Part One

THE INJURY

1 EPIDEMIOLOGY

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1.1 Introduction

The last 20 years have seen major advances in the prevention and treatment of head injury, resulting in a substantial decrease in mortality. Yet head injury remains a major health and social problem both for developed and developing nations. The frequency and diversity of head injury provides organizational problems for retrieval and early response services, accident and emergency wards and rehabilitation departments. The long-term disabilities may be grave and special difficulties are experienced by the community in general and by families in particular when the head-injured patient attempts to re-enter and integrate with society.

In order to meet these challenges, epidemiological information regarding the frequency of occurrence, causes, distribution and outcome of head injury is necessary. Using reliable data, preventive measures may be undertaken as well as measures to minimize brain injury when it occurs. Epidemiological studies are concerned with populations rather than individuals. The methods used, therefore, measure disease rates and population statistics rather than individual case records, although these may be the source of data.

Such information for head injury is not always easy to obtain (Jennett and MacMillan, 1981). Injuries occur in a widely dispersed geographical pattern, care is decentralized and non-systematized in many regions, deaths occur both inside and outside hospitals and the survivors are cared for in the main by family members (Fearnside, McDougall and Lewis, 1993). While the reporting of death and its causation is mandatory in most countries, it is may not be standardized and is often incomplete, providing a bias in the collection of mortality data (Romano and McLoughlin, 1992).

1.2 Definitions in epidemiology

Epidemiology is a quantitative science that measures the occurrence of disease in the human population (Friedman,1987) and is concerned with the patterns of disease in groups of people rather than in individuals.

A disease such as head injury results from an interaction between an individual and an external agent such as a mechanical force. While clinical medicine is concerned with the management of the individual patient, epidemiology deals with the nature and pattern of the interaction as it applies to a population in a particular environment (Walton, Beeson and Bodley-Scott, 1986). An epidemiological study aims to answer questions, therefore, about distribution, causation, age, sex or racial differences that might be important for measures to prevent or treat head injury in a more rational manner within a community.

A number of terms commonly used in epidemiological studies of head injury are shown in Table 1.1. The **count** is made more meaningful by the use of a **denominator** to relate it to the population in which the event occurred and the numerator must include only persons derived from the denominator population. This descriptor of the count related to a population is termed a **rate** and all members of the population must have an opportunity to appear in the numerator.

The **incidence** of head injury describes the occurrence of new cases in the population over a period of time, usually 1 year.

The **prevalence** of head injury describes all cases in a population at a particular time and is a measure of both new and established cases.

1.3 Source data

Epidemiological information involving head injuries may be derived from a number of sources and levels.

(a) National public health records

Necessarily retrospective, these are, in the main, mortality studies from death certificates (Ring, Berry and Dan, 1986; Sosin, Sacks and Smith, 1989). Some national information may also be available based on hospital admissions, using the N (diagnostic) or E

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Table 1.1 Definitions used in epidemiological studies of head injury

Count	The number of instances an event occurs, e.g. number of head injuries admitted to a hospital
Rate	$\frac{\text{Frequency of the observed event}}{\text{Total number in the 'at risk' population}}$
Incidence rate*	$\frac{\text{The number of persons sustaining a head injury}}{\text{The total population from which they are drawn}}$
Prevalence rate	$\frac{\text{The number of persons with a head injury}}{\text{The total population from which they are drawn}}$
Mortality rate	$\frac{\text{The number of persons dying from head injury/unit time}}{\text{The total population from which they are drawn}}$
Age-specific mortality rate†	$\frac{\text{The number of persons dying from head injury in a particular age group}}{\text{The total population from which they are drawn}}$
Case fatality rate‡	$\frac{\text{The number of persons dying from head injury}}{\text{The total number in the sample or population with head injury}}$

* Established cases should be excluded from the numerator but not the denominator
† May be individualized to other parameters, e.g. gender, socioeconomic class
‡ The CFR refers to the proportion of persons who die with head injury, e.g. following hospital admission. Like the incidence rate, a time period need not be specified, but it may be.

(external cause) of the ICD system (see below). In many countries, public authorities maintain records of cause-related injuries, such as industrial injuries.

(b) National head injury studies

A number of these have been undertaken in an attempt to identify broad features such as incidence and mortality rates on a national basis (Anderson and McLaurin 1980). Difficulties with data collection may occur in these larger studies from an inability to capture all events in a large population and the results may underestimate the actual rates.

(c) Population-based studies

These studies investigate a defined, focal population such as a state or county area (Kraus *et al*., 1984, Ring, Berry and Dan, 1986, Hung *et al*., 1991), an urban (Chan, Walker and Cass, 1988) or a rural area (Jagger, Levine and Jane, 1984). The true incidence is more likely to be approached as the size of the sample becomes smaller and capture more complete.

(d) Clinical topic reports

These are based on clinical events or etiological characteristics. Thus, head injuries may be further defined by groupings such as mild (Kraus and Nourjah, 1988) or moderate head injuries (Rimel *et al*., 1982). Head injuries may be associated with a particular mode of transport. Thus, Bucklew *et al*. (1992) described head injuries following falls and ejections from pick-up trucks in New Mexico. Studies of head injuries in sports such as football (Mueller and Cantu, 1988) are further examples of such focused investigations.

1.4 Definitions and classification of head injury

1.4.1 DEFINITIONS IN HEAD INJURY

Head injury demands a broad definition. The anatomical term suggests any trauma to the body above the lower border of the mandible. In general, maxillofacial trauma is considered separately from head injury, although the two frequently coexist. David and Simpson (1995) have used the term 'craniomaxillofacial injury' to group together injuries of the face and frontal region. The head includes the scalp, skull, meninges and blood vessels as well as the brain and its constituent parts. The term 'craniocerebral injury' is often used to emphasize that the brain should not be considered in isolation from its integuments. 'Trauma' refers to an external source of energy, such as a mechanical force, causing a physical injury to any or all of the tissues comprising the head. Electrical, thermal and chemical causes of injury are usually considered separately, in the category of burns, but it should be remembered that deep craniocerebral burns are likely to require neurosurgical management and may appear in neurosurgical statistics. However, they are very rare.

There is no agreed definition of head injury for epidemiological purposes and the definitions in each of the studies shown in Table 1.2 differed. Such differences may result in an inability to compare epidemiological studies. Kraus *et al*. (1984) emphasized the desirability of separating the broader classification of head injury from brain injury, the latter more precisely indicating neurological damage. They stressed the importance of identifying patients having sustained 'neuro-trauma of public health consequence' where there was a probability of ongoing neurological impairment, requiring resources for medical or nursing care. This distinction is of obvious value in the planning of rehabilitation services and community support schemes.

For epidemiological studies, it is often desirable to define a broader range of 'head injury', bearing in mind that many patients sustain an apparently minor injury on presentation but later exhibit evidence of brain injury, intracranial hematoma or skull fracture (Jennett, 1989). Brain injury is best considered as a subgroup of head injury and attention needs to be given to these definitions when assessing various reports in the literature.

Table 1.2 Definitions of head injury showing variations among the series

Field (1976)	'Trauma which caused some risk of damage to the brain'. Used ICD-9 rubrics.
Anderson and McLaurin (1980)	'Trauma to the brain or spinal cord. Here, trauma refers to physical injury to living tissue caused by an external force'.
Jennett and MacMillan (1981)	'Patients with a history of a blow to the head or with altered consciousness after a relevant injury or with a scalp or forehead laceration, or who had an X-ray examinaton'.
Klauber et al (1981)	'Patients whose head injury resulted in skull fracture, unconsciousness, amnesia, neurological deficit or seizure'.
Selecki et al (1981)	'Injuries to the brain or skull'.
Kraus et al (1984)	'Physical damage to,or functional impairment of, the cranial contents from acute mechanical exchange, excluding birth trauma'.
Jagger, Levine and Jane (1984)	'Documented head injury with loss of consciousness, post traumatic amnesia or skull fracture'.
Brookes et al (1990)	'Any injury to the scalp including swelling, abrasion or contusion as well as laceration; or a well authenticated history of a blow to the head; or any patient in whom a skull X-ray was performed immediately following trauma, and patients who had clinical evidence of a fracture at the base of the skull.'

1.4.2 CLASSIFICATION OF HEAD INJURY

The World Health Organization (WHO) publishes an International Classification of Diseases (ICD), where trauma and head injury are included in the chapter 'Injury and poisoning'. Prior to 1950, trauma was classified according to the external cause (E code) and there are no available methods for extracting information regarding the effect of trauma to the head in a systematic manner. The fifth revision, ICD-5, introduced a classification based on the nature and diagnosis of the injury (N code).

However, the fact that all brain injuries were classified as 'Intracranial injury without skull fracture' and included hematomas of the scalp meant that a precise description of the cerebral injury was not available. No doubt this classification reflected the preoccupation of surgeons and pathologists of the time with focal, low-energy impacts such as skull fracture and extradural hematoma, rather than with high-energy impacts that damaged the brain rather than its coverings.

The diagnoses are contained in a series of digital codes or rubrics. The ninth edition, ICD-9-CM (WHO, 1978, 1979), contains a three-digit rubric for the major diagnostic groups (e.g. 800 – Fracture of skull), to which is added a further digit which specifies anatomical, pathological or clinical detail (e.g. 800.1 – Closed head injury with cerebral laceration and contusion; 800.2 – Closed head injury with subarachnoid, subdural and extradural hemorrhage). Using the Clinical Modification (CM), a fifth digit may be added where appropriate, providing information of clinical relevance or further defining a diagnostic statement (Table 1.3).

