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The Epidemiology of Traumatic Brain Injury: A Review

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Summary: *Purpose:* Traumatic brain injury (TBI) not only has considerable morbidity and mortality, but it is a major cause of epilepsy. We wish to determine the frequency of TBI, special groups at risk for TBI, and mortality from TBI.

Methods: We reviewed studies of TBI that are either population based or derived from definable catchment areas that allow determination of incidence, identification of risk groups, and mortality. We review methodology used in epidemiologic studies of TBI and try to distinguish this data from that of head injury not necessarily affecting the brain. We report epidemiologic characteristics of TBI, including incidence, differences by age, gender, race and ethnic group, and geographic variation, and mortality.

Results: Population-based studies in the United States suggest that the incidence of TBI is between 180 and 250 per 100,000 population per year. Incidence may be higher in Europe and South Africa. There are groups at high risk for TBI. This includes males and individuals living in regions characterized by socioeconomic deprivation. There are selective age groups at risk for TBI. This includes the very young, adolescents and young adults, and the elderly. Mortality varies by severity but is high in those with severe injury and in the elderly.

Conclusions: TBI is a major public health problem as well as a major cause of epilepsy. If primary prevention is to be undertaken, we must understand the epidemiology of the condition. The primary causes of TBI vary by age, socioeconomic factors, and geographic region, so any planned interventions must be tailored accordingly. **Key Words:** Brain trauma—Epidemiology—Incidence—Mortality.

In individuals younger than 45 years, injury is the primary cause of death in the United States and other developed nations. Traumatic brain injury (TBI) is the major cause of disability, morbidity, and mortality among this group and is responsible for a significant proportion of all traumatic deaths in the U.S. (1).

Confusion exists regarding head injury (HI) and TBI. HI is a nonspecific and antiquated term, which includes clinically evident external injuries to the face, scalp, and calvarium, such as lacerations, contusions, abrasions, and fractures, and may or may not be associated with TBI. TBI injury is more properly defined as an alteration in brain function manifest as confusion, altered level of consciousness, seizure, coma, or focal sensory or motor neurologic deficit resulting from blunt or penetrating force to the head. In mild TBI, subtle behavioral and neuropsychological changes may be the only symptom(s).

INCIDENCE OF TRAUMATIC BRAIN INJURY

Significant differences in study methods, particularly in case ascertainment and inclusion criteria, make study comparisons difficult, particularly among subgroups of TBI patients. The general incidence of TBI in developed countries is frequently stated to be 200 per 100,000 population at risk per year. This estimate typically includes only TBI patients admitted to hospitals. Medically unattended and emergency department (ED)-managed TBIs are uncounted in some studies, resulting in underestimation of the frequency of milder TBI, and overestimates the proportion of more severe TBIs. A shift in TBI management from the inpatient to outpatient setting has resulted from enhanced neuroimaging capabilities and more rigorous hospital admission policies. Out-of-hospital fatal TBIs are excluded in some studies, which results in underenumeration of overall and most severe/fatal TBIs. At the same time, many of these investigations are hospital or trauma center cohort samples of convenience with a poorly defined denominator and biased by selection mechanisms. This results in overenumeration of TBI quantity and severity. Rubrics screened to identify TBI are shown in Table 1. Incidence data summaries for 12 epidemiologic studies reviewed are presented in Table 2.

Two TBI investigations have used the U.S. National Health Interview Survey (NHIS). Fife (2) estimated the incidence of TBI in the United States between 1977 and 1981. He included TBI with ≥1 day of disability and/or

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TABLE 1. *ICD-9 codes and corresponding traumatic brain injury diagnosis*

ICD 9 Codes	
800.0 to 804.9	Fracture of skull
850	Concussion
851	Cerebral laceration and contusion
852	Subarachnoid, subdural, and extradural hemorrhage after injury
853	Other and unspecified intracranial hemorrhage after injury
854	Intracranial injury of other and unspecified nature

obtaining medical attention, but deaths were excluded. He estimated that 1.9 million people (825 per 100,000 in 1980) sustained a TBI in the United States with ~90% (743 of 100,000) seeking medical attention and ~20% (150 of 100,000) being admitted to the hospital annually. With the same data set and definitions in 1991, Sosin (3) estimated the incidence rate of TBI to be 618 per 100,000 in the United States. Here, 35% were attended in the ED (216 of 100,000) and 25% were admitted to the hospital (155 of 100,000). Whereas little difference was found in the incidence of hospital admissions, the overall and medically attended TBI rates are much higher in the Fife study. The discrepancy in overall incidence between these two NHIS studies may reflect a decreasing incidence of TBI in the United States.

