J Rehabil Med 2004; Suppl. 43: 28–60

Taylor & Francis healthsciences

INCIDENCE, RISK FACTORS AND PREVENTION OF MILD TRAUMATIC BRAIN INJURY: RESULTS OF THE WHO COLLABORATING CENTRE TASK FORCE ON MILD TRAUMATIC BRAIN INJURY

J. David Cassidy,[1,2,3] Linda J. Carroll,[1] Paul M. Peloso,[4] Jörgen Borg,[5] Hans von Holst,[6] Lena Holm,[3] Jess Kraus[7] and Victor G. Coronado[8]

From the [1]Alberta Centre for Injury Control and Research, Department of Public Health Sciences, University of Alberta, Edmonton, Alberta, Canada, [2]Department of Medicine, University of Alberta, Edmonton, Alberta, Canada, [3]Section for Personal Injury Prevention, Department of Clinical Neurosciences, Karolinska Institutet, Stockholm, Sweden, [4]Department of Internal Medicine, University of Iowa Health Center, Iowa City, Iowa, USA, [5]Department of Neuroscience, Rehabilitation Medicine, Uppsala University, Uppsala, Sweden, [6]Department of Neurosurgery, Karolinska Institutet, Stockholm, Sweden, [7]Division of Epidemiology, School of Public Health, University of California, Los Angeles, California, USA, [8]National Center for Injury Prevention and Control, Centers for Disease Control and Prevention, Atlanta, Georgia, USA

Objective: **We undertook a best-evidence synthesis on the incidence, risk factors and prevention of mild traumatic brain injury.**

Methods: **Medline, Cinahl, PsycINFO and Embase were searched for relevant articles. After screening 38,806 abstracts, we critically reviewed 169 studies on incidence, risk and prevention, and accepted 121 (72%).**

Results: **The accepted articles show that 70–90% of all treated brain injuries are mild, and the incidence of hospital-treated patients with mild traumatic brain injury is about 100–300/100,000 population. However, much mild traumatic brain injury is not treated at hospitals, and the true population-based rate is probably above 600/100,000. Mild traumatic brain injury is more common in males and in teenagers and young adults. Falls and motor-vehicle collisions are common causes.**

Conclusion: **Strong evidence supports helmet use to prevent mild traumatic brain injury in motorcyclists and bicyclists. The mild traumatic brain injury literature is of varying quality, and the studies are very heterogeneous. Nevertheless, there is evidence that mild traumatic brain injury is an important public health problem, but we need more high-quality research into this area.**

Key words: mild traumatic brain injury, epidemiology, incidence, risk factors, prevention.

J Rehabil Med 2004; suppl. 43: 28–60

Correspondence address: J. David Cassidy, Division of Outcomes and Population Health, Toronto Western Hospital Research Institute, 399 Bathurst Street, MP 10-328A, Toronto, Ontario, Canada, M5T 2S8.
E-mail: dcassidy@uhnres.utoronto.ca

INTRODUCTION

Traumatic brain injury (TBI) is an important global public health problem as a major cause of traumatic death and disability (1, 2). The spectrum of severity of TBI varies, but most TBI is classified as mild traumatic brain injury (MTBI), based on clinical and surveillance definitions (2). Over the years, a plethora of reports have appeared in the scientific literature estimating the incidence of MTBI, investigating risk factors for the condition and recommending preventive strategies to lessen the burden of MTBI. From a public health perspective, it is important to know the incidence of a condition in order appropriately to plan healthcare policy and provision. Furthermore, determining what factors increase the risk of MTBI is necessary to develop public health programs to prevent the problem and lessen the likelihood of disability.

The main objective of our task force report is systematically to search the world literature on MTBI and produce a best-evidence synthesis on the epidemiology (incidence, risk and prevention), diagnosis, treatment and prognosis regarding MTBI (3, 4). This paper presents the best evidence on the incidence, risk factors and prevention of MTBI, and the other topics are dealt with elsewhere in this supplement. Our purpose is to create a baseline of the best scientific evidence that can inform clinicians, researchers and policymakers about MTBI.

METHODS

Our task force performed a comprehensive systematic search of the world literature on MTBI, the details of which are documented elsewhere (5). Briefly, Medline and PsycInfo were searched from 1980 to 2000, Cinahal from 1982 to 2000 and Embase from 1988 to 2000. All languages were included. Indexed thesaurus terms (e.g. Medical Subject Headings for Medline) and text words, such as concussion, mild brain/head injury and others were used to search these databases to ensure that all relevant articles were captured. We then screened the retrieved abstracts for relevancy to the mandate of the task force (6), by applying our inclusion/exclusion criteria (5). Briefly, these criteria included studies that refer to concussion, MTBI, or criteria that would indicate concussion or MTBI; studies that include data on more than 10 subjects with concussion or MTBI (with the exception of rare complications such as second impact syndrome); and studies that do not deal with penetrating brain injuries or brain damage due to birth trauma, shaken-baby syndrome, or other cerebrovascular events. We also excluded narrative reviews, editorials and letters without data, animal studies, cadaver studies and biomechanical simulation studies.

We then screened the published papers of relevant abstracts to ensure the study met our inclusion/exclusion criteria. Relevant papers were reviewed in detail for methodological quality using *a priori* criteria for scientific acceptance. These criteria have been applied in similar work

DOI 10.1080/16501960410023732

undertaken in the past (7, 8). We carefully considered the merits and biases of each paper separately, and our final decision on the scientific admissibility was made by group consensus (5). Data from accepted papers were extracted into evidence tables that summarize their findings and form the basis of our conclusions and recommendations.

We also screened the reference lists of all reviewed papers to identify additional studies that might be relevant. These would include studies published prior to 1980 and literature not indexed in the electronic databases that we searched. We also solicited studies from experts in the field, brain injury associations, and other sources such as Internet sites and professional associations. In the spring of 2002, we screened Medline one last time, but reviewed only studies that were relevant and of high impact (5). These included randomized clinical trials of interventions, large well-designed cohort and case-control studies, and other studies that addressed gaps in the knowledge on MTBI.

In this present report, we focus on the papers that address incidence, risk factors and prevention of MTBI. Since our mandate was limited to closed MTBI, we did not capture all studies that address prevention of traumatic brain injury in general. This is a limitation, since strategies that prevent moderate, severe and penetrating brain injury, might also prevent MTBI.

In order better to delineate the strength of the evidence on risk factors for MTBI, we have adapted a methodology that has been used to rank the hierarchy of evidence of prognostic factors in breast cancer, whiplash injury and MTBI (7, 9, 10). This methodology distinguishes 3 types of studies of the determinants (risk or prognostic factors) of disease or injury. Phase I studies are hypothesis generating, descriptive investigations that explore crude associations between potential determinants and the outcome of interest (i.e. the onset or recovery from disease or injury). For example, a study that shows that a particular ethnic group has a greater risk for MTBI than other groups would be considered a phase I study. Phase II studies have exploratory, stratified and/or multivariable analyses that focus on determining which factors have important independent associations with the outcome of interest. Using the example, a phase II study might show that the crude association between ethnicity and MTBI remains strong when the results are stratified by age, indicating that this relationship is not changed by this third variable. Finally, phase III studies use more extensive multivariable analyses to confirm the strength and independence of proposed relationships between determinants and the outcome of interest that have been hypothesized in phase I and II studies. In our example, a phase III study would examine the strength and independence of the relationship between MTBI and ethnicity in a multivariable model that controls for any potential confounders of this relationship. For example, the crude (phase I) and stratified (phase II) relationships between ethnicity and MTBI might be confounded by socioeconomic status (SES). A phase III study would examine this relationship in a multivariable statistical model that includes MTBI as the outcome, ethnicity as the exposure variable and then tests the effect of each potential confounder on this relationship. Such a model might find that SES, or other factors explain (confound) the crude relationship between MTBI and ethnicity. Kraus et al. (11) provide a good example of a phase III study that examines the strength and independence of SES as a risk factor for serious brain injury after adjusting for age and ethnicity.

Our evidence tables report annual incidence rates as reported in the results of the original study or rates that we calculated from the raw data presented in each paper. Relative risks and their 95% confidence intervals are reported either directly from the study results, or as we calculated from the crude results. Exact confidence intervals were calculated using the statistical software Stata/SE (12).

RESULTS

After applying our inclusion/exclusion criteria to 38,806 identified abstracts to assess their relevance to MTBI, 741 studies remained to be critically reviewed. Of these, 167 articles dealt with the incidence, risk factors and prevention of MTBI. Some members of our task force also completed 2 original research projects that addressed incidence, risk and prevention (13, 14). These 2 studies were reviewed independently by the other members of the task force, giving a total of 169 reviewed studies on incidence, risk and prevention. After critical scientific appraisal, we accepted 121 (72%) of the 169 reviewed studies. Of these 121 studies, 91 are cohort studies, 3 are case-control studies, 4 are cross-sectional studies, 3 are randomized controlled trials, 13 are case series, 4 are systematic reviews and 3 are ecologic studies.

We have summarized our results on incidence and risk factors by stratifying our tables by geographic locations of the studies (North America vs other countries) and by age (adults vs children). We have also created separate tables addressing risk of MTBI and the effects of education and/or mandatory helmet legislation on the risk of injury while driving motorcycles and riding bicycles. Studies of the incidence and risk factors for MTBI in sports are considered separately, and we stratified our results by the various sporting activities. With respect to prevention, the majority of the reviewed studies address the usefulness of helmets in preventing head injury for those riding bicycles and motorcycles. However, because our literature search was limited to MTBI, we have not reviewed all of the TBI prevention literature. Nevertheless, we did include some of these studies, even if they were not restricted to MTBI.

Incidence and risk factors in adults with MTBI from North American studies

Our task force accepted 14 studies of the incidence and risk factors for MTBI from North America, and these are presented in chronological order of the years of investigation from 1935 to 1995 (Table I). The source population for the studies varies from the entire US population (15–19) down to the state (20, 21), county (22–27) and city level (28). Three studies focus on military personal (29–31) and 1 of these includes their dependents (31). The inclusion/exclusion criteria vary considerably across the studies. Six focus on hospital admissions (17, 20, 21, 23–28, 31), 1 on emergency room (ER) and outpatient visits (16) and 1 on both ER visits and hospital admissions (19). One study includes those treated in hospitals, emergency rooms, as outpatients and during home visits (22). Two studies focus on those treated in military medical facilities, without further specification (29, 30). One Canadian study focuses on those injured in traffic mishaps (13), and 2 studies include anyone reporting MTBI during a household survey (15, 18).

Case definitions for the studies also varied considerably. For example, 5 studies used the International Classification for Disease (ICD) definitions of MTBI (16, 17, 29–31) and 2 used a computer conversion program (ICDMAP) to convert ICD-9 codes to an Abbreviated Injury Scale (AIS) definition of MTBI (AIS 1–2) (19, 20). One defined MTBI as non-hospitalized head injuries (15). Four studies employed clinical definitions of MTBI, including 2 that classified patients as having MTBI if their Glasgow Cancer Scale (GCS) score was 13–15 (21, 23–27) and 2 that defined MTBI as head injury with loss of consciousness (LOC) and post-traumatic amnesia (PTA) of 30 minutes or less (22, 28). One study used a self or proxy-reported

Table I. *Studies of incidence and risk factors in adults with mild traumatic brain injury (MTBI) in North America*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Annual incidence	Risk factors
Annegers et al., 1980 (22)	Residents of Olmstead County, Minnesota, between 1935–74	All hospital admissions, ER visits, outpatient examinations and home visits for head injury with LOC, PTA or neurological signs. Excludes concussion without LOC or PTA	Mild head injury defined as LOC or PTA of <30 minutes without skull fracture	For the decade 1965–74, the male and female rates for mild injury were 149 and 71/100,000. Over the years 1935–74, the rate of mild injuries increased while those for moderate, severe and fatal remained stable	Phase I: RR for males is 2.10 (95% CI 1.57–2.82)
Kalsbeek et al., 1980 (17)	1970–74 US population	National Head and Spinal Cord Injury Survey of persons in the contiguous US (excludes Alaska and Hawaii) who were admitted to hospital for inpatient care for incident traumatic brain or spinal cord injury. Multistage probability sample of cases used. Excludes those that died or had a birth injury	ICD-8 codes used to count and find cases. Medical records examined to confirm cases. Concussion defined as ICD-8 850	74.5% of all incident head injuries between 1970 and 1974 were identified as concussions	N/A
Fife, 1987 (15)	Non-institutionalized civilian US population in 1977–81	NHIS probability sample of 40,000 households. Pooling data from 1977–81 included approximately 200,000 households. Excludes members of the armed forces and persons in long-term care facilities	Only head injuries that resulted in skull fracture or damage to cranial contents and a physician visit and/or 1 day of disability in the 2 weeks prior to the survey were recorded. Mild head injury defined as non-hospitalized cases	Of the 1.87 million persons who received a head injury, 89% consulted a physician, but only 16% were hospitalized. Of the 14 million restricted activity days due to head injury, 52% were in those mild cases that were not hospitalized. Annual incidence of head injury, as calculated by Sosin et al. (18), was 862/100,000	N/A
Whitman et al., 1984 (28)	Chicago inner city community of 148,724 inhabitants (96% African-American) and the Chicago City suburb of Evanston with 73,706 inhabitants (75% white) in 1980	Those admitted to 32 hospitals in these communities (91% of all discharges) between Nov. 1979 and Oct. 1980 with ICD-9 CM codes 800–804, 830, 850–854, 873, 920 and 959.0. Clinical information was abstracted from all charts	Head injury defined as a blow to the head, a blow to the face with LOC and/or a laceration of the scalp or forehead. Mild head injury was defined as LOC or PTA for 30 minutes or less, and trivial head injury was defined as those without LOC or PTA	Incidence/100,000 for inner city African-Americans was 163 for mild and 165 for trivial; for Evanston African-Americans it was 227 for mild and 76 for trivial; for Evanston whites it was 74 for mild and 44 for trivial	Phase II: RR for mild and trivial head injury in inner city African-Americans vs suburban whites is 2.8 (95% CI 2.2–3.5). For all head injuries, males were 2.5 times more likely to be injured and interpersonal attacks were the main cause in the city and MVC in Evanston