The tenth ICD revision (ICD-10, WHO, 1992), soon to be published for general use, contains rubrics that will more accurately reflect clinical diagnosis when compared with the rubrics of ICD-9-CM (Table 1.4). However, the new alphanumeric code will require a considerable change in coding practice.

The ICD system is used in many countries as the basis for public health data from which epidemiological statistics are derived. The system is also used by most hospitals for diagnostic or treatment coding for the purposes of data recording and retrieval. ICD-based epidemiological studies of head injury are necessarily population-based and may be either national (Jennett and MacMillan, 1981; Sosin, Sacks

Table 1.3 ICD-9 CM rubric for 'Intracranial injury excluding those with skull fracture', showing the use of the 3-, 4- and 5-digit rubrics

850	Concussion 850.0–850.6 describe various levels of loss of consciousness e.g. 850.4, with prolongd loss of consciousness, without return to pre–existing conscious level
851	Cerebral laceration and contusion 851.0–851.9 describe various anatomical sites of injury with or without open wound e.g. 851.3, Cortex (cerebral) laceration without open intracranial wound.
852	Subarachnoid, subdural and extradural hemorrhage following injury 852.0–852.5 describe open or closed injury.
853	Other and unspecified intracranial hemorrhage following injury 853.0–853.1 describe open or closed injury
854	Intracranial injury of other or unspecified nature 854.0–854.1 describe open or closed injury

The following fifth digit subclassification is for use with categories 851 to 854 and adds clinical information:

0 Unspecified state of consciousness
1 With no loss of consciousness
2 With brief (less than 1 hour) loss of consciousness
3 With moderate (1–24 hours) loss of consciousness
4 With prolonged (more than 24 hours) loss of consciousness and return to pre-existing conscious level
5 With prolonged (more than 24 hours) loss of consciousness, without return to pre-existing conscious level
6 With loss of consciousness, unspecified duration
7 With concussion, unspecified

Table 1.4 Comparison between ICD-9 CM and ICD 10 chapters 'Intracranial injury, excluding those with skull fractures'

ICD-9 CM	ICD-10
850 Concussion	SO6.0 Concussion
851 Cerebral contusion and laceration	SO6.1 Traumatic cerebral edema SO6.2 Diffuse brain injury SO6.3 Focal brain injury
852 Subarachnoid, subdural and extradural hemorrhage following injury	SO6.4 Epidural hemorrhage SO6.5 Traumatic SDH SO6.6 Traumatic SAH
853 Other and unspecified hemorrhage following injury	SO6.7 Intracranial injury with prolonged coma
854 Intracranial injury of other unspecified nature	SO6.8 Other intracranial injuries SO6.9 Intracranial injury, unspecified

and Smith, 1989), or locality- or hospital-based mortality or morbidity studies (Kraus *et al*., 1984; Kraus and Nourjah, 1988). Like all databases, the ICD system is no better than the people who code it and experience has shown that inaccurate or incomplete coding is more likely to occur when staff are inadequately trained. Klopfer *et al*. (1992) found that ICD coding of external causes of injury had been omitted in the majority of a large sample of USA hospital discharges after eye injury.

1.5 Deaths from trauma

Using ICD-9 chapters, deaths from 'injury and poisoning' rank fourth in age-standardized death rates for males and females in most Western countries, behind circulatory, neoplastic and respiratory diseases (Table 1.5).

In Australia in 1990, deaths from 'injury and poisoning' accounted for 8.6% of male and 4.2% of female deaths (mortality rate 68 per 10^5 of the population for males and 25 per 10^5 of the population for females). ***These deaths comprised 49% of all deaths in the age ranges 1–44 years (Australian Institute of Health and Welfare, 1992). Since the early 1970s, deaths from injury have steadily decreased by annual decrements of 2%, due largely to a decrease in motor-vehicle-related deaths. In 1990, motor vehicle accidents remained the most common cause of death in this group, accounting for 31% of both male and female deaths.*** However, the figure of 2489 motor-vehicle-related deaths was the lowest for several decades and 12% less than in 1989. Suicide accounted for 38% of male and 18% of female deaths from injury or poisoning (Table 1.6).

In the UK, a study of coroner's records of trauma deaths in the south-west Thames region revealed that road traffic deaths were the most common cause of traumatic death (Daly and Thomas, 1992). ***The majority of deaths occurred before arrival at a hospital and were due to chest and multiple injuries, whereas the majority of those who survived to reach hospital and subsequently died did so as the result of a head injury.***

In New Zealand (Table 1.5), injuries ranked fourth as a cause of death and accounted for 32% of potential years of life lost between the ages of 1 and 70 years. The leading causes of injury death were from motor vehicle crashes (37%) and self-inflicted injuries (21%; Langley and McLoughlin, 1989). However, the two leading causes of hospital admissions for trauma were falls (25%) and motor vehicle crashes (19%), where head injuries contributed 35% to the injury morbidity. For children, a similar pattern of falls and motor vehicle accidents emerged as the most common presentations in Accident and Emergency departments following

Table 1.5 Age standardized death rates (per 100 000 population) by ICD-9 chapters for males and females for selected countries. Resp = respiratory; Inj = injury and poisoning. (Source: World Health Organization 1991–92; Australian Institute of Health and Welfare)

	Male				*Female*			
	Circulatory	*Neoplasm*	*Resp*	*Inj*	*Circulatory*	*Neoplasm*	*Resp*	*Inj*
Australia 1990	401	247	81	67	258	150	36	26
Canada 1989	382	260	88	75	221	162	42	30
New Zealand 1987	517	259	130	85	322	186	72	36
UK 1990	469	276	118	48	281	186	61	19
USA 1988	456	246	95	90	283	161	51	32

Table 1.6 Deaths from injury or poisoning (ICD-9), for males and females in Australia, 1990 (Rates per 100 000 of the population; crude rates for individual causes and standardized rates for 'All external causes') (Source: Australian Institute of Health and Welfare, 1992)

	Males		*Females*	
Cause of death	*Number*	*Rate*	*Number*	*Rate*
Motor vehicle traffic accidents	1751	21	738	9
Suicide	1735	20	426	5
Accidents, falls	472	6	558	7
Homicide	239	3	146	2
Accidental drowning	227	3	73	1
Other causes	1164	14	406	5
All external causes	**5558**	**68**	**2347**	**25**

trauma and the head was the most frequently injured part of the body, the incidence increasing with age (Gofin *et al.*, 1989). ***A comprehensive study by Shackford et al. (1993) of all trauma in San Diego County, California, USA for 1 year revealed an incidence rate of 27.3 per 10^5 of the population and among those, motor vehicle accidents were the most common cause of injury. Head injuries were the leading cause of death (48.5%), with a mortality rate of 13.2 deaths per 10^5 of the population.***

Care must be exercised when considering death-certificate-derived data, as failure to specify the entire injury inventory is probably common and would introduce a bias to understate the true incidence. ***Romano and McLoughlin (1992) found that, during a 12-month period, the death certificates of 41% of fatally injured Californian motorcyclists recorded no specific injuries. When autopsy reports were abstracted, 68% of these motorcyclists had sustained a significant head injury.***

1.6 Severity of trauma

With the development of trauma management systems and trauma registries in many hospitals during the 1970s and 1980s, there arose a need to develop a standardized classification of injuries and their severity.

1.6.1 THE ABBREVIATED INJURY SCALE (AIS)

The first AIS was published in 1971 as an initiative of the American Medical Association, the Association for the Advancement of Automotive Medicine and the Society of Automotive Engineers. The scale, originally developed for impact injury assessment, has undergone a number of revisions, the most recent in 1990 (Association for the Advancement of Automotive Medicine, 1990).

The scale uses a numerical method of ranking injuries by severity and is based on the anatomical injury alone, thus allowing no descriptor of the consequences of the injury, such as disabilities. There is only one AIS score for each injury and the scale does not provide a single assessment of multiple injuries. The anatomically based system classifies the single injury by body region on a six-point ordinal scale from 1 (minor) to 6 (maximum). The 1985 revision, AIS 85, introduced a unique six-digit code for each injury based on a body region (digit 1), the type of anatomic structure (digit 2), the specific anatomic structure or the specific nature of the injury if external (digits 3 and 4) and the level of the injury within an anatomic region (digits 5 and 6). The digit to the right of the decimal point identified the AIS score. The most recent revision, AIS 90, expanded the descriptors for brain injury, following data analysis which suggested that

Table 1.7 Examples of derived Abbreviated Injury Scale (AIS) scores (Source: Association for the Advancement of Automotive Medicine, 1990)

1. A patient with a diagnosis of brainstem contusion has an AIS score of 140204.5, which is derived as:

   1 = Head
   4 = Organ
   02 = Brainstem
   04 = Contusion
   .5 = Critical

2. A patient with large, multiple bilateral cerebral contusions has an AIS score of 140624.4, which is derived as:

   1 = Head
   4 = Organ
   06 = Cerebrum
   24 = Large (total volume 30–50 ml)
   .4 = Severe

serious brain injuries were under-recorded (Gennarelli *et al.*, 1989). Two examples of the derivation of AIS scores in head injury are shown in Table 1.7.

