may also directly injure cortical vessels [4]. Mention of the bleeding site was made at operation in 27 of our cases. Eight of these were from bridging veins, four from cortical arteries and seven from contusion/laceration. One was described as a surface vessel without classifying it as arterial or venous. In seven cases no active bleeding was occurring at the time of operation.

2.1 Contusion/laceration ASDH

The type of ASDH due to cortical contusion/laceration is seen in the 'burst lobe'. Histologically this is due to trauma to all types of vessels with prominent perivascular haemorrhages which may coalesce to form intracerebral haematomas.

2.2 Bridging vein ASDH

Bridging veins may be divided into two groups. Venous drainage from the surface of the brain flows mainly into the dural venous sinuses, the largest of which is the superior sagittal sinus. The superficial cerebral veins are closely attached to the pia and must cross (or bridge) the subarachnoid and subdural spaces to enter the sinus, which is enclosed between two layers of dura. The outer wall of the vein fuses with the inner layer of the dura at a variable distance from the sinus [5]. The second group are smaller veins passing from the apex of the temporal lobe to sphenoidal veins or from the lateral convexity to the dura without direct communication with a venous sinus [6].

2.3 Cortical arterial ASDH

Arterial ASDH is less commonly described but has been reported to be responsible for up to 61.5 percent of ASDH related to falls, assaults and pedestrian accidents [7] and has frequently been identified as the source of 'spontaneous' ASDH [8].

2.3.1 Three groups of arterial ASDH can be defined. The first, and most common, is the so-called 'firehose rupture'. These occur over the convexity, usually in relationship to the Sylvian fissure. At operation blood is seen spurting from a pinhole in a surface artery. These have been examined histologically and the hole seen at operation corresponds to the point of origin of a small branch at right angles to the surface artery [9]. Branches passing from the cortical arteries to supplement the dural blood supply have been described in the region of the falx, the tentorial notch and along the floor of the posterior fossa [10].

2.3.2 The second group consists of arterial loops which are adherent to the dura and rupture with movement of the brain. Drake has stated that it is not uncommon to find a knuckle of a surface cerebral artery protruding through the arachnoid to be adherent to the overlying dura [11].

2.3.3 The third group is the least well described. These are bridging arteries passing from the cortex to the region of the superior sagittal sinus. These arteries have only been mentioned anecdotally in the past. Vance in 1950 sectioned a few communicating stalks and found that while some contained veins, others contained both arteries and veins [9]. Our work has confirmed this and shown that such bridging arteries are not uncommon (vide infra).

3. MECHANISMS

Of our traumatic ASDH's only 17 percent were motor cyclists or vehicle occupants whereas 78 percent were due to falls, assaults or pedestrian accidents. Pedestrian accidents are included here because in most cases they can be thought of as a type of fall.

A pedestrian hit by a car is usually thrown forward and falls to the ground or is wrapped around the front of the vehicle with the head impacting on the relatively soft bonnet or windscreen. This is often followed by a secondary road impact as the pedestrian falls off the car. The primary impact point is usually the legs and much of the force of impact is taken up by the lower limbs in a thrown forward trajectory and additionally by the trunk in a wrap trajectory. The head impact may therefore in a large number of cases be approximated to a fall on to a solid surface (the road).

Why are falls responsible for so many ASDH's? Trauma to the head may cause damage directly or indirectly. Direct injuries are contact phenomena such as scalp laceration, vault fracture, extradural haematoma, cortical contusion and contusion related ASDH. Indirect injuries are due either to stress wave phenomena (basal fractures, intracerebral haematoma) or acceleration phenomena which produce rotation of the brain within the skull. This is responsible for diffuse shearing injury and the type of ASDH due to bridging vein (and probably bridging artery) rupture. Acceleration phenomena can be further broken down depending on the pulse duration. Experimentally, a given acceleration applied over a brief period (as occurs in falls) will result in torn bridging veins and ASDH. A longer pulse duration (as seen in typical motor vehicle accidents) will cause diffuse shearing injuries. As one increases both acceleration and pulse duration it is possible to have combinations of ASDH and a shearing injury [12].

Taking this mechanistic approach one would expect that contusion related ASDH's should be a contact phenomenon whereas those from bridging veins or cortical vessels should be due to acceleration injuries. The falx cerebri provides some support to the brain against movement in a coronal plane as after a lateral blow to the head, but there is no equivalent structure to prevent brain movement in a sagittal plane after an axial blow, i.e. frontal or occipital. Axial blows are therefore more likely to produce brain dislocation than lateral blows [13]. In 17 of our cases in which bleeding was seen at operation there was also information available on scalp trauma.

TABLE 2: Bleeding site and mechanism of injury

Mechanism	Contusion	Bridging Veins/ Cortical Vessels	Total
Contact	5	1	6
Acceleration	2	9	11
TOTAL	7	10	17

Comparing contact (lateral impact) and acceleration (axial or no impact) injuries it is seen that nine out of 10 ASDH's due to bridging veins or cortical vessels are associated with acceleration injuries, whereas five out of seven ASDH's due to contusion are associated with contact injuries.

4. CORRELATION

One can see from the foregoing discussion that the interplay of different mechanisms of injury and different pathological findings makes experimental or theoretical reconstruction of a particular case extremely difficult.

To take bridging vein ASDH as an example, there is controversy regarding even the most basic mechanical properties of the subdural bridging veins. Are they strain rate dependent or not? Lowenhielm reported in 1974 on the dynamic properties of the parasagittal bridging veins [14]. Using cadaver specimens he performed 22 stress tests on 11 subjects with no previous head injury. The bridging veins were loaded to the point of rupture in a strain test device consisting of two movable massive steel cyclinders. Using compressed air the movable cylinder's acceleration and final speed could be selected. He found the bridging veins to be strain rate dependent, i.e. for short loading times they could tolerate higher stress. The maximal stress for bridging veins was also low compared with larger veins (popliteal, femoral, inferior vena cava). In a second paper he used collision tests with human cadavers and developed a complicated formula for determining the actual tolerance of bridging veins [15]. These results indicated that bridging vein disruption due to rotational movement of the head is obtained when the angular acceleration exceeds 4500 rads/sec2 and/or the change in angular velocity exceeds 50 rad/sec. Whether this strain rate sensitivity is a real phenomenon or merely an artefact of the experimental set-up, the assumptions involved in these experiments are of interest. Lowenhielm's assumptions were:

1. The tissue is assumed to be homogeneous
2. The wall of the bridging vein is assumed to be of uniform thickness
3. The tissue is assumed to be incompressible.

Some of our work at the Road Accident Research Unit relates to the first two assumptions. The subdural space was studied in 20 autopsies at the R.A.H. The dura was gently reflected bilaterally and all structures passing from the surface of the brain to the region of the superior sagittal sinus were removed and charted and subsequently examined histologically. While most of the structures examined were veins a significant number proved to be bare arteries and an even greater proportion were stalks consisting of both arteries and veins.

Dense adhesions of the arachnoid to the dura were common, especially in the middle third medially, but also occasionally isolated up to 4 cm from the midline. These arachnoid adhesions usually contained loops of small arteries and veins which were lifted up off the surface of the brain but did not actually enter the dura. In some cases large vessels were looped and tethered to the dura without being contained in an arachnoid adhesion.

Not only were there structures other than veins crossing the subdural space, the bridging veins themselves were far from homogeneous or of uniform thickness. Electron micrographs of the same bridging vein in its subdural and subarachnoid portions showed considerable differences between the two.

In cross section the bridging veins were remarkable for their great variability in wall thickness rather than uniformity.

5. SUMMARY

1. 75 percent of ASDH are due to trauma and two-thirds of these are due to road traffic accidents (RTA's). The prognosis is poor with only 22 percent achieving a good result.

2. The pathology of ASDH is varied. It may be due to contusion/ laceration, ruptured bridging veins or ruptured arteries either bridging the subdural space or tethered to the dura.

3. The mechanisms of ASDH are also varied. Contact injuries cause contusion/laceration whereas acceleration phenomena cause ruptured bridging vessels.

4. The correlation of pathological and mechanistic data is fraught with difficulties but is essential to our further understanding of such an important field as head injury following RTA's.

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DISCUSSION OF DR. JONES' PAPER

Dr. D. Viano: It is interesting that the French are making a study of boxers who wear a thin plastic helmet containing accelerometers, during sparring. Hence, the forces acting on the head during the boxing sparring are measured. Rotational accelerations as high as 20,000 radians per second squared are being recorded. What is that going to mean about Lowenhielm's paper on gliding injuries?

Dr. N. Jones: His basic assumptions are really not that valid when one looks at the anatomy of the subdural bridging structures. The veins themselves vary from tiny little things that the technician could barely find to be able to embed them, to huge structures post-durally, which are probably the ones that were taken.

Dr. D. Viano: I have no question that you are doing outstanding clinical work and you are trying to find engineering support for what you are seeing and there is a tremendous weakness in the literature on the engineering side, so a little bit of caution there. This afternoon several people have said that falls are short duration events and car crash injuries are long duration events. Does the work in cooperation with the Road Accident Research Unit here have evidence that that is true?

Dr. N. Jones: I can't really comment on the engineering aspects.

Mr. T. Gibson: The simple classification comes from the pedestrian work where usually we are referring to head impacts on rigid road surfaces as equivalent to falls. In most of the vehicle accidents that we look at, a distinction is needed because the head impact is often on a softer surface, i.e. the vehicle. It's a very coarse classification and it came from the classification used in the Gennarelli paper.

Dr. D. Viano: In fact if you look at what has been done with head impacts with glass or hitting a car rail, these might be only 3 millisecond duration impacts. Inside a 150 millisecond event the real issue is when the injury occurs. That's the real question I have about the type of injury related to the impact. Are you, or the previous speaker, actually including the contact point of the skull in relationship to the internal injuries you are seeing to the brain?

Dr. N. Jones: All of the autopsy cases have detailed work-ups of the external injuries and we have fairly detailed clinical data for non-fatal cases.

Dr. D. Viano: I would really encourage that because Hume Adams had only three cases where he knew contact points on the surface of the skull with relationship to the damage inside.

Dr. N. Jones: We did have a couple of three-quarter spun trajectory cases which were hit on the side and spun around. One of those suffered from a critical acute subdural haematoma.

Dr. H. Pang: Do you think that your study, or those of your colleagues who preceded you, could in due course lead to advice to those of us who are involved in standards for helmets, to change the present structure of helmets. At the moment helmets consist of a hard shell and an absorbing lining. Is it possible that your small sample would show that the vulnerable vascular structures could deserve a modified structure?

Dr. N. Jones: Yes, I see what you mean but I don't know.

CLOSED HEAD INJURIES IN INFANTS AND CHILDREN: CAUSES AND OUTCOMES

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ABSTRACT

The epidemiology of lethal paediatric head and/or spinal injuries has been extensively studied; in a recent South Australian study, the rate in 1977 was 100 per 1,000,000 cases at risk in the age group 0-4 and 92 per 1,000,000 in the age group 5-14; motor vehicle accidents caused about 70 percent of deaths in both age groups. Data for infants are less complete: in this age group the chief causes of lethal or disabling head injury are parturition, falls, assault by adults, and motor vehicle accidents: except in the last category, documentation of the mechanics of injury is often very inadequate or unreliable. There is a need for further epidemiological study of non-fatal injuries in infancy and childhood, using internationally accepted severity scales. The blunt head injuries of infants and young children often show age-specific peculiarities. These may reflect different impact patterns or may result from biological immaturity. The immature skull is thin, flexible, and easily shattered; if a skull fracture in early life is associated with tearing of the bone-forming dura mater, an expanding bone defect may result. The immature brain may suffer local contusion or laceration; it has been said that contusions are less common than shearing injuries in childhood, but this assertion needs autopsy verification. The immature brain is also said to be more prone to acute swelling after injury. The secondary effects of blunt injury in young people also show peculiarities; while extradural haemorrhage is often seen, subdural haemorrhage is quite unusual in older children but common during the first 12 months of life. The peculiarities of the chronic and acute-on-chronic subdural effusions of infancy remain unexplained.

The outcomes of paediatric head injury also deserve more intensive study, using an internationally accepted system of evaluation. It has been argued that children recover from head injuries better and more quickly than adults; while this is true with respect to speech, it may be untrue for other cognitive functions. Learning difficulties are often reported after head injuries, and there is a need for research into the best educational strategies in such cases.