Table I. *Continued.*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Annual incidence	Risk factors
Kraus et al., 1984 (23); Kraus & Fife, 1985 (24); Kraus et al., 1987 (25); Kraus & Nourjah, 1988 (26) and Kraus et al., 1989 (27)	Residents of San Diego County in 1981. 1980 US Census figures used as the denominator giving 1,861,846 persons at risk	Persons with incident traumatic brain injury admitted to hospital or died from the injury. Excludes head injuries seen in emergency and not admitted	MTBI defined as GCS 13–15 and not admitted to hospital for more than 48 hours	MTBI incidence of 131/100,000 with a case fatality rate of 0.1%. 72% of the 3358 cases were mild. 30% of mild injuries over the age 15 were tested for blood alcohol and 71% were positive. ICD 850 accounted for 80.2% of the mild cases	Phase I: RR for males is 2.1 (95% CI 1.6–2.7) compared with females. 42% of mild injuries involved a motor vehicle. Of 251 bicycle-related cases, 86% were mild. 85% of 107 hospital-admitted, work-related head injuries in males over age 15 years were mild
McCarroll & Zych, 1989 (29)	Active duty US Army personnel aged 18–24 and 25–34 years in 1983	Head injury discharges from army medical facilities in 1983. Excludes patients treated in more than 1 facility	Minor head injury defined as ICD-9 850 (concussion)	Rates/100,000 by age and gender are: for ages 18–24 years, 105 and 97 for males and females, respectively; for ages 25–34 years, 51 and 58 for males and females, respectively.	Phase II: RR for males vs females age 18–24 is 1.08 (95% CI 0.81–1.44) and for males vs females age 25–34 is 0.88 (95% CI 0.59–1.30)
McCarroll & Gunderson, 1990 (30)	Active duty US Army personnel aged 18–24 and 25–34 years from 1983 to 1987	Head injury discharges from army medical facilities for 1983–87	Minor head injury defined as ICD-9 850 (concussion)	Concussion accounted for 24% of cases. Rates/100,000 by gender and race for ages 18–24 years were 113 for males and 91 for females, 124 for white males and 92 for African-American males, 113 for white females and 63 for African-American females. Rates/100,000 by gender and race for ages 25–34 years were 51 for males and 48 for females, 52 for white males and 49 for African-American males, 64 for white females and 28 for African-American females	Phase II: RR for ages 18–24 years: males vs females is 1.24 (95% CI 0.93–1.65), white males vs African-American males is 1.35 (95% CI 1.02–1.78) and white females vs African-American females is 1.79 (95% CI 1.31–2.48). RR for ages 25–34 years: males vs females is 1.1 (95% CI 0.70–1.61), white males vs African-American males is 1.06 (95% CI 0.70–1.60) and white females vs African-American females is 2.29 (95% CI 1.44–3.70)
MacKenzie et al., 1989 (20)	Residents of the State of Maryland in 1986	Hospital admissions in Maryland with primary or secondary ICD-9 CM discharge diagnoses for head injury. Excludes injuries treated as outpatients in the ER	ICDMAP used to convert ICD-9 codes to AIS scores (use of administrative data only). Minor head injury defined as ICD/AIS 1–2	Of the 5,838 discharges, 70% were minor with an incidence of 92/100,000 and 33% were diagnosed as concussion (ICD 850) with an incidence of 44/100,000	Phase I: Young adults, aged 15–24 years had the highest risk for minor injury at 167/100,000. RR for males vs females for minor injury was 1.9. The most common causes for minor injury were MVCs (47%) and falls (24%)
Thurman et al., 1996 (21)	Residents of the State of Utah in 1990–92	All head injuries leading to acute care hospital admission or death. Excludes injuries seen in the ER and not admitted	From ICD-9 CM codes 800.0–801.9, 803.0–804.9 and 850.0–854.1, a 10% random sample of hospital records were examined. MTBI was defined as GCS 13–15	Of the random sample of 578, 189 (32.7%; 95% CI 29.5–36.1) were mild	N/A

Study	Source population	Inclusion/exclusion criteria	Case definitions	Annual incidence	Risk factors
Sosin et al., 1996 (18)	Non-institutionalized civilian US population in 1991	NHIS probability sample of 46,761 households, which includes 120,032 persons interviewed. Excludes members of the armed forces and persons in long-term care facilities	Self or proxy-reported brain injury in the past 12 months that resulted in LOC but was not severe enough to cause long-term institutionalization. MTBI not explicitly defined	618/100,000 brain injuries reported: 25% did not seek medical care, 14% seen in clinics and offices, 35% in the ER and 25% admitted to hospital	Phase II: For medically attended brain injury: age 15–24, OR = 2.3 vs other age groups; and for males OR = 1.7 vs females
Ommaya et al., 1996 (31)	Active duty and retiree US Army personnel and their dependents in 1992	Eligible beneficiaries enrolled in the Defense Enrolment Eligibility Reporting System of US Armed Forces that were admitted for head injury. Readmissions were excluded	ICD-9 codes 800.00–801.99, 803.00–804.99 and 850.0–854.19.	Of the 1,360 head-injured beneficiaries treated at private facilities, 16% were for concussion (ICD-9 850). Of the 4,160 beneficiaries treated in military hospitals, 21% were for concussion (ICD-9 850). Overall rate for ICD-9 850 is 16.4/100,000	N/A
Jager et al., 2000 (16)	US population 1990–92	NHAMCS is a national probability sample of ER and outpatient visits to short-stay hospitals that did not lead to hospitalization or death. Excludes federal, military and Veterans Affairs hospitals	Abstractors coded injuries from data collection forms into ICD-9 CM codes 800.0–801.9, 803.0–804.9 and 850.0–854.1. Concussion defined as ICD-9 850	There were an estimated 155,642 concussions with an estimated rate of 60/100,000 persons (95% CI 44–76). The total head injury rate was 444/100,000 (95% CI 390–498)	Phase I: For all injuries, rates were higher in males than females (1.6:1), higher in African-Americans than whites (1.35:1) and falls were the most common cause (39%)
Thurman & Guerrero, 1999 (19)	US population 1980–95 and from 1992–95	NHDS is a multistage probability sample of US hospital discharges (1980–95 data), and the NHAMCS is a multistage national probability sample of ER and outpatient visits to short-stay hospitals that did not lead to hospitalization or death (1992–95 data)	ICD-9 CM codes 800.0–801.9, 803.0–804.9 and 850.0–854.1. MTBI was classified as AIS 1–2 using ICDMAP-90	MTBI hospitalizations decreased from 130–51/100,000 from 1980–95, a 61% decrease	N/A
Cassidy et al., 2004 (13)	Canadian province of Saskatchewan 1994–95	Adults, 18 years and older, who were treated for, or made an insurance claim for a road-traffic injury between July 1994 and December 1995. Excludes those hospitalized for more than 2 days	MTBI defined as blunt head injury with uncertain or definite LOC, but not hospitalized for more than 2 days	In 1994, under tort insurance, the MTBI rate was 72/100,000. In 1995, under no-fault insurance, the MTBI rate was 54/100,000	Phase I: RR for males is 1.41 (95% CI 1.04–1.93). RR for ages 18–23 years vs those over 50 years is 3.78 (95% CI 2.78–5.19)

ER = emergency room; LOC = loss of consciousness; PTA = post-traumatic amnesia; RR = relative risk; CI = confidence interval; ICD = International Classification of Diseases; NHIS = National Health Information Survey; CM = Clinical Modification; MVC = motor vehicle collision; MAP = a computer conversion program; GCS = Glasgow Coma Scale; AIS = Abbreviated Injury Scale; OR = the odds ratio; NHAMCS = National Hospital Ambulatory Medical Care Survey; NHDS = National Hospital Discharge Survey. N/A means the study did not address risk factors or did not provide explicit results for MTBI.

definition of MTBI (18), and another defined MTBI as blunt trauma to the head from a traffic mishap with uncertain or certain LOC (13).

Given the different inception periods, diverse source populations, differing inclusion/exclusion criteria and various case definitions of the accepted studies of MTBI in North American adults, it is not surprising that the reported incidence rates vary from a low of 51 to a high of 618 per 100,000 inhabitants (Table I). Given this heterogeneity, it is not possible to report a summary rate.

Nine of the 14 incidence studies considered risk factors for MTBI, 5 of these were phase I studies and the other 4 phase II studies (Table I). The phase I studies suggest that men have 1.4–2.1 times the risk of women for MTBI. The phase II studies yield similar results, although the risk estimates are more variable (RR = 0.88–2.5). One phase I and 1 phase II study suggest that general population African-Americans are at greater risk than Caucasians for MTBI (RR = 1.35–2.8) (16, 28). However, 1 study of military personal shows that white females are at greater risk for MTBI than African-American females (30). Another study suggests that younger individuals, aged 18–23 years, are at 3.8 times greater risk for traffic-related MTBI than those aged 50 years or older (13). Overall, these reported risks are modest and there are no confirmatory analyses or phase III studies of risk factors for MTBI in North American adults.

Incidence and risk factors in adults with MTBI from non-North American studies

Our task force accepted 14 studies on MTBI incidence and risk factors that presented data from countries outside North America, including 7 from Scandinavia, 3 from other European countries, 1 from South Africa and 3 from Australasia (Tables II–IV). These studies cover inception periods from 1974 to 2000.

Of the 7 Scandinavian studies, 5 are from Sweden and 2 from Norway (Table II). One Swedish study dealt only with concussions due to assaults in Stockholm (32). Two studies took place in northern Sweden (33, 34) and the other 2 included the entire Swedish population (14, 35). One Norwegian study took place in the Oslo area (36) and the other in northern Norway (37). Four of the Scandinavian studies included hospital admissions only (14, 34–36), 1 included those examined in the ER (32), another included ER patients and outpatients (33), and the last included both those seen in the ER and those admitted to hospital (37). In the study of assaults, there was no explicit definition of concussion (32). Three studies used ICD 850 to define concussion (14, 34, 35), and 1 used AIS 1–2 to define MTBI (33). The remaining 2 studies used clinical definitions, including PTA of 24 hours or less (36) and GCS 14–15 (37). Incidence rates varied across these studies from a low of 83/100,000 for concussions due to assaults to a high of 718/100,000 for AIS 1–2 head injuries. Only 2 studies considered risk factors, and they showed that falls were the main cause of MTBI in the Tromsø region of northern Norway (37), and that falls accounted for 50–60% of MTBI admitted to Swedish hospitals from 1987 to 2000, followed by traffic injuries at about 25% (14).

The 3 other European studies and the South African study included inception periods from 1984 to 1988 and only included patients admitted to hospital (Table III). MTBI was defined in 3 studies by GCS 13–15 (38–40) and by contusion to the head without LOC, or with LOC of 15 minutes or less in the other study (41). The incidence rate was lowest in Spain at 80/100,000, but this might be attributed to the case definition, which required the presence of LOC, skull fracture or neurological findings (40). The rates in France (41) and Italy (39) were higher at 207 and 297/100,000, respectively. In the study from France, 59.7% of the cases were caused by traffic collisions and 32.5% by falls.

The Australasian studies covered inception periods from 1986 to 1994 (Table IV). The Auckland, New Zealand study included all patients seen at the emergency department and in the hospital (42), while the Australian (43) and Taiwanese (44) studies included only hospital admissions. All 3 studies used clinical definitions for MTBI that considered LOC and PTA. The incidence of MTBI ranged from 64/100,000 in New South Wales, Australia to 782/100,000 in Auckland. The higher rate in Auckland could be attributed to a very liberal definition of brain injury (Table IV). In Auckland, MTBI was more common in those 15 years of age and older. In the Australian study, traffic collisions were the most common cause of injury.

Incidence and risk factors in children with MTBI from North American studies

The task force accepted 5 North American studies on the incidence and risk factors in children with MTBI, all from the USA, covering time periods from 1978 to 1990 (Table V). Three of the studies looked at the entire US population (45–48) and the other 2 examined children with MTBI admitted to hospitals in San Diego County (49, 50) and Northern Manhattan (51). Two studies focused on consumer product related injuries (45, 47, 48), 2 on hospital admissions (49–51) and the other on injuries at day-care centres (46). Two of the studies did not explicitly define concussion (45, 46); 1 used ICD-9 codes to find cases, and then defined minor concussion as LOC less than 1 hour (51); another study defined MTBI as transient impairment of consciousness (47, 48) and the other used GCS 13–15 to define MTBI (49, 50). The highest rates of MTBI were reported for males and teenagers (Table V). Of the 688 children up to 15 years of age admitted to San Diego hospitals in 1981 with a brain injury, 606 (88%) had a MTBI, and these accounted for 90% of the hospital bed days (49, 50). Two of the studies looked at risk factors, identifying a 2-fold risk of concussion for males (47) and an increased risk in older children (51). Sports and recreational equipment were the main consumer product causes for concussions in older children (48). We also accepted a study of paediatric motor vehicle injuries that used the US National Pediatric Trauma Registry to look at the effectiveness of seat belts (not shown in Table V) (52). The results did not include an incidence rate for MTBI or specific risk factors. It did, however,

