Chapter 1

Epidemiology of head injury

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Introduction

Head injury is a major cause of morbidity and mortality in all age groups. Currently, there is no effective treatment to reverse the effects of the primary brain injury sustained, and treatment is aimed at minimizing the secondary brain injury that can occur due to the effects of ischaemia, hypoxia and raised intracranial pressure. An understanding of the epidemiology of head injury is essential for devising preventive measures, to plan population-based primary prevention strategies and to provide effective and timely treatment including provision of rehabilitation facilities to those who have suffered a head injury.

Epidemiology is the basic science of public health and clinical medicine. It describes the occurrence of health-related states or events, quantifies the risk of disease and its outcome and postulates causal mechanisms for disease in populations. The main function of epidemiology is to provide an evidence-based public health policy thereby guiding clinical practice to protect, restore and promote health. Epidemiological studies have highlighted three important aspects of head injury: (i) socio-demographic factors (age, gender, ethnicity, socio-economic status, geographic location, legislation and enforcement, physical/psychological condition, use of alcohol and drugs); (ii) mechanism of injury (nature of accident or trauma – road traffic accident (RTA), fall, violence, sport injury); and (iii) efficiency of the healthcare system (emergency rescue/ambulance service, in- and out-patient medical care, rehabilitation services). Thus, for devising a prevention programme, we need to identify the risk factors for head injury, the mechanisms and patterns of head injury, possible methods for prevention and the relationship between brain injury and outcome. The aim of this chapter is to describe the descriptive epidemiology of traumatic brain injury (TBI), its causes and preventive measures targeted at the 'at-risk' population.

Definition and classification of traumatic brain injury

While studying the epidemiology of TBI, it is important to realize that definitions, coding practices, inclusion criteria for patients and items of data collected have varied between studies. This has made it difficult to draw meaningful comparisons of rates and risk factors between populations. The term 'head injury' is commonly used to describe injuries affecting not just the brain but also the scalp, skull, maxilla and mandible and special senses of smell, vision and hearing. Head injuries are also commonly referred to as brain injury or traumatic brain injury, depending on the extent of the head trauma. TBI is usually considered an insult or trauma to the brain from an external mechanical force, possibly leading to temporary or permanent impairments of physical, cognitive and psychosocial functions with an associated diminished or altered state of consciousness. It is also important to consider TBI in the context of the skull and other structures above the neck, as well as to identify those with

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Table 1.1. List of ICD-10 codes and categories for injuries to the head

ICD Code	Category
S00	Superficial injury of head
S01	Open wound of head
S02	Fracture of skull and facial bones
S03	Dislocation, sprain and strain of joints and ligaments of head
S04	Injury of cranial nerves
S05	Injury of eye and orbit
S06	**Intracranial injury**
S06.0	Concussion
S06.1	Traumatic cerebral oedema
S06.2	Diffuse brain injury
S06.3	Focal brain injury
S06.4	Epidural haemorrhage
S06.5	Traumatic subdural haemorrhage
S06.6	Traumatic subarachnoid haemorrhage
S06.7	Intracranial injury with prolonged coma
S06.8	Other intracranial injuries
S06.9	Intracranial injury, unspecified
S07	Crushing injury of head
S08	Traumatic amputation of part of head
S09	Other and unspecified injuries of head

Source: *International Statistical Classification of Diseases and Related Health Problems, 10th Revision*, Version for 2007 published by the WHO http://www.who.int/classifications/apps/icd/icd10online/. Reproduced with permission from the World Health Organization, © 2007.

'isolated' head injuries and those with multisystem polytrauma where other injuries may contribute to secondary brain injury. The severity of TBI is usually classified according to the Glasgow Coma Scale (GCS) scores as mild (13–15), moderate (9–12) and severe (3–8).

