Chapter 1

Current evaluation of TBI epidemiology in an ageing society with improved preventive measures

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Introduction

The past decades have seen significant improvement in outcomes for the victims of severe traumatic brain injury (TBI) through better pre-hospital care, rapid investigation with CT scans and high-standard intensive care management [1]. At the same time there is growing knowledge of the biological consequences of brain injury and with it the promise of better and more specific treatments.

Against these positive developments the incidence of TBI continues to increase worldwide.

The often tragic consequences of TBI are compounded by the knowledge that on many occasions it is avoidable. It is too often the product of human error, misjudgment, risk-taking or poor socioeconomic circumstances. In order to respond effectively to reduce the incidence of TBI it is necessary to have high-quality epidemiological data which document the causes, distribution and trends of TBI and the responses to preventive strategies.

These data form the basis of administrative planning of accident services, clinical staffing and the design of appropriate facilities to cope with present needs and anticipate future changes.

To assess the effect of an intervention requires accurate long-term data which plot changing demographics, including changes in injury patterns and the influence of ageing of populations.

The global incidence of TBI has been reported as 200 per 100 000 of population with a mortality of about 20 per 100 000. Incidence reports from individual countries range from 91 to 430 per 100 000, with mortalities of 9 to 89 per 100 000 [2]. This wide range is in part due to difficulties in collecting accurate data and to different methodologies; however, there is no doubt that there are marked country and regional variations in the causes, age range and outcomes from TBI [3]. Overall the greatest burden of TBI falls on low- and middle-income countries, where the incidence of TBI is higher and victims are more likely to die [4].

Within high-income countries there are also marked differences. Population-based studies in the United States showed incidences of TBI ranging between 180 and 250 per 100 000 population per year [5].

In a systematic review of reported series the average incidence of TBI for Europe ranged from 150 to 300/100 000 and the overall mortality rate was 15/100 000. There were regional differences in the incidences and causes of trauma [6]. Mortality in Nordic countries ranged from 21.2/100 000 in Finland to 9.5/100 000 in Sweden and as in other high-income countries mortality has been falling in recent decades [7]. Within country-based figures subgroups require special consideration. There are differences in TBI incidence related to age, gender, socioeconomic status and means of transport.

Definitions and classifications

Epidemiological studies of TBI are complicated by differences in definition and in the wide-ranging sources from which TBI statistics are collected [8]. "Head injury", "head trauma" and "brain injury", which may or may not include TBI, have been defined differently in different epidemiological studies. As distinct from TBI, head injury or head trauma may include extracranial and facial injuries not necessarily associated with injury to the brain [5]. TBI is a subgroup of head injury and in hospital and public health records "brain injury" is usually defined according to the

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International Classification of Diseases system ICD-9 or the later ICD-10. This in itself may lead to difficulties in comparing studies across the systems. In 1999 Deb concluded that ICD-10 codes detect only a proportion of all head injury admissions [9].

Population-based studies which attempt to capture all head injuries in a defined population are necessary to establish the true prevalence and incidence of TBI. This is difficult to achieve, particularly for the more minor degrees of TBI which may not present to hospital. Many epidemiological series are based on National Public Health records, which are retrospective and derived from death certificates or national head injury studies relying on hospital admissions or separations [2, 10]. Mortality figures based on Accident and Emergency admissions or hospital separations alone do not include pre-hospital deaths, which are estimated to account for about 50% of road trauma deaths [11]. In some studies coroner's reports and death certificates may be added to attempt to include those not admitted to hospital.

Referral patterns and admission criteria may influence the hospital-based population. In particular those with mild head injury who are not admitted to hospital are not included in many epidemiological studies.

Populations may be subdivided by causation using a variety of subclasses, making comparisons between studies difficult.

Severity of TBI is generally measured by the Glasgow Coma Scale (GCS), being the sum of the three components of the Glasgow Coma Scale. Severe TBI is defined by a GCS less than 9, moderate by a GCS of 9 to 13 and mild by a GCS of 14 to 15.

A measure of injury severity such as the Abbreviated Injury Scale needs to be included to assess mortality attributable to TBI and to injuries to other body regions in those with multiple injuries.

In comparing studies, the definitions used, the population or subpopulation examined and the source material need to be carefully noted [6].

The human cost

Mortality is the easiest outcome of TBI to measure but taken alone represents only a part of the impact of TBI on a community. For every severe head injury from road trauma reported in the UK there were 17 mild or moderate head injuries [12]. In a European study, for every severe brain injury admitted to one of the 23 hospitals there were 1.5 moderately injured and 22 mildly injured patients [6]. Because of the difficulty in obtaining complete data the significance of mild or moderate head injury is often overlooked.