1. INTRODUCTION

Children are not small adults, and infants are not miniature children: each age has its own peculiarities in almost every respect. Body masses change with age, relatively as well as absolutely, and these changes affect the dynamics of injury. Behaviour and patterns of locomotion also change with increasing age, and this affects the epidemiology of injury. The skull of the infant is thin and relatively flexible, and its individual bones are to some extent mobile; since the strength of a plate of bone is proportional to the cube of its thickness, a 2 mm infant skull plate is very much more likely to shatter or be penetrated than a 6mm adult skull plate. Finally, and this is my main theme today, the immature brain is physically different from the adult; its neuronal linkages are less well established, and the outcomes of brain injury are likely to be different. For many years it has been conventional wisdom to say that children recover more quickly and more completely than adults who have suffered comparable injuries; this belief is now being to some extent challenged, and I want to outline some of the areas in which research is going on in different parts of the world into the special characteristics of childhood head injuries.

2. INJURY PATTERNS

It is one of the basic conventions in head injury pathology to distinguish closed head injury, due to blunt violence transmitting energy to the head as a whole, from open head injury, where a small object such as a bullet imparts energy to a restricted area, causing penetration and localized damage. The first type of injury is likely to cause widespread brain injury, with shearing forces damaging fibre systems in places remote from the impact point, and also movements of the brain, causing impaction of the brain against sharp bone structures inside the skull. Such children are likely to be unconscious for long periods and to show impairments of function expressing the particular fibre systems torn and the cortical areas damaged or contused by brain movements. The second type of injury can show total disruption of brain substance at the site of injury, with very little loss of function elsewhere - children with through-and-through penetration of the head by relatively low velocity missiles, for example, may retain full consciousness and appear normal. I wish to deal chiefly with the first type of injury, due to blunt violence, the commonest consequence of road accidents. However, it should be remembered that children quite often suffer a combination of blunt and open injury; impaction against a hard object inside a car can penetrate a child's thin skull locally but also cause relatively widespread brain damage. There is an urgent need for quantitative studies of the tolerance of the skull and brain at different ages [1]. This has been done in a study of free falls [2], but not to my knowledge for other types of injury. Even quite elementary cadaver studies would be enlightening.

3. CAUSES OF INJURY

The general epidemiology of childhood head injury has been fairly well studied, but it should ideally be reviewed from time to time in all major communities, to identify possibly important changes. A hospital based study of a cohort of 200 cases of all types of head injury was made in 1971, representing all admissions to the Adelaide Children's Hospital over a period of ten weeks; in this series, road accidents accounted for 38.5 percent of admissions, but nearly 80 percent of these were considered to be serious [3]. Of the 77 road accidents, car passengers and bicyclists or tricyclists contributed each nearly 30 percent, and pedestrians 42 percent. We are at present attempting a similar hospital-based review for the period 1982/4, with special emphasis on 33 injuries severe enough to necessitate referral to the neurosurgical unit. In this small series, injuries to pedestrians and cyclists predominate, and it is of some interest that all the cases of surface intracranial bleeding occurred in pedal cyclists, after relatively minor injuries; pedestrian injuries were in general much more severe with an average injury severity score of 31, as against about 20 in the other two groups. We plan to extend this study with more material, to compare causes of injury with the 1971 study.

4. PATHOLOGY

The brain injuries of childhood have been recently reviewed by Jellinger [4] and Shapiro [5]. The primary effects of injury include, as in adult life, local laceration and bruising of brain tissue, and more or less diffuse shearing damage to fibre systems and small blood vessels. Lindenberg and Freytag [6] have shown that infants are especially likely to suffer from gross disruption of brain tissue from closed head injury, and there are two possible explanations for this. First, the thin skull may transmit blunt force directly and locally, causing maximum damage to a restricted area of the brain - much as in a penetrating injury. Second, the infant's nerve fibre systems have not, for the most part, developed their normal adult structure; they do not have their fully developed myelin insulation. It is common experience both at autopsy and in the operating theatre that the brains of neonates and infants are easily torn. Studies of the neuropathology of childhood injury are being carried out in the South Australian Institute of Medical and Veterinary Science. So far, we have seen nothing unexpected in older children: lacerations and contusions are seen as in adults, and the foci of acute haemorrhage which we regard as markers of diffuse damage are found in the anticipated situations, such as the corpus callosum. In the small number of infants so far studied, we are seeing some challenging variants in the expected pathology.

4.1 <u>Case Report</u>. A six month old infant was a passenger in a bassinet in a station wagon struck by another vehicle. She sustained a closed head injury with a right parietal skull fracture. She exhibited a left hemiparesis, and developed a recurrent subdural collection on the right side. She died two months after injury, under anaesthesia, from cardiac arrest possibly related to an undetected cardiac injury. At autopsy the chief finding was an extensive area of demyelination in the white matter of the right cerebral hemisphere. This was not typical of vascular infarction, but neither was it obviously due to axonal disruption, and I am at present at a loss to explain the mechanism of the cerebral injury. Descriptive studies of head injuries at different ages, with correlative examinations of CT scans, are needed to determine to what degree age modifies the response to injury. One very obvious unsolved question is the propensity of infants to develop recurrent collections of subdural fluid after injury. We attribute these to recurrent bleeding or fluid transudation from capillaries in the subdural membrane, formed from the dura mater, but nothing quite like this recurrent leakage happens in older life and I don't know whether we should postulate a special capillary defect in infants, or whether we should explain the phenomenon on the lower intracranial pressure associated with the infant's open fontanelle.

5. OUTCOME

There is nothing to suggest that the cellular response of the infant's brain to injury is qualitatively different: the mature cells of the infant's brain, like the adult's neurons, have no capacity to regenerate, and although the infant's brain does have foci of immature nerve cells in various loci, there is no evidence to suggest that they can replace damaged neurons. It is nevertheless generally believed that children recover better after closed head injury than adults [7]. The best known and most convincing proof of this is the fact that infants can survive loss of the entire left cerebral hemisphere without permanent loss of speech [8]; it is also common experience that young children recover from post-traumatic decerebrate rigidity [9] and speech impairment [10] better than is expected from adult experience. It has been hypothesized that the immature brain is more plastic than the adult brain, that it is able to readjust functional localization; more excitingly, it has been hypothesized that new synapses may be sprouted off onto neurones which have lost their input, and this certainly happens in lower mammals. Recent very elegant studies done in Oxford [11,12] suggest that in the infant monkey's motor system, this may happen but only to a very limited and functionally insignificant degree. Clinical experience is, in fact, making most people less enthusiastic about the long-term quality of recovery after childhood brain injury; Alajouanine and Lhermitte [10] pointed out that many of their cases of speech loss after injury later showed poor school performances despite seemingly excellent return of fluent speech. Moreover, brain injury in childhood can interfere with limb growth in a way not seen in adult life. We have studied cases of limb weakness after childhood head injury by serial tests of hand facility, using a timed peg-board procedure: even where there has been excellent recovery of strength, there is likely to be some measurable slowing of fine movement and this is accompanied with striking reduction in the size of the affected hand, bones as well as soft tissues being under developed.

Such experiences make one very hesitant to say that cerebral recovery in childhood is necessarily 'better'. What one can say is that childhood recovery patterns, like childhood injury patterns, are <u>different</u>; whether they are really better in any statistical sense is a question that can only be answered by long-term case studies, and these must use quantitative measures of injury severity and of outcome. These quantitative measures are not yet available; simple outcome scoring such as the Glasgow Outcome Scale [13] and the Chicago Outcome Scale for Infants [14] are clearly unsuitable, and I see this as a challenging field for paediatric neuropsychology.

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DISCUSSION OF MR. SIMPSON'S PAPER

Dr. G. Trinca: Your last point regarding the neuropsychologist in the coordination of this whole process of watching the child for quite some time is an important one - also that we should wait a long time before being pessimistic with regard to the prognosis of recovery of small children.

Dr. D. Viano: You showed a picture where your nurses had given popular road magazines to the child who was more severely injured and unable to read the magazine. Do you have social disability and cognitive procedures that you use with the children to get them immediately reintegrated?

Mr. D. Simpson: We try to, yes. We have a program involving occupational therapists, physiotherapists, a clinical psychologist and a social worker on a coordinated team; we endeavour to start rehabilitation even while the child is still not fully responsive. We believe that some contact can be made earlier perhaps than one would realize from the child's reactions. The photograph I showed, as I think I said, was the sardonic humour of one of my colleagues, it was not part of a program.

Dr. P. Last: I think that Mr. Simpson is completely correct in relation to the final social outcome for some of these children. From time to time I face what's known in my trade as the 're-entry problem' which is what occurs when aging parents are looking for placement for an individual who is often in the thirties, forties or even older, who had disappeared back into the family circle following an injury in childhood. There they remained hidden from most caregivers except, perhaps, the general practitioner, and the hospital system does not become aware of the existence of the person until that time. We then have to turn around and rediagnose the individual, because the labels are often wrong. I suspect that as we start the head injury registry here in South Australia and we start advertising, as it were, we are going to find surprisingly large numbers of individuals who meet the doctor's description of the good initial recovery and then, sad to say, the bad late outcome.

We have, for example, a woman of fifty who had extensive neurosurgery for tractable epilepsy at the age of about 15 or 16 - about 30 years ago. The original pathology behind the epilepsy happened in a tragic crash at the age of three or four.

Mr. G. Rodsted: I was interested in your comment about the g-forces in young children, a tolerance level of 200-250 g. We in Australia have been working with an impact attenuation of 400 g and I know the American Snell Foundation works on a level of 300 g. Particularly in relation to children, are the helmet manufacturers in fact needing more guidance in this direction and are they working on the wrong hypothesis as to what the g level would be in these protective helmets being manufactured?

Mr. D. Simpson: Yes. I can't vouch for those data personally. They come from a study in which a whole mass of injuries from free-falls on different surfaces were analysed and to me, as a non-engineer, the paper read quite convincingly. I think there are people in the audience here who could criticize it better than I can. But one thing I should say about it is that the figure given there, 200-250 g, was the tolerance level above which a skull fracture or some other fairly obvious marker occurred, but it wasn't a tolerance level for lethal injuries.

Dr. H. Pang: You drew our attention to the significant differences in bony structure and other factors between children and adults. Now the Australian Standard for bicycle helmets doesn't make any specific provision for children and I do notice that Bell are now marketing a special children's helmet which does not have a shell and therefore doesn't really comply with our Standard. There could well be a case for standard specifications for children's bicycle helmets which would accommodate the differences you've alluded to. Would you like to comment on that?

Mr. D. Simpson: I think the case for a separate standard for children, if we are to make one, should rest more on convenience and acceptability than on any evidence that we may have for the need for a different pattern of protection. The point I wish to make from our studies up to the present, is that a lot of childhood injuries result from contact deformity of the skull and underlying vascular damage and a helmet, particularly a hard-shell helmet, will I think give probably proportionately more protection there than in adults. So I think helmet usage in childhood is very worthwhile, I should make that point strongly, but I don't feel at the moment that the guesses that we're making from the studies I've presented to you are firm enough to say that a particular pattern of helmet or particular degree of protection are specifically required in childhood. I don't think we're at that point at all. All we can say is that helmets are very worthwhile.

CERVICAL SPINAL INJURY FOLLOWING ROAD TRAUMA

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ABSTRACT

Road trauma is responsible for approximately 80 percent of all serious neck injuries admitted to the Royal Adelaide Hospital. In addition it is responsible for a large number of less severe soft tissue injuries to the neck which may still result in chronic neck symptoms. The various types of neck injuries, together with principles of management and final outcome, will be discussed.

1. EPIDEMIOLOGY

The motor vehicle is responsible for approximately 75 percent of patients admitted to the Spinal Injuries Unit with cervical spinal injuries, and approximately one-third of these have significant neurological involvement. The type of injuries include dislocations, fractures, central cord syndrome and hyper-extension injuries. A very large number of patients with soft tissue injuries of less severe magnitude do not require admission to such a specialised unit but still represent a very major cost to the community.

2. BIOMECHANICS

The biomechanics of cervical spine injuries can be assessed by mathematical modelling, anatomical specimens, animals in vivo, man in vivo, and by clinical observation. Anatomical variations are of great importance, particularly the relative size of the vertebral canal. Pathological changes such as annular bulging and indentation of the ligamentum flavum narrow the vertebral canal predisposing a patient to a more severe neurological loss with injury to the cervical spine. The traditional concept of flexion, extension, lateral bending and compression injuries is too simplistic as in most injuries a combination of these forces has acted. Assessment of the 'major injuring factor' is useful in understanding the mechanism of injury. This is the resultant of the various factors acting at the time of injury. This can be applied to such injuries as unilateral dislocation, bilateral dislocation, Jefferson fractures, and fracture dislocations. The resultant injury as shown on plain x-rays may be the same with different forces acting. For example, an antero-inferior fracture may occur as a result of a compression force causing a shear fracture or as a result of an extension force causing an avulsion fracture. Care has to be taken in determining the direction of relative stability from plain x-rays.