Table II. *Studies of incidence and risk factors in adults with mild traumatic brain injury (MTBI) from Scandinavia*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Nestvold et al., 1988 (36)	Akershus County (Oslo area) in Norway in 1974, which included 350,000 inhabitants	All patients admitted to Akershus county hospitals between March 1974 and Feb. 1975 with trauma to the head, face or neck, including those who died during transportation	Minor head injury was defined as PTA of 24 hours or less	Of the 433 head injured patients with PTA data, 394 (91%) were minor	N/A
Johansson et al., 1991 (34)	Umeå district of Northern Sweden with a population of 70,000 residents aged 16–60 years in 1984	All residents aged 16–60 years admitted to hospital in Umeå from April 15, 1984 to Oct. 14, 1985 with a diagnosis of traumatic brain injury coded ICD-9850.00–854.00	Concussion defined as ICD 850	Incidence of concussion was 220/100,000	N/A
Bring et al., 1996 (33)	Residents aged 15–65 years from Umeå ($n = 82,400$) and Skellefteå ($n = 51,400$), 2 cities in Northern Sweden during 1988–90	All emergency inpatients and outpatients between ages 15–65 years after head or neck injury of AIS 1–2 between July 1988 to June 1990	Injuries were defined as AIS 1–2 head injury, neck injury and combination head and neck injury	Of the 1,568 injury incidents, 53% were head injuries, 39% neck injury and 8% were both. A total of 961 AIS 1–2 head injuries yields a rate of 718/100,000 inhabitants (95% CI 667–772) 15–65 years of age	N/A
Ingebrigtsen et al., 1998 (37)	Northern Norwegian area of Tromsø with 108,017 inhabitants in 1993	All head-injured patients seen at the ER and discharged and those admitted to hospital. Excludes those with isolated injuries to the scalp, face or cervical spine and birth injuries	Head injury defined as physical damage to the brain or skull caused by external force. Head injury severity defined by the HISS (minimal injury is GCS 15 with no LOC or PTA; and mild injury is GCS 14–15 with PTA or <5 minutes of LOC)	The incidence for minimal head injury was 73/100,000 and 112/100,000 for the mild. Combined minimal and mild rate is 185/100,000. The overall head injury rate was 229/100,000 for all severities. 81% of all head injuries were minimal or mild	Phase I: Falls were the main cause for minimal and mild injuries (exact numbers not given)
Boström, 1997 (32)	All assaulted persons who attended the ER of Sabbatsberg Hospital in Central Stockholm, serving a population of 139,000 inhabitants in 1992	Between April 1, 1992 and March 31, 1993, 1,158 persons were examined by surgeons in the ER because of assaults	No explicit definition of concussion	116 patients had concussion due to assaults giving an incidence of 83/100,000 inhabitants. Of these 104 were males, 94 were drunk, and 71 were admitted for observation	N/A
Britton et al., 2000 (35)	Swedish population over the 11 years of 1987–97 (varied between 8.5–8.85 million inhabitants)	All Swedish hospital admissions for 1987–97 (does not include ER visits with no admission, but does include readmissions)	ICD-9 850 used to define concussion	The number of concussion discharges varied from 14,662 in 1991 to 17,443 in 1995. The incidence for 1996 was given as 191/100,000 inhabitants, based on 16,877 hospital discharges	N/A
Peloso et al., 2004 (14)	Swedish population over the 14 years from 1987–2000 (varied between 8.4–8.8 million inhabitants)	All Swedish hospital admissions for 1987–2000 (does not include ER visits with no admission or readmissions)	ICD–9 850 used to define concussion	Annual incidence of concussion per 100,000 males ranged from 196 in 1991 to 228 in 1995. Annual incidence of concussion per 100,000 females ranged from 132 in 1991 to 228 in 1994	Phase I: Falls accounted for the majority of cases (50–60%) followed by traffic injuries at about 25%

PTA = post-traumatic amnesia; N/A = the study did not address risk factors or did not provide explicit results for MTBI; ICD = International Classification of Diseases; AIS = Abbreviated Injury Scale; CI = confidence interval; ER = emergency room; HISS = Head Injury Severity Scale; GCS = Glasgow Coma Scale; LOC = loss of consciousness.

Table III. *Studies of incidence and risk factors in adults with mild traumatic brain injury (MTBI) from Italy, France, Spain and South Africa*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Servadei et al., 1988 (39)	Comune of Ravenna, Italy with a population of 172,000 residents in 1984–85	All residents and non-residents of Ravenna who sustained a head injury, during April 1984 to March 1985, and were admitted to hospital. Includes deaths due to head injury. Excluded were 66 cases injured in Ravenna, but admitted to hospitals outside of the Commune	MTBI defined as GCS 13–15	543 cases were admitted to hospital alive and 510 (88.4%) were MTBI. The incidence of admitted MTBI was 297/100,000	N/A
Tiret et al., 1990 (41)	Aquitaine region of France in 1986, with a population of 2.7 million residents representing 4.9% of the population of France	Representative sample of hospital admissions because of head injury, including deaths. Patients with facial injuries without LOC were excluded	Mild injury defined as contusions without LOC or with LOC of 15 minutes or less. Injuries also coded into AIS and ISS	The overall estimate of head injury was 281/100,000 residents and 80% of head injuries were mild giving an incidence of 207/100,000, excluding deaths	Phase I: 59.7% of mild head injuries were caused by traffic collisions and 32.5% were caused by falls
Nell & Brown, 1991 (38)	All residents of Johannesburg aged 15 years or more in 1986	All cases of traumatic head injury admitted to Johannesburg hospitals. Excludes non-residents and those head injuries not admitted to hospital	MTBI defined as GCS 13–15	Of the 772 incident cases of head injury, GCS was available for 697 (90.3%). 87.5% of these had a GCS between 13–15 (77.9% were GCS 15)	N/A
Vázquez-Barquero et al., 1992 (40)	Region of Cantabria, Spain, in 1988, with a population of 523,000 inhabitants	All cases of head injury admitted for 24 hours at the region's only hospital. Excluded were non-residents of the region, those that died from the injury and those seen more than 24 hours after their injury	An admitted head injury had to have 1 or more of: LOC, skull fracture, or objective neurological findings attributed to the head injury. Minor head injury was defined as GCS 13–15	The overall incidence of admitted head injury was 91/100,000 and 88% were classified as minor, giving an incidence of 80/100,000	N/A

GCS = Glasgow Coma Scale; N/A = the study did not address risk factors or did not provide explicit results for MTBI; LOC = loss of consciousness; AIS = Abbreviated Injury Scale; ISS = Injury Severity Scale.

Table IV. *Studies of incidence and risk factors in adults with mild traumatic brain injury (MTBI) from Australasia*

Study	Source population	Inclusion/Exclusion criteria	Case definitions	Incidence	Risk factors
Wrightson & Gronwall, 1998 (42)	850,000 residents of Auckland, New Zealand from March to May 1986	All patients with injuries above the clavicle seen in the ERs and wards of Auckland's 4 hospitals	MTBI defined as any alteration of consciousness, disturbed behaviour not due to alcohol or drugs, amnesia, or other neurological signs	Estimated annual incidence of MTBI was 782/100,000. The majority of MTBI (>80%) were not admitted to hospital	Phase I: RR for those 15 years and older was 1.83 (95% CI 1.58–2.13) compared with those under age 15
Tate et al., 1998 (43)	343,140 residents of the North Coast Health Region of NSW, Australia, in 1988	Admissions to hospital for head injury in 1988. Excluded were cases transferred between hospitals, deaths, non-residents of the region, and residents admitted to hospitals outside the region	Head injury defined as causing a period of alteration of consciousness, including LOC, PTA, or amnesia for the injury event. MTBI defined as PTA and/or LOC of <1 hour, or amnesia for the event	Annual incidence of mild injury was 64/100,000. 71.4% of MTBI was ICD coded as 854, 23.2% as 850, 3.6% as 800 and 1.8% as 801	Phase I: 58% of the mild injuries occurred in those 5–24 years of age, 33.9% were caused by traffic collisions, 27.2% by sports or recreation and 23.3% by falls
Chiu et al., 1997 (44)	Taiwan, July 1988 through June 1994	Patients hospitalized for head injury in 114 hospitals in Taiwan. Excludes patients that were dead on arrival at the hospital	Brain injury defined as patients with at least 1 of: LOC or PTA; neurological deficit; skull fracture; or intracranial haemorrhage. MTBI defined as GCS 13–15	58,563 cases of brain injury were hospitalized during the study. Of the 52,361 cases with GCS scores, 41,646 (79.5%) were diagnosed as MTBI (GCS 13–15)	N/A

ER = emergency room; RR = relative risk; CI = confidence interval; LOC = loss of consciousness; PTA = post-traumatic amnesia; ICD = International Classification of Diseases; GCS = Glasgow Coma Scale; N/A = the study did not address risk factors or did not provide explicit results for MTBI.

suggest that head injuries are more severe in children who are not belted at the time of the crash.

Incidence and risk factors in children with MTBI from non-North American studies

We accepted 6 non-North American studies on the incidence and risk factors for paediatric MTBI that spanned inception periods from 1972 to 1995 (Table VI). These studies were conducted in New Zealand (53), Denmark (54), Israel (55), Iceland (56), Hong Kong (57) and Nigeria (58). With the exception of the New Zealand and Nigerian studies, all included hospital admissions only. Two studies defined MTBI by ICD-9 850 (concussion) (54, 56), 3 used GCS 13–15 (55, 57, 58) and 1 used AIS 1–2 (53). In Denmark, the rate of all TBI hospital discharges ranged from 430/100,000 in 1979 to 240/100,000 in 1993, and about 90% were coded as concussions. In Haifa, Israel, during 1984 to 1988, 23.3/100,000 children aged 0–14 years required hospitalization in a neurosurgical ward for MTBI. During 1987 to 1991 in Reykjavik, Iceland, 359 brain-injured children 0–14 years of age were admitted for overnight observation, and 309 (86%) were coded as concussions. In Hong Kong during 1990 to 1993, there were 601 Vietnamese refugee children aged 0–12 years admitted to hospital for TBI, and 551 (92%) had a GCS score of 13–15. In Ile-Ife, Nigeria, MTBI made up the majority of traffic-related head injuries treated at 1 hospital (58). The New Zealand study followed a birth cohort to their ninth birthday and then assessed the number of concussions in the preceding 2 years. Only 1.8% of these children's parents reported a concussion in their child in the preceding 2 years. Only 1 study looked at risk factors, and it showed that males were at 50% greater risk for MTBI compared with females (56).

Incidence and risk factors for MTBI associated with motorcycle collisions

Our task force accepted 5 studies on the incidence and risk factors for MTBI associated with motorcycle collisions, covering inception periods from 1977 through to 1992 (Table VII). Two of the 3 US studies came from the State of Illinois (59, 60) and the other from the State of Connecticut (61). One study came from the county of Skaraborg, Sweden (62), and the final study came from Taipei, Taiwan (63). The Swedish study included moped collisions and the Taipei study included a majority of collisions involving step-through scooters. Two studies obtained cases from the ER (59, 63) and the others included hospital admissions only (60–62). Three of the studies did not explicitly define MTBI (59, 61, 62) and the other 2 used GCS 13–15 (63) and AIS 1–2 (60) to define MTBI. In Connecticut, 3.3% of all motorcycle-related injuries were coded as concussions; while in Skaraborg, Sweden, 39% of all moped-related injuries and 44% of all motorcycle-related injuries were defined as concussions. One study showed that the mean admission GCS score for head-injured motorcyclists that had not worn a helmet was lower (13.7) than in those that had worn a helmet (14.4) (59). Another study showed that TBI was more common in injured motorcyclists not wearing helmets (60). One

Table V. *Studies of incidence and risk factors in children with mild traumatic brain injury (MTBI) in North America*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Rivera et al., 1982 (47) and Rivera, 1984 (48)	US residents aged 0–18 years during 1978	ER-treated consumer product-related injuries in the USA recorded in the NEISS, based on a representative sample of 130 hospitals. Excludes non-ER-treated injuries and non-consumer-product-related injuries including motor-vehicle injuries	Concussion was defined as transient impairment of consciousness immediately after head trauma	Of 33,635 concussions in the study, the rates /100,000 by age group were 50 for under age 1 year, 110 for ages 1–2 years, 74 for ages 3–6 years, 83 for ages 7–12 years and 85 for ages 13–18 years. 33.8% of these cases were admitted (48). By gender, the rates were 110/100,000 concussions for males and 55/100,000 concussions for females. The gender rates varied by age group from 63 to 130/100,000 for males <1 year to those 13–18 years and from 28 to 95/100,000 for females <1 year to those 1–2 years, respectively (47)	Phase I (47): RR for males vs females is 2.0 (95% CI 1.4–2.8). Phase II (48): Home structures (furnishings and fixtures) were the main cause of concussion in those under 7 years and sports and recreational equipment were the main cause in those 7–18 years
Kraus et al., 1986 (49) and Kraus et al., 1987 (50)	Residents of San Diego County up to 15 years of age in 1981	Children with incident traumatic brain injury admitted to hospital or died from the injury. Excludes head injuries seen in emergency and not admitted	Mild brain injury defined as GCS 13–15 and not admitted for more than 48 hours	Of the 688 children with brain injury admitted alive to hospital, 606 (88%) had a MTBI. There were no deaths in this group. Among the 483 children diagnosed with concussion, 471 (98%) had a GCS of 13 or more. Of the total of 1,589 hospital bed days, 1426 (90%) were for MTBI (median LOS of between 1–2 days)	N/A
CDC, 1988 (45)	US children 1–4 years of age during the period 1983–87	Data from the NEISS, which includes ER visits from 62 US hospitals due to consumer product-related injuries and playground equipment-related injuries	Unique coding system for NEISS. Concussion not defined	Of the 27,232 school playground equipment-related injuries, 468 (1.7%) were classified as concussions	N/A
Durkin et al., 1998 (51)	Northern Manhattan children 0–16 years during 1983–92 (n = 101,198 in 1990).	Northern Manhattan Injury Surveillance System records severe injuries resulting in hospitalization or death to northern Manhattan residents	ICD-9 codes used to classify minor head injury, including isolated cranial fractures, minor concussions (LOC <1 hour) and unspecified minor head injury	Minor head injuries accounted for 76.3% of head injuries (n = 1,128) of which minor concussions accounted for 58.4% (n = 863). The rate of minor concussion was 88.6/100,000	Phase I: RR of minor concussion for those aged 5–16 years vs those aged 0–1 years was 1.67 (95% CI 1.21–2.34)
Briss et al., 1994 (46)	US daycare centres from Oct. to Dec. 1990	Licensed daycare centres opened full time during the 2 months preceding the survey and in operation at least 30 hours per week	Injury defined as bodily harm that required a visit to a doctor, dentist or ER. Concussion was not explicitly defined	Overall injury rate was 1.5/100,000 child-hours in daycare. There were 14 concussions, representing 2% of these injuries. 51% of all injuries occurred in the playground and most were falls	N/A

ER = emergency room; NEISS = the National Electronic Injury Surveillance System: RR = relative risk; CI = confidence interval; GCS = Glasgow Coma Scale; LOS = hospital length of stay; N/A = the study did not address risk factors or did not provide explicit results for MTBI; CDC = Center for Disease Control and Prevention, Atlanta; ICD = International Classification of Diseases; LOC = loss of consciousness.