The International Classification of Diseases (ICD) is the standard diagnostic classification for clinical, epidemiological and health service data and is used to classify diseases and other health problems recorded on many types of health and vital records (e.g. hospital records, death certificates).[1] It is used for compilation of morbidity and mortality statistics and comparison of health data collected in different countries at different times. In ICD-10, which was implemented in 1994, 'accidents, poisonings and violence' are classified according to their 'external cause' in the interests of strategic planning of preventive policy and action. The codes for recording injuries to the head (S00–S09) include injuries of ear, eye, face, gum, jaw, mandibular joint area, oral cavity, palate, periocular area, scalp, tongue and tooth (Table 1.1). This excludes burns, corrosions and effects of a foreign body. As with all coding systems, they may be applied in different ways and the use of general codes (e.g. S09, other and unspecified injuries of the head) may underestimate more specific injuries.[2] One of

Table 1.2. Sources of data on accidents and injury in the UK

- Hospital records/statistics (including A&E departments): presentation to health services is dependent on severity of head injury and proximity/access to services.
- Mortality data: the most reliable and complete source of information on deaths due to external causes (http://www.statistics.gov.uk).
- HASS and LASS (Home and Leisure Accident Surveillance System): a reliable source of information on home and leisure accidents, dependent on data from A&E departments (http://www.hassandlass.org.uk).
- Health and Safety Executive: collects data on serious employment-related injuries and accidents (http://www.hse.gov.uk).
- Police services: collate data on RTAs and their causes (speeding, traffic law violations, drink-driving, use of illicit drugs, etc.).
- Surveys such as the General Household Survey and Labour Force Survey (http://www.statistics.gov.uk).

the problems of head injury research is case ascertainment. The most reliable sources of data on head injury and its outcome include hospital records (i.e. in- and out-patient records, hospital discharge register, radiology reports, accident and emergency department attendance records), prospective observational studies and death certification (Table 1.2).[3]

While studying the epidemiology of head injury, it is important to understand that patients with TBI may not survive before reaching hospital or may even present after a delay to primary care; they may present to an accident and emergency department, with subsequent admission to an observation or neurosurgical ward or a neurosurgical intensive care. Following admission, they may not survive the injury or may be discharged home or to a rehabilitation facility or long-term institutional care. This information is essential for planning, resource allocation and efficient delivery of treatment and rehabilitation services to patients with TBI.

Burden of traumatic brain injury

TBI is an important global public health problem. It is a major cause of disability. Survivors often suffer cognitive, mood and behavioural disorders. The societal cost of the disability following TBI can be substantial due to loss of years of productive life and a need for long-term or lifelong services. Worldwide, it has been estimated that around 10 million TBIs serious enough to result in hospitalization, long-term or lifelong disability, or death occur annually.[4] In the USA, an average of 1.4 million TBIs occur each year, including 1.1 million A&E department visits, 235 000 hospitalizations and 50 000 deaths.[5] In a recent report, it was estimated that about 5.3 million people have some TBI-related disability, impairment, complaint, or handicap in the USA.[5] Similarly, it has been estimated that about 6.2 million people in the European Union have some form of TBI-related disability.[6]

Incidence of TBI

Incidence is a count of *new cases* of TBI in the population during a specified time period. The *incidence rate* is the number of *new cases* of TBI in a defined population within a specified time period (usually a calendar year), divided by the total number of persons in that population (usually expressed as per 100 000 population). Like most conditions, the incidence of TBI varies according to age, gender and geographic location. Most of the published reports are from developed countries in Europe and North America, and there is little

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Table 1.3. Incidence of traumatic head injury in different populations (selected studies)

Population	Annual incidence per 100 000 population	Male : female ratio
Africa		
South Africa, Johannesburg (Nell & Brown, 1991)	316	4.8:1
Asia		
India (Gururaj *et al*. 2004)	160	NR
Taiwan, Taipei City (Chiu *et al*. 2007)	218	1.9:1
Europe		
Spain, Cantabria (Vazquez-Barquero *et al*. 1992)	91	2.7:1
Finland (Alaranta *et al*. 2000)	95	1.5:1
Portugal (Santos *et al*. 2003)	137	1.8:1
Denmark (Engberg & Teasdale, 2001)	157	2.2:1
Italy, Northeast (Baldo *et al*. 2003)	212	1.6:1
Norway, Tromso (Ingebrigtsen *et al*. 1998)	229	1.7:1
UK, England (Tennant, 2005)	229	NR
Sweden (Kleiven *et al*. 2003)	259	2.1:1
Italy, Romagna (Servadei *et al*. 2002)	297	1.6:1
UK, Staffordshire (Hawley *et al*. 2003)	280[a]	1.8:1
France, Aquitaine (Tiret *et al*. 1990)	282	2.1:1
Italy, Trentino (Servadei *et al*. 2002)	332	1.8:1
Germany (Steudel *et al*. 2005)	337	NR
Germany (Firsching & Woischneck, 2001)	350	NR
Sweden, Northern (Styrke *et al*. 2007)	354	1.2:1
UK, Southwest England (Yates *et al*. 2006)	453	1.6:1
Sweden, Western (Andersson *et al*. 2003)	546	1.4:1
North America		
USA, Alaska (Sallee *et al*. 2000)	105	2.3:1
USA, Utah (Thurman *et al*. 1996)	109	2.2:1
USA (Guerrero *et al*. 2000)	392	1.6:1
USA (Jager *et al*. 2000)	444	1.7:1
Oceania		
Australia, NSW (Tate *et al*. 1998)	100	NR
Australia, South (Hillier *et al*. 1997)	322	2.3:1