3. PRINCIPLES OF MANAGEMENT

This includes management at the site of injury and transport to hospital. A careful clinical assessment is paramount and needs to be followed by plain radiographs including flexion and extension views if the injury is not first apparent. Reduction of dislocations and fracture dislocations should be carried out as soon as possible particularly where there is a neurological deficit. Special procedures to aid in the management of these injuries include postural reduction, traction, manipulative reduction, open reduction and fixation, and external supports.

Suggested further reading: Augustus A. White III and Manohar M. Panjabi (1978) Clinical Biomechanics of the Spine. J.B. Lippincott Co., Philadelphia.

DISCUSSION OF MR. FRASER'S PAPER

Mr. D. Simpson: The small number of cervical spinal injuries for motorcycle accidents was interesting: one from Adelaide and two from Perth. A lot of concern was expressed yesterday about the possible role of protective crash helmets with regard to neck injuries, which wouldn't appear from your figures to have much validity. Could you comment on that, and also on whether you have any figures about fatal cervical injuries in motorcyclists, because after all for every case that dies in hospital I think 3 or 4 die out of hospital.

Mr. R. Fraser: The figures I gave on cervical injuries apply purely to dislocations. Unfortunately we don't have details for fractures at this stage. That study is being carried out at the present time. Regarding dislocations, it stands to reason that, in a collision, a person restrained in a motor vehicle with a safety belt will be more likely to have rotation induced type of strain to the neck, whereas the motorcyclist is likely to be thrown from the motorcycle and perhaps sustain injury by direct impact on the head. I suspect we may see a greater incidence of fractures in that group but I agree that, for dislocations, it is a very small component of the total. We have no figures, at this stage, for the number of motorcyclists who fail to reach a hospital because of early death from neck injuries.

Dr. H. Pang: Is any prevention possible?

Mr. R. Fraser: I was discussing really the causes and the biomechanics and the management. Obviously the best form of treatment is prevention, but there is concern that certain treatments in one area will increase the risk of injuries in another: for example, safety belts with a lap and sash may reduce injury of the low lumbar spine, but may well increase injuries further up in the spine. The cost to the community in this area is enormous and there are a whole range of preventive measures one could look at. Very careful evaluation is needed.

Dr. G. Trinca: On a slightly different point: motorcyclists sustain quite a high incidence of fractures of the thoracic spine and they have a more complete cord lesion than car occupants. Could you comment on the common omission of C7 and T1 from that first important X-ray in the casualty department?

Mr. R. Fraser: In most cases the main assessment is clinical. In any case where there has been significant trauma with tenderness localised over the spine, particularly if there is difficulty in lifting the head off the examination couch, one must suspect a severe injury to the spine. That area of the spine, as you mentioned, is difficult to evaluate and that's why we use special X-rays such as the swimmer's view and in obese patients, if this is not satisfactory, tomography of the area.

Dr. G. Trinca: Regarding movement of the person at the roadside: we are concerned with the airway and in the case of the unconscious casualty, the best position is the semi-prone or sleeping position. I've had no evidence from neurosurgeons that, when there has been a suspected or even a known spinal injury, movement of the patient to the semi-prone has done any damage. Have you any cases where keeping a patient alive by restoring the airway has produced cord damage?

Mr. R. Fraser: This is a very difficult area. Obviously there's no point in preserving the spine but failing to resuscitate the patient. Some injuries are quite unstable with extension force at the time of examination but, provided attention is paid to the posture of the patient in that position, they should not come to harm. However, to put the patient into a semi-prone position without attention to pillows to support the neck could be hazardous for a patient with a particular type of injury.

Dr. G. Trinca: The person doing the first movement is the untrained person, the ordinary citizen. It's an important point to make in any first-aid or roadside management training or education of the public.

Mr. R. Fraser: I think it would be quite hazardous if it became routine to put a patient in the semi-prone position, but obviously there is a need to do so for a patient where it's life-threatening to nurse in the traditional supine position. It's a matter of balancing the risks.

Dr. P. Tamblyn: Regarding seatbelts: I feel that cervical spine injuries have probably been reduced since people have been kept inside cars in crashes and not ejected. In both the Road Accident Research Unit and the Spinal Injuries Unit, I have observed that all cases in which there is a cervical spine injury leading to cord damage have involved some impact on the head. I haven't seen any case, or documentation of one, in which a spinal cord injury occurred purely due to restraint of the body. I supppose it could happen in a person with a very stiff cervical spine, such as a spondilitis sufferer or a very elderly person, but in the majority of fit young people who seem to suffer these injuries there's always some impact to the head leading to cord damage.

Mr. R. Fraser: I certainly wasn't meaning to suggest that we should do without safety belts, I was just making the point that when you bring in one thing it may influence the type of injury. I think that's well demonstrated by the alteration from the Chance fracture, with simply a lap belt, to virtual elimination of that type of injury, with a sash. Certainly, those patients who have a fracture of the spine with cord injury tend to have definite blows to the head, but we see a large number with purely a dislocation or unilateral dislocation where that doesn't occur. That's really an impression rather than hard data and needs to be looked at more closely.

Dr. D. Viano: Seatbelts are probably the most important ingredient in reducing the risk of neck injuries and recent studies showed they were most effective in reducing the risk of a fatality.

SUMMARY OF DISCUSSION SESSION B

Is there a Case for Head and Spinal Injury to be Made a Notifiable Disease?

There is a prima facie case for neurotrauma to be made a notifiable disease. In the event of that happening, the creation of a register of such cases would be a relatively straightforward task. Until that occurs, any register would have to be based on routinely available data. Steps are currently being taken to establish a head injury register in South Australia, where a condition of registration of nursing homes and hospitals is that they must supply statistical data to the Health Commission if required. There is also a trial injury surveillance system being set up in some hospitals in Adelaide. In the USA, head and neck injuries registers are most often kept separately, but it would seem to be preferable to combine them. The Motor Accidents Board in Victoria is the most nearly complete set of road accident trauma and outcome data in Australia. Although statutory registers have the attraction of providing complete injury counts they record purely statistical data and so it is rarely possible to obtain information on the identity of individuals should additional follow up data be required.

The quality and detail of the information recorded in a register is largely dependent on the resources available. To be able to code primary (such as contusion) and secondary (such as extradural haemorrhage) brain injuries requires a high standard of medical analysis of data, which would be expensive. However, such data would be particularly valuable in assessment of, for example, the effects of time delays and emergency care and treatment on the final outcome.

Consequences of Neurotrauma

Fatalities are adequately counted at present but for non-fatal cases of head and neck injury it is desirable to have a register of the outcome - possibly in the form of a disability* register.

A disability register is a controversial topic with some disabled groups on the grounds that such registers stigmatise the disabled. There are also confidentiality problems and difficulties with record linkage across the several agencies which might be involved. A surveillance system based on sampling from selected agencies could be more practicable than a complete register. Any information collection should make use of the International Classification of Impairment, Disability and Handicap, and be carried out on a prospective basis rather than a review of routinely recorded data.

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* Impairment, disability and handicap are defined as follows:

Impairment - anatomical or physiological loss of function;
Disability - those actions which cannot be performed because of the impairment;
Handicap - social consequence of impairment.

It was noted that a session on crash injury impairment was scheduled as part of the Society of Automotive Engineers Congress in Detroit in 1986 and that the American Association for Automotive Medicine has a group working on an impairment scale to match the Abbreviated Injury Scale which is used for trauma scaling with emphasis being placed on danger to life.

Preventing Impact to the Head for the Vehicle Occupant

In the USA the further development of occupant protection measures has become bogged down in the seat belt vs airbag argument. However these are both partial solutions only; every means possible must be used to protect occupants. Some improvements to restraint systems and energy absorbing structures are likely to be quite rapidly implemented in the near future.

In countries with relatively high seat belt wearing rates there are indications that severe facial fractures are being caused by the impact of restrained drivers with the steering wheel. Cars are currently fitted with an energy absorbing element in the steering column which is designed to take the force of impact of the torso of an unrestrained driver in an accident. This is inappropriate for protecting the face. There is a whole spectrum of contact points where concussive injuries occur and it is best to minimise the frequency of contact with the interior of the vehicle by means of improvements in airbag and seatbelt restraint systems. It seems that it is better to try to avoid the contact than to engineer the surface to minimise injuries as a result of contact.

Several improvements are available for seat belts which will minimise the likelihood of contacts with the interior. These improvements include seat belt tensioning devices and self adjusting mounting systems which are all in production in some other countries. The introduction of these and similar devices into the Australian Design Rule system for motor vehicle safety is likely to be dependent on their introduction into the relevant European (ECE) vehicle safety regulations. This is because of the prevailing practice which is aimed at harmonization of the ADR system with the ECE draft regulations. The undesirability of the possible delay in introducing new safety measures into Australian vehicles was noted.

Particular mention was made of the problems associated with the provision and use of lap belts in buses, notably the risk of head and face injury from striking the back of the seat in front. The seat back, padded and strengthened, together with strengthened seat mounting points, may be a preferable restraint system in all but the front row of seats in a bus. In the USA and Canada school children are encouraged to use the school bus because it is the safest means of transport.

HEAD AND NECK MODELLING

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ABSTRACT

Realistic simulation of the neck response in a dummy or a mathematical model is of vital importance to obtain a humanlike dynamical behavior of the head. Trajectories of the head and the nature of head contact with vehicle interior or exterior are critically dependent on the dummy's neck design.

In this study dynamical tests with human volunteers conducted by the Naval Biodynamics Laboratory (NBDL) in New Orleans are analysed. These subjects were exposed to impacts in frontal, lateral and oblique direction. Results of this analysis are presented.

It follows that the observed head-neck motions in these types of impacts can be represented quite well by a simple linkage mechanism with two joints. Mathematical simulations for this linkage mechanism were conducted using the Crash Victim Simulation Program MADYMO, in order to verify the proposed system. Results of these simulations are presented and it is shown that this analogue is adequate for the types of test conditions involved.

Evaluation of the Part 572 and Hybrid III mechanical head-neck systems in frontal impacts shows that both necks are much stiffer than the human volunteers for the impact ranges to which the volunteers were exposed.

1. HUMAN VOLUNTEER TESTS

In the past year the Naval Biodynamics Laboratory (NBDL) has conducted an extensive research program to determine the dynamic head-neck response of volunteer subjects under various test conditions and impact directions. In these tests the subjects are seated in an upright position on a HYGE Accelerator (0.3048 m) and exposed to short duration accelerations simulating frontal, oblique or lateral impacts. The resulting three-dimensional motions of the head and first thoracic vertebral body (T1) are monitored by anatomically mounted clusters of accelerometers and photographic targets. A detailed description of the instrumentation and test methods is provided in [1,2].

In the frontal impact tests, the subjects are restrained by shoulder straps, a lap belt and an inverted V-pelvic strap tied to the lap belt. Upper arm and wrist restraints were used to prevent flailing [2]. In addition a loose safety belt around the chest is employed. The same restraint system is used in lateral and oblique tests. In addition a lightly padded wooden board is placed against the right shoulder of the subject to limit the upper torso motion.

Figure 1 illustrates the location of the head and spine anatomical coordinate system as defined by NBDL [3]. Both coordinate systems are orthogonal and right-handed. Three-dimensional X-ray techniques were used to specify in each test these coordinate systems relative to head and T1 anatomical landmarks.

For each test 96 time-histories are available based on processed photographic and accelerometer data describing three-dimensional kinematics (i.e. displacements, velocities and accelerations) of the head and T1 anatomical coordinate systems [1].

In total, test results of 338 tests with 17 subjects were available for our analysis. Table 1 summarizes the test conditions for the most severe frontal, lateral and oblique tests, respectively, in this database.

TABLE 1: Test characteristics of the most severe NBDL human volunteer tests.

Impact Direction	Sled Velocity (m/s)	Peak Sled Acceleration (g)
Frontal	17	15
Oblique	14	11
Lateral	7	7

Figure 2 presents a comparison of typical sled accelerations in one of the most severe frontal, lateral and oblique tests, respectively, (i.e. test numbers LX 3616, LX 2302 and LX 3148). The oblique test appears to be more severe than the lateral one, while the frontal test is more severe than the oblique one.

In this paper results of tests with two subjects (H00083 and H00093) in frontal, lateral and oblique direction will be presented. A more detailed presentation specific for frontal tests is given in [4] and for lateral tests in [3].

1.1 Analysis of T1 Motions

Analysis of T1 rotations from the processed photographic data showed that rotations are considered small enough to justify neglecting them further in our analyses. The same holds for vertical displacements of T1 and displacements out of the plane of impact. Consequently the only significant displacement of T1 is a horizontal translation in the impact direction.