Four U.S. studies that estimate the incidence of TBI include patients evaluated in EDs. In a population-based historical cohort study, the Anneger study (4) ascertained all Olmsted County residents medically attended for TBI, including MD office, ED, and hospitalized and medical examiner (ME) cases from 1935 to 1974. Incidence, age adjusted to the 1970 U.S. population, was 180 of 100,000. Cooper (5) prospectively determined the incidence of TBI, including ME cases, hospitalized cases, and cases discharged from the ED in 1980. When age adjusted to the white 1970 U.S. population, the incidence was 209 of 100,000.

Two studies of TBI in EDs using a national multistage probability sampling (NMPS) design have been undertaken in the United States. Jager (6) (including hospital admissions and excluding out-of-hospital deaths) estimated the annual TBI-related ED incidence to be 444 of 100,000 from 1992 to 1994. Guerrero (7), excluding prehospital deaths, ED deaths, and hospital admissions, estimated an ED annual TBI incidence of 392 of 100,000 in 1995. The incidence estimates using sampling methods are not only inconsistent with each other but are 2 to 3 times higher than that reported in Olmsted County or the Bronx, even though these studies also included patients seen only in the ED. These discrepancies raise questions regarding the estimates from this sampling methods.

In a population-based study reviewing ED contacts, radiology referrals, and hospital admissions in the Netherlands in 1997, the incidence of HI was reported to be 836 of 100,000 population. Only 26% (217 of 100,000) had brain injury, and 11% were admitted to hospital (8). This again suggests that the sampling techniques probably identify head trauma but not specifically TBI.

In San Diego County in 1980, the incidence of hospitalized or fatal TBI was 180 of 100,000 (216 of 100,000 age adjusted to the 1970 U.S. population) (9). People hospitalized for skull fracture alone were excluded. A study including hospitalized HI (not TBI) or HI resulting in death before hospitalization in Aquitaine, France, reported an incidence of 280 of 100,000 when age adjusted to the 1970 U.S. population (10). The higher incidence in France could be due to the inclusion of non-TBI head injury.

The incidence of TBI was reported from a randomized door-to-door survey conducted in six urban cities in the People's Republic of China. The survey identified potential TBI cases subsequently confirmed by a neurosurgeon's medical record review. The incidence rate in 1982 was estimated to be 56 per 100,000 (11). The strategy should have included TBI not seen medically but would have missed fatal cases. The low incidence when compared with studies in the United States may reflect a society with low numbers of automobiles and infrequent nonfatal acts of interpersonal violence.

In New South Wales, Australia, the incidence of TBI was 100 of 100,000 in 1988 (12). This study screened hospital admissions with ICD-9 codes with potential TBI or direct medical record review for identification of subjects in a defined geographic locale (North Coast Health Region). Admissions were included as TBI cases only if medical record review revealed documentation of loss of consciousness (LOC), posttraumatic amnesia (PTA), confusion, or amnesia for the event. Catchment area residents treated outside of the region, TBIs without medical care, and prehospital or ED deaths were excluded, as were nonresidents. Medical record review for documentation of TBI resulted in the exclusion of two thirds of the potential TBI cases identified in the screening process.

AGE-SPECIFIC INCIDENCE

In population-based studies that include all ages, a trimodal age-specific TBI incidence has generally been reported. Incidence peaks in early childhood, late adolescence/early adulthood, and in the elderly. Comparison of age-specific incidence between studies is often difficult because of nonuniformity of age categorization, different case-ascertainment methods, and confounders such as gender, socioeconomic status, and race; however, interstudy similarities do exist, particularly in incidence trends. Figure 1 demonstrates the age-specific TBI incidence for each study for which data are provided. Some studies also have been done in selected age groups, for example, in only