The AIS also contains a means of classifying head injury based on the level of consciousness (Glasgow Coma Scale) and the duration of coma. These parameters are used only when the clinical features reflect a more serious injury than the anatomical lesion suggests, or when no anatomical lesion is identified using imaging or at autopsy. Ross *et al.* (1992) tried to use the AIS for the head region to predict outcome, but found it inadequate.

1.6.2 THE INJURY SEVERITY SCORE

The AIS provides no means to assess the effects of multiple injury and, clearly, such a measure is needed. This requirement was fulfilled by the Injury Severity Score (ISS) (Baker *et al.*, 1974), which is derived by calculating the sum of the squares of the highest AIS score in three different body regions. The six body regions used in the ISS are:

1. Head or neck
2. Face
3. Chest
4. Abdomen or pelvic contents
5. Extremities or pelvic girdle
6. External.

The ISS provides a range from 1 (mild) to 75 (most severe) and provides a much better correlation between the injury, the severity and the probability of survival than does the AIS (Bull, 1975). A derived example of the ISS for a patient who sustained multiple injuries including a severe head injury with diffuse axonal injury and a cerebral contusion, a penetrating wound of the face and an open chest injury is shown in Table 1.8. A Trauma Score has been devised to assess the early effects of injury (Boyd *et al.*, 1987, Champion *et al.*, 1990). This score allocates points for the conscious level (0–5), respiratory rate (0–5), respiratory expansion (0–1), systolic blood pressure (0–4) and capillary refill (0–2). The perfect score is 16. This can be combined with the ISS, the type of injury (whether penetrating or blunt) and the patient's age to give a severity index called the TRISS. The system is chiefly of value in assessing the overall severity of multiple injuries and in auditing the quality of management.

1.7 Population-based national studies

(Table 1.9)

A survey of an entire population with capture of all head-injury patients at each severity level would be necessary to satisfy epidemiological requirements to determine the real incidence and prevalence rates of head injury for that population. However, the majority of such injuries are towards the minor end of the severity spectrum and are probably under-reported, as they may only present as a casualty attendance for observation (Jennett, 1975; Jennett and MacMillan, 1981). No such comprehensive survey has yet been reported. However, minor head injury is now recognized as having a potential morbidity (Gronwall and Wrightson, 1974; Marshall and Ruff, 1989) and should be regarded as of major social and economic significance.

Table 1.8 Derivation of the Injury Severity Score (ISS) in a patient with head, facial and chest injuries

Injury	*AIS score*	*Highest AIS score*	*AIS^2*	*ISS group*
Diffuse axonal injury	140628.5	5	25	Head/neck
Small intracerebral hematoma	140640.4			Head/neck
Penetrating injury of the face with blood loss	216006.3	3	9	Face
Open wound of the chest	415000.4	4	16	Thorax

Injury Severity Score = 25 + 9 + 16 = 50

Table 1.9 Incidence, mortality and case fatality rates in population based studies of head injuries from various countries

Country or area	*Incidence (/10^5 pop.)*	*Deaths (/10^5 pop.)*	*Case fatality rate (CFR) (%)*	*Source data*
Britain (Field, 1976)	430		1.6–2.5*	Live hospital adms GP consultations
Britain (Jennett and MacMillan, 1981)	270	9		Deaths, hosp adms and casualty attendances
Rural USA (Jagger, Levine and Jane, 1984)	208		6.5	Live hospital adms
San Diego (Kraus *et al.*, 1984)	180	30	17	Severe brain injury including gunshot
People's Republic of China (Wang *et al.*, 1986)	56			All head injuries in 6 defined urban areas
Sweden (Hook, 1988)	300			All 'registered' cases
NSW, Australia (Selecki, 1988)	392			Deaths and hospital admissions
Aquitaine, France (Tiret *et al.*, 1990)	281	22	4.4	Hospital deaths and hospital admissions
Hualien Province Taiwan (Hung *et al.*, 1990)	333	89		Hospital admissions and deaths
Taipei, Taiwan (Lee *et al.*, 1992)	180	23		Deaths and hospital admissions
Cantabria, Spain (Vasquez-Barquero *et al.*, 1992)	91	19.7		Cross-sectional sample

* CFR was 1.6% for deaths on arrival at hospital and 2.5% when deaths in hospital were included

1.7.1 UNITED STATES OF AMERICA

An enumerative population study (National Head and Spinal Cord Injury Study, NHSCIS) aiming to determine the frequency, prevalence and economic cost of head-injured patients requiring hospital admission for the year of 1974 was undertaken for the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS; Anderson and McLaurin, 1980), where the sample was the entire US population. Prevalence was estimated by including those who required inpatient care between 1970 and 1974 (Anderson, Kalsbeek and Hartwell, 1980). Eligibility required live hospital admission. Accident and Emergency attenders or those dead on arrival were excluded. The incidence rate for head injury using these criteria was 200 per 10^5 of the population, the age range with highest incidence being 15–24 years and the male incidence being more than twice that for females. The case fatality rate was 3% and 97% were alive at discharge.

A review of mortality data in the USA from 1979–1986 using information from the National Center for Health Statistics and based on ICD-9 codes was reported by Sosin, Sacks and Smith (1989). The deaths associated with head injury represented 2% of all deaths and 26% of injury deaths, with an annnualized death rate of 16.9 per 10^5 residents. The age distribution was bimodal, with peaks at 15–24 years and over 75 years. The younger group was particularly affected by motor vehicle accidents (77%) and the older group by falls (73%).

1.7.2 UNITED KINGDOM

In an extensive study of head injury in England and Wales for the year 1972, Field (1976) relied on hospital diagnosis defined by ICD-8 rubrics and general practitioner consultations, the latter estimated from a sample of general practices with due regard to regional and urban/rural variations. There were 142 016 admissions for head injury and an estimated 68 000 consultations for head injury, giving an estimated head injury incidence of 430 per 10^5 of the population. This was probably an overestimate, as a significant number were considered likely to have been admitted to hospital following a consultation with a general practitioner or to have seen a general practitioner following discharge from hospital. Males outnumbered females by more than two to one and over 50% of admitted patients were younger than 20 years. For those admitted to a hospital, the case fatality rate was 1.6% but if all who died at the hospital, whether admitted or not, were included the case fatality rate rose to 2.5%.

Further information from the UK was provided by Jennett and MacMillan (1981), who discussed yearly death rates, hospital admissions in England, Scotland and Wales and Accident and Emergency attendances for head injury (Scotland only) for the year 1974. The ICD-8 codes were used for death records by the Registrar General and for hospital admission and diagnosis, whereas attendances at casualties were identified retrospectively using particular criteria for head injury (Table 1.2). Head injury accounted for 9 deaths per 10^5 of the population each year, less than 1% of all deaths. As expected, there was a much higher incidence in the young; in the age group 15–24 years head injury caused 15% of all deaths. ***The annual admission rate to hospitals following a head injury was 270 per 10^5 of the population in England and Wales that year and in Scotland 313 per 10^5 of the population. The authors estimated that there was a Accident and Emergency attendance rate of 1780 per 10^5 of the population, which accounted for around 10% of all Accident and Emergency attendances.***

1.7.3 AUSTRALIA

The Trauma Subcommittee of the Neurosurgical Society of Australasia conducted a retrospective analysis of patients with neurotrauma (injuries to the head, spinal cord and nerves), identified by ICD-8 rubrics, who either died or were discharged from hospitals in New South Wales (NSW) or South Australia (SA) in 1977. The hospitals were either major teaching hospitals, metropolitan or country-based hospitals. The mortality rate was 28 per 10^5 of the population in NSW and 25 per 10^5 of the population in SA. The rate of hospital admission for all neurotrauma was 443 per $10^5$of the population and for head injury 392 per 10^5 of the population. The study analyzed data to provide information regarding the nature, extent, distribution and cost of neurotrauma (Selecki *et al.*, 1981, 1982a, b; Simpson *et al.*, 1981).

1.8 Population-based regional studies

Comprehensive data are available when smaller samples are studied, but even then, difficulties in total capture of events probably result in underestimation of the true incidence. ***The observed values vary greatly among different countries (Table 1.9), with the highest recorded in Hualien Province, Taiwan (Hung, 1991) of 333 per 10^5 of the population and a mortality rate of 89 per 10^5 of the population. This extraordinarily high incidence is considered to be due to the high usage of pedal and motor bicycles without mandatory head protection by the use of helmets.*** The various studies also reveal considerable variation in both incidence and mortality rates, probably because of variability in definitions of head injury, variations in target populations (e.g. predominantly young or elderly in a region), and the accuracy of data sources and recording systems.