Corresponding T1 accelerations as a function of time together with the sled deceleration are presented in Figure 3 for three impact directions. For each impact direction, results of one typical severe

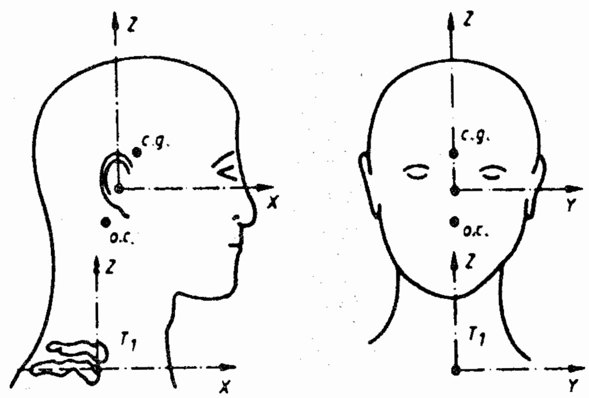

Fig. 1: Location of anatomical coordinate systems according to NBDL (o.c. = occipital condyles, c.g. = center of gravity)

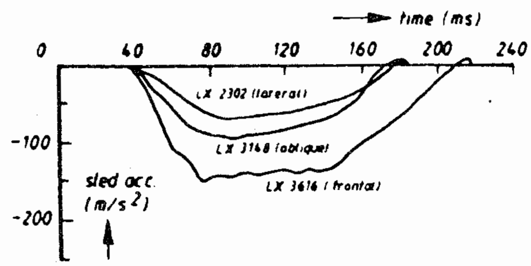

Fig. 2: Comparison of sled accelerations in one of the most severe frontal, lateral and oblique tests.

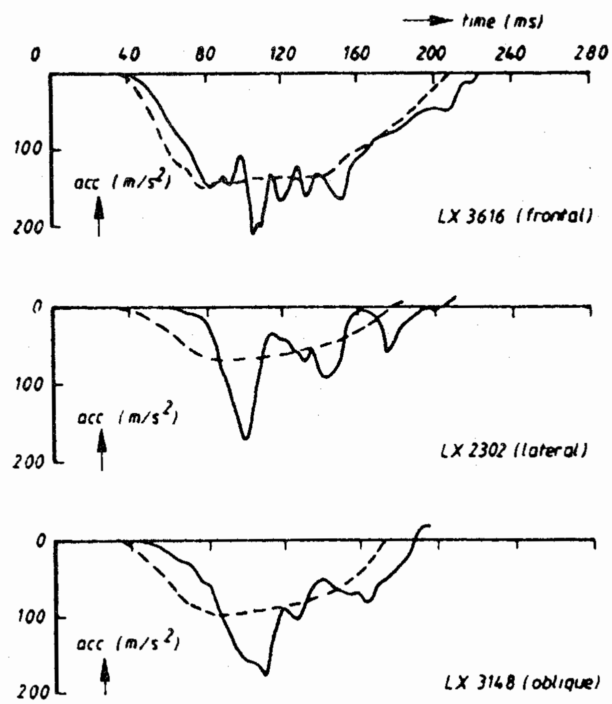

Fig. 3: Typical examples of horizontal T1 and sled acceleration as a function of time in three different impact directions.
——— = T1; ------ = sled.

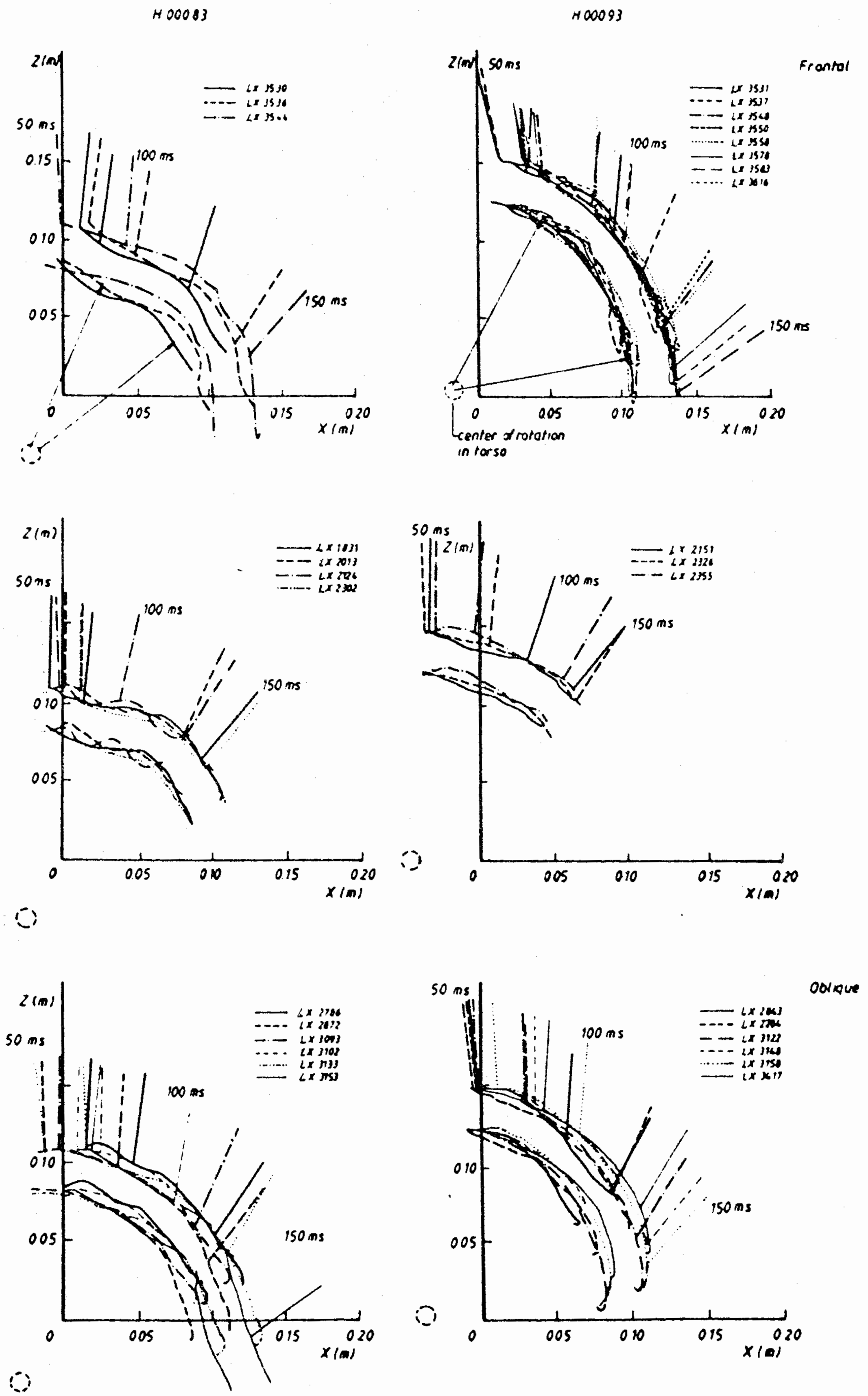

Fig. 4: Head displacements relative to corrected T1 coordinate system [4] for three impact directions. Upper curves: head anatomical origin. Lower curves: occipital condyles. Stick figures: head z-axis at 50, 100 and 150 ms.

test are shown. In frontal impacts this T1 acceleration curve, except for some small oscillations and a phase shift, appears to be close to the sled acceleration curve. In lateral and oblique impacts, however, a much larger deviation between both curves can be observed, indicating the different nature of the interaction between the restraint system and the torso or shoulder in these types of tests.

1.2 Analysis of Relative Head Motions

Figure 4 presents for the loading phase of the motion, trajectories in the plane of impact of the head anatomical origin and the occipital condyles. The position of the head anatomical z-axis at three different time frames (i.e. 50, 100 and 150 ms) is also given. The displacements are presented relative to the corrected T1 coordinate system [4] and for each subject and impact direction the results are summarized in a separate figure. The following observations can be made:

- trajectories from tests are quite close to each other, in particular for the tests of subject H00093;

- for the same subject more severe impact levels in general cause larger head excursions;

- maximum head excursions in frontal impacts are slightly larger than in oblique impacts and much larger than in lateral impacts;

- in the initial phase the head motion is more of a translational nature than in the remaining part of the motion;

- both the anatomical and occipital condyle trajectories can be approximated quite well by a circular arc.

This last finding allows the relative head motions in the plane of impact to be approximated in a simple way by a 2-pivot linkage mechanism.

The upper pivot will be located near the occipital condyles and the lower pivot in the torso in the center of a circular arc segment approximating the occipital condyle trajectories (see Figure 4 for this location). Using graphical techniques the link length, i.e. the distance between upper and lower pivot, is estimated to be 0.125 m. Figure 5 illustrates this linkage mechanism.

For each impact direction 3 degrees of freedom can be distinguished (Figure 5):

- the neck link flexion θ;
- the head flexion ϕ;
- the head twist or torsion ψ (absent in frontal tests).

The relation between neck link flexion and head flexion will be considered here in more detail.

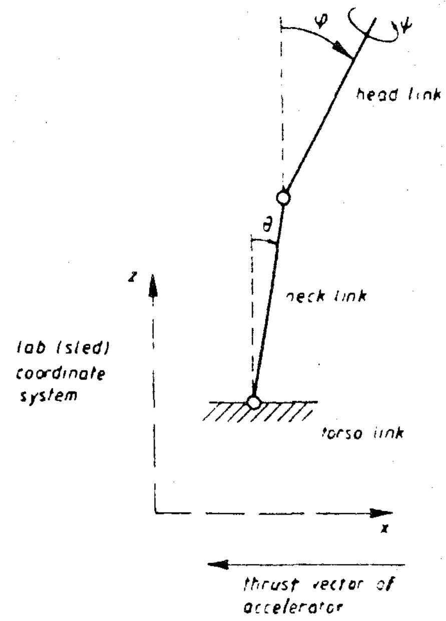

Fig. 5: Two-pivot linkage mechanism

The neck link rotation $(\theta - \theta_o)$ is presented in Figure 6 as a function of the head flexion $(\phi - \phi_o)$. For each subject and impact direction these curves are summarized in a separate figure. In the initial phase of the motion the head flexion is smaller than the neck link rotation for all runs, illustrating the presence of a response which is frequently perceived as a translation of the head. As soon as the relative rotation $(\theta - \theta_o) - (\phi - \phi_o)$ is 15-30 degrees in frontal or oblique impacts, changes in head and neck angle become almost identical. In other words, the head and neck link are more or less locked. A similar behaviour can be observed for the lateral impact response. However here the maximum angle between head and neck link is smaller, namely between 5 and 15 degrees, while in addition this relative angle appears to become smaller in the final part of the loading phase.

1.3. <u>Analysis of Neck Loads</u>

The loads applied by the neck to the head near the occipital condyles can be calculated by using measurements of head acceleration and angular velocity, if the head is regarded as rigid body and does not come into contact with any other object or body part (for neck load equations see [3]). Some of the reasons for performing these calculations are:

- they offer an excellent insight into the system's behaviour, for instance with respect to the role of muscle activity;
- load-displacement relations can be used to formulate dummy performance requirements and dummy design specifications;