TABLE 2. *Summary of traumatic brain injury incidence studies*

Author/ locale/ dates	Study design inclusion criteria	Exclusion criteria	Incidence/ 100,000	Mechanism (% of TBI)	Age in years, incidence/ 100,000 (% TBI)	Severity incidence (% of TBI)	Fatal TBI, incidence/ 100,000 (CFP)
Fife/ U.S. National/ 1977–81	Phone survey, household telephone, HI with evidence of TBI	Death, institutionalized HI without TBI	1.87 Million TBIs per year	Occupational 50 MVC 25 Home 11 School/ recreation 7		16.4% Hospitalized	
Annegers/ Olmsted County, Minnesota, U.S./ 1965–74	HI with evidence of TBI, medical attention in home, ED, hospital, death	No medical attention, recurrent TBI visit	270 Males 116 Females Lifetime cumulative risk M 20% F 8%	MVC 36.8 MCC 3.6 Occupational 4.4 Bicycle 6.4 Falls 28.8 Recreation 9.4 Assault 3.8 GSW 2.6	Male Female 0–1 200 180 2–10 260 170 11–20 475 170 21–30 430 100 31–70 175 75 >70 100 175	Male Female Mild 149 71 Moderate 69 29 Severe 17 6 Fatal 35 10	MVC 50% MCC 1.7% Occupational 2.4% Bicycle 1.7% Falls 14.2% Recreation 0.2% Assault 1.1% GSW 20.1%
Cooper/ Bronx, New York/ 1980–81	Hospital admission, evidence of TBI (ICD-9), medical examiner case	TBI without medical care	Overall 249 Male 391 Female 142 White 209 Hispanic 262 Black 278	Traffic 27 Falls 32 Violence 34			Overall 27.9 Male 50.2 Female 10.2 Traffic 69.5 (5.4) Falls 81.2 (5.2) Violence 86.5 (15.6) Other 18.4 (1.8)
Guerrero/ U.S. National Sample/ 1995—96	ED presentation and discharge, evidence of TBI by ICD-9	Death, hospital admission	1.027 Million ED visits/year	Motor vehicle 22 Falls 31 Struck 20 Assault 15 Other 11	0–14 692 (40) 15–24 567 (20) 25–44 313 (25) >44 180 (15)		
Jager/ U.S. National Sample/ 1992–94	ED presentation, evidence of TBI by ICD-9	Out of hospital, death, non-ED outpatients	1.145 Million ED visits/year Total 444 White 429 Black 582 Other 333	Motor vehicle 95 (23) Bicycle/ pedestrian 25 (6) Falls 160 (39) Struck/assault 94 (23) Other 36 (9)	0–4 1091 5–14 571 15–24 639 25–34 361 35–44 335 45–54 181 55–64 165 65–74 233 75–84 331 >84 1026	Skull Fx 16 (3.5) Concussion 60 (14) Intracranial injury (nonconcussion) 11 (2.5) Intracranial injury unspecified 241 (54)	Overall 30 (17%)

Continued

TABLE 2. *Continued*

Author/ locale/ dates	Study design inclusion criteria	Exclusion criteria	Incidence/ 100,000	Mechanism (% of TBI)	Age in years, incidence/ 100,000 (% TBI)	Severity incidence (% of TBI)	Fatal TBI, incidence/ 100,000 (CFP)
Kraus/ San Diego, California/ 1980	HI with concussion, contusion, hemorrhage, or laceration to the brain or brainstem by physician or ME Dx	Skull Fx alone, recurrent TBI, Dx R/O TBI admit	Total 180 Male 247 Female 111	Transport 48 Fall 21 Assault 12 Sport/ recreation 10 Firearms 6	0–4 190 5–15 185 16–25 270 26–40 140 41–70 90 >70 180	%TBI Mild 72.5 Moderate 8 Severe 7.9 DOA 11.5	Severity CFP Mild 0.1 Moderate 7 Severe 58
Durkin/ Northern Manhattan, New York City/ 1983–89	Age <17 years, neurological trauma with death or hospital admission, residence in a defined area of Northern Manhattan	Nonresident of area	Total 155	Motor vehicle 8.7 Pedestrian 41.2 Assault 13.8	Male Female < 1 338 279 1–4 134 78 5–12 225 66 13–16 333 98	% Neurotrauma Inc Minor 76 118 Major 18 21 Fatal 4.1 6.29	Inc CFP < 1 16.7 5.4 1–4 7.4 7.0 5–12 2.8 1.9 13–16 8.9 5.2 Overall 6.3 4.1
Wang/ China/ 1983	Random door to door survey for HI, medical record review for TBI	Non TBI HI	Overall 56 Male 62 Female 49 Lifetime prev 709 Male 883 Female 536	MVCs 31.7 Occupational 23.8 Recreational 15.4 GSW 1.4	Government employees 46.3% Students 13.5% Preschool children 11.2%	Concussion 78 Contusion 20 Intracranial Hematoma 2	
Brown, Nell/ Johannesburg, South Africa	Prospective sampling, all Johannesburg trauma hospitals, ICD-9 c/w TBI, ME autopsy c/w TBI, Johannesburg residence	Non TBI HI, no hospital admission	Overall 316		15–24 359 25–44 409 45–64 227 >64 63	Very mild 77.9% Mild 9.6% Moderate 7.9% Severe 4.6% Concussion 89.2% Cerebral contusion 1.9% Intracranial hemorrhage 6.7%	Overall 20% of TBI <u>Incidence</u> Male 138 Female 24
Aquitaine, France/ 1986	Prospective sampling death prior to hospitalization requiring hospitalization	No hospital admission	<u>Incidence</u> Overall 281 Male 384 Female 185	MVC 60% Falls 33 Struck object 6 GSW 1 Other 1	<u>Age</u> <u>Male</u> <u>Female</u> 1 370 310 2–6 360 255 7–12 325 220 13–20 540 275 21–30 590 225 31–40 350 140 41–50 300 130 51–60 250 105 61–70 240 120 71–80 290 215	Mild 80% Moderate 11% Severe 9%	<u>Incidence</u> Overall 22 Male 33 Female 12 Prehospital deaths 54.8%