Community surveys give another perspective of the prevalence of TBI. An Australian survey determined a lifetime prevalence of head injury with at least a 15-minute loss of consciousness to be about 6% [13]. A northern Finland birth cohort study found that 3.8% of the population had experienced at least one hospitalization due to TBI by the age of 35 years. In a New Zealand birth cohort study by 25 years of age 31.6% of the population had experienced at least one TBI requiring medical attention (defined as hospitalization, or attendance at an emergency department or physician's office) [14].

A World Health Organization (WHO) review found that 70–90% of all treated brain injuries are mild. The incidence of hospital-treated patients with mild TBI is 100–300 per 100 000 population; however, the true population-based rate is probably over 600 per 100 000 [15].

The human cost of the large number of head injury fatalities and survivors can be measured in terms of the cognitive, economic and psychological effects on the survivors and the effects on the families of victims and on the community. Many with severe to mild head injuries suffer persisting and disabling symptoms. In one study only 3 of 45 survivors of severe TBI did not suffer neurological, neuropsychological or behavioral consequences 3 years after injury [16]. An estimated 1.1% of the US population experiences long-term disability from TBI [17]. Despite the lack of evidence of structural brain injury on imaging, many with mild or moderate injury suffer significant long-term effects.

In a German study 90% of patients admitted to a hospital emergency department were classified as mild TBI. Fifty percent of all patients continued to need treatment at 1 year [18].

Thornhill *et al.* in 2000 reported that 1 year following mild head injury (GCS of 13–15) 47% had moderate or severe disability and 79% showed persistent headache, 59% showed memory problems and 34% remained unemployed [19]. Those who survive after in-hospital care have high rates of long-term morbidity [20, 21]. The recognition of the true incidence of mild and moderate TBI has implications in rehabilitation as the needs of these patients may be quite different to those recovering from severe TBI injury.

Millar *et al.* found evidence of late cognitive decline unrelated to the apolipoprotein (APO) E genotype [22]. Another study found a higher mortality rate among functionally dependent survivors of TBI, with a bimodal distribution of death suggesting different early and late mechanisms [23].

Clearly to obtain a complete picture of the influence of TBI on a community requires the inclusion of all patients who have suffered minor to severe TBI including long-term follow-up.

The economic cost

A heavy financial burden may fall on families through the loss of the income of the victim and long-term medical and social support costs. The direct costs of TBI extend from the need to provide well-equipped and trained retrieval systems and multidisciplinary management in intensive care units to rehabilitation and support of the long-term permanently incapacitated.

Indirect costs arise from the loss of productivity of victims, who are often young males and their lost years of productive life represent a substantial economic loss to the community. Head injuries in children may be associated with short-term educational costs and long-term economic costs, including loss of productive work.

The WHO (2004) estimated that road traffic injuries cost worldwide the equivalent of 2% of gross domestic product [24].

The UK Transport Research Laboratory in 1998 estimated this cost worldwide to be $500 billion [25].

In the state of Missouri the mean age of TBI fatality was 44 years. Over 5 years to 2005 the cost of lost productivity was about $18.8 million and the medical costs were about $1.6 million per 100 000 Missourians [26]. In Australia alone in 2008, TBI resulted in 700 deaths and over 1700 patients requiring long-term care with a total lifetime cost estimated at $8.6 billion (Access Economics, 2009).

Causes, trends and prevention

The common causes of TBI are similar in all communities – traffic-related injury, falls, violence (assault or self-harm) and sport. Globally the main cause of TBI is transport-related.

In many developing countries road deaths are increasing [27] and by 2020 they are projected to become the third most important global health problem [28].

A population-based study using prospective and retrospective data from Sweden found an annual incidence of 546 per 100 000 [29]. The cause of TBI was fall in 58%, traffic accident 16% and having been struck by objects in 15%. A study based on state-wide hospital separations in South Australia found a high incidence of 322 per 100 000 population, mostly involving young males driving on country roads [30]. In a survey of TBI deaths from 1989 to 1998 from the US National Center for Health Statistics the major causes were firearm (40%), motor vehicle (34%) and fall (10%) [31].

Many studies show that males have a higher incidence of TBI and that the predominant causes are age-related. A study in Sweden showed that males had twice the injury rate compared to females for all external causes of injury [32]. The US study found that vehicle-related injury was the leading cause of TBI death among 0–19-year-olds, firearm-related among 20–74-year-olds and falls for those 75 years and over [31].

Trends

There have been clear changes in the incidence and causes of TBI in recent decades. The most marked change has been the fall in TBI mortality in high-income countries, largely due to a fall in transport-related injury, while traffic-related TBI mortality continues to rise elsewhere (Figures 1.1 and 1.2).