Table VI. *Studies of incidence and risk factors in children with mild traumatic brain injury (MTBI) outside of North America*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Langley & Silva, 1985 (53)	Birth cohort of children born in Dunedin, New Zealand between April 1972 and March 1973	Of the 1,139 eligible children, 955 (84%) were assessed on their 9th birthday	Concussion defined as AIS 1–2 head injury that required medical attention in the preceding 2 years	17 children (1.8%) experienced a concussion in the preceding 2 years	N/A
Engberg & Teasdale, 1998 (54)	Children 0–14 years in Denmark during 1979–93 (numbers ranging from 882,563 to 1,102,404)	Children identified as brain-injured from the Danish hospital discharge registry. For those admitted with more than 1 brain injury during the study, the most serious was counted. Excludes ER visits	MTBI defined as ICD-9 850 (concussion)	The incidence of TBI ranged from 430/100,000 in 1979 to 240/100,000 in 1993 and the majority were concussions (88% for boys and 90% for girls)	N/A
Levi et al., 1991 (55)	Children aged 0–14 years in Haifa, Israel during 54 months in 1984–88 (catchment area of 385,000 children at risk)	Children with neurological deficit, continued vomiting and/or headache and lack of reliable observation at home admitted for neurosurgical evaluation within 48 hours of acute head trauma. Excludes discharges from ER and admissions to other wards	MTBI defined by GCS 13–15	Annual incidence of TBI requiring neurosurgical hospitalization was 36.6/100,000 children and 63.7% of these were GCS 13–15 (equal to 23.3/100,000)	N/A
Arnarson & Halldórsson, 1995 (56)	Children 0–14 years in Reykjavik, Iceland during 1987–91 (denominator not given)	Children admitted to a hospital ward for at least overnight observation in Reykjavik over a 5-year period. Children transferred between hospitals were only counted once	MTBI defined as ICD-9 850 (concussion)	A total of 359 brain-injured cases were admitted, of which 309 (86%) were concussions	Phase I: RR for males vs females was 1.53 (95% CI 1.21–1.94)
Goh & Poon, 1995 (57)	65,000 Vietnamese refugees in Hong Kong during 1990–93	Children up to 12 years of age admitted to hospital with a head injury	MTBI defined by GCS 13–15	Of the 601 children admitted, 551 (91.7%) were MTBI	N/A
Adesunkanmi et al., 2000 (58)	Children in Ile-Ife, Nigeria during 1992–95 (denominator not given)	All children treated at a single hospital in Ile-Ife for injuries sustained in road traffic collisions	MTBI defined by GCS 13–15	Of the 324 children injured in traffic, 82 patients sustained a head injury and 45 (55%) had a MTBI	N/A

AIS = Abbreviated Injury Scale; N/A = the study did not address risk factors or did not provide explicit results for MTBI; ER = emergency room; ICD = International Classification of Diseases; TBI = traumatic brain injury; GCS = Glasgow Coma Scale; RR = relative risk; CI = confidence interval.

Table VII. *Studies of the incidence and risk factors for mild traumatic brain injury (MTBI) associated with motorcycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Mätzsch and Karlsson, 1986 (62)	Skaraborg County, Sweden (population 270,000) during the 5-year period 1977–81	Motorcycle and moped injuries admitted to hospital. Excludes those under 15 years of age. Excludes those not admitted to hospital	Concussion not defined	Of the 414 moped injuries admitted to hospital, 182 (44%) were head injuries of which 71 (39%) were defined as concussion. Of the 378 motorcycle injuries admitted to hospital, 128 (34%) were head injuries of which 56 (44%) were defined as concussion	N/A
Kelly et al., 1991 (59)	Admissions due to motorcycle injury at 8 medical centres in Illinois from April through October 1988 (population at risk not given)	Passengers or drivers on motorcycles presenting to the ER because of crash-related injuries that had occurred within 24 hours. Helmet information had to be available and crashes with smaller motorcycles (<150 cc engines) were excluded	Brain injuries defined by AIS, ISS and GCS (MTBI not explicitly defined)	N/A	Phase I: The mean GCS for those wearing a helmet was 14.4 compared with 13.7 for those without a helmet ($p = 0.05$)
Braddock et al., 1992 (61)	The State of Connecticut from 1987 through 1989, with a population of 3,190,240	Motorcycle injuries admitted to hospitals in Connecticut that had a 70% E-coding (about 36% of all admissions). Non-residents were not excluded. Excludes those not admitted to hospital	ICD-9 CM codes used to identify concussions and other brain injuries, but no explicit definition of MTBI	Concussion was estimated to represent 3.3% of all motorcycle injuries in Connecticut over the study period	N/A
Tsai et al., 1995 (63)	Taipei, Taiwan motorcyclists (majority are step-through scooters) between Aug. 1 and Oct. 15, 1990 (8,460,138 motorcyclists at risk)	Cases and controls sampled from those with motorcycle injuries that received ER care at the 16 approved acute care hospitals in Taipei and street controls sampled on Taipei streets. Minibike-related injuries were excluded	Brain injuries identified by the GCS score, and MTBI defined as GCS 13–15	Case-control risk estimates based on 562 cases, 789 emergency controls (motorcyclists with injuries other than brain injuries) and 1094 street controls. 479 (85%) of the 562 brain-injured cases were MTBI	Phase III: OR for brain injury for helmeted (full-face) vs non-helmeted motorcyclists = 0.64 (95% CI 0.43–0.96) for daytime cases vs street controls and 0.54 (95% CI 0.41–0.70) for cases vs emergency controls. The use of other helmets (without full-face shield) was not protective of brain injury
Orsay et al., 1995 (60)	State of Illinois from July 1991 through Dec. 1992 (population at risk not given)	All motorcycle trauma patients treated over 18 months at Illinois' 73 Level I or II Trauma Centers. Excludes mild cases treated in the ER or other hospitals	MTBI defined as AIS 1–2	Of the 1,231 motorcycle trauma patients, 819 had a TBI and 237 (29%) were classified as MTBI	Phase I: Motorcyclists with a TBI were more than twice as likely to have not been wearing a helmet (OR 2.41; 95% CI 1.7–3.45)

N/A = the study did not address risk factors or did not provide explicit results for MTBI; ER = emergency room; AIS = Abbreviated Injury Scale; ISS = Injury Severity Scale; GCS = Glasgow Coma Scale; ICD-9 CM = International Classification of Diseases (9th edn) Clinical Modification; OR = odds ratio; CI = confidence interval; TBI = traumatic brain injury.

case-control study showed a significantly reduced risk for head injury in motorcyclists wearing a full-face-shield helmet compared with a half-face-shield helmet and no helmet (63).

We also accepted 4 studies of the effect of legislation on the risk of MTBI associated with motorcycle collisions (Table VIII). Three of these studies used the same data set on injured motorcyclists presenting to a sample of emergency rooms and admitted to a sample of hospitals in California, excluding Orange County, before and after the implementation of a motorcycle helmet law in 1992 (64–66). The other study reported on the proportion of MTBI admitted to hospital in Taiwan, before and after implementation of a helmet law in 1997 (67). The 3 Californian papers reported on different outcome measures, and all indicated a decrease in head injury severity for helmeted motorcyclists and an important protective effect for helmet use. In both jurisdictions, the law significantly increased the use of motorcycle helmets. In California, the proportion of MTBI in head-injured motorcyclists presenting to ER and admitted to hospitals increased, but the number and severity of all head injuries decreased overall. In Taiwan, the proportion of MTBI admitted to hospital remained the same after the law, but the number of cases decreased by 32%. These studies show that helmet legislation is an important preventive strategy for motorcycle-related head injury.

Incidence and risk factors for MTBI associated with bicycle collisions

Our task force accepted 7 studies dealing with the incidence of MTBI associated with bicycle collisions that spanned inception periods from 1981 to 1995 (Table IX). However, in only 2 of these studies was it possible to calculate an incidence rate for bicycle-related MTBI because the authors provided enough information about the population at risk (denominator) (25, 68). The other studies gave crude numbers of injuries only. Four of the studies originated from the USA (25, 69–71) and 1 each came from Australia (72), Canada (73) and northern Sweden (68). The inclusion/exclusion criteria varied, with 3 including hospital admissions only (25, 70, 72) and the other 4 including patients treated at emergency rooms (68, 69, 71, 73). Two studies defined MTBI as ICD-850 (70, 71), 2 used GCS 13–15 (25, 72), 1 used AIS-2 (68), another used a clinical definition of concussion that included the presence of LOC and amnesia (69) and 1 did not have an explicit definition of MTBI (73). The results of these studies are variable, but all show that MTBI is a common bicycle-related head injury. In northern Sweden, the incidence of hospital-treated, bicycle-related MTBI in 1985–86 was 49.7/100,000 population (68) and in 1981 in San Diego County, it was 11.6/100,000 (25). The higher rate in Sweden might reflect greater use of bicycles for transportation, a lower rate of helmet use and/or the inclusion of those treated as outpatients.

The task force also accepted as evidence 3 original studies and a meta-analysis of the effect of helmets in preventing MTBI in bicycle crashes (Table X). Two of the original studies were completed in Australia (74, 75) and the other in Seattle, Washington (76). They span inception periods from 1986 to 1992. One study of hospital-treated bicycle injuries showed that head injuries occurred significantly less in those wearing approved helmets (74). The other 2 studies used a case-control approach to measure the risk reduction associated with helmet use (75, 76). Both reported a significant protective effect for helmets. In addition, the meta-analysis confirmed that helmets substantially reduce the risk of brain injury in bicyclists (77).

Since our literature search strategy was confined to MTBI, we did not comprehensively search for all studies addressing prevention of traumatic brain injury. For example, we did not focus our search to find studies on educational interventions to promote helmet use in bicyclists, even though this might prevent some MTBI. Nevertheless, we found and reviewed some of these studies (Table XI). Of the 4 we accepted, 3 are ecologic studies (78–80) and 1 is a randomized controlled trial (81). All showed varying degrees of increased helmet use after various educational interventions, including subsidizing the cost of helmet purchases. One study suggested that education was less successful in a low-income group (79).

We also accepted 3 studies of the effect of bicycle helmet legislation on the risk of head injury, even though they did not address MTBI directly (Table XII). Two of the studies used a historical cohort design (82, 83) and the other was a cross-sectional analysis (84). All came from North America, including 2 from the USA (82, 84) and 1 from Canada (83). The 2 US studies showed a modest increase in helmet use after legislation, and the Canadian study documented a 45% reduction in paediatric head-injury hospital admissions after mandatory bicycle helmet legislation.

Incidence and risk factors for MTBI associated with sports

Our task force accepted 10 studies concerning the incidence and risk factors for concussion while playing rugby (Table XIII). Six of the studies came from Australia (85–90), 3 from the UK (91–94) and 1 from New Zealand (95). All were completed between 1979 and 1994, except for 1, where the date of the data collection was not specified (87). Two studies focused on children playing rugby (88, 93) and the others focused on older teenagers and adults. Two studies included female players (88, 95). Although all the studies either included an incidence rate for concussions or gave enough information to calculate a rate, only 2 explicitly defined concussion (87, 89). Six studies yielded rates of concussions in games only (85, 86, 89, 91, 92, 94, 95) and the other 4 included concussions occurring during training and games (87, 88, 90, 93). Overall, the concussion rates for games varied from 0.62 to 8.0/1000 athlete-game-hours. For games and practices combined, the range of rates was from 0.1/1000 athlete-hours for children under 15 years of age (88) to 17.1/1000 athlete-hours for senior players in Edinburgh (93). One athlete-hour of exposure refers to 1 athlete being exposed to the possibility of sustaining an injury during 1 hour of play or practice. Only 1 study focused on risk factors, showing that forwards have twice the risk of backs for concussion (92, 94).

Table VIII. *Studies of the effect of legislation on the risk of mild traumatic brain injury (MTBI) associated with motorcycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Kraus et al., 1994 (64)	Injured motorcycle riders treated in hospitals in the California counties in 1991 (before the helmet use law) and 1992 (after the helmet use law)	Injured motorcyclists admitted to 28 hospitals and those seen in the ER, but not admitted, at 9 of these hospitals	MTBI was defined as MAIS 1–2	N/A (no denominator given). Results based on 3252 non-fatal injured riders	Phase I: The proportion of MAIS-1 head injuries decreased from 1991 to 1992 from 5.3% to 1.7% and for MAIS-2 from 10.6% to 6.6%. The percentage of helmeted, non-fatal injury cases increased from 28.6% to 83.9% during this period
Kraus & Peek, 1995 (65)	Injured motorcycle riders treated at California hospitals in 1991 (before the helmet use law) and 1992 and 1993 (after the helmet use law)	Injured motorcyclists admitted to 1 of 18 hospitals in 10 California counties and those seen in the ER and released at 8 of these hospitals	MTBI was defined as GCS 13–15	N/A (no denominator given). Results based on 4790 non-fatally injured riders	Phase III: The number of treated motorcycle injuries decreased by 32–33% in 1992–93. Helmet use increased from 56.2% in 1991 to 99% in 1992–93. The proportion of MTBI increased after the law (fewer severe cases). RR for head injury by helmet use was 0.53 (95% CI 0.49–0.58) vs non-use. RR for head injury after the law was 0.61 (95% CI 0.56–0.66) vs before the law
Peek-Asa & Kraus, 1997 (66)	Injured motorcycle riders treated at California hospitals in 1991 (before the helmet use law) and 1992 and 1993 (after the helmet use law)	Injured motorcyclists admitted to 1 of 18 hospitals in 10 California counties and those seen in the ER and released at 8 of these hospitals	MTBI not explicitly defined, but impairment from head injury defined by IIS	N/A (no denominator given). Results based on 4790 non-fatally injured riders	Phase III: Proportion of head injuries with IIS = 0 (no impairment) increased by 16% after the law. Not wearing a helmet was associated with the highest odds of impairment OR = 1.86 (95% CI 1.53–2.26). The helmet law was significantly protective against head injury when not adjusted for helmet use OR = 0.60 (95% CI 0.52–0.69), but not significant when adjusted for helmet use OR = 0.99 (95% CI 0.82–1.22)
Chiu et al., 2000 (67)	Injured motorcycle riders admitted to 56 Taiwan major teaching hospitals in 1996–97 (1 year before a helmet use law) and 1997–98 (1 year after a helmet use law)	Motorcycle-related head injured patients admitted to major teaching hospitals were included. Excludes those dead on arrival to hospital and those not admitted to these hospitals	MTBI defined as GCS 13–15	N/A (no denominator given). Results based on 8795 non-fatally injured riders	Phase I: The proportion of MTBI remained stable at about 80% before and after the law, but there was a 32% decrease in the number of MTBI cases after the law. Helmet use increased from 21% to 96% after the law

ER = emergency room; MAIS = Maximum Abbreviated Injury Scale; N/A = the study did not report the incidence of MTBI; GCS = Glasgow Coma Scale; RR = relative risk; CI = confidence interval; IIS = Injury Impairment Scale; OR = odds ratio.