HI, head injury; TBI, traumatic brain injury; MVC, motor vehicle accidents; CFP, case fatality proportions; ED, emergency department; MCC, motorcycle collisions; GSW, gun shot wound; Fx, fracture; ME, medical examiner; Dx., diagnosis; R/O, rule out; DOA, dead on arrival; Inc, incidence.

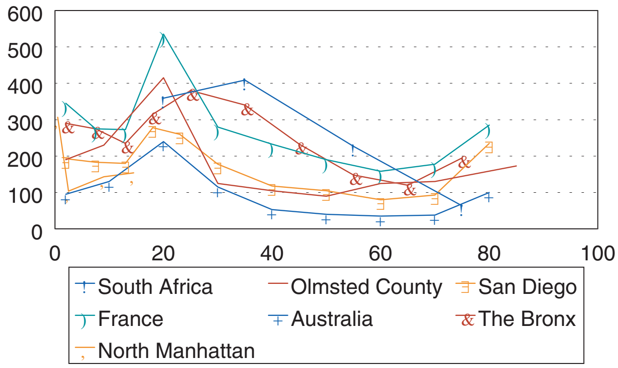

FIG. 1. Age-specific incidence of traumatic brain injury.

children or only adults. These studies are not included in Fig. 1 but are summarized.

Infants (younger than 1 year)

A study in Northern Manhattan (13) reported the incidence of pediatric (younger than 16 years) neurologic injury resulting in death or hospitalization to be 155 of 100,000. In this study, TBI incidence in infants was 307 of 100,000. The French study of HI reported an incidence of 350 of 100,000 in those younger than 1 year, and the incidence was 190 of 100,000 in Olmsted County for the same age group (4).

Toddlers

In Northern Manhattan, children aged 1–4 years had a TBI incidence of 104 per 100,000 (13). Overall, toddlers have a lower TBI incidence than do infants. The incidence was reported for all children younger than 5 years in the Bronx, San Diego, and Australia; the incidence was 296 for this age group in the Bronx (5), 190 in San Diego (9), and 100 of 100,000 for children younger than 5 years in Australia (5,12). The more inclusive French study reported the highest toddler incidence rate at 345 of 100,000.

Children

School-aged children and preadolescents represent the first nadir in the trimodal age-specific incidence of TBI. An inverse relation of TBI incidence with child's age was observed in Olmsted County (4), San Diego (9), the Bronx, and France (10). This TBI incidence nadir may be due to a reduction in fall-related injuries from improved motor control and balance and an absence of the high-risk behaviors of adolescence. The exceptions to this trend are the 5- to 12-year age group in Northern Manhattan and 5- to 14-year ages in the Australian investigation, which had a slightly higher TBI rate than the preceding age group (10,13).

Adolescents and young adults

For most TBI studies, a trimodal distribution exists, with the highest age-specific incidence in the adolescent/young adult age group. The peak incidence was seen in this age group in San Diego (age 16–25 years; 280 of 100,000) (9), Olmsted County (age 15–24 years; 415 of 100,000) (4), and the Bronx (16–30 years; 350) (5). In the Northern Manhattan investigation, rates in young adolescents (age 13–17 years) also increased to 154 of 100,000 (13).