[a] In children aged ≤15 years. NR, not reported
This table is adapted from data reviewed by Tagliaferri *et al*., 6 with permission.

information on epidemiology of head injury from most developing countries. The annual incidence rates of TBI range from a low of 91 per 100 000 population in a province in Spain to a high of 546 per 100 000 in western Sweden (Table 1.3). The rate from Spain included only hospitalized patients, while the rate from Sweden included hospital admissions, A&E attendances and deaths. Most rates are in the range of 150–450 new cases per 100 000 per year. The variation observed could be partly explained by differences in criteria used to define TBI or identify patients. In a recent study from England, the incidence rates of head injury varied by a factor of 4.6 across different health authorities (range 91–419 per 100 000).[7] Similarly, in the USA incidence rates of TBI vary from a low of 101 per 100 000 in Colorado to a high of 367 per 100 000 in Chicago.[8] In a recent review of TBI epidemiology in the European Union (EU), an overall average rate of 235 per 100 000 per year was obtained. Considering the EU population of about 330 million, this accounts for about 775 500 new cases of TBI per year.[6]

Variation by age

In most studies, three distinct peaks in the incidence of TBI are noted. The risk of having a TBI is particularly high among children, young adults and the elderly population.[9] The highest incidence, in most studies, is reported in adolescents and young adults. For A&E visits, hospitalizations and deaths combined, children aged 0–4 years and adolescents aged 15–19 years are more likely to sustain a TBI than persons in other age groups.[5] For hospitalizations only, persons aged ≥75 years have the highest incidence of TBI.[5] In a study of hospital admissions due to TBI in the UK, 30% were children aged <15 years.[10] Among those attending A&E departments in the UK with head injuries the highest rates are observed in urban males aged 15–19 years.[10] In the European Brain Injury Consortium (EBIC) study of patients admitted to neurosurgical centres in 12 European countries, the median age of the subjects was 38 years with a higher preponderance of male patients.[3]

Variation by gender

Almost all studies show a male preponderance. Overall, males are about twice as likely as females to experience a TBI. For studies from Europe and North America, the male : female ratio varies from 1.2:1 in Sweden to 2.7:1 in Spain. Males in developing countries apparently have a much higher risk of TBI compared with those in developed countries. In a study from South Africa, the male : female ratio was 4.8 : 1 (Table 1.3). In the UK study of TBI-related hospital admissions, 72% were male patients.[10] In the EBIC study of severe head injuries, 74% of the patients were males.[3] In the Traumatic Coma Data Bank of patients with severe head injury, about 77% were males.[11] In the CRASH study of the effect of corticosteroids on death within 14 days, which included 10 008 patients with clinically significant head injury, 81% were males.[12] The male excess of TBI is attributed to greater exposure and more risk-taking behaviour. At younger ages the exposure of males to violence and RTAs leads to a male : female ratio of head injury incidence of about 4:1.