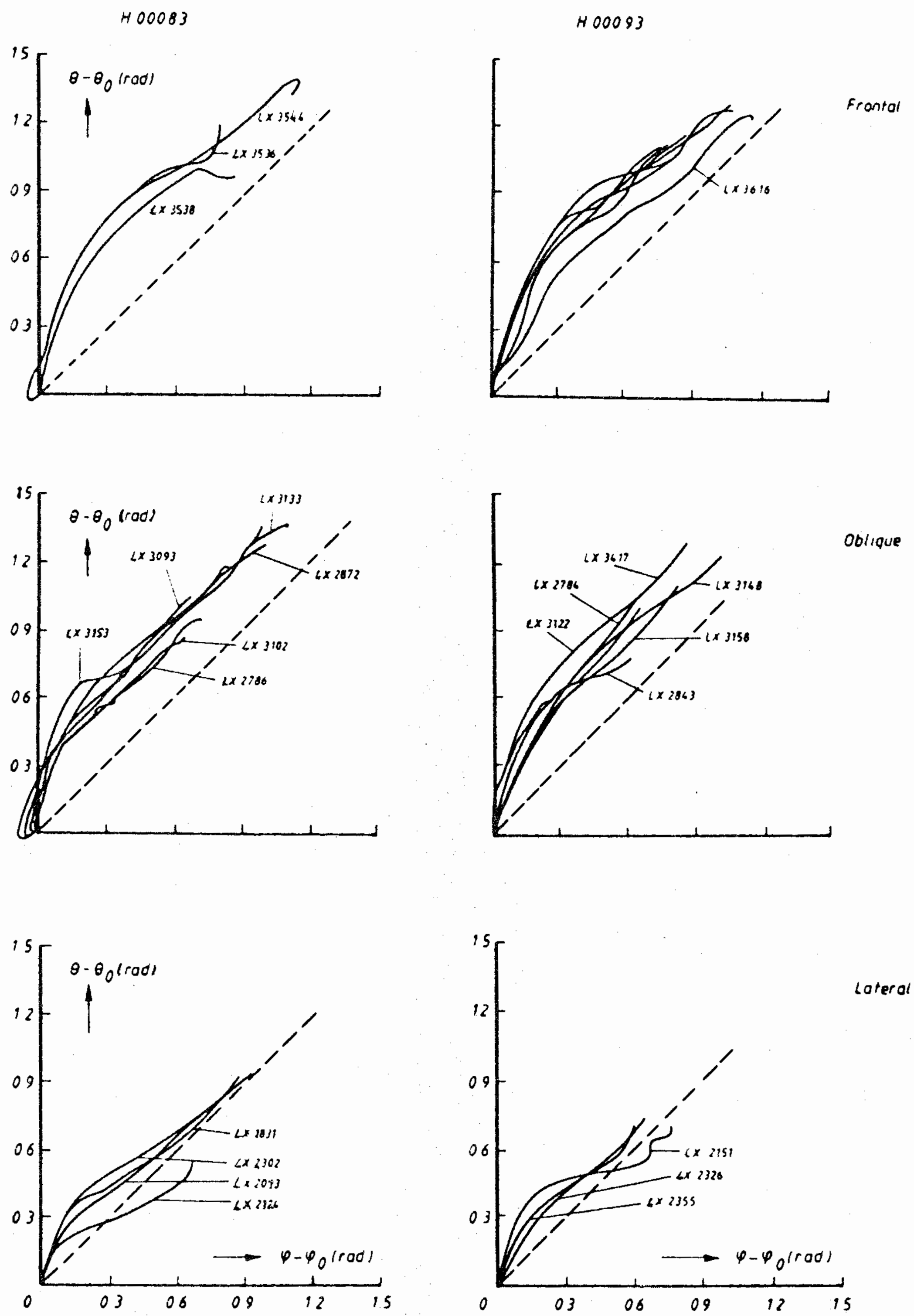

Fig. 6: Neck link rotation ($\theta - \theta_o$) as function of head flexion ($\phi - \phi_o$) in 30 tests with 2 subjects.

- dynamic properties can be determined in a mathematical analogue;
- it is generally assumed that neck loads correlate quite well with neck injuries.

Figure 7 illustrates the torques near the occipital condyles as functions of the head flexion angles. Results in this figure are presented along with the corridor proposed by Mertz et al [5]. The calculated torque-head flexion characteristics appear to lie within or close to this corridor. Our calculations seem to suggest that this Mertz corridor is too wide. Largest torque values (i.e. 45-55 Nm) can be observed in the frontal tests with subject H00093.

2. MATHEMATICAL SIMULATIONS

Mathematical simulations have been conducted for the analogue systems presented in Figure 5 in order to verify these systems. Geometrical data for this system have been selected on the basis of kinematics observed in the human volunteer tests while mass distribution data were based on average values for subjects H00083 and H00093. The stiffness data for the joints could be determined using the results of neck load calculations. Geometrical and mass distribution properties are identical for the three impact directions. The joint stiffness values however are different.

The calculations were conducted with the three-dimensional version of the Crash Victim Simulation Program MADYMO [6]. The results of two simulations in frontal impacts will be presented here. The first simulation is a moderate impact (9.5 g, 12.5 m/s) using as model input the average value of the T1 acceleration in three tests (LX 3544, LX 3548 and LX 3550). The second simulation is a 15.3 g, 17.2 m/s impact using as input the T1 acceleration measured in test LX 3616.

Figure 8 shows, for both impact severities, model and experimental occipital condyle trajectories relative to a coordinate system with the same orientation as the sled coordinate system and its origin in the lower pivot. Results for the head flexion ϕ as a function of time are presented in Figure 9.

It can be concluded that the results of these simulations are very realistic. More detailed results of these and other simulations are provided in [7].

3. COMPARISON BETWEEN DUMMY AND VOLUNTEER

The Part 572 and Hybrid III neck were both designed to perform realistically in frontal impacts. At the Vehicle Research and Test Center an experimental study has been conducted where both necks were exposed to various impact levels [8]. In one of the tests the sled acceleration pulse was based on one of the most severe NBDL human volunteer tests (LX 3616: 15.3 g sled pulse, 17.2 m/s sled velocity). These tests were conducted on a HYGE sled.

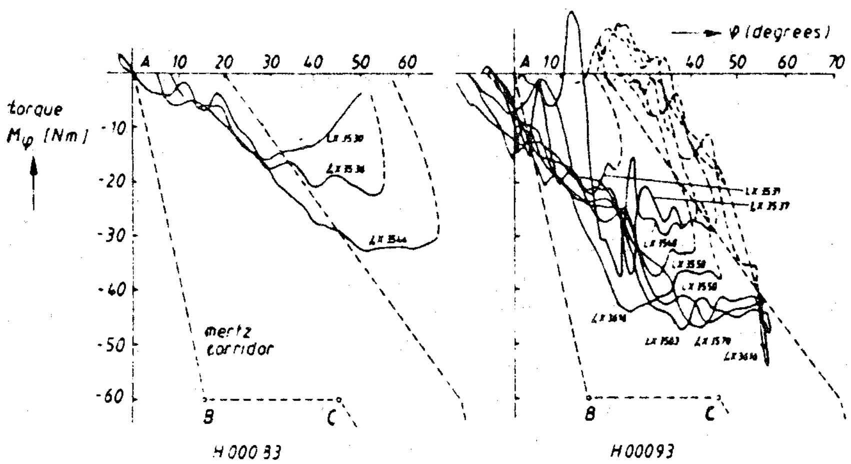

Fig. 7: Torque M_ϕ near occipital condyles about an axis perpendicular to the plane of impact as a function of head flexion $(\phi - \phi_o)$.

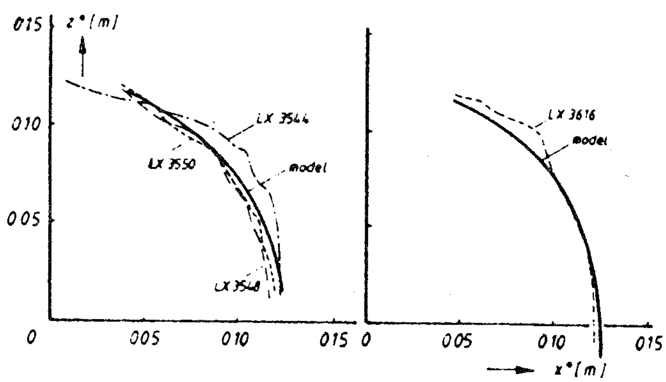

Fig. 8: Comparison between the trajectories of the occipital condyles in human volunteer tests and analogue. (left: moderate impact; right: most severe impact).

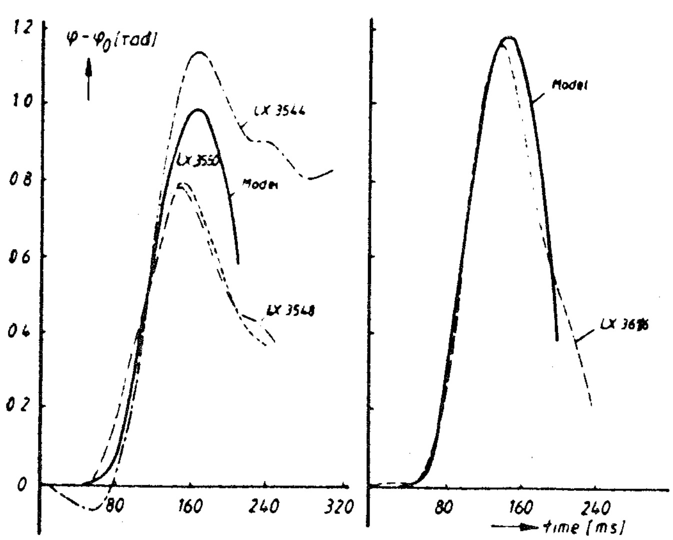

Fig. 9: Comparison between head flexion $(\phi - \phi_o)$ as a function of time in human volunteer tests and analogue. (left: moderate impact; right: most severe impact).

Both dummy head-neck assemblies were equipped with one translational and two rotary potentiometers in order to determine the relative head displacements.

Figure 10 presents center of gravity trajectories calculated from the instrumentation data together with the human volunteer trajectory of test LX 3616 (subject H00093). Head rotation-time histories for dummies and volunteers are also shown in this figure. It follows that head rotation and horizontal centre of gravity displacement are slightly smaller for both head-neck assemblies. Much larger deviations, however, are found for the vertical displacements: both neck designs appear to be stiff in comparison with the volunteer behaviour. These differences between dummy and volunteer are even more apparent if one considers that subject H00093 shows relatively small head excursions compared to subject H00083.

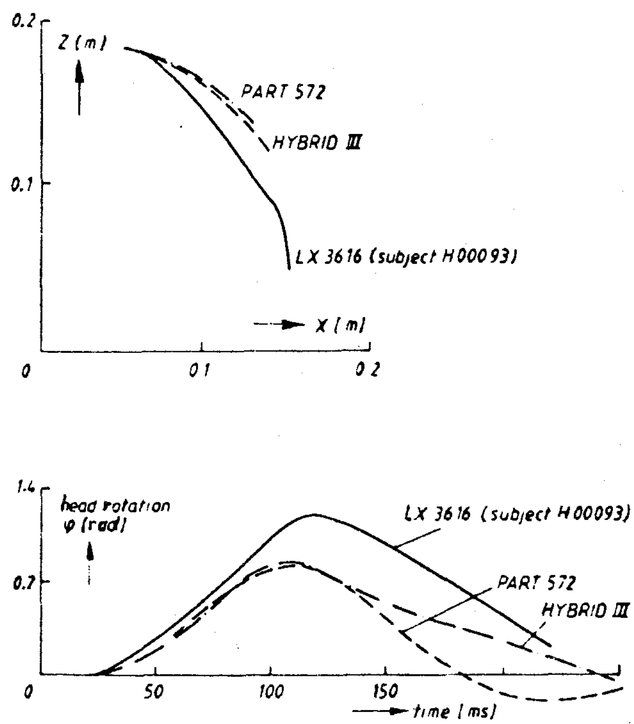

Fig. 10: Comparison of centre of gravity trajectories and head rotation in two dummy neck designs and the most severe human volunteer test.

4. CONCLUSIONS

- The complex head-neck kinematics in frontal, lateral as well as oblique impact tests with human volunteers can be simulated by a simple 2-pivot analogue system.

- Mathematical simulations that were conducted to verify this analogue show very realistic results.

- Existing dummy neck designs appear to be too stiff in frontal flexion compared to the human volunteers.

- The NBDL human volunteer tests were conducted for a relative low impact severity. Additional information should be obtained for higher impact levels from human cadaver tests.

ACKNOWLEDGEMENTS

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DISCUSSION OF DR. WISMANS' PAPER

Mr. M. Williams: In the case of the naval volunteers who were tested on a sled, the acceleration forces that they were subjected to were very severe, probably equivalent to about 20 or 30 mph barrier impacts. Were any of those people injured at all?

Dr. J. Wismans: Not that I know of.

Mr. M. Williams: How many tests were done?

Dr. J. Wismans: Fifteen hundred to two thousand. We have conducted these tests since 1978 and are still doing them. So far we have not done hyperextension tests, which are quite interesting with respect to whiplash. I'm not sure whether they are going to do these tests due to the much more dangerous environment for this type of neck motion. But in the cadaver program we are planning to do a couple of hyperextension tests too.

Mr. M. Williams: I could add on this basis that, in Victoria, there is a pretty large number of insurance claims for whiplash injuries that involve acceleration levels about one-seventh of those that are represented there.

Dr. J. Wismans: The problem often is, I think, that it is hard to tell whether or not impact to the head has occurred.

Mr. M. Williams: In this there is no impact at all.

Dr. J. Wismans: But what is impact - a certain part of the head comes into contact with the door or part of the vehicle?

Dr. P. Tamblyn: I wondered whether the volunteers had warning of the exact moment at which the accelerations occurred and whether they braced themselves for the impact. Also, really what are your thoughts on voluntary muscle bracing with regard to its effect on the impact injury?

Dr. J. Wismans: My opinion of these kinds of tests was that subjects were more or less aware of what time the impacts would occur due to lights and sound, and that they were using their muscles to prevent the head from moving. So in general, what we see here, since it is also young strong people, is a representation of what is not a reality. In reality, necks will be much softer, less stiff, than what we see in these voluntary tests. That makes a greater difference between dummies and human beings.

Dr. P. Tamblyn: In the cadaver tests, you didn't really deal with any torque. At what level of acceleration do fractures and dislocations of the neck occur in terms of g forces in cadavers?