1.9 Causation

1.9.1 TRANSPORT-RELATED INJURIES

For both mortality studies (Sosin, Sacks and Smith, 1989) and studies with a broader definition of head injury (Kalsbeek *et al.*, 1980; Kraus *et al.*, 1984) the most frequent cause of head injuries is motor vehicle accidents. ***In the USA study by Sosin, Sacks and Smith (1989), deaths from head injury were related to motor vehicle accidents in 57%, firearms in 14% and unintentional falls in 12%.*** Age-specific incidence rates were bimodal and related to the causes, with motor vehicle deaths most frequent in the 15–24-year-old age group (26.7 per 10^5 of the population) and ***falls most frequent in those over 75 years of age*** (34.1 per 10^5 of the population). ***The annualized death rate was 17 per 10^5 of the population.***

For severe primary head injuries producing coma, motor vehicles were again the most frequent cause (Miller *et al.*, 1978; Kalsbeek *et al.*, 1980). Kalsbeek *et al.* (1980) found that ***head injury was most likely to occur when the injured person was out of doors and traveling by motor car during the warmer months of the year at a weekend.*** In several geographically localized population studies in developed countries, motor vehicles were the most frequent cause of head injury: 48% in San Diego (Kraus *et al.*, 1984) and 53% in NSW, Australia (Ring, Berry and Dan, 1986; Figure 1.1).

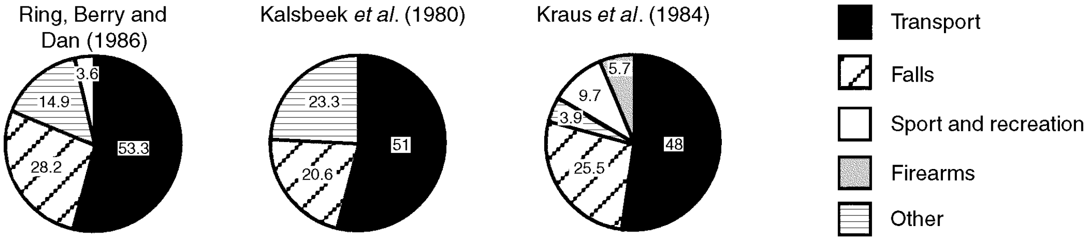

Figure 1.1 Causation of head injury in various studies.

Of transport-related injuries (Kraus *et al*., 1984), 92% were due to on road crashes and of these, 62% were to occupants of vehicles. Injuries to motorcyclists accounted for 20%, pedestrians 12% and bicyclists 6%. Children, on the other hand, were more likely to be injured as pedestrians (68%) or cyclists (24%) than as passengers in a motor vehicle (Craft, Shaw and Cartlidge, 1972).

Patterns may also be influenced by the country, and in the Norwegian province of Trondelag (Edna and Cappelen, 1985), bicycle accidents were the most common cause of road-traffic-accident-related head injury, reflecting the prevalence of that form of transport. In this study, the annual incidence of road traffic related head injury was 89 per 10^5 of the population.

Causation is affected by a variety of factors, including age, gender, locality and method of presentation. Jennett and MacMillan (1981) found assault to be twice as common as motor vehicle accidents as a cause among Scottish men aged 15–24 years presenting at Accident and Emergency departments. This study also found that road accidents were responsible for only a minority of Accident and Emergency attenders who were not admitted, but they accounted for over half of the severe injuries and deaths.

(a) Patterns of injury from motor vehicles

Analysis of the patterns of damage to motor vehicles is of value in determining the severity and type of injury sustained by the passengers. After examining the effects of 500 accidents Fox *et al*. (1991) concluded that the severity of the injury correlated principally with the incidence of head injury, pelvic and femoral fractures and abdominal injury. These severe injuries related to such motor-vehicle damage as dashboard intrusion, steering wheel deformity, windshield violation and the vehicle being non-reparable. Frontal and lateral impacts were associated with significant intrusion into the passenger capsule (Mackay *et al*., 1992) and where the occupant was restrained with a seat belt maximum loading occurred to the head and chest. Under-run crashes with trucks constituted about 30% of such frontal impacts. Where a restrained front seat passenger was situated on the side opposite to a lateral impact, the injuries were generally less severe and head injury was caused by ejection from the shoulder strap of the seat belt (Mackay *et al*., 1992). More general factors are also relevant when considering the effects of road traffic crashes. Van Beeck *et al*. (1991) identified such diverse factors as traffic density and the availability of advanced trauma care (particularly CT scanning and neurosurgical facilities) and found an inverse relationship to death from road traffic accidents in each when geographical regions in the Netherlands were compared.

(b) Motorcycles

Motorcyclists contribute substantially to motor-vehicle-related deaths, at around 12% (Sosin, Sacks and Holmgreen, 1990) and around 20% of all transport-related brain injury (Kraus *et al*., 1984). Of the deaths, head injury was the cause in over half; collision with another vehicle (52%) and loss of control of the motorcycle (40%) were the common antecedents. The compulsory use of helmets for head protection does reduce the death rate. The evidence for this statement is discussed below.

(c) Pedal cycles

Pedal cyclists are more exposed to injury in a collision than the occupants of motor vehicles and the need for protection is greater. Collision with a motor vehicle is the most common cause of all bicycle injuries on the roads. Off-road bicycle accidents are also common and usually result from falls or loss of directional control. In both, the most common region injured is the head (Sacks, Holmgreen and Smith, 1991; Silverberg, Meer and Silvinger, 1992). Spence *et al*. (1993) examined fatal bicycle accidents in Ontario, Canada. The annualized death rate for children in this province was 1.44 per 10^5 of the population. Of 540 deaths, 81 were due to bicycle accidents and the great majority of these were from head injuries. None of the victims was wearing a helmet. Police investigations suggested that, in 70% of these deaths, errors made by the children were responsible. This raises the question of the child's awareness of road safety. There is some evidence to suggest that, in younger children, immaturity of judgment prevents full awareness of danger (Sandels, 1977). ***Sacks, Holmgreen and Smith (1991) reviewed death certificate and emergency room data for the entire USA over a 4-year period from 1984–1988 and identified 62% of all bicycle deaths as being due to head injury. Of injuries following a bicycle accident, 41% of the head-injury-related deaths and 76% of all head injuries occurred among children aged 0–14 years.***

(d) Pedestrians

Pedestrians fare poorly when exposed to motor vehicles. ***Of 115 pedestrians so injured, 22% died (Brainard, Slauterbeck and Benjamin, 1989) and the majority who died did so during the initial resuscitation phase as a result of a combination of head, chest and abdominal injuries.***

The average ISS among those who died was 46. The most frequent injuries were musculoskeletal (77%), head (34%), abdomen (21%) and chest (15%). Pelvic and lower limb fractures were the most frequent musculoskeletal injuries. A similar pattern of injury was reported by Hill, West and Abraham (1993) ***although these investigators found head injury to be more frequent (66%) in a series of pedestrian injuries from inner Sydney, Australia. A hospital mortality of 30%, mainly from head injuries or blood loss*** emphasized the need for coordinated pre-hospital resuscitation and evacuation services, together with an integrated in-hospital trauma team approach to management.

For pediatric pedestrians injured by motor vehicles, a similar pattern was reported from New Zealand by Roberts *et al.* (1991), where ***life-threatening injuries were most commonly to the head and less severe injuries to the limbs. The mortality among the children was 14%, all due to head injury.***

1.9.2 SPORTING AND RECREATION

Sport is generally considered an uncommon cause of more than trivial head injury but the incidence may be expected to increase in the future as technological advances allow more freedom and the leisure-based industries expand. Whereas sport accounted for 3–5% of head injuries in studies in the 1950s (Rowbotham *et al.*, 1954) and 1960s (Klonoff and Thomson, 1969) it had increased to 12% in the 1980s (Kraus *et al.*, 1984), when sport accounted for 6% and recreation for 6%. Mild head injuries associated with sport were more common in males than in females, with a male peak at 10–14 years of age but females showing an earlier peak by 5 years.

(a) Horseback riding

This has become an increasingly popular recreation during recent decades. Höök (1988) has estimated that, in Sweden, there were some 1200 riding accidents, causing a head injury incidence of 0.48% of 10 million 'riding occasions' in a population of 250 000 riders, yet there were only two fatalities. The incidence was somewhat higher in Alberta, Canada, where, in a 6-year retrospective study, ***head injuries occurred in 92% of 156 riding injuries and accounted for all 11 deaths. These 11 deaths accounted for 79% of all deaths associated with horseback riding (Hamilton and Tranmer, 1993).***

(b) Boxing

This ancient sport has attracted much controversy. The desirability of tolerating a competition in which victory may be won by rendering an opponent brain-injured is often questioned. Whatever the view taken, boxing has provided the neurosurgeon with much information as to the effects of acute and chronic brain damage from repeated blows to the head (Pincemaille, 1989). Two of the considerations are of the acute effects of a single blow to the head and the cumulative effects of recurrent blows during sparring practice and actual bouts. Increased regulation of the sport has led to fewer fatalities (Adelson *et al.*, 1991). Between 1918 and 1983 there were 645 deaths from boxing reported worldwide, of which 190 were amateurs. From 1918–1945 there were 10.1 deaths per year, from 1970–1981 there were 4.5 deaths per year and there were 4.6 deaths per year from 1979–1985. A 'knockout' is a head injury producing coma exceeding 10 seconds and occurs in 1–4% of boxing matches (McGowan, 1959a, b). Such head injuries can be considered as frequent, when 8.7–19% of pugilists are 'knocked out' in a bout (Larsson *et al.*, 1954; Estwanik, Boitano and Ari, 1984). In the longer term, traumatic encephalopathy can be identified in around 17% of former professional boxers (Roberts, 1969). Amateur boxing appears to be a safer recreation, although occasional disasters have been reported. ***Several investigations have failed to show convincing evidence of intellectual impairment in amateur boxers studied under control conditions (Butler et al., 1993).***

1.10 Children

In all types of pediatric trauma in which head injury is a component, the patterns differ between children (0–15 years) and adults. For children, falls are the most common cause of injury (Chan, Walker and Cass, 1989).These investigators reported that the majority of injuries requiring hospital admission were minor (87% of total), but for more serious injuries, with an ISS of more than 16, (13% of total), pedestrian injuries from motor vehicles were the most common cause (31%), followed by falls (22%), as pedal cyclists (19%) and as occupants of motor vehicles (19%). ***The head was the most commonly injured region in this group of more severe injuries.*** Studies of such target populations (0–15 years of age) characteristically (Gallagher and Finison, 1984), but not invariably (Chan, Walker and Cass, 1989) show a bimodal distribution for frequency with peaks at 0–1 year of age from falls and a second peak in adolescence.