To accurately assess trends requires comparable data which include at least incidence changes per 100 000 population, mortality due to TBI, causes, age-specific mortality and economic and occupation subgroups.

In the USA between 1989 and 1998 motor vehicle-related TBI declined by 22% and firearm by 14%, whereas fall-related death rates increased by 25% (Table 1.1) [31]. These trends have been found in many other high-income countries and identifying them is necessary in planning effective prevention and allocating resources for the management of TBI.

Prevention

The fall in TBI mortality in high-income countries may be due to a combination of strategies which reduce the incidence of injury and ameliorate the magnitude of injury, and to better treatment.

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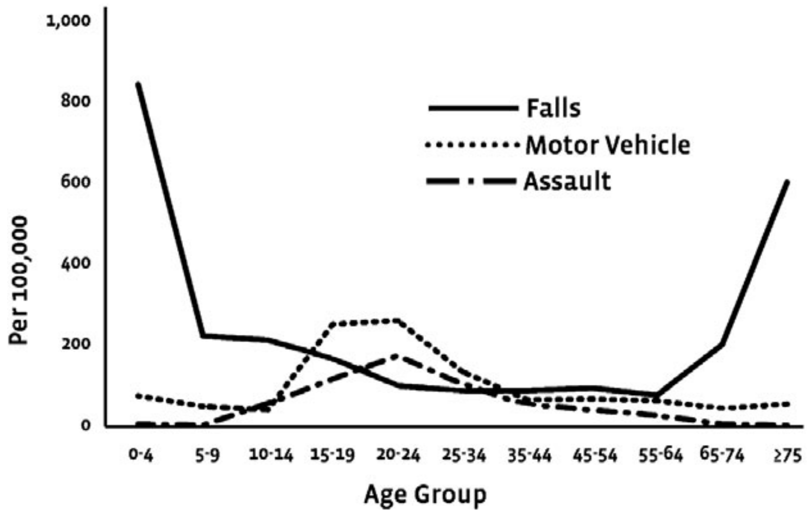

Figure 1.1. Causes of TBI according to age in the USA from 2002 to 2006. Falls are the leading cause of TBI, with rates being highest among children aged 0 to 4 and adults aged 75 and older. Motor vehicle-related brain injury is predominant in the young adult population between 14 and 34 years of age. Assault as well is most common in the population around 20 years of age. Modified with permission from *Traumatic Brain Injury in the United States: Emergency Department Visits, Hospitalizations and Deaths 2002–2006*. US Department of Health and Human Services, Center for Disease Control and Prevention; 2010.

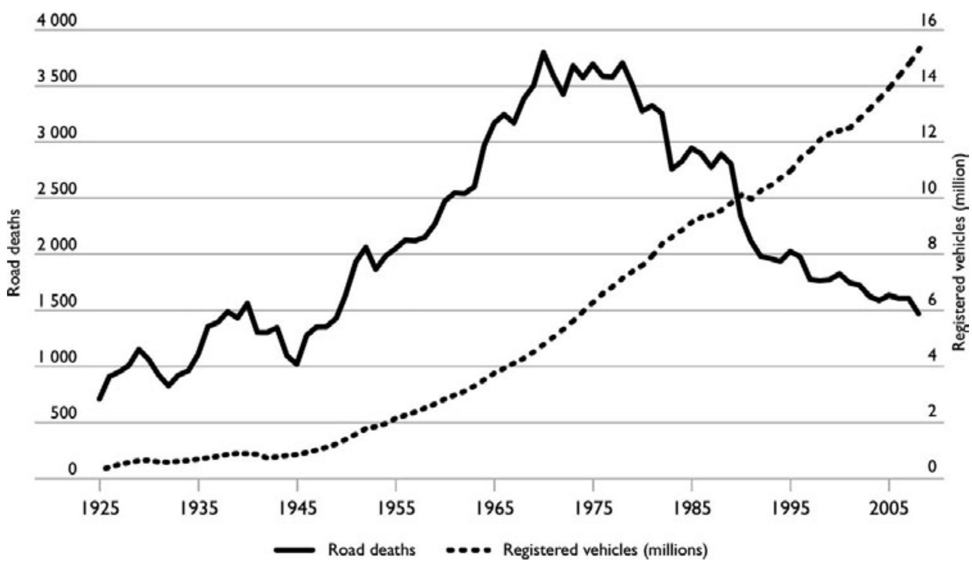

Figure 1.2. Total annual road deaths and registered vehicles in Australia, from 1925 to 2008. The number of vehicles on the roads has increased steadily from 1925 to the present. Annual road fatalities increased in parallel until the mid-1970s when a combination of preventive strategies were introduced and the road death numbers have dropped steadily since despite a continuing increase in the number of registered vehicles. Reproduced with permission from *Road Deaths in Australia 1925–2008*. Bureau of Infrastructure, Transport and Regional Economics, Canberra; 2010.