Dr. J. Wismans: The cadaver tests conducted were very limited. The only tests I know about that were conducted for lateral impacts were by Peugot/Renault but their test conditions were different from ours. So it's hard to really compare the impact severity in such a cadaver test with the volunteer tests. NHTSA is planning to conduct a couple of tests in more or less identical situations at the beginning of next year. We are really looking forward to these tests because they will help us to understand the effect of the muscles in these impact situations. The injuries in the lateral impact tests which I have seen occur at an impact level of 23 or 24 g. So I don't think there were injuries in the tests compared with these lateral 7 g impact levels. These tests, which were conducted by Peugeot/Renault, were recently presented at the ESV (Experimental Safety Vehicles Conference) in Oxford but the final manuscript for the ESV is not available yet, so it is hard to know exactly what the results of their tests were.

Mr. A. Whittle: What was the weight of the mask used by the volunteers?

Dr. J. Wismans: Five hundred grams of the weight was due to the addition of instrumentation. In the load calculations, we have accounted for this as well as the mask effects, and also allowed for the contribution of the instrumentation to the moment of inertia.

Mr. M.K. Holloway: In your film, particularly in frontal impacts, necks seemed to extend even before the head started to rotate. It was as though the neck extended before it had any head force acting on it.

Dr. J. Wismans: That elongation has often been discussed in the literature. To measure elongation you have to define two points where there appear to be differences during the impact. To establish a reference point, we looked through the final trajectories and defined one point which was at the centre of the trajectory. So certain parts of the neck I'm sure were elongated, and other parts were more or less kept the same length in these types of impacts.

SIMULATION OF PEDESTRIAN HEAD IMPACTS

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(Presented by Mr. T. Gibson)

ABSTRACT

This paper discusses the method used to predict the characteristics of the head in pedestrian accidents investigated by the NH&MRC Road Accident Research Unit. A mathematical crash victim simulation model (MADYMO) is used to predict the dynamics of the pedestrian vehicle interaction. The model is used to simulate a series of seven pedestrian accident reconstructions using cadavers. The results demonstrate that a relatively simple two dimensional simulation can be used to predict the timing, position and velocity of a pedestrian head impact. The limitations and future development of the model are discussed.

1. INTRODUCTION

The NH&MRC Road Accident Research Unit is undertaking a major study of head injury in road accidents [1]. There is a need to have more information of the injury causing events in each accident than is available from a detailed accident investigation. In particular, an understanding of the accelerations of the head in both rotation and translation is required before the mechanisms of brain injury can be fully understood.

This information can be obtained by reconstructing the accident using a surrogate crash victim such as an anthropomorphic dummy (ATD), a cadaver or an animal. However this type of testing is difficult and expensive. The data obtained are of limited value due to the difficulty in extrapolating the results to the living human. As a result there has been an increasing use of mathematical simulation as a means of studying the various events in an accident which may have a part in injury causation [2]. This paper discusses the development of a relatively simple two dimensional mathematical simulation of a pedestrian which is being used by this Unit to produce more information about pedestrian impacts than is available from a detailed accident investigation. The aim is to be able better to specify the loading which occurred to the head as a result of the impact in order to gain a better understanding of the mechanisms of brain injury causation. As such, the simulation forms a bridge between the detailed neuropathology and the results of the accident investigation [1].

Being able to reliably estimate a head impact velocity for a pedestrian accident allows the next step to be taken in matching the head injuries to the accident circumstances. This next step in the development of the project will be to develop a head impact tester to reproduce physically the vehicle damage caused by the pedestrian head impact. The procedure that will be used is as follows:

- a preliminary simulation will be run which will give a head impact velocity prediction and also a prediction of the effective mass of the impact;

- a vehicle identical to that involved in the accident will need to be obtained. Using the predicted values for head impact velocity and effective mass as a starting point it will be necessary to reproduce the vehicle damage recorded during the accident investigation. An accurate value for the dynamic stiffness of the vehicle component in a similar loading situation to the actual head impact will be available as a result of the impact testing;
- this will be put back into the simulation to give an accurate assessment of the force on the head as a result of the impact, as well as a prediction of the head acceleration during the impact.

The results of this final simulation will then be used in correlating the types of brain injuries suffered in the accident with the forces applied to the head and the accelerations of the head.

2. DESCRIPTION OF THE PEDESTRIAN MODEL

2.1 Basis of the Model

This Unit uses the MADYMO crash victim simulation computer program to model pedestrian accidents. This program was developed by the Research Institute for Road Vehicles, TNO, in The Netherlands [2]. The application of MADYMO to pedestrian accidents has been described previously [3]. MADYMO has been shown to be capable of accurately simulating accident reconstructions using ATDs [4]. The accuracy of simulation is dependent on the complexity of the model (i.e. the number of body elements) used to simulate the ATD and on the accuracy of the input data in terms of ATD characteristics, contact characteristics and the initial conditions (before impact).

The validation carried out at TNO for Part 572 ATDs was accepted as a basis from which to work [4]. The 7 segment 2D model (head, upper and lower thorax, left upper and lower leg and right upper and lower leg) presented in [4] was selected as a starting point. The aim was to develop this into a simple model which could be used routinely to model actual pedestrian accidents using the amount of data available from a detailed accident investigation. The inadequacies of this model were accepted (see [4] for a discussion of these inadequacies) but it was felt that the model was a useful tool for classifying the severity of the head impact and understanding the events leading up to that impact.

The 7 segment 2D model predicts too high a head impact acceleration due partly to an inadequate representation of the head and neck kinematics. To improve this, extra segments to represent the neck and abdomen were added to the model. The inclusion of these segments had the desired effect of reducing the peak head accelerations and of making the head impact occur slightly later in the simulation. See [1] for a discussion of the changes.

The purpose of the pedestrian model was to use it routinely in the head injury project as an adjunct to the detailed accident investigation being carried out. To do this successfully there needed to be a balance between ease of use and accuracy. A sensitivity analysis of the input parameters was carried out to give guidelines for the critical areas of the input data. The model needed to be able accurately to predict the velocity of the head impact. Other output results were not so important because the data was already available from the accident investigation. With the accurate prediction of the head impact velocity as the major output requirement, the following areas of the input data were found to be important:

- the initial estimate of the speed of the impact between the pedestrian and the vehicle;
- the geometry of the vehicle;
- the geometry of the lower body of the pedestrian, particularly the length of the lower leg and thigh;
- the characteristics of the joint functions defined in the model;
- the dynamic characteristics of the interactions at the various contacts between the vehicle and the pedestrian.

Further development of the model was carried out to improve these critical areas.

2.2 Improvements to the Data Collection

The first step was to review the accident investigation procedures used within the Unit, to improve the quality of data coming from this source. Revisions were made to the methods used to estimate the point of impact with the pedestrian and the speed of the vehicle. The methods used to measure the geometry of the vehicle were improved, and the measurement of the vehicle damage was brought more into line with that used in the PAIDS study [5], a major pedestrian accident study carried out in the USA. The procedure used to collect data from the autopsies and the hospitals was changed to include direct measurements of the lower limbs of the pedestrian, including position of injuries and some link lengths.

2.3 Modelling the Human Pedestrian

At the same time as the data collection methods were being improved, the model itself was also developed while still remaining a 9 segment 2D model of a pedestrian. The pedestrian model originally produced at TNO was to simulate a fifty percentile Part 572 ATD. The characteristics inherent in the structure of this type of mathematical model make it more suited to modelling ATDs than human beings. However it was possible to improve the match with a human pedestrian in several ways. The first was to improve the anthropometry of the

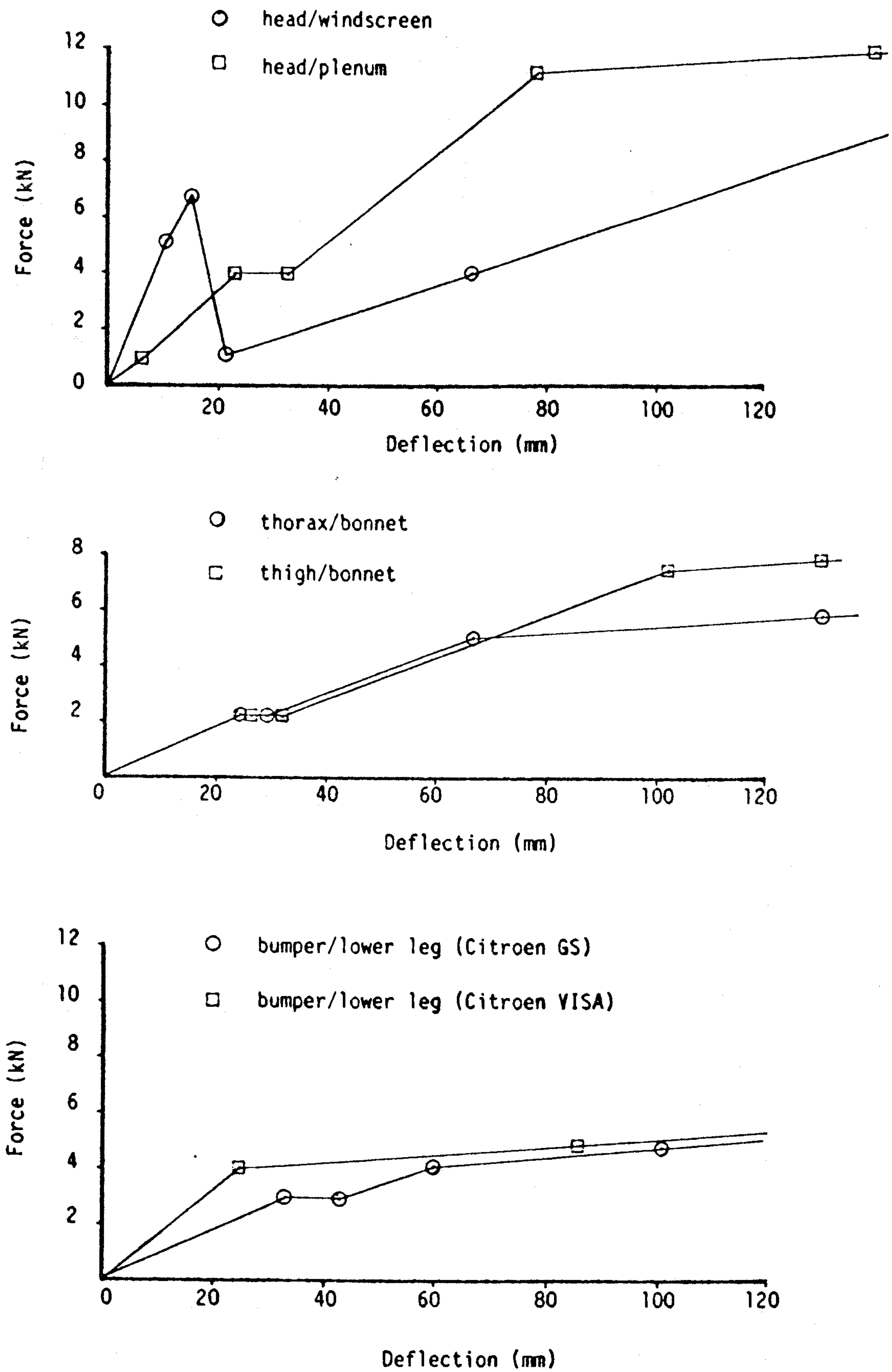

Fig. 1: Combined vehicle and body stiffness

model. An extensive literature review was carried out for information about human body measurements including link lengths (i.e. the distance between major joints of the body), mass distribution and allowable joint motion [6] and [7]. It was found that these all vary, in many cases significantly, from values specified for a Part 572 ATD.

A scheme was developed to predict the values for the link lengths, segment masses and segment moments of inertia required for the pedestrian model. These predicted values are used in conjunction with the measurements of critical limb lengths taken at the autopsy or in the hospital to produce a unique data set describing the anthropometry of the particular pedestrian being studied.

The other input parameter which could be developed more adequately to reflect general human data was the load/deflection characteristics of the body/vehicle contacts. In the version of MADYMO used by this Unit these are specified as a combined stiffness for the two surfaces involved. The Part 572 dummy data used by TNO in the original version of the simulation was also for a specific vehicle. Almost every vehicle/pedestrian interaction is going to have a different dynamic stiffness characteristic. The differences will be not just in terms of the load/deflection but also in the amount of damping and the exact amount of restitution which will occur on rebound.

For the model it was necessary to find data from cadaver and volunteer tests to use as a basis for the human stiffness. This is available from several sources for the head [8], thorax [9] and lower legs [10] (but not in an easily useable form). The experiments had usually been carried out for other purposes and the results were neither directly comparable nor in strictly the correct form for this use.