For more severe injuries, where the ISS is more than 16, head injury is the major cause. Walker and Cass (1987) reported a 91% incidence of head injury in such a subgroup of 78 (13%) of a sample of 598 children. Abdominal injury was associated frequently with head injury and pedestrian accidents were the most frequent cause of injury. The overall mortality for the group was 1.5% and all deaths were due to head injury, with a case fatality rate of 11% in the more severe subgroup.

When causation was compared between a sample of 3124 adults and 2118 children who attended Scottish Accident and Emergency departments in 1985, Brookes *et al.* (1990) reported that, for children, falls were the most frequent cause for the presentation for all grades of severity of head injury (57%) and were also the leading cause of adult presentation (33%). The definition of head injury included scalp injuries, blows and those who had a skull radiograph following presentation. For all causes, the frequency rates for children (4011 per 10^5 of the population per year) were more than twice that for adults (1473 per 10^5 of the population per year). For falls a fourfold difference was found between adults and children, but little difference in frequency was found for road traffic accidents. Using a particular definition of brain injury (Table 1.2) and excluding less severe injuries not requiring hospital admission, but including deaths and hospital admissions, Kraus *et al.* (1984) identified an annual frequency rate for San Diego, CA, of around 190 per 10^5 of the pediatric population.

More severe head injuries in children are most frequently related to the use of motor vehicles. Of fatal pediatric head injuries between 1979 and 1986 in Newcastle upon Tyne, UK, Sharples *et al.* (1990) reported that 76% were caused by motor vehicles, most often occurring when the children were pedestrians and at play. These investigators found that the fatalities occurred most often within 2 km of the child's home (67%) and in the afternoon between 3 pm and 9 pm (63%). The frequency was noted to be high in areas of the city considered to be socially deprived.

Simpson *et al.* (1992) studied a consecutive series of 12 infants (birth to 24 months) and 103 children (2–14 years) dying after road accidents in South Australia and found brain injuries in the majority. In this series of road fatalities (Table 1.10), the victims were most often car passengers (51.3%), followed by pedestrians (30.4%) and pedal cyclists (18.3%). Not surprisingly, the infants were almost all passengers, but the childhood deaths also showed a preponderance of car occupants. The high proportion of car passengers reflects the degree of motor vehicle use in Australia, and perhaps the attention given in areas of high population density to the design of road systems to minimize risk to child pedestrians. In both pediatric groups there was a male preponderance.

The majority of pediatric head injuries are of minor severity and the incidence may be underestimated as the victims do not present at Accident and Emergency departments or require hospital admission. Using the Glasgow Coma Scale (GCS) as a criterion of severity of head injury, Henry, Hauber and Rice (1992) reported that 56.5% of a sample of 138 children were classified as having sustained a mild injury, 17.4% as moderate and 26.1% as severe. They found an 8% mortality in the series.

The Scottish study of Brookes *et al.* (1990), identified only 1% of children (and 5% of adults) in the sample as having evidence of altered consciousness at the time of presentation to Accident and Emergency departments. In a wide and comprehensive study of deaths from head injury in Scotland and England, hospital admissions for head injuries in Scotland, England and Wales and attendances at casualties in Scotland for head injury for the year 1974, Jennett and MacMillan (1981) found that, for children, the overall rate of attendance at Accident and Emergency departments following a head injury was 3017 per 10^5 of the population and that this figure accounted for 40% of the attenders. They concluded that the attendance rate at Accident and Emergency departments following head injury is a reliable guide to the incidence of head injury in the community, although access to a hospital (e.g. in rural areas) might bias the findings.

The NHSCIS study (Kalsbeek *et al.*, 1980) used a more restricted definition of head injury, by excluding attenders who were not admitted and including all deaths from head injury and hospital admissions. This study identified an annual rate of 230 per 10^5 of the population and an annual prevalence rate of 524 per 10^5 of the population for children (0–15 years of age). For all ages, the prevalence rate was 439 per 10^5 of the population. Severity was classified as 'concussion only' (78.9%), while the more severe groups were

Table 1.10 Deaths in infancy and childhood from road crashes in South Australia, 1983–1988 (Source: from Simpson *et al.*, 1992)

	Age 0–24 months		*Age 2–14 years*		
Type of road user	*Male*	*Female*	*Male*	*Female*	*Total (<15 years)*
Car passengers	8	3	22	26	59
Pedestrians	1	0	19	15	35
Pedal cyclists	0	0	17	4	21
Total	9	3	58	45	115

characterized as ‘contusion/laceration’ (5.7%) and ‘hematoma’ (1.2%).

Benefits of seat belt use for children were demonstrated by Osberg and Di Scala (1992) for 413 children with a head injury, where the mortality for restrained children was 2.4% and for unrestrained children 4.5%. The children who were unrestrained exhibited more body areas injured, injuries of greater severity, longer hospital stays and were 15% more likely to be discharged with an impairment. Agran, Winn and Dunkle (1989) focused on a subset of 4–9-year-olds, often too large for child-type safety seats and too small for adult-type lap-sash belts, where, of the children injured, 70% sustained head and facial injuries.

1.11 Minor head injury

Epidemiological studies of minor head injury cause greater methodological difficulties in attempting to obtain accurate data than those of severe head injury, where death and hospital statistics provide objective records. When there are more serious injuries, together with a minor head injury, hospital codings often omit reference to the associated minor head injury. Particularly in rural areas or when hospital access is difficult, it is probable that many minor head injuries are unreported because the patients do not attend an Accident and Emergency department. In hospital, responsibility for care is often shared among neurosurgeons, general or orthopedic surgeons, neurologists, pediatricians, geriatricians and primary care physicians.

The Health Interview Survey (National Center for Health Statistics, 1977) of households in the USA was based on a national probability sample of 116 000 persons in 1975. ***It yielded an estimated annual rate of head injury of 6 per 1000 of the population.*** This was probably an overestimate as facial injuries were included in the definition of head injury.

Definitional issues as to what constitutes a minor head injury further compound the problem. Three major population studies (Table 1.11) used differing definitions for minor head injury and differences at this level render comparisons between studies difficult. While the Glasgow Coma Scale has provided useful descriptors for more severe head injury, it was never intended to classify the different types of minor head injury (Jennett 1989). Neither is the level of consciousness on admission or presentation at Accident and Emergency departments necessarily a guide as to the severity of a head injury, and serious low-energy injuries such as an extradural hematoma may be present in patients with no history of loss of consciousness or only a transient alteration.

Jennett and Miller (1972) found that, of patients who were admitted to the neurosurgical unit in Glasgow with a compound depressed skull fracture, 44% had never lost consciousness. Kraus and Nourjah (1988) commented that in 5% of patients categorized as having a minor head injury with a GCS between 13 and 15, a hospital physician made a diagnosis consistent with the code of ‘cerebral contusion, laceration or hemorrhage’ and the authors questioned the adequacy of the GCS as an accurate descriptor for the less severe end of the head injury spectrum when describing intracranial pathology. Those with a ‘contusion, laceration or hemorrhage’ had a longer median hospital admission with necessarily increased costs. Russell and Nathan (1946) used the duration of post-traumatic amnesia (PTA) to rank head injuries in severity and Gronwall and Wrightson (1974) ***defined a study group of minor head injuries by a PTA less than 24 hours. This latter definition or an even shorter period is probably a better criterion,*** but a comprehensive and uniform definition of minor head injury has as yet eluded the neurosurgical community and there is a clear need to establish adequate descriptors that are generally acceptable and applicable in order

Table 1.11 Epidemiological data for minor head injury (LOC = loss of consciousness; PTA = post-traumatic amnesia)

Author	*Year of study*	*% of all head injury*	*Rate/10^5 population*	*Definition*
Annegers, Grabow and Kurland, 1980 Olmstead County, MN, USA	1935–74	60%	149.0	LOC or PTA < 30 min Fractures excluded
Kraus and Nourjah, 1988 San Diego, CA, USA	1981	72% all cases, including deaths. 82% of hospitalized cases	130.8	Glasgow Coma Scale 13–15
Whitman, Coonley-Hoganson and Desai, 1984, Chicago, IL, USA	1979–80	80%	74–163*	LOC < 30 min and ‘trivial’

A range for three area populations studied; inner city, predominately African American people (163 per 105 population); Evanston Caucasian (74 per 105 population) and Evanston African American people (227 per 105 population). See text.

to standardize the terminology so that valid comparison can be made between studies.

The three population studies shown in Table 1.11 reveal that, of all head injuries, those classified as minor account for between 60% and 80% and these studies suggest that the annual rate lies between 130.8 and 163 per 10^5 of the population. No doubt, however, there are great variations according to the community under study.