Table IX. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) associated with bicycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Kraus et al., 1987 (25)	Residents of San Diego County in 1981. 1980 US Census figures used as the denominator giving 1,861,846 persons at risk	Persons with incident traumatic brain injury admitted to hospital or died from the injury. Excludes head injuries seen in emergency and not admitted	Mild brain injury defined as GCS 13–15 and not admitted for more than 48 hours	Of 3,358 brain injuries, 251 were bicycle-related and 86% of these were MTBI for an incidence of 11.6/100,000	N/A
O'Rourke et al., 1987 (72)	Children aged 12 years or younger in Brisbane, Australia during Jan. 1985 to April 1986 (number at risk not given)	Children with head injury admitted to the 5 Brisbane hospitals with neurosurgical units. Criteria for admission included LOC, confusion, amnesia, focal neurological signs/symptoms, headaches, nausea/vomiting and skull fracture	MTBI defined as GCS 13–15	Of the 150 bicycle-related head injuries, 143 were given a GCS score and 135 (94%) were MTBI. Incidence rates not given	N/A
Belongia et al., 1988 (69)	Adult ER admissions to 3 of 4 hospitals in Madison, Wisconsin (population 175,000) during April 1 to October 31, 1981–83 and April 1 to July 31, 1984	Adults attending the ER for bicycle-related head injury during spring, summer and fall. Excludes bicycle-related head injuries that occurred during the winter months	Concussion defined as head injury with LOC or changes in mental status such as disorientation or amnesia	Of the 187 cases of bicycle-related head trauma, 59 had evidence of brain injury and 55 (93%) of these were classified as concussions. Incidence rates not given	N/A
Sacks et al., 1991 (71)	US population during 1984–88 (denominator not given)	NEISS data was used. It uses a national sample of hospital ER reported product-associated injuries. All bicycle-related head injuries were included	Concussion not explicitly defined, but was probably defined as ICD-850	Of the 905,752 bicycle-related head injuries in NEISS during the study period, 6.5% were coded as concussions	N/A
Björnstig et al., 1992 (68)	Populations of Umeå region (115,000) and Skellefteå region (80,000) of northern Sweden during a 1-year period (1985–86)	All injured bicyclists treated at the only 2 hospitals in the Umeå and Skellefteå regions. Excludes about 10% of minor injuries treated at medical outpatient clinics	Concussion defined as AIS-2 (LOC required)	Of the 321 bicyclists with head or face injuries, 97 (30%) sustained a concussion (49.7/100,000)	N/A
Li et al., 1995 (70)	NPTR 1989–92, which collects data on paediatric trauma patients admitted into 61 US centres and 1 Canadian trauma centre (source population not defined)	2,333 patients ages 14 or younger who were recorded in the NPTR during 1989 to 1992 because of bicycle-related injuries. Excludes those not admitted to hospital	Concussion defined as ICD-9850	Of the 1,252 patients with bicycle-related head injury, 604 (48.2%) were classified as concussion. 68% of the concussions had associated LOC, 7% had a skull fracture and 6% had intracranial injury	N/A
Linn et al., 1998 (73)	Source population not identified	Children, aged 1–19 years, treated at the British Columbia Children's Hospital for bicycle injuries between 1991–95	MTBI and concussion not explicitly defined	Of the 1,462 bicycle injuries, 72 (4.9%) were classified as minor and 62 (4.2%) were classified as concussions	N/A

GCS = Glasgow Coma Scale; N/A = the study not address risk factors or did not provide explicit results for MTBI; ER = emergency room; LOC = loss of consciousness; AIS = Abbreviated Injury Scale; NEISS = National Electronic Injury Surveillance System; ICD = International Classification of Diseases; NPTR = National Pediatric Trauma Registry.

Table X. *Studies of the preventive effect of helmets on the risk of mild traumatic brain injury (MTBI) associated with bicycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Risk measures
Thompson et al., 1989 (76)	Injured bicyclists treated at hospitals in Seattle, Washington during Dec. 1, 1986 through Nov. 30, 1987, and a sample of bicyclists from a health-maintenance organization that had been involved in a past accident, whether injured or not	Cases: 235 head-injured bicyclists presenting to the ER of 5 major Seattle hospitals. Controls: 433 non-head injured bicyclists presenting to the same hospitals and a random sample of 558 bicyclists (injured or not) that had been in a bicycle-related accident from Group Health Cooperative. Excluded injuries to the face and neck	TBI defined as a concussion with LOC or more serious brain dysfunction as diagnosed by the ER physician. MTBI not explicitly defined	Phase III: OR = 0.19 (95% CI 0.06–0.57) for TBI comparing ER-presenting bicyclists with vs without helmets. OR = 0.12 (95% CI 0.04–0.40) for TBI comparing ER cases with vs without helmets to health-maintenance controls
McDermontt et al., 1993 (74)	Melbourne (population of about 3 million) and Geelong (population of about 150,000) during April–Dec. 1988 and Sept.–May 1989	Bicycle injuries treated at Melbourne and Geelong public hospitals. Excludes those not treated at hospitals	TBI defined by AIS, MAIS, ISS, GCS and PTA. MTBI not explicitly defined	Phase I: Of 1,710 bicycle casualties, 261 wore approved helmets. TBI occurred significantly less in those with approved helmets (21.1%) compared with those without helmets (34.8%)
Thomas et al., 1994 (75)	Brisbane, Australia between April 1991 and June 1992 (population about 1.3 million in 1986)	Cases: 102 children with bicycle-related head injuries. Controls: 278 bicycle-related non-head injuries and 65 bicycle-related face injuries presenting to 2 large children's hospital ERs	Head injury defined as injury to upper head (skull, forehead and scalp) or LOC. MTBI not explicitly defined	Phase III: Risk for injury to upper head vs other injury in non-helmeted bicyclists was greater OR = 2.7 (95% CI 1.5–4.9). Risk for LOC was higher in non-helmeted bicyclists OR = 7.3 (95% CI 2.6–20.4).
Attewell et al., 2001 (77)	Meta-analysis of articles cited in Medline from 1987 to 1998	Search keywords: bicycle helmet, efficacy and head injury. 16 English language articles with enough detail to calculate an OR of the protective effect of helmets against head and brain injury in bicyclists	Brain injury includes concussion and/or intracranial injury. MTBI not explicitly defined	Summary OR for protective effect of wearing helmet vs not wearing helmet for brain injury was 0.42 (95% CI 0.26–0.67)

ER = emergency room; TBI = traumatic brain injury; LOC = loss of consciousness; OR = odds ratio; CI = confidence interval; AIS = Abbreviated Injury Scale; MAIS = Maximum Abbreviated Injury Scale; ISS = Injury Severity Scale; GCS = Glasgow Coma Scale; PTA = post-traumatic amnesia.

Table XI. *Studies of the effect of education on the risk of mild traumatic brain injury (MTBI) associated with bicycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Intervention	Results
DiGuiseppi et al., 1989 (78)	4,940 children riding bicycles in Seattle (pop. 5–15 years 56,179) and 4,887 in Portland (pop. 5–15 years 41,431), Oregon, during 1987–88	Children, 5–14 years old, observed riding bicycles at schools, playgrounds, parks, bicycle paths and streets, before and after the campaign	N/A	Educational and promotional material and helmet purchase discounts made available in Seattle during 1986–88, but not in Portland	Ecologic study: Helmet use increased from 5.5% to 15.7% in Seattle, but only from 1% to 2.9% in Portland. African-American ethnicity was associated with less helmet use
Weiss, 1992 (80)	Tucson, Arizona elementary, middle and high-school students and university students (no denominators given)	An observer recorded helmet use in 468 bicyclists coming to school in 1985 and 400 in 1990	N/A	There was no intervention, except at 1 elementary school, where helmet use was promoted in class	Ecologic study: Elementary helmet use went from 2% to 17%, with the 1 intervention school accounting for the change. Helmet use remained the same at the other schools at less than 5%
Parkin et al., 1993 (79)	Borough of East York in Toronto, Ontario, with approximately 10,000 school-aged children in 1991	Four of 22 elementary schools received an educational intervention and financial incentive to promote helmet use in student bicyclist, aged 5–14 years	N/A	Student and parent education and an annual bike rally with educational presentations. 20% discount on helmet sales and $5 rebate on helmet purchase	Ecologic study: Helmet use increased in both control and intervention areas, but more so in intervention areas. The greatest increase was in high-income intervention areas, which went from 4% to 36%, and the smallest was in low-income intervention areas, which went from 1% to 7%
Hendrickson & Becker, 1998 (81)	10–12 year old students in Central Texas (source population and time not given)	163 children given classroom intervention, 142 children in parental intervention group and 102 controls	N/A	Classroom intervention: educational video, discussions and helmet distribution. Parental intervention: classroom intervention plus parental telephone call. Control: no intervention	Randomized controlled trial: Helmet use increased by 55% in both intervention groups and by 16% in the control group. Helmet ownership accounted for 70% of the variance in helmet use at follow up

N/A = the study did not report MTBI-specific findings.

The task force accepted 7 studies of the incidence and risk factors for concussion during American football, 6 from the US and 1 from Canada (Table XIV). The studies have inception periods from 1975 to 1997 and do not include females. Three studies looked at high-school injuries (96–98), 3 looked at college injuries (99–102) and 1 included both high-school and college American football players (103). Two studies explicitly defined concussion (97, 103) and the others did not. All studies included injuries that occurred during games and practices, but only 3 stratified rates by practice and games (98–100, 103). This is a problem, in that 1 study showed an 11-fold increase in the risk of concussion during games vs practices (98). Overall, game rates varied from 2.8/1000 athlete-exposures for high-school athletes (98) to 3.3/1000 athlete-exposures for college athletes (99, 100). Practice rates varied from 0.25/1000 athlete-exposures for high-school athletes (98) to 0.46/1000 athlete-exposures for college athletes (99, 100). One athlete-exposure refers to 1 athlete being exposed to the possibility of sustaining an injury during either a game or a practice session. Quarterbacks, running backs and defensive secondary players had the greatest risk for concussion (98–100), and players with a previous history of concussion had an elevated risk for a second concussion (98, 102). This finding, however, might be confounded by player position. In 1 study, the rates of concussion varied by the type of helmet worn (102).

There were only 4 acceptable studies on the incidence and risk of MTBI in soccer players, all from the USA with study inception periods from 1993 to 1997 (Table XV). One study included male and female players at an indoor arena in Cincinnati over a 7-week period (104). Another study included male and female participants at an Olympic festival (105), while another included male and female college players (106). The final study included high-school boys and girls (98). Only 1 study provided an explicit definition of concussion (106). Three of the studies included concussions sustained during games and practices, and the other just included games (104). The study of high-school athletes gave separate rates for games and practices (98). The Cincinnati study included a wide age group, from as young as 12 years to over 25 years of age. The authors reported no concussions in females (95% CI 0–3.20/1000 athlete-game-hours) and 2 concussions in males, giving a rate of 1.29/1000 athlete-game-hours (104). For college soccer players, males had an incidence of 0.6/1000 athlete-exposures and females had an incidence of 0.4/1000 athlete-exposures during games and practices (106). High-school boys had an incidence of 0.57/1000 game-exposures and 0.04/1000 practice-exposures. High-school girls had an incidence of 0.71/1000 game-exposures and 0.05/1000 practice-exposures (98).