A prospective sampling survey of adult TBI in Johannesburg, South Africa, including out-of-hospital mortality and cases from all traumas to receiving hospitals, reported an incidence of 360 of 100,000 in 15- to 24-year-olds (14). In France, the age-specific TBI incidence peaked in those aged 16–25 years at ∼535 of 100,000 (10). In Australia, the incidence escalated to a maximum at ages 15–24 years (240 of 100,000) (12). For each of these studies, incidence decreased in subsequent age groups from the peak in the teenage/young adult years, only to increase again in the oldest age groups. The exceptions were the studies in adults in South Africa and the total population study in China. The TBI incidence peaked in South Africa at 409 of 100,000 in the 25- to 44-year age group, which is higher than comparable aged strata in other studies (14).

Adults

After the high-risk adolescent and young adult years, incidence rates for TBI decline throughout adulthood to a nadir in middle-aged individuals. In Olmsted County, the incidence of TBI for those aged 35–64 years was 107 of 100,000 (4), whereas in San Diego, the incidence was 148 of 100,000 (aged 26–45 years) and 93 of 100,000 (aged 46–74 years) (9). In France, the annual average incidence for ages 36–75 years was 190, with a J-shaped incidence curve for each sequential decade. In Australia, the TBI incidence progressively decreased across age strata after adolescents/young adults to a nadir of 35 of 100,000 in ages 55–64 years. A similar trend was seen in the Bronx, where the incidence decreased from 340 of 100,000 in the 31- to 40-year-old age group to a minimum in those aged 61–70 years.

Although TBI incidence varies with population and locale, the trends of lower rates in adult and middle to aged cohorts is almost universal. It results from a decline in the impulsivity of the younger years and precedes the increase in TBI seen in the geriatric population, which results predominantly from falls.

Geriatric population

The geriatric population experiences an increased incidence of TBI relative to many younger age groups, representing the final peak in the trimodal TBI incidence distribution. This high incidence is attributed to motor vehicle accidents and falls and may be due to a combination of sensory and motor decline, deconditioning, and cognitive or conscious impairments. When more refined age strata are used, incidence increases with advancing age, and individuals older than 85 years are at greatest risk for TBI.

The TBI incidence in those aged 80 years or older was 173 of 100,000 in Olmsted County (4). In those older than 74 years, the TBI incidence was 275 in France (10), 235 in San Diego (9), and 100 of 100,000 in Australia (12). In each of these studies, these incidences were higher than those in adults. In the Bronx, the incidence of TBI in those older than 70 years was 195 of 100,000 (5). In South Africa, the TBI incidence in those older than 64 years was 63 of 100,000 population, a decline from younger cohorts (14).

In China, the age-specific strata have few cases, resulting in wide confidence intervals. This prohibits ascertainable differences between different age groups. The trimodal age distribution is seen with highest incidences in the youngest and oldest age groups and with peak incidence in those from 40 to 49 years (97 of 100,000) (11).

AGE SPECIFICITY IN EMERGENCY DEPARTMENT STUDIES

Unlike the population-based studies, the two U.S. National multistage probability sampling ED studies report age-specific TBI incidence to be bimodal with peaks at the extremes of age. The national sampling ED studies lack the adolescent/young adult incidence peak. Guerrero (7) and Jager (6) both reported higher TBI incidence for young children than did all other investigations. In adolescents and young adults, the TBI rates decreased and then reached nadir in those older than 44 years (7) and in the 55- to 64-year group (6).

GENDER DIFFERENCES

Males are uniformly at higher risk of TBI than are females, with the highest male-to-female (M/F) ratios typically occurring in adolescence and young adulthood. In the national sample U.S. ED studies, the M/F ratio was 1.5:1 (7) and 1.7:1 (6). In Olmsted County, the highest incidence of TBI was present in the adolescent and young adult ages, where the M/F ratio is >2:1. TBI incidence in females exceeded TBI incidence in males in the geriatric population (4). Similar M/F ratios of 2:1 are reported in San Diego, however (9); the male and female TBI rates were essentially equal at the extremes of age. In the Bronx, the overall M/F ratio was 2.8:1, with the male TBI incidence exceeding that in females for all age groups and all injury mechanisms.

Among South African adults, a very high overall M/F ratio (>4:1) was reported, with a peak gender difference in young adults. This extraordinarily high ratio was attributable largely to interpersonal violence. In Australia, the overall M/F ratio was 2.7:1 (12). In France, the overall M/F ratio was 2:1 (10). In China, the M/F ratio was 1.3:1 (11). The latter two studies had a paucity of violence-related TBI.