The Chicago study (Whitman, Coonley-Hoganson and Desai, 1984) compared three areas of Chicago, IL. Among inner-city African Americans the incidence of minor head injury was 163 per 10^5 of the population. In Evanston, a suburb of Chicago, the population consisted of 75% Caucasian and 21% African Americans at the time of the study. The incidence of minor head injury for the former was 74 per 10^5 of the population and for the latter 227 per 10^5 of the population.

Annegers, Grabow and Kurland (1980) reported that for minor head injury, the peak incidence was 15–24 years for both males and females but females had only a slightly lower incidence in the 5–14-year age group. The study period stretched from 1935–1970 and during this time there was a steady increase in the incidence of minor head injury.

Kraus and Nourjah (1988) studied 2435 patients with minor head injury in San Diego, CA. They found, like Annegers, Grabow and Kurland (1980), that males showed a peak incidence for the age group 15–24 years, with an annualized rate of 174.7 per 10^5 of the population. A differing age pattern was identified for females, for whom the incidence showed a bimodal distribution with peaks at 0–5 years and at over 75 years of age. Overall, males were twice as likely to sustain a minor head injury, except those under 5 years of age or over 45 years of age where, in the latter group, males remained in excess, but the male to female ratio decreased. Motor-vehicle-related accidents were the most frequent cause of minor head injury in this study (42%), with falls (23%) next most frequent, followed by assault (14%), sport and recreation (12%) and other causes at 9% (Figure 1.2). Costs were related largely to the length of hospital admission. In San Diego, 64% remained in hospital less than 3 days, 87% less than 1 week and 5% more than 2 weeks. This last group was considered to be most probably due to associated injuries. Costs of care were US$6.3 million dollars (1981 dollar value) or an average cost of US$2774 per admission, increasing with the length of stay.

Minor head injury is a serious and underestimated public health problem, deserving of more attention by investigators and health planners. While a physical disability following a minor head injury is unusual and recovery is the rule, there is good evidence

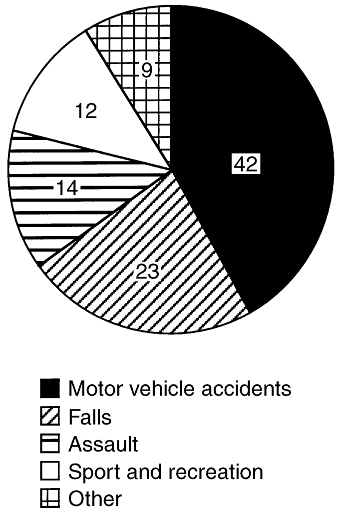

Figure 1.2 Causes of minor head injury according to Kraus and Nourjah, 1988.

(Gronwall and Wrightson, 1974, Wrightson and Gronwall, 1981) that cognitive and neurobehavioral impairments may cause substantial disruption to individuals and families, with the loss of many hours of productive work.

1.12 Counting the cost

Monetary costs in head injury are directed towards provision of medical and hospital care in the acute phase, rehabilitation and specialized retraining in the months after the injury and then to many areas such as community and family support services for the head-injured as they attempt to reintegrate with society. Costs incurred also include lost earning capacity and the effect on family units.

The NHSCIS study (Kalsbeek *et al.*, 1980) divided costs into direct and indirect. Direct costs were associated with the monetary values of real goods and services that were provided for health care and indirect costs were the monetary loss incurred by society because of interruption of productivity by the injured person. In 1974 US dollar values, the total cost for all head injuries studied was $2384 million, of which $696 million was related to the direct costs of care and $1688 million to indirect costs. On a per patient basis, the average cost was $2534. The largest annual cost was $889 million in the 25–44-year age group where the losses incurred due to productivity were maximal. Costs associated with motor vehicle crashes as a cause of head injury were the highest at $1639 million, reflecting both the high frequency and severity of these injuries, followed by falls at $316 million and all other causes at $429 million.

Families provide the major support and respite for head-injured patients after they leave hospital (Jacobs, 1988; Fearnside, McDougall and Lewis, 1993). In the Los Angeles study (Jacobs, 1988) it was found that most families experienced substantial financial stresses, ranging from mild to severe and particularly relating to medical and rehabilitation costs where insurance was inadequate. In over one-third of families, a member was required to act as a permanent supervisor, often at the cost of employment, compounding already existing losses and estimated as an annual cost of around $28 000.

The economics of the care of head injury is most accurately measured when the costs against the injured person are provided by insurance. In NSW, Australia, a compulsory insurance scheme, subsidized by all drivers, is provided to cover all persons injured through no fault of their own in motor vehicle accidents. The scheme is administered by the Motor Accident Authority, a statutory body independent of the government.

Between 1989 and 1993 in NSW large claims (defined as in excess of Aust$0.5 million) for injuries sustained as a result of motor vehicle accidents amounted to $29.7 million, of which 54% were for brain injury, 22% for spinal cord injury, 3% for both head and spinal cord injury and 11% for other claims (Motor Accidents Authority, 1993). Although claims in excess of $0.5 million numbered only 0.7% of all the motor vehicle claims over that period, they exceeded 30% of the total estimated dollar costs. For claims in excess of $2 million, 60% were for brain injury. Males accounted for over two-thirds (69%) and females for less than one-third (31%) of these large claims.

Costs were incurred in various categories, including medical and hospital (3.7%), rehabilitation services (4%), long-term care and home care (40.7%), past and future economic loss (28.7%), general damages (20.8%), legal costs (5.1%), aids and appliances (2.3%), home and vehicle modifications (0.5%) and other miscellaneous costs (20.2%). ***Payments for indirect costs such as damages and economic losses were by far the greatest quantum and legal charges were only slightly less than the cost for the entire medical, hospital and rehabilitation services provided.***

Table 1.12 Projected costs of care by severity of disability – 'statutory discount rate' (prepared by Walsh, J. and Cuff, C. for the Motor Accidents Authority of NSW, 1992)

Category of care	*Projected annual cost (Australian $ – 1992 value)*
Persistent vegetative state. No level of meaningful responsiveness	132 235
Profound physical and cognitive disability, possible ongoing medical problems	117 385
Severe cognitive disability. No behavioral disability or ongoing medical problems	56 074
Little or no physical disability: severe cognitive disability, no behavioral disability but no family support	42 686
Moderate disability (includes a range of outcomes)	27 136

Projected annual costs varied with the level of neurological disability and functional independence. Table 1.12 shows the classification devised to categorize these various levels and the projected annual costs for each level. These costs covered such supportive areas as day activity, accommodation, attendant care and respite care and did not include costs of any ongoing medical problems requiring hospital admission. For categories A and B, those most severely disabled, permanent accommodation was planned and for categories D and E the emphasis was on outpatient day activities.

1.13 Reducing the burden

1.13.1 PREVENTION BY PUBLIC EDUCATION

Prevention is better than cure and much less expensive. Measures aimed at prevention of head injury are therefore important public policy initiatives, both for developed and developing countries (Trinca *et al.*, 1988). Risk reduction as a public health measure demands a national response. Community awareness of the problem of head injury generates public and political education to establish programs to prevent such injuries.

A program to promote public education and awareness was undertaken by the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) in 1985–1986, the 'Think First Prevention Program' (Eyester and Watts, 1992). ***The aim of this program was to persuade individuals to alter their risk-taking behavior using a State-based syllabus of youth-oriented programs, a reinforcement and public education program and a program to influence government policy.*** The program provided lectures by neurosurgeons or lay members, videos, brochures and a film entitled *Harm's Way.*

Transport-related accidents are the most frequent cause of severe head injury and much effort is aimed at modification of the environment in which the motorist, motorcyclist, pedal cyclist or pedestrian interacts with the environment. Public awareness campaigns are crucial in providing information to the community such that individuals can use the information to protect themselves or demand better protection. One example of this is the realization by some motor vehicle manufacturers that cars can be sold successfully using safety devices such as airbags and reinforced passenger capsules as features, rather than the engine capacity and acceleration rate.

1.13.2 ROAD TRAFFIC SAFETY

Evans (1991) in his thoughtful book *Traffic Safety and the Driver* made a judgmental assessment of the factors that led to the decrease in car-related fatalities recorded in many developed countries after 1975. He concluded that changes in human behavior had been much more influential than changes in transport technology. Within the realm of transport technology, he saw better roads as more influential than improved traffic control or safer vehicles. Few road crashes, however, are monocausal and crashes commonly result from a mix of behavioral and environmental factors, often cumulative and imponderable.

1.13.3 ALCOHOL CONTROL

Ethanol (ethyl alcohol) is a well-documented cause of road crashes. There is also reason to believe that a high blood alcohol concentration (BAC) reduces the individual's capacity to survive a crash (Waller *et al.*, 1986), especially if associated with head impact. Alcohol control is therefore a central issue in head injury prevention programs.

Borkestein *et al.* (1964) performed random BAC estimations on some 1300 drivers in the state of Michigan, USA. ***From this large database, a case-control study showed that the risk of crash involvement rose rapidly when the BAC exceeded 100 mg/dl. Later studies have confirmed this finding.*** Evans (1991) reviewed recent USA data on BAC findings in fatally injured drivers. Data from 26 states showed that concentrations in excess of 100 mg/dl were found in 24.9% of drivers killed in two-vehicle crashes, but in 54.7% of drivers killed in single-vehicle crashes. Evans pointed out that the first figure understates the role of alcohol in two-vehicle crashes, since sober drivers are often killed by drunk drivers.