Since many injuries are the result of human error, preventing injury by encouraging safer behavior is clearly the most desirable approach. Thus, campaigns promoting safety supported by enforcing legislation are major components of the public response.

An important example is the "Think First" program developed by the neurosurgical societies in the USA and now internationally, which encourages safe behavior from an early age.

Traffic-related injury

From the late nineteenth century, when transport became motorized, to 1997 it is estimated that motor vehicles have been responsible for 25 million deaths [27]. In 2002 the global death rate from road traffic accidents was estimated to be 1.2 million and between 20 and 50 million were estimated to be injured or disabled each year [24, 33]. The WHO Global Burden of

Table 1.1. Incidence and causes of TBI in representative countries and regions. The data show differences in incidence, mortality and type of accident in Sweden, Australia, Europe and US. Epidemiological data from the US show the trends in the major causes of TBI between 1989 and 1998

	Incidence per 100 000	Mortality per 100 000	Traffic-related (%)	Falls (%)	Assault/ self-harm (%)	Source
Sweden 2003 [29]	546	N/A	16	58	15	Admissions, attendance at ED and deaths
Australia 1997 [30]	322	N/A	72	4	14 GSW 0.25	Hospital separations
US 1989 1998 [31]		21.9 19.4	34 ↓22	10 ↑25	40 ↓14	National Center for Health Statistics
Europe 2006 [6]	235	15	11–60	12–62	<1–28	Admissions and deaths

GSW, gunshot wounds.

Disease forecasts that by 2020 road crashes will be the third leading cause of death and disability in the world [28].

Of deaths due to road trauma it is estimated that one-third to one-half are due to brain injury. There are clear interrelationships between the economic status of a country, the dominant form of vehicular transport and TBI. With regard to economic status, 90% of road traffic accident deaths occur in low- or middle-income countries, at nearly twice the population adjusted rate for high-income countries [34]. Road traffic fatalities in the year 2000 ranged from 28.4 per 100 000 of population in Africa to 5.9 per 100 000 in the UK [24]. Motorcycles remain the most dangerous form of motorized transport. According to the Department for Transport in the UK in 1998 motorcycle riders accounted for less than 1% of total road users in Britain but contributed to 15% of those killed or seriously injured. The risk of injury to motorcyclists is 50 times higher and the risk of death about 14 times higher than for the occupants of cars [35, 36]. Motorcycles have gained particular prevalence in low- and middle-income countries, with consequent effect on the rate of TBI.

Other risk factors include age and gender, young males having the highest rate of vehicle-related TBI, and rural traffic accidents tending to have a higher mortality than urban accidents [30, 37].

Whereas the rapid growth of motorized transport in low- and middle-income countries is associated with greater rates of injury, TBI and death, the converse has been observed in high-income countries for some years. Soderlund and Zwi [34] confirmed that after adjusting for motor vehicle numbers the poorest countries showed the highest road traffic-related mortality rates. There was a negative correlation between traffic deaths per 1000 registered vehicles and gross national product (GNP). In many industrialized countries increasing GNP and proportional spending on healthcare were associated with decreased fatalities, suggesting the benefits of interventions to reduce the incidence of road traffic injury and improve survival [34].

Bicycle riding, which has been the primary form of transport in low- and middle-income countries for many years, is being progressively replaced by motorized transport with consequent increase in TBI incidence and mortality. Conversely, in developed countries bicycle riding has become more popular for easy transport and recreation and this has been associated with an increase in injuries. Head injury is the major injury risk to bicycle riders and is responsible for three-quarters of deaths among bicyclists involved in accidents. Low-velocity accidents on bicycles and mopeds have been typically associated with a high proportion of extradural hematomas [38].

Trends in traffic-related injury

The most striking trend has been the fall in traffic-related TBI in high-income countries since about 1970, despite increased motorization and growing populations (Figure 1.2). In a detailed analysis of traffic fatality risk per capita income, Kopits and Cropper noted the threshold income at which traffic fatality begins to fall, even though with increasing prosperity the number of vehicles per population continues to rise [39].