The high M/F ratio is mainly the result of interpersonal violence and motor vehicle collisions during adolescence and young adulthood. During these "testosterone years," the M/F ratio can approach or exceed 3 to 4:1 (4,5,13,14). By contrast, there is approximate unity or inversion of the gender ratios at the extremes of age, particularly in the elderly. In general, TBI from assaults and motor vehicle accidents (MVCs) have greater severities than do all other etiologies combined. As a result, the M/F ratio may be partially dependent on the case-ascertainment method used, with ED studies having a lower M/F ratio than do hospital-admission studies. No studies report overall higher incidence rates in females than in males.

RACE AND ETHNICITY

Whereas epidemiologic studies are often stratified by race/ethnicity, these categorizations are confounded by socioeconomic status. TBI studies report higher incidences for blacks compared with nonblacks, particularly in young males. Among TBIs evaluated in U.S. EDs between 1992 and 1994, race-specific annual incidence per 100,000 was 582 for blacks, 429 for whites, and 333 for "other" racial groups (6). In the Bronx, the incidence was highest for blacks at 278 of 100,000 (males, 457; females, 145), slightly lower for Hispanics, 262 of 100,000 (males, 401; females, 148), and lowest for whites at 209 of 100,000 (males, 301; females, 119) (5).

In adults in Johannesburg, South Africa, the greatest discrepancy in race-specific TBI ratios is reported. Compared with whites, the rate ratio for sustaining TBI is 3.3 in Africans, 2.7 in Coloreds, and 1.9 in Asians (14).

MECHANISM OF INJURY

TBI mechanism of injury is strongly associated with the individual's demographics in developed countries. In Olmsted County between 1935 and 1974, automobile, motorcycle, and bicycle collisions were responsible for half of all TBIs. One third of TBIs resulted from falls, and 10%, from recreational injuries. The principal recreational activity was horseback riding (4). Almost identical causal proportions of TBI were reported in San Diego County: 50% transport related, 20% falls, 10% sports and recreation, and 6% firearms (9). In Australia, road traffic accidents (40%), sports or recreation (25%), and falls (21%) accounted for the majority of TBIs. The high incidence of recreation-related TBI is attributed to the region's climate, coastline, and rural setting.

The greatest proportion of violence-related TBI is in the Bronx, which is characterized by dense population, poverty, and high rates of unemployment, crime, and substance abuse. In the Bronx, violence was responsible for the largest proportion (34%) of TBI, followed by falls (32%) and traffic accidents (27%). Falls were the main cause of TBI in those younger than 10 years and older than 70 years (5).

In China, attribution for TBI was 32% to motor vehicle accidents, 24% to occupational accidents, 22% for falls from height, 16% to recreational activities, 1.4% to gunshot wounds (GSWs), and 6% were of unknown etiology (11). In France, the main causes of head trauma were traffic accidents (60%) and falls (33%) (10).

Overall, falls predominate as a cause of injury in the children and elderly, regardless of race and gender. In the adolescent and young adults, males and ethnic minorities are at increased risk of TBI due to violence and MVCs. Just as frequent difficulties occur in interstudy comparisons regarding age, race, and ethnicity, challenges frequently exist in equating and stratifying the mechanisms causing TBI.

In Guerrero's national ED study (7), the primary cause of TBI in children was falls, and the secondary cause was "struck by object." In adolescents and young adults, it was MVCs and nonassault "struck." The incidence of TBI then declined in adults; MVCs and assaults were the primary injury etiology, replaced by falls in those older than 44 years (7). The ED TBI study of Jager (6) reported similar TBI mechanism distributions to those of Guerrero: falls (39%), MVCs (23%), struck/assault (23%), and bicycle/pedestrian MVCs (6%).

In the Northern Manhattan pediatric study, MVCs and falls were each responsible for one third of neurologic injuries. Seventy percent of MVCs were pedestrian related. A very high incidence of infant TBI was undetermined in cause, which is largely thought to be secondary to child abuse (13).

SEVERITY

Multiple classification schemes for TBI severity appear in the literature. Historically, the Glasgow Coma Scale (GCS, Table 3) has been the most widely used clinical TBI severity classification. The GCS is based on the patient's responses of eye opening, verbal function, and motor function to various stimuli. Most often, a score of 13 to 15 is considered mild, 9 to 12 is considered moderate, and <9 is considered severe TBI. However, the elapsed time from injury, hemodynamic parameters, and intoxicating substances often confound GCS scoring.