The reason for this very clear relationship is, of course, the effect of alcohol on neuronal function, and especially on the neurological and neuropsychological functions relevant in driving. Moskowitz and Robinson (1987) reviewed the English literature on the relations between BAC and testable skills relevant in driving. They concluded that some important skills are impaired well below the level of 100 mg/dl, the legal BAC limit in many states in the USA. However, there is much variation in individual tolerance of alcohol.

Awareness of the importance of alcohol in road crashes, and indeed in other accidents likely to cause head injury, has prompted much legislation and educational endeavor. The Scandinavian countries led the way by making it a crime to drive with a BAC in excess of a specified level. Norway (Glad, 1987) first set this level at 50 mg/dl, and many countries have accepted this figure. In the UK, a level of 80 mg/dl was fixed and after the enactment of what was then a very controversial measure, a dramatic fall in drunk driving was reported (Ross, 1982). The deterrent effect of such legislation depends largely on the public's perception of the risk of detection. Frequent random breath testing has been shown to increase general awareness of the risks incurred by drinking before driving. Public support for alcohol control is also important. In many countries, government-funded educational campaigns have been conducted. In the USA, independent bodies of activists such as MADD (Mothers Against Drink Driving) have been prominent, and Evans (1991) credits these bodies, together with the media, for much of the change in societal attitudes to alcohol which have been seen in North America, mirrored in declining *per capita* consumption of alcoholic drinks. Nevertheless, drunk driving remains a major cause of injury, even in countries where it is severely penalized (Glad, 1987) or under a religious prohibition (Mekky, 1984).

1.13.4 ROAD CONSTRUCTION AND SPEED CONTROL

Road engineering has become an exact science, and crash prevention is one of its objectives. Speed control is a key part of crash-prevention strategy. In this strategy, driver education and law-enforcement are essential elements, but a well designed road system is also of great importance.

Road design can prevent road crashes in several ways. Appropriate banking and well-maintained surfaces make loss of directional control less likely. Good visibility and warning signs make collisions less likely at intersections. Unidirectional traffic flow in rural areas makes head-on collisions less likely. In cities, separation of traffic streams by a median strip helps pedestrians to cross in safety.

Control of access is an important strategy for all categories of road. Pedestrians and pedal cyclists are segregated by footpaths and cyclepaths. Traffic lights facilitate pedestrian crossings at predictable sites. Lights also control speed, especially if monitored by infrared cameras. Urban street speed control can be achieved by obstacles. Brindle (1992) found this method of speed control effective but unpopular.

Fast driving is nevertheless an economic imperative in modern society, especially in thinly populated countries. Well-designed freeways allow fast driving under optimal conditions by removing pedestrians, segregating slow traffic and avoiding intersections.

When crashes do occur on freeways, they are likely to be more serious. However, there is general agreement that limited-access freeways can reduce rural road deaths and severe injuries (Evans, 1991; Kraus *et al.*, 1993). This achievable only when drivers appreciate the purpose of the road system: in Nigeria, Asogwa (1992) found that better roads resulted in excessive speed and reckless driving, with an actual increase in the death toll.

1.13.5 MOTOR VEHICLE DESIGN

Improvements in motor vehicle design, combined with quality control in manufacture, can reduce the incidence of head injuries in two ways, by making the vehicle less likely to crash and by making crashes more survivable. Motor vehicle designs intended to promote these benefits are (or should be) tested experimentally and in the field. If successful, the design is standardized and becomes the basis of a safety standard which can be tested and enforced by governmental agencies.

Much effort has gone into the design of improved engine performance, lights, steering systems and other aspects of roadworthiness. It is often difficult to prove that improved car design will prevent road crashes. Defective or inappropriate car design certainly can cause crashes, as was argued by Nader (1966) in his memorable polemic *Unsafe At Any Speed*. He denounced the Chevrolet Corvair with fervor, and linked reported accidents with this car to the design of the rear suspension. Nader's book has been compared with *Uncle Tom's Cabin*, the novel that helped to abolish slavery in the USA. It certainly publicized the dangers of bad car design. It has, however, been difficult to show that a seemingly good design will lower the road toll. Thus antilock electronic braking systems increased vehicle stability in tests demanding rapid braking on surfaces of various adhesive properties (Rompe, Schneider and Wailrich, 1988). However, field trials by taxi drivers in Munich showed no advantage in crash rates, perhaps because these brakes encouraged drivers to take risks (Evans, 1991). ***One of the few certain facts about the relation between vehicle design and road safety is that the occupants of large vehicles are safer than the occupants of small vehicles.***

Cars and other vehicles can be designed to minimize the risk of injury, and especially head injury, by absorbing some or all of the impact energy that might otherwise cause injury to the occupants of the vehicle. To absorb the energy of a frontal crash, the forward components of the vehicle can be designed to crumple. It is harder to design protection against the effects of a side impact. Car occupants often suffer head injuries by impact on some structure in the interior of the car and these structures can be designed to modify the nature of the impact on the head. Projections capable of inflicting a penetrating injury are eliminated in modern cars. As a consequence, compound skull fractures are now rare in car occupants, except after very severe crashes with massive intrusion into the car interior.

1.13.6 WINDSCREENS

These are a common site of head impact and can be made of laminated glass, which absorbs energy by yielding and does not often shatter into knife-like fragments capable of penetrating the brain or the eyes. This safety measure appears to have performed well in real-life crashes (Hass and Chapman-Smith, 1976). Attention is now being given to the steering wheel and to the hard components of the roof and its supporting pillars. In an in-depth study of 26 car occupants sustaining severe or fatal head injury, Paix *et al.* (1991) identified the impacting agents in 22. The roof or its supporting pillars appeared responsible in nine and the steering wheel in two of the accidents.

1.13.7 AIRBAGS

In frontal crashes, the impact energy transmitted to a car occupant can be further reduced by inserting an airbag between the occupant and the striking force. Zador and Ciccone (1991) assessed the value of airbags in preventing fatalities by comparing frontal crashes in cars fitted with airbags with non-frontal crashes and with crashes in cars fitted with manually secured seat belts only. ***They concluded that airbags alone reduced the risk of driver death by 21% when compared with the risk to an unsecured driver, and by 9% when compared with the risk to a belted driver. The advantage was greater with large cars.*** Airbags can also be used to mitigate the effect of side impacts. It has been convincingly shown that the occupants of vehicles who are ejected are at greater risk than those remaining in the vehicle. Cars can be fitted with devices to prevent ejection, such as effective door locks and seat belts.

1.13.8 SEAT BELTS

The evidence that seat belt use in motor vehicles does decrease injury is conclusive. The Iowa Safety Restraint Assessment 1987–88 (ISRA, 1989) was a population based study of 16 hospitals in Iowa over a period of 5 months from November 1987 until March 1988. ***Of the 1454 persons injured, 48% were wearing a restraint and 52% were unbelted. Unbelted persons were 8.4 times more likely to sustain a head injury and 2.7 times more likely to sustain a fracture. The***

average length of stay and the hospital costs were both greater for the unbelted. The investigators urged increased public awareness and education, emphasizing the ability of safety restraints to reduce crash injuries, the instruction of children about the importance of wearing seat restraints and the education of the 16–24-year-old age group, who are most at risk. Other studies support the assertion that the use of restraints in motor vehicles decreases the frequency and severity of injury (Orsay, Dunne and Turnbull, 1990; Bradbury and Robertson, 1993).

It is now agreed that seat belts should embody thoracic restraint as well as a pelvic band. The three point lap-sash system is a convenient and popular means of achieving this goal, but seat belts must be properly fitted and sited. There are many reports of lumbar spinal and abdominal visceral injury from the lap belt, especially in children (Newman *et al.*, 1990). Some of these have resulted from failure to site the belt to lie below the anterior superior iliac spines. Devastating injury to the cervical carotid artery may occur from a shoulder sash, possibly caused by an inappropriately high siting of the anchorage.

1.13.9 DRIVER BEHAVIOR

There is also ample evidence that individuals do alter their risk-taking behavior when faced with legislative penalties. States, Annecharico and Good (1990) compared the frequency and severity of all injuries in New York State over a period of 18 months, before and after the introduction of a law making the use of seat belts in motor vehicles mandatory. The use of seat belts increased from 11.2% before the law was enacted to 53% afterward. Hospital admission for motor vehicle trauma fell by 11.9% after, but had increased by 2.6% in the study period prior to the law.

Salmi *et al.* (1989) used a regional study before and after seat belt legislation was introduced in France in 1979 to show a significant decrease in motor-vehicle-related head injury after the law was enacted. Thomas (1990) also used a regional study in south London to confirm a significant decrease in head injury following the introduction of seat belt legislation in England.

Rutherford *et al.* (1985) compared hospital attendances before and after the introduction of the mandatory use of seat belts in the UK. There was a large fall in the number of brain injuries of all types, but a slight rise in the number of serious (AIS ≥ 3) brain injuries. This appeared to be because seat belts gave good protection to front seat passengers, but did not reduce the risk of impact of the driver's head on the steering wheel. This interpretation provides powerful support for the use of a driver's-side airbag. All occupants benefit from seat belt use and airbags should be regarded as complementary rather than as an alternative to a seat belt.