Between 1968 and 1983 road traffic accident mortality declined by more than 20% in Europe. At the

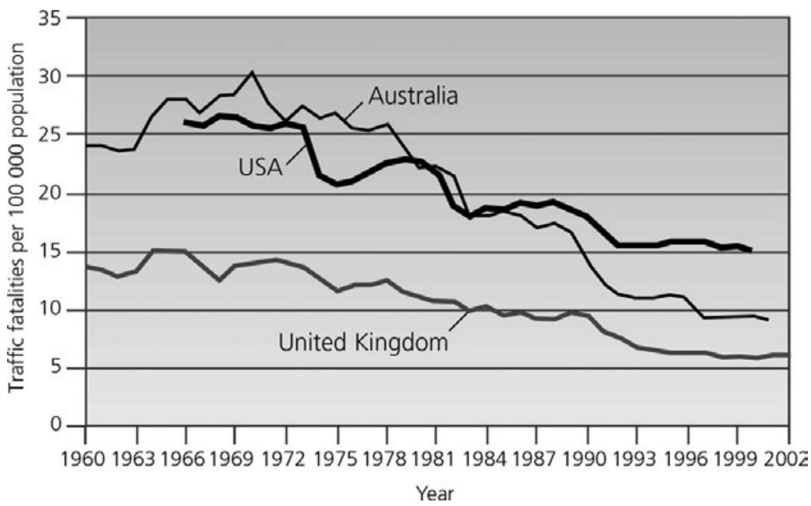

Figure 1.3. Road traffic fatality trends in three high-income countries (Australia, United Kingdom, and United States) from 1960 to 2002. Note the marked decline in mortality in all countries, probably due to implementation of preventive injury measures and legislation. Sources: Transport Safety Bureau, Australia; Department of Transport, United Kingdom; Fatality Analysis Reporting System, United States of America. Reproduced with permission from *World Report on Road Traffic Injury Prevention.* World Health Organization, Geneva; 2004.

same time it rose by more than 150% in Asia and by more than 200% in African countries [34].

In Australia there has been an average yearly decline in TBI of 5% mostly due to an 8% decline in vehicle occupancy injury [40]. Between 1970 and 1995 fatalities from road accidents fell by 47% despite an increase in population by about 40% and an increase in the number of vehicles by 120%. Fatalities per registered vehicle fell in that period from 8.05% to 1.84% [41]. The fatality rate as measured by deaths per billion kilometers traveled had fallen by 2010 to about one-tenth of its level in the 1960s [42] (Figure 1.3).

In Germany increased motorization has also been accompanied by a reduction in TBI mortality from 27.2 to 9.0/100 000 between 1972 and 2000. As in other studies there was an increase in fatal injuries in the elderly, mainly due to falls [43].

With an improving economy the mode of transport changes from low-velocity vehicles such as mopeds to motorbikes and cars. The type of traffic affects the trends in TBI. In Taiwan a high rate of TBI was considered to be related to the rapid increase in the use of motorcycles [44]. In contrast to the dominance of the motor vehicle occupants in high-income countries, in India pedestrians account for 15–35% of injuries, two-wheeler users to 20–40% and bicyclists 5–15% [45].

In eastern China, TBI increased from 32% in the early 1980s to 62% in 2004. In contrast to high-income countries, only 9% of the injured were car occupants whereas 20% were motorcyclists, 19% pedestrians and 13% bicyclists. Injured motorcyclists were more often male and pedestrians more often female. An increase in injury due to "stumbles" in the elderly was also noted [46].

In the US National Center for Health Statistics (NCHS) from 1989 to 1998 TBI-related death rates declined by 11.4%, from 21.9 to 19.4/100 000 population, and during that time vehicle-related deaths decreased by 22%. Firearm-related deaths fell by 14% while fall-related deaths increased by 25% [31] (Table 1.1). Over this period there was evidence of improved outcome in the victims of TBI. A retrospective review of US databases found that mortality for severe brain injury had declined steadily from 39% in 1984 to 27% in 1996 [1]. In a western Europe study conducted over 10 years there was an annual incidence of severe TBI of only 7.3 per 100 000 but a high overall mortality rate of 45.8%; 39.2% suffered persisting deficits [47]. Masson *et al.* showed a decreased TBI incidence compared with a study undertaken 10 years earlier. This decrease was due to traffic accidents but there was also an increase in TBI due to falls and in the median age of patients [48]. In a review of patients with moderate or severe head injury selected for clinical trials in southern Europe, TBI was most often due to motor vehicle accidents (MVAs) while in northern Europe falls predominated [3].

In Australia the mean age of admission to ICU in major trauma centers following TBI was 41.6 years; 74.2% were male; 61.4% were due to vehicle trauma and 24.9% due to falls in the elderly [49].

An increase was noted in serious injuries in adults involved in bicycle falls and collisions over 20 years. Seventy-five percent were not wearing a helmet and 16% had a positive blood alcohol [50].

Prevention of traffic-related injury

In general, strategies to reduce traffic-related injury aim to prevent an accident occurring or to protect the vehicle occupant should an accident occur.