Mortality from TBI

The *mortality rate* is the number of deaths from TBI in a defined population within a specified time period (usually a calendar year), divided by the total number of persons in that population (usually expressed as per 100 000 population). The mortality rate varies considerably in different countries. In the UK, the mortality rate from head injury is 6–10 per 100 000 population per year.[13] For France, a mortality rate of about 22 per 100 000 has been reported.[14] In the EU, the mortality from TBI varies from a low of 9.4 per 100 000 in

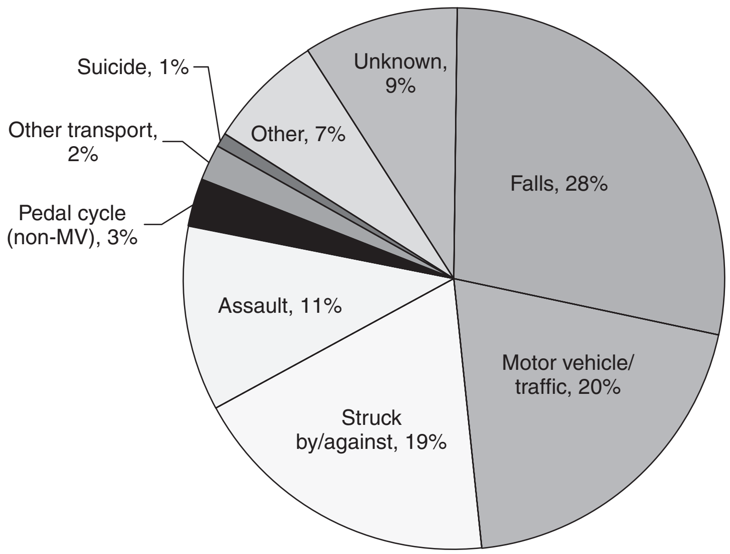

Fig. 1.1. Percentage of average annual TBI-related A&E department visits, hospitalizations, and deaths, by external cause, USA, 1995–2001.
[Source: Centre for Disease Control, USA.]

Germany to a high of 24.4 per 100 000 in Ravenna, Italy, with an overall average rate of about 15 deaths per 100 000 population per year.[6] In the USA, the overall mortality rate is 20–30 per 100 000 with half of the patients dying out of hospital.[15] For the Bronx area in New York, a rate of 28 per 100 000 has been reported.[16] Among adults in Johannesburg, South Africa, a much higher mortality rate of 138 per 100 000 for males and 24 per 100 000 for females has been reported, with 20% of TBIs resulting in death.[17]

Causes of head injury

The most common causes of TBI are RTAs, falls, 'struck by' or 'struck against' events, assault/violence and sporting or recreation activities (Fig. 1.1). The majority of reports show RTAs as the leading cause of TBI followed by falls (which is reported as the leading cause in a few studies). In a review of studies from the EU, 21%–60% of TBIs were caused by RTAs (from a low of 21% in Norway and UK to a high of 60% in Sweden and Spain); 15%–62% were caused by falls (15% in Italy, 62% in Norway).[6] One study from Glasgow, Scotland, reported violence/assault (28%) as the second most common cause after falls (46%).[18] Overall, it has been estimated that, in the EU, 40% of TBIs are caused by RTAs, 37% are caused by falls, 7% are caused by violence/assault and 16% by other causes.[6]

It may be realized that the cause–effect relationships between the mechanisms of injury and TBI is confounded by age, gender, car ownership, urban residence and socioeconomic factors. For example, elderly people who have a relatively high incidence of falls are more likely than other age groups to be pedestrian victims of RTAs. The contributing factors may include side effects of medication, poor vision/hearing, slow reaction time and impairment of balance and mobility. In a study of TBI in children, the most common cause of injury was accidents involving children as pedestrians (36%), followed by falls (24%), cycling accidents (10%), as motor vehicle occupants (9%) and assault (6%).[19] In a UK study of minor head injury in adults, the common causes of injury were assault (30%–50%), RTA (25%) and falls (22%–43%).[10] It was reported that alcohol might be involved in 65% of adult head injuries. In a study from the USA, RTAs accounted for 50%, falls for 23%–30% and assaults for 20% of head injuries.[9] In the USA gunshot wound to the head is now a more frequent cause of serious head injury than RTA with a case fatality of about 90%.[9] In a study from Canada, RTAs accounted for 43% and assault for 11% of head injuries. In the EBIC study of patients admitted to neurosurgical units (with GCS ≤ 12), 51% were involved in a RTA, 12% in falls and 5% in assaults.[3] In the CRASH trial, the RTAs accounted for 64% and falls 13% of all head injuries.[12]

Sporting head injuries

The study of the epidemiology of traumatic brain injury in sports is an area where significant advances in the prevention of head injuries by alteration of rules of participation and protective equipment have been made. Epidemiological studies are difficult to interpret, as they may be reported as relative frequencies compared to other mechanisms of head injuries, other types of sports injuries, injuries in other sports or often reported as incidence of injury per participant exposure within the sport. Media reporting of high profile sports injuries may give the perception of a much higher incidence rate than actually occurs both within the sport and compared to other sports. In certain sports such as boxing where there may be repetitive head injuries, epidemiological studies of chronic traumatic brain injury are important to inform opinion.