The majority of TBI epidemiologic studies rely on preexisting data sets not originally intended for research endeavors. Frequently the diagnosing practitioner fails to specify the precise injury sustained (i.e., a diagnosis of head injury unspecified instead of postconcussive syndrome or acute subdural hematoma). Therefore, the ability to determine TBI severity is difficult when the specific type of TBI is used as a severity surrogate. The percentages of TBI severity are typically mild, 80%; moderate, 10%; and severe, 10%.

TABLE 3. *Glasgow Coma Scale scoring*

Glasgow Coma Scale (22)		
Eye opening	Verbal response	Motor response
Spontaneous 4	Oriented 5	Obeys 6
To speech 3	Confused 4	Localizes 5
To pain 2	Inappropriate 3	Withdraws 4
None 1	Incomprehensible 2	Flexion/decorticate 3
	None 1	Extension/decerebrate 2
		None 1

In Olmsted County, severity was defined by a combination of duration of LOC and identified intracranial pathology: mild, LOC or PTA <30-min duration; moderate, LOC/PTA, 30 min to 24 h; and severe, LOC/PTA >24 h, intracranial hematoma or contusion, and death. Under this schema, 11% of TBI was fatal, 6% severe, 25% moderate, and 58% mild (4). Severe TBI was clustered in the 15- to 24-year age group and was secondary to MVCs. Motorcycle collisions (MCCs) were responsible for a disproportionately large number of severe TBIs, and firearms, for fatal TBIs when compared with all other injury mechanisms.

In the San Diego study, GCS was used to classify severity: 73% of TBI was mild severity [GCS of 13 to 15, no brain surgery or head computed tomography (CT) abnormality and a brief hospital stay]. Eight percent had moderate TBI (GCS, 9 to 12, or a GCS >8 and >48-h hospital stay, brain surgery, or head CT abnormalities). Eight percent had severe TBI (GCS, <9), and 12% were dead on arrival (9).

In the French investigation, among nonfatal cases, 80% were mild (head contusions without LOC or with LOC of <15-min duration), 11% were moderate (skull fractures without diagnosed TBI or LOC of a duration between 16 min and 6 h), and 9% were severe (brain injuries or coma >6-h duration) (10). These proportions are comparable to those of other studies; however, the inclusion of non-TBI HI makes overestimation of the mild cases likely.

In Australia (12), the distribution of TBI severity is as follows: mild (PTA + LOC <1-h duration, 62%); moderate (PTA 1–24 h and/or GCS score 9–12 at 6 h after injury, 20%); and severe (PTA >24 h, neurosurgical procedure and/or GCS <9 at 6 h after injury, 14%). The decreased proportion of mild TBI compared with that in other studies most likely results from those classified as not brain injured on medical record review.

In the South African study of adults, 78% of cases were very mild TBI (GCS, 15); 10% mild (GCS, 14 or 13); 8% moderate (GCS, 7–12); and 5% severe (GCS, <6) (14). The lower rate of severe TBIs may result from the lower GCS score cutoff of 6 for severe compared with ≤8 in San Diego.

In the Northern Manhattan pediatric report (13), minor HI defined by minor concussion (LOC <1 h) or facial fracture represented 76% of HI. Major HI, defined by major concussion (LOC >1 h), cerebral contusion/laceration, or intracranial hemorrhage, represented 18%. This categorization schema cannot be directly compared with GCS scoring because it includes HI that may not be TBI as defined in other studies; however, the proportion of major TBI is probably higher than that in comparison pediatric populations. This may be attributable to the larger numbers of pedestrian MVCs, assaults, and suspected child abuse TBIs.

MORTALITY

TBI is estimated to be the primary cause of death in one third to one half of all traumatic deaths (15). Approximately half of all TBI deaths occur at the scene, during transport in the ambulance, or during the emergency medical phase of treatment, before hospital admission. In studies using hospital admission as inclusion criteria, severity, case fatality proportions (CFPs), and the overall incidence of TBI is frequently biased and underreported. In studies that do report prehospital death, results are based on case reviews from medical examiner (ME) referrals (Bronx). If the injury occurs outside the study's defined geographic locale, the result is underenumeration of fatal TBIs. Death certificates of all San Diego residents were reviewed for indications of HI or TBI prompting autopsy report review.