Accident rates may be reduced by good road and vehicle design and by discouraging risk-taking behavior by enforced speed limits and random blood alcohol testing. Modern car design incorporates such prevention measures as crumple zones, side impact reinforcement and anti-skid braking systems. Bicyclists and motor cyclists may reduce their risk of accident by using designated lanes and wearing reflective clothing [51].

The relation between speed and the risk of injury was assessed in two case control studies of urban and rural roads. The risk of a casualty crash was found to double for each 5 kph in free traveling speed above the 60 kph speed limit [52].

On rural roads the risk of a casualty crash rose exponentially at speeds above the average speed and small reductions in traveling speed would substantially reduce the risk of crash and injury [53].

The major contribution of a high blood alcohol in many fatal car crashes is well known [54]. The risk of accident involvement rises steeply above a blood alcohol level of 0.05 mg/dl [55]. A systematic review found that enforcing a driving limit of blood alcohol of 0.08 mg/dl reduced MVAs in the community [56].

Seat belts

Seat belts are at present the most effective means of reducing fatal and non-fatal injury, including TBI. They reduce the risk of ejection from the vehicle, which markedly decreases the risk of injury, as well as the frontal impact against the interior of the car and head impact with other occupants [57]. Front seat belts were introduced in the 1950s and their use first enforced by law in Victoria, Australia, in 1970. Front and rear seat belts and restraint systems for infants and young children are now widely available and mandated in many countries. An assessment from the US Center for Disease Control in 1988 found that unbelted persons were 8.4 times more likely to sustain a head injury [58]. In a review from 1973 to 1981, seat belts reduced the risk of serious injury to the driver by 51–53% and of fatal injury by 63–67%. For the front seat passenger, the reduction of serious injury was 43–44% and for fatal injury 53–55% [59]. Seat belts can rarely cause injury to the thoraco-lumbar spine, abdominal viscera and cervical carotid artery, particularly if they are ill-fitted. In utero injuries have been reported [60] but in the event of a vehicular accident the risk to the fetus is regarded as less if the mother is using a properly fitted seat belt.

Airbags

Full-sized driver's airbags were introduced in the USA in the 1970s, initially to compensate for inadequate seat belt usage. Airbags provide protection against a frontal impact but not against side impact or ejection and they are far less effective than seat belts if used alone.

The National Highway Traffic Safety Administration (NHTSA) report of 2001 found that airbags reduced fatality by 11% for belted drivers and 14% for unbelted drivers in all crashes. Combined with a lap-sash belt the effectiveness was 51% [61].

Airbags in combination with seat belts reduce injury to the brain, face, cervical spine and thorax. This combination of restraints also reduced infectious complications and in-hospital mortality [62].

Soon after the introduction of frontal passenger airbags, there were many reports of fatal injuries to children traveling in the front passenger seat, some in rear-facing child safety seats. This has led to recommendations that children should always travel in the rear of the vehicle in appropriate safety seats.

Side airbags have been introduced more recently to protect the head, neck and torso against side impacts, which are less common than frontal impacts but carry a higher mortality and morbidity. They have been shown on crash tests to be highly effective [63].

Helmets

Motorcycle helmets

In 1941 Cairns advocated the use of motorcycle helmets for military dispatch riders and later charted a fall in head injury fatalities in this group [64].

The use of motorcycle helmets, obligatory for many years on the race track, has substantial benefit in reducing the effects of impact to the head. A Cochrane review [65] estimated that motorcycle helmets reduced the risk of death by 42% and of head injury by 69%.

The US National Highway Traffic Safety Administration found that motorcycle helmets were 37% effective in preventing death and 65% in preventing brain injury [66]. The incidence of brain injury was found to be nearly twice as high and that of severe brain injury 600 times higher in riders without helmets [35]. Motorcycle rider death rates are lower in states with full motorcycle helmet laws [67]. In Taiwan the use of helmets substantially reduced the incidence of TBI, which had been rising due to the increasing popularity of motorbikes [68]. Helmets have not unexpectedly been shown to reduce injuries to the head and face in riders of all-terrain vehicles [69].

Bicycle helmets

Many studies indicate that bicycle helmets provide significant protection against TBI [70]. A Cochrane review based on five case control studies estimated that bicycle helmets provided a 63% to 88% reduction in the risk of severe brain injury [71]. A study of UK hospital admissions reported that bicycle helmets prevented 60% of head injuries [72]. A hospital-based study in California found a reduction of TBI in riders aged 17 years and under of 18.2% but not in older riders [73].

Legislation mandating the wearing of bicycle helmets was introduced in Victoria, Australia, in 1990, again the first in the world to do so, and reduced the risk of injury by 39% [74].