Overall, sports and recreation may account for up to 5%–10% of head injuries in studies of mechanism. Non-fatal traumatic brain injuries from sports and recreational activities are reported for hospital emergency department presentations in the USA from 2001–2005 as part of the National Electronic Injury Surveillance System – All Injury Program. An estimated 207 830 patients with sports- and recreation-related TBIs accounted for 5.1% of sports-related emergency department visits. Approximately 10.3% of patients with sports-related TBIs required subsequent transfer to a specialist facility or hospitalization. The most frequent causes of TBI were horse riding (11.7%), ice-skating (10.4%), riding all terrain vehicles (8.4%), tobogganing/sledding (8.3%) and bicycling (7.7%). American football accounted for 5.7% and combative sports including boxing, wrestling, martial arts and fencing made up 4.8%.[20]

Much work has been done on the epidemiology of American football-related head injuries. The annual rate of non-fatal head-related catastrophic injuries in American football has averaged around 0.3 per 100 000 for high school and college participants. The rate of fatal injuries has stabilised at 0.32 per 100 000 per year.[21]

The participant rate of acute head injury in amateur boxing is often less than in more popular sports such as horse riding and rugby union and absolute incidence is less. Fatalities in the ring are rare in amateur and professional boxing. There were 335 deaths between 1945 and 1979. The incidence of acute TBI has been reported in exposure terms, one study in the USA reporting a rate of 8.7 head injuries per 100 bouts in amateur boxing. In a study of amateur boxing in Denmark 5.7% to 7.8% of bouts were stopped because of a knockout.[22]

The cumulative effect of blows to the head and cerebral injury may result in chronic traumatic brain injury. A recent systematic review of observational studies has failed to find strong evidence to associate chronic traumatic brain injury with amateur boxing.[23] It is therefore important for the moral and philosophical arguments often cited against amateur and professional boxing to be informed by epidemiological data.

Head injury requiring intensive care or neurosurgery

In a study from the UK, a rate of 40 per 100 000 was found for moderate to severe (10.9%) head injuries with a Glasgow Coma Scale of ≤12.[24] A figure of 4000 patients a year requiring neurosurgery in the UK has been reported.[25] In the paediatric population aged 0–14 years, an incidence of 5.6 per 100 000 per year has been quoted for admission to intensive care following a head injury.[19]

Susceptibility to head injuries – apoE

There is evidence that genetic factors may predispose to a poorer outcome following head injury. The apolipoprotein E (apoE) is a protein that can influence the deposition of amyloid beta-protein in the cerebral cortex and is involved in neurodegeneration, brain injury and repair. Polymorphism of the apoE allele is associated with a worse outcome following head injury. Patients with the apoE epsilon 4 allele are more than twice as likely to have a poorer outcome at 6 months following head injury than those without.[26] Further studies have also shown that apoE epsilon 4 allele presence influences recovery from traumatic brain injury and this may be age dependent.[27]

Prevention of head injury

Most TBI cases present with characteristic patterns of injury that are predictable and potentially preventable. Particular patterns may be caused by social, economic, behavioural or environmental factors. Identification of risk factors is therefore a prerequisite for devising preventive measures and public health policy. Attempts at reducing trauma from all mechanisms will also have the effect of reducing TBI to varying degrees. The prevention programmes for TBI focus on RTA prevention, cessation of drinking and driving, minimizing falls (particularly in the elderly), reducing sport injuries and decreasing violence and domestic abuse (particularly child abuse). Based on the standard principles of public health, William Haddon Jr, the first director of National Traffic Safety Bureau in the USA, proposed a conceptual model in the 1970s, the Haddon matrix, to address the problem of traffic safety.[28] The matrix illustrates the interaction of three factors – human, vehicle and environment – during three phases of an accident event – pre-accident, accident and post-accident. This concept has been successfully applied to the primary, secondary and tertiary prevention of RTAs and other types of accident (Table 1.4). In the USA, the remarkable reduction in mortality attributed to RTAs has been hailed as one of the main public health achievements of the twentieth century.[8] In the UK, primary prevention of accidents forms part of the government strategy for *Saving Lives: Our Healthier Nation*. This sets a public health target for reducing the incidence of serious injury from accidents by 10% and the mortality rate from accidents by 20% – saving 12 000 lives by the year 2010. A recent WHO report on road traffic injury prevention has summarized risk factors and interventions to reduce trauma from this common cause.[29]