However, a set of load/deflection curves was derived for the various body segments. This set of curves must be used in conjunction with the load/deflection of the particular vehicle contact for use in the model (see Figure 1 for the values used in the simulation work presented in this paper).

3. COMPARISON OF THE SIMULATION WITH CADAVER TEST RESULTS

The pedestrian model development had reached a stage where some form of validation was required before it could be used on a regular basis in the project. It is difficult to obtain appropriate test information for comparison with this type of mathematical model. However the results of a series of seven staged car/pedestrian accident reconstructions using cadavers were published by the Organisme National de Securite Routiere (ONSER) in France [11] and [12]. The tests were carefully controlled to improve the repeatability of the impacts. Briefly the procedure used in the tests was as follows (see also Table 1 for the individual test data):

- the pedestrian was an unembalmed human cadaver which was held in a standing position until just before impact. The test subject was impacted from the right side;

- two test vehicles were used, a Citroen VISA and a Citroen GS. The suspension of the vehicle was locked in a braking position (equivalent to 6 m/s2) and the vehicle was braking at impact. The impact speed was nominally 40 km/h (11 m/s);

- the kinematic analysis of the cadavers was carried out using high speed films;

- the VISA was fitted with a standard bumper bar and the GS with an experimental bumper bar of approximtely half the dynamic stiffness;

- following the impact the cadavers were examined for injuries sustained and these were scaled according to the Abbreviated Injury Scale (AIS).

TABLE 1: Pedestrian Accident Reconstruction Data [11]

Test Number	Height (cm)	Weight (kg)	Vehicle	Impact Speed m/s	Head Injury Severity (AIS)	Cause
FOC 10	167	55	GS	10.92	5	Plenum & Ground
FOC 12	185	77	GS	10.93	5	Plenum & Ground
FOC 52	166	62	GS	10.61	3	Plenum
FOC 06	176	50	VISA	10.87	1	Windshield
FOC 08	180	63	VISA	10.79	1	Windshield
FOC 41	173	63	VISA	10.78	1	Windshield
FOC 45	156	70	VISA	10.78	1	Windshield

These tests were published with enough detail to form the basis of a validation of the ability of the Unit's model to predict the velocity of the head impact.

A simulation was made of each of the seven tests. The input data to the pedestrian model was changed to reflect the test to test variation in the following ways:

- the input data was modified using the methods described earlier in this paper to fit the physical characteristics of the cadavers. These varied significantly in height (from 156 cm to 185 cm) and weight (from 50 kg to 77 kg);

- the impact speed was varied according to that recorded for the test (this varied from 38.9 km/h to 40.1 km/h);
- the geometry of the car was matched to the actual vehicles used in the tests;
- the vehicle structural stiffnesses were approximations of the results of actual tests carried out on the experimental vehicles.

The model, therefore, simulated each test as an individual case much in the same way as it would be used to model a real accident.

4. DISCUSSION OF VALIDATION

4.1 Comparison of Results

The pedestrian is impacted on the right lower leg by the bumper bar of the vehicle. This initiates the trajectory of the pedestrian. In Figures 2 and 3 a comparison is made between the kinematics of the cadaver and those of the model for two of the tests. Figure 2 is with the Citroen VISA and Figure 3 is with the Citroen GS. These two figures show good agreement between the cadaver test and the simulation in terms of the kinematics of the pedestrian. They also illustrate the areas where the model is not able to simulate exactly the kinematics of the cadaver.

In both cases shown the initial impact between the bumper bar and the lower legs of the model has caused the legs to be flicked out from the front of the vehicle too rapidly. The cadaver legs have wrapped further around the front of both vehicles and have remained in contact with both the vehicle and the ground for longer. This initial flick given to the legs in the model leads to the torso also rotating too quickly and causes the head impact to be early (Figure 4) and slightly too far forward (Figure 5). Figure 6 shows a comparison of the predicted resultant velocity of the head at impact, with the cadaver head velocity measured by analysis of the high speed film [12]. The average head impact velocity predicted by the model is 7 percent greater than that of the cadavers. This high result is due to the same factors which cause the head impact to be short and early.

4.2 Interpretation

In the model all the links are rigid and the joints at the knee and hip are pin joints. It is not possible to match the motion and energy absorbing characteristics of the human frame with such a simple model. On impact the cadaver legs absorb more energy through wrapping around the vehicle. When a cadaver impact is viewed on high speed film the joints no longer exist as discrete discontinuities in the structure. There is a gradual flowing of the body around the front of the vehicle. This tendency is increased by the fractures to the lower legs and pelvis, such as were recorded in the cadaver reconstructions [11]. The inadequate modelling of the energy absorbed in the lower legs imparts too high a rotational velocity to the body of the pedestrian, leading to the head impact being short, early and having too high a velocity. In addition, constraining the model to act in

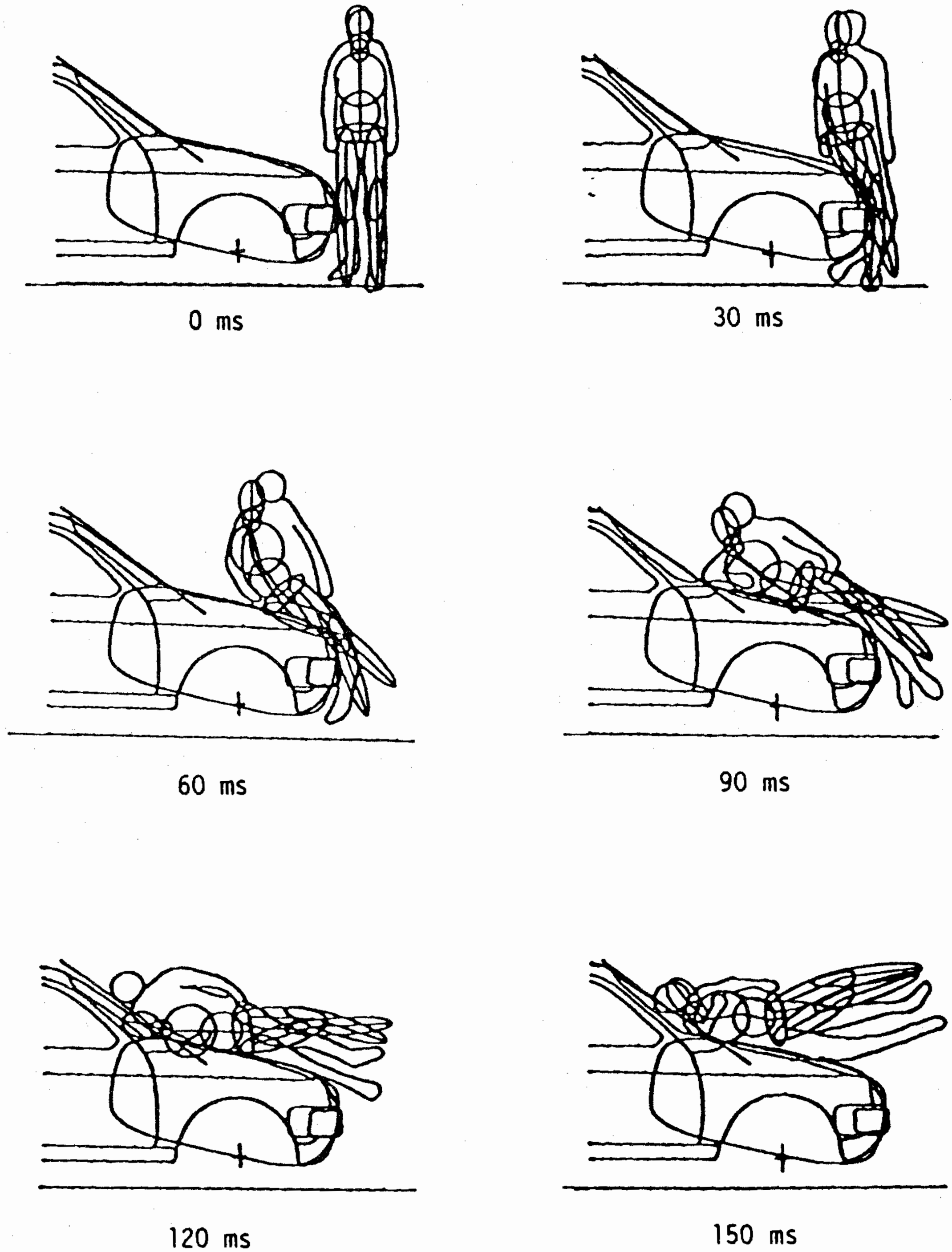

Fig. 2: Comparison of pedestrian trajectory sequence for the segmented model and a cadaver test (Citroen VISA - FOC 45).

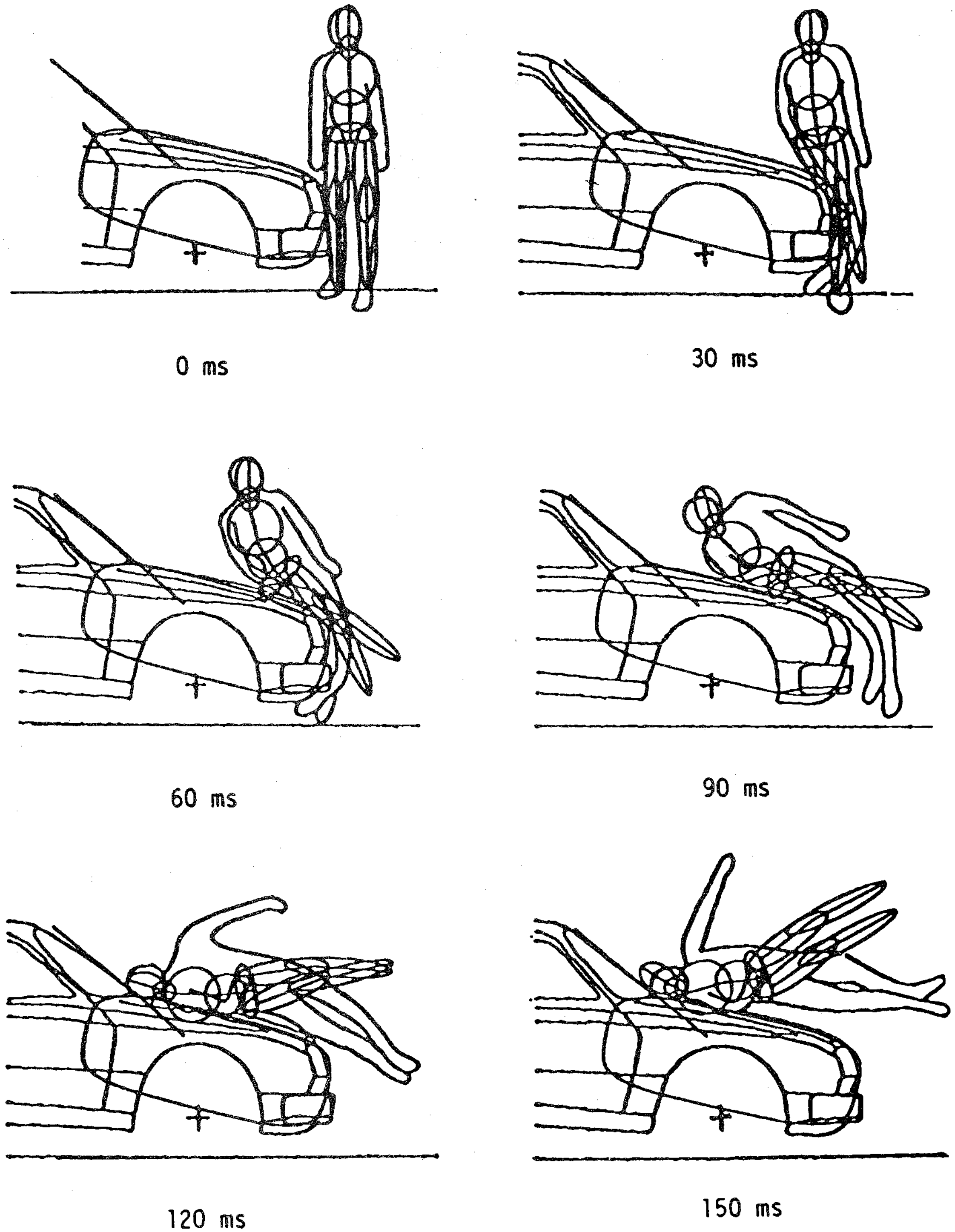

Fig. 3: Comparison of pedestrian tragectory sequence for the segmented model and a cadaver test (Citroen GS - FOC 52).