Child safety seats

The number of serious and fatal injuries to children in the front seat of cars led to the recommendation that children should ride in the rear seat in properly fitted and age-appropriate restraints [75, 76]. Rear-facing seats or "capsules" for infants less than 6 months and booster seats fixed by a belt system in the rear seat are mandated in some countries. A systematic review identified strong evidence of effectiveness for child safety seat laws combined with education programs [77].

Falls

Falls are the dominant cause of TBI in infancy to young childhood and again in old age, usually exceeding TBI due to vehicle-related injury in both groups (Figure 1.1). In the elderly falls are common due to lost agility, or unsteadiness for medical reasons. Hospitalization due to falling increases exponentially with age beyond 65 years and is most often due to a fracture of a long bone or pelvis, although the incidence of fall-related TBI has markedly increased in developed countries. This increase has counterbalanced the gains made by reduction in traffic-related TBI (see sections on children and the ageing society and TBI).

Sport and recreational injury

The incidence and type of sporting injuries vary widely between sports, which often carry specific risks. Head injuries are the commonest cause of death among skiers and snowboarders, particularly young males [78]. Skateboarding injuries are associated with a high risk of TBI, which appears to be significantly reduced by wearing helmets [79]. Small specific increases in TBI have been associated with new sports such as skateboarding and "Heelys", a type of roller shoe, but the majority occur in body contact sports such as football and boxing. In professional rugby the incidence of match concussions was 4.1 injuries per 1000 player hours. Headgear wearing was associated with a reduced risk of concussion [80]. Non-professional rugby players had an incidence of mild TBI of 7.97 per 1000 player game hours, risk factors being absence of headgear and a recent mild TBI [81].

Trends in TBI due to sport and recreational injuries

A particularly dangerous pastime is "car surfing", which has caused a rising number of fatalities due to TBI in the USA since 2000 [82]. In response to the high number of head and spinal injuries in high school and college football in the USA, regulations including game rules, equipment standards and on-site management of TBI were introduced, with a consequent fall in the incidence of severe neurological events, including brain and spinal cord injury [83]. In all sports mild TBI fell from 19 per 100 participants in 1983 to 4 per 100 in 1999 [84].

Prevention of TBI in sport and recreational injuries

Helmets for horseback riding are mandatory for most recreational and sporting riders and reduce the risk of TBI [85]. In alpine skiing and snowboarding helmets reduce the risk of TBI by 22–60% [78]. Snowboarding injuries may be reduced by protecting the occipital region due to a high risk of falls onto the back of the head [86].

Management guidelines for minor head injury in school and professional American football emphasize the risks associated with apparently minor TBI and the occasional serious effects of repeated TBI.

Assault and self-harm

TBI due to violence may result from self-inflicted injury or from assault. The incidence varies widely between countries. In a Canadian study, firearm injuries were mostly self-inflicted and assaults mainly due to fighting or being struck by objects [87]. Low-income status, social disadvantage and drugs are risk factors [88].

Assault, whether by missile injury or blows to the head, is often a component of social dysfunction and in many countries is prevalent among disadvantaged communities. In Australian indigenous communities interpersonal violence is responsible for a disproportionate number of head injuries, which are generally caused by blows to the head. The incidence of TBI due to assault in the Australian population is 40.7 per 100 000 but among the indigenous population is 854.8 per 100 000, greater by a factor of 21. Indigenous females suffered nearly 70 times the rate of head injury due to assault compared with non-indigenous females [89].

The USA has the highest incidence of fatal gunshot wounds to the head among high-income countries. In 1990 firearm injury nationally exceeded transport-related injury as a cause of fatal TBI for the first time [90]. Later reports indicate some fall in this figure and marked differences between states.

The explosive devices used in Iraq and Afghanistan and in civilian terrorist attacks have introduced a new form of brain injury, blast injury, the neuropathology of which is complex. These areas of conflict have placed an enormous burden of post-traumatic physical and psychological injury on the countries involved.

Trends in assault and self-harm

A US study reported that firearm-related TBI death, which had been increasing in the early 1990s, had fallen in the 5 years to 1998 [31]. Ninety percent of cranial gunshot wounds are fatal.

In Australia there has been a steady fall in firearm-related TBI from 4.8 per 100 000 in 1980 to 2.6 per 100 000 in 1995. Over 70% of the injuries were suicidal [91].

Prevention in assault and self-harm – gun laws

To reduce firearm-related TBI requires addressing the causes of violence in a community and the reasons for self-harm, issues that are beyond the scope of this chapter. A study of the major differences between communities in the incidence of firearm-related TBI, gun availability and legislative approaches to gun ownership may lead to effective legislation and a significant degree of prevention.