Legislative policy and enforcement to control motor vehicle accidents by making wearing of helmets compulsory for cyclists and motorcyclists and reducing legal permissible alcohol levels for driving have been shown to be associated with a reduction in RTA associated head injuries.[29–31] Some countries have recently introduced a new regulation to prohibit the use of a handheld mobile phone while driving. Several studies have shown that the wearing of helmets by cyclists reduces the risk of head injury. In a recent Cochrane review of case-control studies, safety helmet use was associated with a 63%–88% reduction in the incidence of brain injury for all ages of cyclists. This protection was provided for crashes involving motor vehicles (69%) and all other causes (68%).[32] Evidence that wearing of helmets reduces injuries in skiers and snowboarders is also compelling.[33] Systematic reviews have shown that it is possible to reduce the incidence of falls by about 35% among older

Table 1.4. The Haddon matrix applied to prevention of road traffic accidents

	Factors		
Phase	**People**	**Vehicle and equipment**	**Environment**
Pre-accident (accident prevention)	Education Attitudes/behaviour Impairment (alcohol, drugs, fatigue) Police enforcement (traffic laws) Reflective clothing for pedestrians and cyclists	Roadworthiness Lighting (daytime lights on motorcycles) Braking and handling Speed limitation systems	Road design and layout (separation of car, cyclists, and pedestrians; better road marking and lighting) Speed limits Provision of transport alternatives
Accident (injury prevention/ limitation)	Use of seat belts Impairment (drink driving)	Crash-protective design and engineering Occupant restraints and safety devices (seat belts, air bags, child restraints) Use of helmets	Crash-protective roadside barriers/ objects (central reservation barrier, pedestrian crossing)
Post-accident (life sustaining and health improvement)	First aid and resuscitation Access to medical and rehabilitation services	Ease of access Fire risk	CCTV at danger points Access for rescue services (congestion)

people.[34] Considering the wider determinants of public health, the role of health education and environmental engineering has been emphasized in the prevention of TBI. Examples of these efforts include education in schools about potential dangers around the home and road safety; education and examination of new motor vehicle drivers about risk factors for accidents; public health promotion campaigns to encourage use of helmets and seat belts and avoidance of alcohol and drugs when driving; better house designs to prevent falls and accidents; safer play areas for children and provision of cycle lanes.

Summary

- TBI is an important global public health problem. Worldwide, around 10 million TBIs serious enough to result in hospitalization, long-term or lifelong disability, or death occur annually.
- About 5.3 million people in the USA and 6.2 million in the EU have some TBI-related disability, impairment, complaint or handicap.
- Average annual incidence rate of TBI in the EU is about 235 per 100 000 population.
- Average annual mortality rate of TBI in the EU is about 15 per 100 000 population.
- The risk of experiencing TBI is particularly high among children, young adults and the elderly.
- At all ages, males are about twice as likely as females to experience a TBI.
- The leading causes of TBI are RTAs, falls, struck by or against events, assault/violence and sports or recreation activities.

- Primary prevention of TBI includes prevention of RTAs, drinking and driving, falls, sport injuries and decreasing violence and domestic abuse.
- Legislation (e.g. seat belts, helmets, speed limits) and enforcement have been shown to reduce the incidence of TBI in the population.
- TBI is a public health problem that requires ongoing surveillance to monitor trends in the incidence and mortality, risk factors, causes and outcome (NCIPC has developed guidelines for surveillance of TBI http://www.cdc.gov/ncipc/). These data may help inform planning of services and identify individuals who are prone to suffering TBI and the situations where these accidents may occur.

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