The task force accepted 5 studies of concussion in ice-hockey players, 2 involving male Canadian college players (107–109), 1 including males from the Danish elite league (110), 1 of males from the Swedish elite league (111) and 1 of males and females in a community-based tournament in Minnesota (112) (Table XVI). In 1 of these studies, there was an explicit definition of concussion (111). It is not possible to compare the incidence

Table XII. *Studies of the effect of helmet legislation on the risk of mild traumatic brain injury (MTBI) associated with bicycle collisions*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Intervention	Results
Dannenberg et al., 1993 (84)	Baltimore, Howard and Montgomery counties in Maryland with populations of 692,000, 187,000 and 757,000 in 1990	7,217 4th, 7th and 9th-grade students from 47 schools were surveyed about past and present helmet use, and 3,494 (48.4%) responded	N/A	Howard: education and mandatory helmet legislation for children under 16 years. Montgomery: educational campaign only. Baltimore: no intervention	Cross-sectional study: Helmet use increase pre-post interventions: Howard: 11.4–37.5%; Montgomery: 8.4–12.6%; Baltimore: 6.7–11.1%. Having friends that wear helmets was highly associated with helmet use
Shafi et al., 1998 (82)	Paediatric trauma centre admissions from 1993 to 1995 at Children's Hospital of Buffalo (source population not defined)	208 children admitted to hospital with bicycle injuries. Excludes those treated at the ER	MTBI defined as concussion	1994 mandated state law requiring all children less than 14 years to wear a helmet while bicycling	Historical cohort study: Of 208 bicycle injuries, concussion alone occurred in 97 (47%) of children. Only 31 (15%) of children wore a helmet. Helmet use increased from 2% pre-legislation to 26% post-legislation
Macpherson et al., 2002 (83)	Canadian children 5–19 years of age in 1996 (denominator not given)	Children, 5–19 years, admitted to Canadian hospitals from 1994 to 1998 because of bicycle related injuries. Excludes those treated at the ER	TBI identified by ICD-9. MTBI not defined	Four provinces enacted mandatory helmet legislation for children on bicycles during the study period. The other 8 provinces and territories did not enact legislation	Historical cohort study: Over the 4 years there were 9,650 admissions for bicycle-related injuries and 3,426 (35%) sustained a head injury. Pre-legislation incidence rate was 18/100,000. There was a 45% reduction in head injury after legislation: 18/100,000 to 10/100,000, and a 27% reduction in the other regions with no legislation

N/A = the study did not report MTBI-specific findings; ER = emergency room; TBI = traumatic brain injury; ICD = International Classification of Diseases

rates across these studies since the denominators include different activities at risk, such as league and non-league games (109), practice and game time (107, 108, 110) and different age groups. One Canadian college study of league and non-league games reported 1.5 concussions per 1000 athlete-game-hours (109), and the Swedish study of elite players reported 6.5 concussions per 1000 athlete-game hours (111). The Minnesota tournament included girls and boys, ages 11–19. In this study, there were no reported concussions in girls, but boys had an incidence rate of 17.6/1000 athlete-game-hours (112). The other Canadian college study showed similar concussion rates for games and practices in college players wearing full vs half-face shields, even though the former reduced dental and facial injuries (107, 108).

Our task force accepted 10 studies concerning fighting sports, spanning inception periods from 1976 to 1999 (Table XVII). These include 3 studies of boxing (113–115) and 7 of martial arts, including 2 studies of karate (116, 117) and 5 of taekwondo (118–122). The boxing studies only include young males, but all of the martial arts studies included men and women, except 1 study of karate that only included men (117). There was only 1 study of children, aged 6–16 years, in a junior taekwondo championship (122). Only 4 of the studies included explicit definitions of brain injury (114, 115, 119, 121). It is difficult to compare the incidence rates of MTBI between boxing and martial arts because the boxing studies use different denominators to capture time at risk and include different levels of competition. However, Dublin amateur boxers experienced 7.9 concussions/1000 minutes of exposure (114) compared with 0.95 concussions/1000 minutes of exposure in US male senior taekwondo championship contenders (121). With respect to taekwondo, the concussion rates in males varied from 5.1 to 15.5/1000 athlete-exposures as opposed to women, where the rates varied from 2.4 to 8.8/1000 athlete-exposures. There was little information about risk factors for MTBI in these studies.

The task force accepted 3 studies of the incidence and risk of MTBI in Nordic or winter sports (Table XVIII). These include studies of ski jumpers (123) and luge athletes (124) at the Lake Placid Olympic Training Center and a study of all skiing injuries that occurred over 1 winter in Trondheim, Norway (125). Although the number of concussions is reported in these studies, none explicitly defined concussion. Furthermore, 2 of these studies do not provide a denominator of person-time or number of persons at risk, so it is not possible to calculate an incidence rate for MTBI. The study of luge athletes yields an incidence of 0.17 concussions/1000 runs (124). These studies did not quantitatively assess risk factors for concussion during these activities.

We also accepted 4 studies of the incidence and risk of concussion during leisure activities such as playing on trampolines (126), riding all-terrain vehicles (127, 128) and riding horses (129) (Table XIX). However, because these studies do not provide person-time or number of persons at risk, we could not calculate incidence rates. The authors present the proportion of concussions among head injuries or among all injuries. None

Table XIII. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in rugby*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Myers, 1980 (89)	Brisbane rugby union season in 1979 with 8,365 athlete-hours at risk	221 matches for men aged 18–32 years	Head injury treated by medical officer defined as any period of LOC, confusion, amnesia, unsteadiness, or altered vision, whether or not neurological signs were present	Of the 271 injured athletes, 24 had a head injury giving an incidence of 2.87 (95% CI 1.84–4.27)/1000 athlete-game-hours	N/A
Dicker et al., 1986 (85)	Senior Victorian Football League over 3 seasons (1979, 1980 and 1982). 29,568 athlete-game hours studied	Included 12 teams in 1979 and 11 in 1980 and 1982	Injury defined as a game trauma that came to the attention of the medical officer, required treatment and interfered with play or training. No explicit definition of concussion	Of 1,408 game injuries, a total of 74 concussions occurred for an incidence of 2.5 (95% CI 1.9–3.1)/1000 athlete-game-hours	N/A
Gibbs, 1993 (86)	South Sydney Rugby League Football Club (SSRLFC) 1989–91; 3,140 athlete-game-hours over 3 seasons	All 3 teams of the SSRLFC, which included 94 male athletes, aged 16–30 years	Injury defined as an event that causes the athlete to miss a subsequent game. No explicit definition of concussion	5 concussions; incidence of 1.6 (95% CI 0.52–3.71/1000 athlete-game-hours (another 23 concussions were mild and did not require loss of game time)	N/A
McMahon et al., 1993 (88)	Children playing in the Victoria Metropolitan Football League in Australia in 1992	1,253 children under 15 years of age (98% boys) from 18 randomly selected teams	Injury was defined as any trauma causing disability or pain during games or practice. Concussion not explicitly defined	From a total of 264 injuries, there were 15 concussions, giving a rate of 0.1 (95% CI 0–0.21)/1000 athlete-hours (practice and games). Overall injury rate was 11.6 times more common in games	N/A
Seward et al., 1993 (90)	Australian Football League (AFL), New South Wales Rugby League (RL) and New South Wales Rugby Union (RU) in 1992	All athletes participating in competition and training from 57 teams during the week of the survey	Injury defined as causing the athlete to be unavailable for play/training and any other injury that required specific medical treatment. No explicit definition of concussion and total number not given	For the AFL the injury incidence was 62/1000 athlete-hours of which 3.6% were concussions (2.3/1000 athlete-hours). For the RL the injury incidence was 139/1000 athlete-hours of which 8.5% were concussions (11.8/1000 athlete-hours). For the RU the injury incidence was 53/1000 athlete-hours of which 5.3% were concussions (2.8/1000 athlete-hours)	N/A
Bird et al., 1998 (95)	Rugby Injury and Performance Project in Dunedin, New Zealand during the 1993 competitive season representing 4,403 athlete games and 8,653 athlete practices	22 rugby teams selected to participate and 2 declined, representing 356 male and female athletes	Injury defined as an event that caused medical attention or resulted in missing at least 1 scheduled game or team practice. Concussion not explicitly defined	Overall injury incidence was 99/1000 athlete-games. 22 concussions occurred during games giving a rate of 5.0 (95% CI 3.1–7.6)/1000 athlete-games	N/A
Stephenson et al., 1996 (94); Gissane et al., 1997 (92)	English professional rugby league over four playing seasons, 1990–94, representing 4,305 athlete-game-hours	One rugby league club involved in 249 games	Site and nature of the injury described by the club doctor or physiotherapist. Concussion not explicitly defined	Of 492 game injuries, 35 concussions occurred giving a rate of 8 (95% CI 6–11)/1000 athlete-game-hours	Phase I: RR for concussion in forwards vs backs: 1.97 (95% CI 0.95–4.27)
Garraway & Macleod, 1995 (91)	Senior rugby clubs in the South of Scotland District of the Scottish Rugby Union (SRU) during the 1993–94 season	All 26 SRU clubs representing 1,216 athletes, of which 1,169 provided data	Injury was defined as an event that prevented further play. Concussion not explicitly defined	Of 358 injuries, 19 concussions occurred during games giving a rate of 0.62 (95% CI 0.34–0.90)/1000 athlete-game-hours	N/A

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Lee & Garraway, 1996 (93)	Rugby schools in Edinburgh and senior rugby clubs in South Scotland representing 1,705 athletes in the 1993–4 season	All 9 rugby schools (ages 11–19 years) and all 26 clubs (ages 16 years and up), men only	Injury prevalence defined as a new or recurrent injury event occurring during game or practice that prevented further play of practice. Injuries coded by ICD-9, but concussion not explicitly defined	154 of 1,705 athletes were injured. 80% of injuries occurred during games. Prevalence of concussions: 10.6 (95% CI 5.7–15.4)/1000 athlete-sessions for schoolboys and 17.1 (95% CI 9.7–24.5)/1000 athlete sessions for men's clubs	N/A
McCrory et al., 2000 (87)	303 elite Australian football athletes over a single season	None given. No differentiation between games and practice	Concussion defined as immediate and transient impairment of neural function such as altered consciousness and disturbed vision or equilibrium	23 concussions over the 20-week football season for an incidence of 3.3/1000 athlete-hours. LOC occurred in 3 (13%) cases	N/A

LOC = loss of consciousness; CI = confidence interval; N/A = the study did not address risk factors or did not provide explicit results for MTBI; RR = relative risk; ICD-9 = International Classification of Disease, 9th Edition.

of these studies quantitatively accessed risk factors for concussion during these activities.

One study that deserves attention is a large and comprehensive report of the incidence and risk of MTBI in US high-school athletes over a 3-year period from 1995 to 1997 (Table XX) (98). We have already highlighted some results from this study with respect to American football and soccer injuries in Tables XIV and XV, respectively. However, the study also gives incidence and risk information about boys and girls playing basketball and baseball, boys' wrestling, and girls' field hockey and volleyball. A total of 114 high-schools participated in this study over a 3-year period (1995–97), and concussions where identified by certified athletic trainers. The results show that boys' American football has the highest rate of concussion at 2.82/1000 athlete-game-exposures. For girls, soccer has the highest incidence at 0.71 concussions/1000 athlete-game-exposures. For boys, baseball has the lowest rate at 0.12 concussions/1000 athlete-game-exposures, and for girls, volleyball has the lowest rate at 0.01 concussions/1000 athlete-game-exposures. In most cases, the risk of injury is greater during games than during practice sessions.

Second impact syndrome

The task force accepted 1 study on the incidence and risk of second impact syndrome (SIS) during sports (Table XXI) (130). This systematic review of case reports of SIS found 17 published reports, but only 5 cases satisfied the authors' criteria for "probable SIS". The authors conclude that the evidence that a first concussion is a risk factor for a second concussion with diffuse cerebral swelling and catastrophic deterioration is not established, and that the incidence of this rare outcome is not known.

DISCUSSION

Our task force accepted 119 (71%) of the 167 papers that we reviewed and when we include our 2 original research studies, we have a total of 121 studies on the incidence, risk factors and prevention of MTBI. However, this literature has many limitations, and it is difficult to draw consistent conclusions from it. Some of these problems are inherent in all studies of MTBI. For example, there is no universally accepted definition of MTBI, and the studies are so heterogeneous that it is difficult to compare incidence rates and risk factors. Different authors use different criteria to define and ascertain cases of MTBI, and these criteria are all susceptible to information bias and misclassification of cases. One major problem is the lack of a standard definition of the lower range of severity for MTBI. In particular, studies of sport injuries that define athletes as being concussed when they have been "dinged," and suffer from momentary feelings of being dazed, would include more cases than studies that require evidence of LOC or PTA. As can be seen from our evidence tables, many studies do not even include a definition of MTBI, particularly studies of sports concussions. Those studies that use the common criteria of GCS 13–15 to

Table XIV. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in American football*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Gerberich et al., 1983 (97)	Minnesota secondary school football teams in the 1977 football season	Random sample of 103 of 499 schools gave 3,802 football athletes. 3,063 (81%) of athletes responded to the survey. Includes games and practices	Concussion defined as blow to the head resulting in LOC or loss of awareness, or diagnosed by a physician	581 concussions gave an incidence of 19 concussions/100 athletes	N/A
Buckley, 1986 (99) and 1988 (100)	National Athletic Injury/Illness Reporting System over 8 years (1975–82) representing over 36,000 athlete-seasons of college football	36,749 US college athletes over 395 team-seasons during the years 1975–82. Includes injuries during games and practices (3,012,063 athlete-practice-exposures and 216,691 athlete-game-exposures)	Concussion defined as any brain injury that required the athlete to cease participation for observation before returning to play	A total of 2,124 concussions over 8 years (725 game-related and 1,399 practice-related). Incidence of concussion was 3.3 (95% CI 3.1–3.6)/1000 athlete-game-exposures and 0.46 (95% CI 0.44–0.49)/1000 athlete-practice-exposures	Phase I: Highest risk for minor concussion is for quarterbacks (1.6/100 games), followed by running backs (1.4/100 games) and the defensive secondary (1/100 games)
Zemper, 1994 (102)	Athletic Injury Monitoring System during 5 seasons (1986–90)	3% sample of US intercollegiate football athletes, representing 8,312 athlete-seasons and 618,596 athlete-exposures. Includes games and practices	Concussion was not explicitly defined	245 concussions reported giving an incidence of 0.40/1000 athlete-exposures	Phase I: Players wearing the Riddell M155 helmet had the lowest rate of concussion (0.13/1000 athlete-exposures). Players wearing the Bike Air Power helmet had the highest rate of concussion (0.54/1000 athlete-exposures). Players with a previous history of concussion were more likely to sustain a second concussion (RR = 5.95; 95% CI 4.3–8.2)
DeLee & Farney, 1992 (96)	86 Texas high-schools: total game time of 2,156.7 hours and total practice time of 11,869.76 hours during the 1989 football season	4,399 high-school football athletes from a random sample of Texas schools that have more than 740 students and employ a full-time athletic trainer. Includes games and practices	Reportable injury: causes loss of game or practice time, is treated by a physician, or head injury is reported to trainer. No explicit definition of concussion	Of 2,228 injuries reported, 101 (4.5%) were concussions (not stratified by games and practices), which gives a rate of 2.3/100 athletes	N/A
Powell & Barber-Foss, 1999 (98)	National Athletic Trainers' Association (NATA) database over the 3 years of 1995–97	246 of 350 trainers gave data on 10 high-school sports, documenting 21,122 male athlete-seasons of football. Includes games and practice sessions	A reportable injury caused cessation of participation in current game or practice, or on the next day. MTBI was identified by certified athletic trainers (explicit definition not given)	A total of 773 MTBI cases gave incidence rates of 0.25 (95% CI 0.16–0.34)/1000 athlete-practice-exposures and 2.82 (95% CI 2.58–3.07) athlete-game-exposures. There were 4 cases of subdural haematoma and 2 cases of intracerebral bleeding reported over the 3 seasons	Phase I: RR = 11 (95% CI 10–13) for games vs practice sessions. The highest injury rates/100 team-game positions were for the quarterbacks (1.3), followed by the running backs (0.74) and linebackers (0.52)