In Olmsted County between 1965 and 1974, the incidence of fatal TBI-related trauma was 35 of 100,000 for males and 10 of 100,000 for females (4). The highest CFP was seen in the geriatric population, resulting from falls and suicides (4). In the Bronx, the overall TBI mortality incidence was 28 per 100,000. Race-specific mortality rates were highest for blacks, intermediate for Hispanics, and lowest for whites. Violence was predominantly responsible (38%) for fatal TBI, followed by MVCs (10%) and falls (10%). The highest mortality rates occurred in the 20- to 49-year age group, and the highest CFP was in the elderly (5). In San Diego, the overall TBI mortality rate was 30 of 100,000, with two thirds dying before hospital admission (9). In Aquitaine, France, the annual death rate was 22 of 100,000 (33 of 100,000 male and 12 of 100,000 female). In Australia (12), the out-of-hospital fatalities were not enumerated; therefore, mortality rates cannot be calculated.

The overall incidence in studies limited to specific age groups can be misleading. In the Northern Manhattan pediatric neuroinjury study (13), the overall pediatric mortality rate was 6 of 100,000, with an associated CFP of 4%. The mortality rate in infants (17 of 100,000) was twice as high as that in any other age group. Toddlers had higher fatality (7.4 of 100,000) than did children and preadolescents (2 of 100,000). Mortality increased in adolescents (9 of 100,000).

In Johannesburg adults, 20% of all TBIs resulted in death, with an astonishing fatal TBI incidence of 138 for males and 24 of 100,000 for females. This corresponded to 43% of all nonnatural deaths in Johannesburg having an associated TBI.

TRENDS IN BRAIN INJURY AND TBI-RELATED HOSPITALIZATION

A combination of influences has resulted in an overall decrease in the proportion of TBI leading to hospital admission. Alterations in hospital admission policies, enhanced intracranial imaging with CT scanning, and improvements in prehospital and acute inhospital trauma care probably contribute to these trends. Comparing 1994 and 1995 with 1980 and 1981, hospitalized TBIs decreased 51%. The proportion of inhospital severe TBI (abbreviated injury score, 4 to 6) increased from 10 to 19%, and as a corollary, decreased in mild (61%) and moderate (19%) TBIs (16). This is probably reflected in the low proportion of cases of TBI admitted to hospital in the Dutch study in 1997 (8). A true decrease may occur in incidence of TBI based on data from several western states (17,18). Intervention strategies also may be effective in reducing the incidence of TBI (19).

TRENDS IN TBI-RELATED MORTALITY

The U.S. TBI death rate decreased from 25 per 100,000 population in 1979 to 19 per 100,000 in 1992 (1). The TBI death rate decreased across most etiologies, but the mortality rate for firearm-related TBI increased 13% from 1984 to 1992. In 1990, firearms surpassed MVCs as the leading mechanism of TBI fatality. This increase is seen predominantly in males and is distressingly high in black males. The TBI death rate for black males in the United States increased from 36 in 1984 to 42 of 100,000 in 1992. However, the TBI death rate for white males decreased from 33 to 29 per 100,000 during the same period (15).

TBI death rate in the 15- to 24-year age group was highest (33 of 100,000) with etiologies of firearms, 49%; MVC, 44%; and falls, 1%. The second highest death rate (32 of 100,000) exists in the elderly, with etiologic distributions of 35% MVC, 29% falls, and 20% firearms (15). The U.S. mortality rate for TBI in 1994 was 20 per 100,000; however, it was much higher in the elderly (46 per 100,000) (20). In general, CFP is higher in the elderly as a result of limited physiologic reserve, and mortality rates are higher in males as a result of GSWs.

SUMMARY

Differences in TBI study methods may result in divergent estimates of numbers and make interstudy comparison difficult. However, when inclusion and exclusion criteria are considered, the relative incidences and trends are congruent. General formulas have been imposed to depict the ratio of fatal, hospitalized, and ED-attended TBIs (21). The United States annual HI (not necessarily TBI) incidence ranges from 600 to 900 per 100,000 U.S. population. Of these, ∼200 to 500 per 100,000 are treated in EDs or other outpatient settings, 150 to 250 per 100,000 are admitted to a hospital with TBI, and 20 to 30 per 100,000 die (50% in hospital, and 50% out of hospital) per year. Other industrialized nations have similar fatal TBI incidence rate estimates. As societies and ethos vary, so does the risk of injury to the brain. This may explain the incidence differences from Johannesburg and China.

Whereas there is variation in the stratified incidence rates of TBI, some general trends are universal. TBI occurs in higher frequencies in the very young, adolescent and young adult, and elderly. Males are at higher risk of TBI, particularly during adolescence and young adulthood. Minorities have a higher incidence of TBI, although this is confounded by socioeconomic factors. By focusing preventive and educational efforts on these high-risk groups, it may be possible to maximize the positive impact on this significant public health problem.

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