Uniform gun laws were introduced in Australia in 1996 banning automatic and semiautomatic weapons. The low incidence of firearm injury was already falling by 3% per year and this decrease doubled to 6% after the law, reaching 0.27 firearm deaths per 100 000 in 2002/03 [92].

Occupational injuries

Most industrialized countries have rigorous occupational safety standards, particularly in the high-risk industries of mining, construction and transport. A review of work-related injuries in Australia found an incidence of workplace deaths of 8.6% per 100 000 employees. Brain injury was the cause of death in 23.3% and multiple injuries, which often included brain injury, in 18.2% [93]. In the construction industry TBI mainly occurs through falls or by being struck by an object [94]. Accordingly, safety helmets on construction sites are designed to mitigate vertical impact and give little protection against a side impact.

Traumatic brain injury in children

In children most head injuries are mild and many may not attend hospital. The commonest cause of minor or mild head injury is a fall, often at home, becoming the most frequent cause for admission to hospital in children under 14 years [95]. Fifty-nine percent of falls are from playground equipment and 2.6% of these falls are associated with TBI requiring hospital admission [96].

Serious TBI is most often due to motor vehicle accident as either a pedestrian or a car occupant [75, 97]. Non-accidental injury is a major cause of death among infants and young children and is associated with worse outcome compared to children presenting with accidental injuries [98].

While it is commonly believed that children recover more rapidly than adults from TBI, they may more often suffer unexpected long-term effects and assessing the consequences of a pediatric brain injury requires long follow-up [99].

A US National Inpatient Sample from 1991–2005 showed a decrease in inpatient admission for TBI of 39% at age 0–19 years from 119.4 to 72.7 per 100 000. Fatalities decreased from 3.5 per 100 000 in 1991–1993 to 2.8 in 2003–2005. The fall in incidence was mainly in mild head injuries [100].

Prevention strategies for childhood head injury must be directed to the causes: education of parents and carers regarding the risk of falls; standards for playground equipment; proper restraints in cars and addressing the socio economic circumstances that underlie non-accidental injury.

Legislating for prevention

The importance of legislation in supporting safety initiatives and publicity campaigns has been shown in many countries. Studies have also indicated that self-administered protection is only substantially adopted by the community when it is supported by legislation [41].

In Italy a motorcycle-moped-motor scooter law increased helmet usage from less than 20% to over 96%, leading to a reduction in TBI admissions and in the incidence in epidural hematoma [38].

In Arkansas motorcycle helmet usage was reinforced by legislation, which was subsequently repealed and helmet usage fell [101]. As a consequence Evans estimated that there was an 18% increase in fatalities [54]. A helmet law in California resulted in an increase in usage from 38.2% to over 85% and a fall in head injuries [102]. A Maryland study found that motorcyclist fatality rate fell from 10.3 per 100 000 before legislation enforcing the wearing of helmets to 4.5 per 100 000 post law [103].

Comparing helmet use and the associated reduction in motorcyclist head injury fatality rates in US states provides a strong argument for uniform laws [66].

As would be expected, helmet laws are associated with a substantial reduction in medical costs [104].

In Taiwan, which was faced with a rapid rise in motorcycle injuries, introducing a helmet law decreased motorcycle-related head injuries by 33% [68].

Similar experiences have been reported with bicycle helmets. In Victoria, Australia, when education campaigns were followed by legislation, helmet use increased from 36% to 83% and the number of bicyclists admitted to hospital with a head injury decreased by 40% during the first 4 years after legislation [105]. Nolen and Lindqvist noted the lack of benefit of a legislated but not legally binding recommendation to wear bicycle helmets in a Swedish town [106]. The lack of optional wearing is particularly notable among young children, for whom peer pressure is an important determinant and where legislation may be particularly effective [107].

Measuring the effects of preventive strategies

Clearly, each major identified cause of TBI needs regular epidemiological review to determine the effectiveness of preventive strategies. Reports have largely concentrated on transport-related TBI and have been observational, either case control or population-based before and after studies, rather than randomized controlled trials. These types of studies may be supplemented by biomechanical and simulation evidence.

The effectiveness of individual measures aimed at changing behavior such as publicity campaigns, random breath testing and speed cameras is harder to assess.

The US National Highway Traffic Safety Administration in their report of 2010 document a falling fatality rate of road traffic accidents per 100 000 miles traveled since 1966 in the USA and relate the fall to the introduction of various behavioral and vehicle improvement milestones [108].

In Australia the Department of Infrastructure and Transport concluded from simple regression models that almost all the decrease in fatality rates since the late 1960s could be explained by the introduction of seat belts, random breath testing and speed cameras [42].