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Meeuwisse et al., 2000 (101)	Canada West division of the Canadian Intercollegiate Sports Injury Registry over 5 seasons, 1993–97	Five western Canadian university football teams. Includes games and practices during the 1993–97 seasons, representing 1,010 athletes	Injury defined as any event requiring assessment and treatment by a team therapist or any transient neurological injury. Concussion was not explicitly defined	There were 101 concussions reported for a rate of 10/10,000 athlete-exposures. Concussion was the most common injury reported	N/A
Guskiewicz et al., 2000 (103)	NATA database over 3 years (1995–97)	242 (62%) of 580 trainers gave information on 17,549 US high-school and college football athletes. Includes games and practice sessions	Concussion defined as acceleration/deceleration injury with immediate and transient post-traumatic impairment of neural functions, such as altered consciousness, blurred vision, dizziness, amnesia, or memory impairments	Of the 17,549 athletes, 888 (5.1%) sustained at least 1 concussion and 131 (14.7%) of these sustained a second concussion. The overall rate of concussion was 0.70/1000 athlete-exposures and 1.28/1000 athlete exposures involving live play. Only 8.8% of concussions involved LOC	Phase I: The incidence of concussion was higher in high-school athletes (1.63/1000 athlete exposures) than in division I college athletes (0.94/1000 athlete exposures)

CI = confidence interval; LOC = loss of consciousness; N/A = the study did not address risk factors or did not provide explicit results for MTBI; RR = relative risk.

define MTBI also do not specify the mildest end of the severity spectrum. Other studies that define MTBI by ICD coding are also susceptible to information bias. For example, 1 accepted study showed that the commonly used ICD definition of ICD 850 (concussion) captured only 23% of MTBI admitted to hospital. In that study, 71% of the MTBI was coded as ICD 854 (intracranial injury of other and unspecified nature) (43). Another study showed a huge disagreement between the numbers of TBI cases captured from hospital discharge codes and the emergency room registry (131). Also, in studies where MTBI is coded as AIS 1–2, there is the possibility of missing cases and misclassifying other cases as MTBI. There is an urgent need for workable clinical and surveillance definitions of MTBI and subsequent studies to validate various methods of capturing cases (132). Until there is some consistency of definitions and appropriate validation of them, studies of the incidence of MTBI will remain so heterogeneous that we will be unable to compare the incidence rates.

Another obvious problem is that many studies do not identify the population at risk that should form the denominator in any incidence calculation. Many studies report the number of cases admitted to hospitals over a specified time period, but do not provide information on the population at risk of being admitted. Without this information, the authors can only report on the proportion of MTBI cases, among all injuries, or among all head injuries, seen at these institutions. In some cases, it might not be possible to determine a denominator, since it is difficult to define the population that is exclusively served by these institutions. Nevertheless, there are good examples in our tables where authors did define the population at risk for hospitalization and were able to calculate an incidence rate based on that information (22, 23, 26–28, 33, 34, 37, 39–42, 51). We also found some excellent studies that included entire populations at risk (16, 18–21, 30, 35, 47). Special mention should be made of studies of concussion in sports (Tables XIII–XX). Many of these studies report person-time at risk and provide incidence density calculations, rather than just the cumulative incidence. Whenever possible, it is desirable to present the incidence density, since the incidence density denominator is a more accurate measure of the population-time at risk.

Our accepted studies also have variable inclusion/exclusion criteria that impact on the interpretation of the findings. Many of the studies include hospital admissions only. This is a problem since hospital admission policy for MTBI can vary over jurisdictions and time (19). In addition, these studies fail to capture cases of MTBI treated at the ER, but not admitted to hospital. All of the studies that use hospital discharge data suffer from this selection bias. Even studies that capture ER cases miss those that are treated at outpatient clinics away from the hospital, or receive no treatment at all. One population-based survey of self-reported MTBI in the USA showed that 25% of those reporting a brain injury did not seek medical care (18). This same study reported that 25% of cases were admitted to hospital, 35% were seen at the hospital ER without being admitted and 14% attended private clinics and medical offices.

Table XV. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in soccer*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Lindenfeld et al., 1994 (104)	Seven-week period at a Cincinnati indoor soccer arena (2,700 athlete-hours)	Males and females aged as young as 12 years and up to or over 25 years (1,548 male-athlete-game-hours and 1,152 female- athlete-hours)	Injury defined as an event causing the athlete to leave the game, caused the game to be stopped, or the athlete required medical attention. Concussion not explicitly defined	Of the 58 injuries in females, there were no concussions, giving an incidence rate of 0 (95% CI 0–3.20)/1000 athlete-game-hours. Of the 78 injuries in males, there were 2 concussions giving an incidence rate of 1.29 (95% CI 0.16–4.66)/1000 athlete-game-hours	N/A
Barnes et al., 1998 (105)	144 athletes at the 1993 United States Olympic Festival in San Antonio, Texas	72 males (939 athlete-years) and 72 females (924 athlete-years) players. Includes practice and games	Concussion required the attention of a physician, dentist or athletic trainer, required stoppage and removal from play, resulted in sequelae or prevented further participation (explicit definition not given)	89% of men and 43% of women had experienced a concussion	N/A
Boden et al., 1998 (106)	United States Atlantic Coast Conference (ACC) varsity soccer during the 1995 and 1996 seasons, representing 28,450 male athlete-exposures and 30,338 female athlete-exposures	Male and female soccer athletes in the 15 Division I ACC teams. Includes practice and games	Grade I concussion had <30 minutes PTA and no LOC; Grade II had LOC <5 minutes or PTA >30 minutes; Grade III had LOC >5 minutes or PTA >24 hours	29 concussions were diagnosed in 26 athletes giving an incidence of 0.49/1000 athlete-exposures. Eight (28%) had LOC	Phase I: Rates for men and women were 0.6/1000 and 0.4/1000 athlete-exposures respectively (RR = 1.5). 20 (69%) of concussions occurred during games and 9 (31%) during practice (RR = 2.2)
Powell & Barber-Foss, 1999 (98)	National Athletic Trainer Association database over the 3 years of 1995–97	246 of 350 trainers gave data on 10 high-school sports, documenting 7,539 male athlete-seasons and 5,642 female athlete-seasons of soccer. Includes games and practice sessions	A reportable injury caused cessation of participation in current game or practice or on the next day. MTBI was identified by certified athletic trainers (explicit definition not given)	For boys, 69 MTBIs gave an incidence of 0.04 (95% CI 0.01–0.06)/1000 practice-exposures and 0.57 (95% CI 0.43–0.72)/1000 game-exposures. For girls, 76 MTBIs gave an incidence of 0.05 (95% CI 0.02–0.08)/1000 practice-exposures and 0.71 (95% CI 0.53–0.88)/1000 game-exposures	Phase I: RR = 16.2 (95% CI 9.9–26.6) for games vs practice sessions in boys. RR = 14.4 (95% CI 9.0–23.0) for games vs practice sessions in girls. MTBI most often occurred from collisions while heading the ball for both boys and girls

CI = confidence interval; N/A = the study did not address risk factors or did not provide explicit results for MTBI; PTA = post-traumatic amnesia; LOC = loss of consciousness; RR = relative risk.

Table XVI. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in ice hockey*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Jørgensen & Schmidt-Olsen, 1986 (110)	Danish elite ice-hockey players over 2 consecutive seasons (years not specified)	Fourteen randomly chosen teams. Out of 266 athletes, 210 (79%) answered the survey. Included injuries from match play and training	Injury defined as an event that hindered activity, and/or required special treatment to be able to play, or made play impossible. Concussion not explicitly defined	Total of 27 concussions (6 from play and 21 from matches)	N/A
Pelletier et al., 1993 (109)	Canadian Interuniversity Ice Hockey League, Sept. 1979 to May 1985	All male inter-university hockey athletes ages 19–25 years over 6 hockey seasons (9,424 athlete-games, including league and non-league games)	Injury defined as an event that causes cessation of participation or requires professional attention. Concussion not explicitly defined	Of 186 reported injuries, 14 (7.5%) were concussions giving an incidence of 1.5 (95% CI 0.8–2.5)/1000 athlete-game-hours).	N/A
Tegner & Lorentzon, 1996 (111)	265 male athletes from the 1988–89 season (retrospective study) and 8,736 athlete-game-hours from the 1988–89 to the 1991–92 season (4 year prospective study) of the Swedish elite league	All athletes on the teams were included as were all games and practices. 11 of 12 teams (227 players of 265 total) participated in the retrospective study and 7,536 athlete-game-hours were included in the prospective study. Of the 888 games played during the prospective study, 260 were excluded because of poor co-operation in reporting injuries	Injuries that forced the athlete to stop playing or miss the next practice or game. Concussions defined as grade 1: dizziness after head trauma with no LOC or PTA; grade 2: PTA or LOC <30 seconds; grade 3: LOC >30 seconds	In the retrospective study 51 athletes (22%) had a total of 87 concussions during their hockey careers. During the prospective study, 805 injuries were reported and 52 (6%) were concussions. 42 of 52 concussions occurred during games. The incidence of concussion was 6.5 (95% CI 4.8–8.6)/1000 athlete-game-hours	Phase I: Body checking accounted for 56% of the concussions
Roberts et al., 1999 (112)	Five community-sponsored tournaments in Minnesota during the winter of 1993–94	695 boys and 112 girls, ages 11–19 years. For boys: 511.2 athlete-game hours. For girls: 79.2 athlete-game-hours	Concussion defined as any brain concussion causing cessation of participation before return to play	Of the 60 injuries in boys, 9 (15%) were concussions, giving an incidence rate of 17.6/1000 athlete-game-hours. There were no concussions in girls	N/A
Benson et al., 1999 (107) and Benson et al., 2002 (108)	Canadian Inter University Athletic Union hockey teams during the 1997–98 season	642 athletes from 22 teams. 11 teams used full-face shields (24,147.5 athlete-exposures) and the other 11 used half-face shields (26,823 athlete-exposures). Goalies were excluded. Includes practice and game injuries	Concussion defined as any concussive head injury including all transient traumatic brain injuries, regardless of time loss	For those with half-face shields the incidence of concussion was 1.53/1000 athlete-exposures and for those with full shields the incidence was 1.57/1000 athlete-exposures	Phase I: RR for half-shield vs full shield was 0.97 (95% CI 0.61–1.54)

N/A = the study did not address risk factors or did not provide explicit results for MTBI; CI = confidence interval; LOC = loss of consciousness; PTA = post-traumatic amnesia; RR = relative risk.

Table XVII. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in fighting sports*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Stricevic et al., 1983 (117)	Three national and 3 international karate tournaments over the years 1976–82 (a total of 618 athlete-exposures)	284 male athletes aged 23–27 years, in 309 matches	Injuries defined on ability to continue competition, or being hospitalized. No explicit definition of concussion	One concussion resulting in hospitalization gives an incidence of 1.62 (95% CI 0.04–8.98)/1000 athlete-exposures	N/A
Welch et al., 1986 (115)	US Military Academy in West Point, New York, boxing program during 1983–85	2,100 young male cadets participating in 23,625 hours of instruction and 1,680 hours of competition	Head injury defined as any signs of vertigo, nausea, or any other physical signs or symptoms of head injury	A total of 22 concussions (18 during instruction) gives an incidence of 0.76 (95% CI 0.45–1.20)/1000 hours of instruction and 2.38 (95% CI 0.65–6.08)/1000 hours of competition	N/A
Jordan & Campbell, 1988 (113)	Sanctioned New York State Athletic Commission (NYSAC) boxing matches during August 1982 to July 1984 (3,110 rounds)	All physicians' injury reports from boxing matches sanctioned by the NYSAC. Excludes training and sparring	Craniocerebral injury defined as any technical knockout or knockout from head blows	Of 376 reported injuries, 262 were identified as craniocerebral, giving an incidence rate of 0.84 (95% CI 0.75–0.95)/10 rounds boxed	N/A
Pieter & Lufting, 1994 (119)	1991 World Taekwondo Championships (433 athletes from 49 countries). Total athlete-exposures not reported	273 male and 160 female athletes. Ages not given	Injury defined as an event that leads to time loss from competition for 1 day or more. Concussions classified using criteria of Nelson et al., 1984 (134)	Of a total of 18 injuries in males, 9 (50%) were concussions giving an incidence rate of 15.27/1000 male-athlete-exposures. Of a total of 4 injuries in females, 1 (25%) was a concussion giving an incidence of 3.23/1000 female-athlete-exposures	N/A
Pieter et al., 1995 (120)	1993 European Taekwondo Cup (97 athletes from 16 countries giving 372 athlete-exposures)	67 men (258 athlete-exposures) and 30 women (114 athlete-exposures) from 4 weight divisions	Injury defined as occurring in the ring or during warm-up that were brought to the attention of medical personnel. No explicit definition of concussion	Of 48 injuries 5 (10.4%) were concussions, 4 in men and 1 in women, giving an incidence of 15.5 (95% CI 4.2–39.2)/1000 male-athlete-exposures and 8.8 (95% CI 0.2–47.9)/1000 female-athlete-exposures	N/A
Porter & O'Brien, 1996 (114)	Six amateur boxing clubs in Dublin, Ireland, including 4,170 man-minutes of boxing in bouts during Nov. 1992 to March 1993	147 male participants in amateur boxing competitions in Dublin. Excludes those less than 16 years of age	Injury defined as an event that necessitated stoppage of the bout. Concussions defined as grade 1: confusion with no PTA or LOC; grade 2: confusion with PTA but no LOC; grade 3: any LOC	A total of 33 concussions occurred, all during competition, gave an incidence rate of 7.9 (95% CI 5.45–11.09)/1000 man-minutes in competition. 92% of concussions were grade 1 and the rest were grade 2	N/A
Pieter & Zemper, 1998 (121)	US National Senior Taekwondo Championships in 1989, 1990 and 1991 and the US Taekwondo Team Trials in 1988, 1989 and 1990 (3,408 male athlete-exposures and 1,654 female athlete-exposures)	A total of 1,665 men and 742 women athletes in competition	Injury defined as any event for which medical assistance was sought. Concussions graded according to Nelson et al., 1984 (134)	In men there were 24 concussions for an incidence of 7.04 (95% CI 4.52–10.46)/1000 athlete-exposures, or 0.95 (95% CI 0.61–1.41)/1000 minute-exposures. In females, there were 4 concussions for an incidence of 2.42 (95% CI 0.66–6.18)/1000 athlete-exposures, or 0.31 (95% CI 0.08–0.79)/1000 minute-exposures	Phase I: Of the 28 concussions, 25 were caused by an unblocked attack