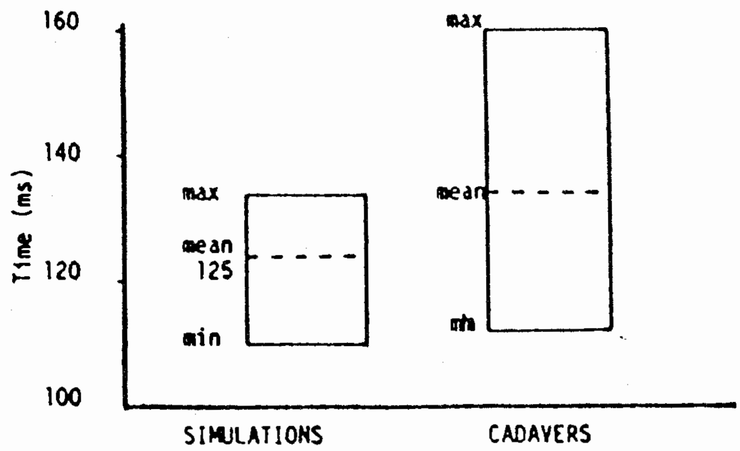

Fig. 4: Head impact time.

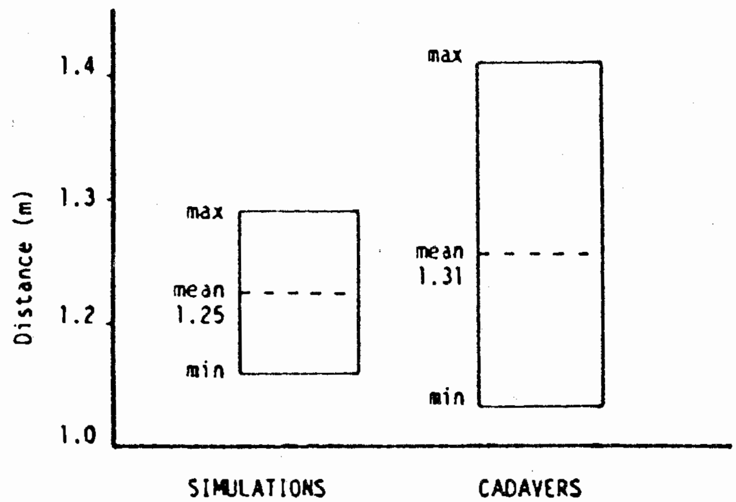

Fig. 5: Head impact distance and rearward from bumper.

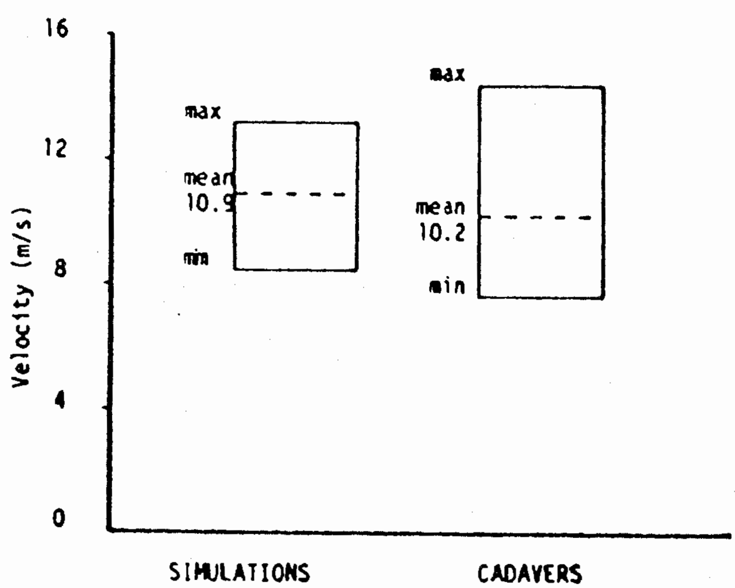

Fig. 6: Head impact velocity - resultant.

only two dimensions limits the energy transfer into axial rotation of the body and this also tends to increase the velocity of the head impact [4].

Even though the predicted head impact occurs early (by about 7 percent on average) and a little close to the front of the car (by less than 5 percent short on average), the simulation results all fall within the variability of the test results, (as seen in Figures 4, 5 and 6). Two of the seven tests had anomalies which caused fairly major discrepancies between the test and the predicted results. In FOC 41 with the VISA the legs of the cadaver were trapped by the bumper bar, resulting in a large number of fractures in the lower legs and pelvis. This trapping may have been due to the weakened bones in the cadaver, but it gave rise to an early head impact close to the front of the vehicle. The second anomaly occurred in test FOC 12 which involved a particularly tall cadaver and the model values for the time and position of the head impact which were both 16 percent early and 16 percent too short. In the test, more sliding over the vehicle bonnet occurred in the case of the cadaver than in the model.

5. FUTURE DEVELOPMENTS

Several areas of the simulation could be developed further:

- the lower leg needs refining to simulate better the kinematics of a cadaver and a real pedestrian;
- refinements in head and neck modelling are needed especially with respect to being able to predict rotational motion of the head on impact - an important component in brain injury causation;
- a three-dimensional simulation is required to allow axial rotation of the body segments on impact.

These refinements would help improve the kinematics of the head impact of the pedestrian model. However the improvements to be gained from a three-dimensional model will only be of use if current head and neck models are improved to include response due to direct impact.

6. CONCLUSIONS

This paper has presented the rationale behind the development of a mathematical model to simulate pedestrian accidents involving human beings. A comparison with a set of seven pedestrian accident reconstructions using cadavers shows that on average the model is able to predict the head impact velocity within 7 percent of the measured result. In using this model to reconstruct real accidents the final accuracy will depend on the precision of the data from the accident investigation, especially the estimate of the vehicle speed at impact.

The next phase of this work will involve dynamic testing of vehicle stiffness to use as an input into the simulation. This next stage is necessary if accurate two-dimensional force and acceleration data is to be predicted for use in correlation studies with the brain injury information currently being collected.

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DISCUSSION OF MR. GIBSON'S PAPER

Mr. P. Chapman: You mentioned that in the simulation you are only able to cope with the complexities of the simulation of lateral impacts. Have you any idea what percentage of real impacts are purely lateral?

Mr. T. Gibson: Impacts that are generally lateral are close to 75 per cent; purely laterals would be less than that.

Mr. P. Chapman: I refer to those you are able to simulate.

Mr. T. Gibson: It would depend on just how far out of that lateral mode they are as to whether they would be worth simulating. Obviously that would have to be done on an individual basis when you actually look at the accident investigation results. At present we are able to simulate 10 to 15 per cent of the pedestrian accidents we investigate.

Mr. M. Griffiths: You said that the pedestrian model was perhaps one of the simplest ones to deal with. Do the complexities of pedal cyclists or motorcyclists rule out that sort of modelling technique?

Mr. T. Gibson: I think that it would be quite easy to adapt this particular model to work with pedal cyclists. TNO has already done quite a lot of work on that. They presented a paper at the last ESV Conference and the previous IRCOBI Conference, which actually had a 3-dimensional model of a pedal cyclist dummy. It gives quite good results because a pedal cyclist accident in many cases is very similar to a pedestrian accident except that the initial height of the victim is slightly different. So the head impact tends to occur in a different place on the vehicle and with slightly different head kinematics. Motorcycle impacts are a lot more difficult because of the actual type of impact that occurs.

Dr. G. Trinca: A motorcycle tends to slam into the side of a motor car - for example when the vehicle does a right hand turn unexpectedly. There are a number of reasons for that, inconspicuity being one of them, and difficulty of judging distance. But these are very common accidents - about a third of the total - they are the ones that the motorcyclists complain about and the ones we see the most with regard to those who survive.

Mr. T. Gibson: A very common motorcycle accident is to run into the side of the car and the cyclist is impacted either in the face or somewhere in the chest region, by the roof. I don't know how you would be able to simulate that very easily. We considered it at one time but decided that simulation wasn't possible. Another type of vehicle user that is obviously important is the occupant. In many ways the occupant is probably more important in terms of actual numbers of head injuries but there is difficulty there because in Australia, with almost universal belt usage, the accidents in which severe head injuries occur tend to be ones with intrusion. However, as soon as intrusion occurs, you don't know what the input parameters have to be for the model.

SUMMARY OF DISCUSSION SESSION C

Helmets for Vehicle Occupants

If a vehicle occupant were to wear a helmet of similar standard to a bicycle helmet the risk of head injury would be significantly reduced. The position is very similar to motorcyclists in the early 1950's - some people would like to wear one but peer group pressure is still too strong. One solution would be to introduce a specialised cap but it would require skillful marketing. A motorist's safety hat, which looked like a cloth cap, was marketed in England in the early 1960's. It would be difficult to have this type of cap accepted by the general population and this is partly due to the small perceived risk of head injury in cars. There are no insoluble problems in designing cars to remove the risk of head injury for restrained occupants in frontal impacts, but this is more difficult if not impossible in side impacts. A Traffic Accident Research Unit study (unpublished) estimated that vehicle occupant fatalities would be reduced by 10 per cent if all occupants wore helmets.

Pedal Cycle Helmets for Children

The industry view is that children below the age of nine should not be out on the road riding pedal cycles - encouraging early use of pedal cycles possibly could be considered an irresponsible act. In terms of helmet performance criteria, there does not seem to be any difference in injury causation above this age and so there is no need for a specialised helmet. The basic motive of the manufacturers is profit and on current sales of the smallest size Stackhat there is no reason to produce a smaller size. The coverage of the helmets available is difficult to put in age-based terms. The smallest helmet in the Guardian range (51 cm size) will fit about 50 per cent of five year old children. One of the difficulties is the perceived high cost of the helmet by the parents who will often buy an oversize helmet so that a young child can grow into it. The problem with the large helmet is that it will move on the head and be unstable. Providing a thicker comfort liner only partially solves this problem and pedal cycle activists are already critical of the amount of comfort padding in the smallest size of Stackhat. More accurate anthropometric data to be used in the design process would improve the match between helmets and actual head shapes.

Bicycles have high exposure (in terms of travel time on the road) particularly in the 12 to 18 year age group where large amounts of time are spent out riding. The younger age group also has high exposure and this group does not seem well catered for in terms of helmet availability. It must be remembered that although this younger group is often not riding on the roads but on paths and in parks it still needs protection. The helmet for this age group must be robust to withstand the type of treatment given to it.

Should the Standard become a Legal Document

It is inevitable that it will be mandatory for bicycle helmets to comply with AS 2063 and wearing of pedal cycle helmets will be made compulsory. The HORSCORS recommended that: AS 2063 be declared a product safety standard; any helmet not reaching the required standard should be declared unsafe; and, 'toy' helmets should be marked 'not to be used for safety purposes'. These provisions will cause problems with the retailers of helmets because they will require a range of general purpose helmets to meet the requirements for horse riding, pedal cycling and so on. The current standard AS 2063.1 does not cover helmets used for ball games such as cricket because it was not felt to be suitable. A specific standard needs to be drawn up because the quality of some of the helmets used in sport shows a poor understanding of the necessary protection requirements, for instance the lack of energy absorbing liners and poor retention systems using chin cups.

Motorcycle Helmets - Importance of Rotational Effects

BSI has just introduced a quantitative test to measure the rotational acceleration imparted to a helmet due to an impact on a projection. This test has an arbitrary pass/fail criterion and is yet to be properly validated. There seem to be difficulties with reproducibility as well. At this stage it would appear to be better to stay with a physical requirement in the standard for the maximum projection allowable.

The projections clause currently in the Australian Standard is obviously a commonsense clause and it has been very difficult to define better the meaning of projection. This is due to the current inability to describe adequately the exact circumstances where rotation might be a problem. Also an operational definition of a projection is difficult to produce.

It is common to see accident-involved helmets with deep abrasions due to road impacts and yet the wearer has suffered no measurable head injury - indicating that no intolerable rotational forces have been produced. A direct impact leading to high rotational and translational accelerations would often appear to be the cause of head injury. In addition the integral face guard is effectively a large projection in many circumstances. It is important not to get things out of proportion when considering the original projection clause in the Australian Standard.

General Discussion

There is a need for local specific data collection at specialist centres to identify the factors involved in head injury causation. The Australian Institute of Health will be setting up a general injury surveillance system and the involvement of any of the specialist centres in designing the system will be very useful.

There has been a great deal of discussion on the optimum stiffness of the rigid foam helmet liner. Field accident data is inconclusive as to the effect of more severe impact standards. A stiff liner will be better for high energy impacts while a softer liner will be more effective in lower energy impacts which are perhaps more typical of survivable accident situations. A possible solution to this in the Standard would be to have two impact tests defined, one low energy and one high energy with appropriate attenuation requirements.

In a community the size of Australia it is difficult to have special units for bicycle helmet research. It is possibly better to encourage different people with varying areas of expertise to contribute by whatever means they can. An example of this is the cooperation between the NH&MRC Road Accident Research Unit, the Royal Adelaide Hospital and the Institute of Medical & Veterinary Science, which combines both engineering and medical expertise.

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