Child occupants of cars provide special problems and Simpson *et al.* (1992) reviewed these in the context of a series of 115 fatalities. The infant's thin, flexible skull gives little protection against impacts of any kind. Attention, therefore, has been given to the design of safety capsules in which the infant is secured against a sudden dislocation and head impact against some part of the interior of the car. Children may be too small to be safely fitted with an adult-size seat belt, and may suffer a spinal injury from violent deceleration while belted inappropriately. At present, most authorities advise a special harness for small children with a four or five point anchorage. Older children may use an adult belt system if a foam chair-like support is inserted to give a better fit. In Sweden, backward-facing child seats are favored and these may give superior protection, at least in frontal crashes (Carlsson, Norm and Ysander, 1989).

1.13.10 MOTORCYCLE HELMETS

Studies of the effects of legislative compulsion in the wearing of helmets by motorcyclists have revealed findings similar to seat belt studies in that the incidence and severity of head injury among motorcyclists has decreased. Many studies have confirmed this hypothesis and the most convincing derive from the astonishing decision of 27 states in the USA to repeal laws enforcing mandatory use of helmets. ***Sosin, Sacks and Holmgreen (1990), in a mortality study of National Center for Health Statistics data from 1979–1986, found that 53% of the 28 749 motorcyclist deaths were due to head injury.*** The annual death rate was 5.5 per 10^6 of the population for states with full helmet laws, 10.2 per 10^6 of the population in states with partial laws and 10.4 per 10^6 of the population in states with no helmet laws. Death rates increased in three states which changed from full to partial laws during the study and were lowest in states with comprehensive helmet laws.

McSwaine and Belles (1990) found that the incidence of injury rose where motorcycle helmet laws were repealed (Kentucky and Louisiana) and fell again after their reintroduction (Louisiana). Based on 1989 US$ values, an annual $121 million of additional medical care and rehabilitation costs were ascribed directly to the non-use of helmets.

One 12-month study in Maryland, where no helmet laws were in place (Shankar, Ramzy and Soderstrom, 1992) found that helmet usage was only 35%, and was 30% for those who were fatally injured. While head injuries are the most common cause of death among motorcyclists in most studies, injuries to the integument and fractures to the extremities and pelvis are more frequent non-fatal injuries, as shown in Singapore, where helmet laws were in place (Wong, Phoon and Lee, 1989; Shankar, Ramzy and Soderstrom, 1992).

1.13.11 BICYCLE HELMETS

Of all road users, the cyclist and pedestrian are the least well protected from injury on the roads and attention is now focused on the value of helmets for pedal cyclists. Of fatal bicycle accidents in the 0–15-year group in Ontario, Canada, Spence *et al.* (1993) found that 91% were considered unsurvivable and 89% were due to head injury. No victim was wearing a helmet and the authors concluded that emphasis should be placed on bicycle safety education for children and the promotion of helmet use. Helmets do prevent death from head injury, as McDermott *et al.* (1993) showed in Victoria, Australia: there, in a series of 1710 consecutive injuries in pedal cyclists, the head injury rate was significantly less for the helmeted riders (34.8%). The AIS scores were also significantly less for helmeted than unhelmeted riders. After legislation was introduced in Victoria making the wearing of bicycle helmets compulsory, usage increased from 31% to 75% (Lane and McDermott, 1993). Uniform legislation throughout Australia requiring compulsory bicycle helmet usage was introduced sequentially in 1991 and 1992 and the effects on head injury are yet to be evaluated. ***Data from the Victorian Traffic Accident Corporation has shown that the number of cyclists admitted to Victorian Public Hospitals fell by 37% after the law was enacted.***

1.13.12 HEAD INJURY SURVEILLANCE

In order to plan prevention and treatment programs for the head-injured and to evaluate such programs, data collection is essential. The increasing use of head injury surveillance or registry systems will provide information regarding the changing patterns in a geographical area, which should allow for equitable resource distribution. Head injury surveillance uses passive methods of data collection such as death records or hospital diagnosis at separation, reported to a central data collection point. Surveillance systems may have low capture rates, whereas head injury registries identify new cases using a researcher, often a nurse investigator specially trained in methods of data collection and recording. Head injury registries are generally more expensive to maintain than surveillance, but data capture is more complete.

While such data collection is successfully established in many developed countries (Woodward, Dorsch and Simpson, 1984; Parkinson, Stephenson and Phillips, 1985), particular problems emerge in developing countries where injury now outranks infectious disease as a cause of death (Mock *et al.*, 1993). These authors identified the need for trauma registries in developing countries when they compared trauma profiles at a rural African hospital in Berekum, Ghana and a Level 1 center in Seattle, WA, USA. They found that vital registry data was incomplete in Ghana as only a minority of deaths, namely those occurring in hospital, were recorded, and that there was a need for accurate registrations. ***The study identified a lack of pre-hospital care and delays in transport to hospital and considered these less costly to improve and more likely to improve mortality rates than expensive improvements in hospital services.*** A simple method to obtain incidence data based on a capture-recapture–technique has been suggested by Chiu *et al.* (1993) which might be useful for developing countries with limited resources.

1.13.13 TRAUMA CARE SYSTEMS

Recognition of the importance of the coordination of resuscitation, triage, evacuation and primary and secondary care for the patient with severe or multiple injuries has led to the development of trauma care systems that aim to provide systematized management from the time of injury through initial resuscitation and definitive treatment to rehabilitation. The system is regionalized to ensure that the severity of the injury is appropriate to the resources available in a particular geographical area (Eastman *et al.*, 1987). Such systems are complex and include pre-hospital personnel such as ambulance officers and police, systems management personnel and staff at acute care and rehabilitation facilities (American College of Emergency Physicians, 1987). A process for the stepwise establishment for such a system of trauma care has been described (West, Williams and Trunkey, 1988; US Department of Transportation, 1989).

In the USA and elsewhere, involvement of hospitals in such programs has led to their categorization at various levels, depending on the resources available:

- **Level 1 – Regional Resource Trauma Center**. These are capable of providing total care at all levels as well as education and research programs.
- **Level 2 – Community Trauma Center**. These centers provide total care but not the education and research programs.
- **Level 3 – Rural Trauma Hospital**. These centers serve local communities and provide care dependent upon resources available, often stabilization and transfer only.

Head injuries are responsible for the majority of trauma deaths (Chan, Walker and Cass, 1989; Sosin, Sacks and Smith, 1989; Daly and Thomas, 1992) and the involvement of neurosurgeons is pivotal in the design of these systems. The Joint Section of the AANS and the CNS has recommended minimal standards for an institution to qualify as a designated center for the treatment of severe neurological trauma (Pitts, Ojemann and Quest, 1987):

- a specifically named neurosurgeon 'on call' at all times;
- an emergency room staffed 24 hours per day by a physician certified in Advanced Trauma Life Support (ATLS);
- an operating department capable of rapid acceptance of a patient for a craniotomy or spinal surgery at all times;
- availability of a CT scanner and a technician at all times;
- an appropriately equipped and staffed intensive care unit;
- a clearly defined bypass plan in the event of an unavoidable lack of availability of a neurosurgeon.

The establishment of trauma systems does result in improvements in mortality (Shacksford *et al.*, 1986), although problems of underfunding, difficulties in recruitment of residents to careers in trauma care and problems of the establishment of such systems in rural areas have impeded development in many areas of the USA (Eastman *et al.*, 1991; Esposito *et al.*, 1991).

1.13.14 REHABILITATION

A comprehensive trauma care system for head injury includes rehabilitation services that aim to minimize any disability and maximize the potential for functional and meaningful recovery. Neurological rehabilitation has a longer time profile and consists of several stages, characterized initially by involvement of the rehabilitationist during the acute phase of management of the head-injured patient and the family. After the acute phase, subacute programs are generally designated for 'slower stream' patients who remain in coma or post-traumatic amnesia (PTA) and consist of coma management and neurobehavioral therapy. Later, after the PTA resolves, an individual program is prepared to provide for transitional living, day care and activities, and supported or sheltered employment. Thus the trauma service forms an integrated therapy system with the rehabilitation unit, providing facilities for research, education and a standardized data base for the assessment of performance.

There is evidence that early intervention with rehabilitation therapy does decrease the length of admission and treatment in a rehabilitation facility (Cope and Hall, 1982). The establishment of designated and purpose built brain injury units such as established by the Motor Accident Authority in NSW, Australia, will focus attention on the particular needs of the brain injured and hopefully result in improved outcomes.

The quality and cost-effectiveness of rehabilitation programs has now become an important issue in an era of cost containment. If patients can become independent and even return to some form of gainful employment as a result of early intensive rehabilitation, the cost savings over nursing or group home care would be substantial (Aronow, 1987). However, concerns might arise as to the selection of patients for such programs if they were perceived to be potentially 'slow stream'. Some who were denied the equality of access to such a program might not achieve their full potential for recovery.

There is now good evidence of improved survival following head injury compared with outcomes 10–20 years ago (Bowers and Marshall, 1980; Fearnside *et al.*, 1993). It will be of considerable interest and importance to see whether the many improvements in head injury care and neurological rehabilitation programs can be translated into objective improvements in the quality of life and its value to the survivors of head injury and their families.

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