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Pieter & Zemper, 1999 (122)	United States National Junior Taekwondo Championships in 1989 and 1990 and the unofficial Junior Taekwondo World Championship in 1989, representing a total of 6,068 male athlete-exposures and 1,538 female athlete-exposures	3,341 boys and 917 girls aged 6–16 years	Injury defined by treatment sought from medical staff at competition site. No explicit definition of concussion	A total of 31 concussions in boys gave a rate of 5.1 (95% CI 3.4–7.2)/1000 athlete-exposures or 1.4 (95% CI 1.0–2.0)/1000 minute-exposures. A total of 7 concussions in girls for a rate of 4.6 (95% CI 1.8–9.4)/1000 athlete-exposures or 1.2 (95% CI 0.5–2.5)/1000 minute-exposures	N/A
Critchley et al., 1999 (116)	1,770 bouts in 3 British National Shotokan Karate Championships over the 3 years 1996–98	1,273 men and women competitors between the ages of 10 and 21 years	Self-reported injury or injury sustained on the mats. No explicit definition of concussion	A total of 12 concussions, 11 with no LOC and 1 with LOC. Incidence rate for concussion is 9.4 (95% CI 4.9–16.4)/1000 athlete exposures. Results not stratified by gender	N/A
Koh et al., 2001 (118)	1999 World Taekwondo Championships (563 athletes from 66 countries giving 1,018 athlete-exposures)	330 men (596 athlete-exposures) and 211 women (422 athlete-exposures) aged 15 to 38 years	Injuries sustained while fighting that result in the athlete missing the remainder of the match and/or requires the athlete to consult a health professional. No explicit definition of concussion	Of 72 reported injuries in men, 6 (8%) were concussions giving an incidence of 10.1 (95% CI 3.7–21.8)/1000 male-athlete-exposures. Of the 38 reported injuries in women, 2 (5%) were concussions giving an incidence of 4.7 (95% CI 0.6–17.0)/1000 female-athlete-exposures	N/A

CI = confidence interval; N/A = the study did not address risk factors or did not provide explicit results for MTBI; PTA = post-traumatic amnesia; LOC = loss of consciousness.

Table XVIII. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in Nordic sports*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Wright et al., 1986 (123)	Ski jumpers at Lake Placid, New York, over the 5-year period of 1980–85. Number of jumps and jumpers not available	All injuries occurring during competition and training	No explicit definition for concussion	Of the 72 injuries reported, 7 (10%) were concussions, and only 2 of these required overnight hospital observation	N/A
Sahlin, 1989 (125)	Skiers in Trondheim, Norway, during the winter of 1985–86. The Trondheim region has only 1 hospital that serves a population of 610,000 inhabitants	All skiing injuries seen as inpatients or outpatients at the Trondheim University Hospital	Injury defined as an occurrence that required medical care. No explicit definition of concussion	Of the 347 injuries recorded in 339 patients, 11 (3%) were concussions	N/A
Cummings et al., 1997 (124)	1,043 luge athletes that took 57,244 runs at the Olympic Training Center at Lake Placid, New York, for the years 1985–92	All athletes taking luge runs at the centre	No explicit definition of concussion. Either trainers or physicians examined all injuries	Of the 407 injuries reported, 10 (2.5%) were concussions, giving an incidence of 0.17 (95% CI 0.08–0.32)/1000 runs	N/A

N/A = the study did not address risk factors or did not provide explicit results for MTBI; CI = confidence interval.

Table XIX. *Studies of the incidence and risk of mild traumatic brain injury (MTBI) in other leisure activities*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Smith & Middaugh, 1986 (128)	Alaska in 1983 and 1984 (population not given)	All hospitalizations for ATV-related injuries	ICD-9 codes used to classify injuries, but MTBI not defined	Of 320 hospitalizations for ATV-related injuries, 33 (10%) were concussions	N/A
McGhee et al., 1987 (129)	Patients served by the Head Injury Unit at Edinburgh Royal Infirmary over a 5-year period from May 1980 to April 1985 (South East Scotland, population 1.2 million)	Patients admitted to the hospital's Head Injury Unit with head injury related to horse riding	MTBI defined by GCS 13–15	Of a total of 59 head-injured patients (85% female), 56 had MTBI	N/A
Cardoso & Pyper, 1989 (127)	The 2 largest cities in Manitoba, Canada, with a total population of 659,529, or 62.5% of Manitoba's total population. Study took place from April 1979 to August 1986	Children, up to 15 years of age, admitted to 1 of 8 acute-care hospitals that manage paediatric trauma, with head injury associated with off-road vehicle collisions (minibikes, snowmobiles and ATVs)	Head injury classified by GCS (only recorded in 13) and LOC	Of the 83 off-road vehicle head injuries admitted, 50 suffered LOC, which lasted only seconds in 14 and minutes in 30	N/A
Chalmers et al., 1994 (126)	New Zealand population during 1979–88 (population 3.5 million)	National hospital discharge data on trampoline injuries. Hospital readmissions were excluded	Injuries defined by ICD-N codes. No explicit definition for MTBI	Of 2,098 injuries recorded, 118 (6%) were coded as concussions	N/A

ICD-N = International Classification of Diseases (Nature of Injury); N/A = the study did not address risk factors or did not provide explicit results for MTBI; ATV = all-terrain vehicle; GCS = Glasgow Coma Scale; LOC = loss of consciousness; ICD-9 = International Classification of Diseases (9th edn).

With respect to sports-related concussions, some studies include injuries that occur during games and practices, but do not produce separate incidence rates for these activities. This is a problem, since in many sports the incidence rate for concussions is much higher during games than practices (98, 106, 111, 115). Many incidence studies of concussion in sports define all injuries, including concussions, by an inability to continue play. This definition would vary depending on the threshold of the athletes to continue after injury, or even the threshold of the coaching and training staff for the same.

Despite the foregoing limitations of the studies that we present in our Tables, there are some important conclusions that we can make from this literature. In most studies, MTBI represents between 70% and 90% of all adult TBI cases treated at hospital ER and/or admitted to hospitals, giving incidence rates that vary from about 100 to 300/100,000 adults at risk (Tables I–IV). The incidence of hospital-treated cases seems to be slightly lower in the USA than elsewhere, but this could be due to different definitions of cases and varying inclusion/exclusion criteria for studies, or different hospital admission policies. Two studies, 1 from northern Sweden (33) and 1 from Auckland, New Zealand (42), reported much higher incidence rates for hospital-treated MTBI, at 718/100,000 and 782/100,000, respectively. The reason for these higher rates is not clear. However, 2 high-quality national household surveys from the US showed that the incidence of self- or proxy-reported TBI was more than 600/100,000 and that most cases could be considered MTBI, in that many did not seek medical care and less than 25% were admitted to hospital (15, 18). These findings suggest that the incidence of adult MTBI is much higher than most studies report, and is highly dependent on the method of case definition and ascertainment. There is good evidence that the incidence of MTBI is mostly underestimated when rates are based on those presenting to hospitals.

Of the 27 accepted studies of the incidence of MTBI in adults, only 13 addressed risk factors. Of these, 9 reported crude associations (phase I studies) and the other 4 reported associations from stratified or exploratory multivariable analyses (phase II studies). There were no confirmatory phase III studies. Thus, we have limited information on risk factors for adult MTBI. Nevertheless, these studies do consistently suggest that the risk for MTBI is greater for males and higher in teenage and young adults (Tables I–IV). There is also some evidence that the risk might be greater in African-Americans than Caucasians in the USA, but this relationship is likely confounded by socio-economic status, or other risk factors (11, 16, 28). For example, 1 study of active duty US army personnel showed that white men and women aged 18–24 years had a greater risk for MTBI than their African-American counterparts (30). This suggests that ethnic risk factors are confounded by other determinants. Several studies report that MTBI is mostly caused by motor-vehicle collisions and falls (20, 37, 41, 43).

We have very limited information on paediatric MTBI (Tables V and VI). For the most part, 80–90% of treated paediatric head injuries are mild (49, 51, 54, 56, 57), but there is

Table XX. *Incidence and risk of mild traumatic brain injury (MTBI) in US high-school athletes (98)*

Study	Source population	Inclusion/exclusion criteria	Case definitions	Incidence	Risk factors
Powell & Barber-Foss, 1999 (98)	NATA database over the 3 years of 1995–97	246 of 350 trainers gave data on 10 high-school sports	A reportable injury caused cessation of participation in current game or practice or on the next day. MTBI was identified by certified athletic trainers (explicit definition not given)		
American football injuries		Documenting 21,122 male athlete-seasons of football. Includes games and practice sessions		A total of 773 MTBI cases gave incidence rates of 0.25 (95% CI 0.16–0.34)/1000 athlete-practice-exposures and 2.82 (95% CI 2.58–3.07) athlete-game-exposures. There were 4 cases of subdural haematoma and 2 cases of intracerebral bleeding reported over the 3 seasons	Phase I: RR = 11 (95% CI 10–13) for games vs practice sessions. The highest injury rates/100 team-game positions were for the quarterback (1.3), followed by the running backs (0.74) and linebackers (0.52)
Soccer injuries		Documenting 7,539 male athlete-seasons and 5,642 female athlete-seasons of soccer. Includes games and practice sessions		For boys, 69 MTBIs gave an incidence of 0.04 (95% CI 0.01–0.06)/1000 practice-exposures and 0.57 (95% CI 0.43–0.72) game-exposures. For girls, 76 MTBIs gave an incidence of 0.05 (95% CI 0.02–0.08)/1000 practice-exposures and 0.71 (95% CI 0.53–0.88) game-exposures	Phase I: RR = 16.2 (95% CI 9.9–26.6) for games vs practice sessions in boys. RR = 14.4 (95% CI 9.0–23.0) for games vs practice sessions in girls. MTBI most often occurred from collisions while heading the ball for both boys and girls
Basketball injuries		Documenting 6,831 male athlete-seasons and 6,083 female athlete-seasons of basketball. Includes games and practice sessions		For boys, 51 MTBIs gave an incidence of 0.06 (95% CI 0.03–0.08)/1000 practice-exposures and 0.28 (95% CI 0.18–0.38) game-exposures. For girls, 63 MTBIs gave an incidence of 0.07 (95% CI 0.04–0.10)/1000 practice-exposures and 0.42 (95% CI 0.29–0.54) game-exposures	Phase I: RR = 4.9 (95% CI 2.9–8.1) for games vs practice sessions in boys. RR = 6.1 (95% CI 3.8–9.7) for games vs practice sessions in girls. MTBI was more common in girls and more common during games. Collision between players was the most common cause of MTBI in boys and girls
Baseball (boys) and softball (girls) injuries		Documenting 6,502 male athlete-seasons and 5,435 female athlete-seasons of baseball (boys) and softball (girls). Includes games and practice sessions		For boys, 15 MTBIs gave an incidence of 0.03 (95% CI 0.01–0.05)/1000 practice-exposures and 0.12 (95% CI 0.04–0.19) game-exposures. For girls, 25 MTBIs gave an incidence of 0.08 (95% CI 0.04–0.12)/1000 practice-exposures and 0.13 (95% CI 0.05–0.22) game-exposures	Phase I: RR = 4.5 (95% CI 1.76–11.5) for games vs practice sessions in boys. RR = 1.6 (95% CI 0.70–3.5) for games vs practice sessions in girls. MTBI was more common in girls and more common during games. Collision between players was the most common cause of MTBI in boys and girls.
Wrestling injuries		Documenting 8,117 male athlete-seasons of wrestling		For boys, 128 MTBIs gave an incidence of 0.17 (95% CI 0.13–0.21)/1000 practice-exposures and 0.51 (95% CI 0.38–0.64) game-exposures	Phase I: RR = 3.1 (95% CI 2.2–4.2) for match vs practice sessions in boys. Although 53% of the MTBI occurred during practice, the rate/1000 exposures was 3 times greater during matches
Field hockey injuries		Documenting 2,805 female athlete-seasons of field hockey		For girls, 13 MTBIs gave an incidence of 0.02 (95% CI 0–0.05)/1000 practice-exposures and 0.29 (95% CI 0.12–0.46) game-exposures	Phase I: RR = 14.4 (95% CI 4.6–44.9) for games vs practice sessions in girls. The rate/1000 exposures was 14 times greater during games
Volleyball injuries		Documenting 4,222 female athlete-seasons of volleyball		For girls, 6 MTBIs gave an incidence of 0.02 (95% CI 0–0.05)/1000 practice-exposures and 0.01 (95% CI 0–0.03) game-exposures	Phase I: RR = 0.5 (95% CI 0.09–2.48) for games vs practice sessions in girls. The rate/1000 exposures was greater during practice and 3 of the 6 concussions were caused by collision with the ball

NATA = National Athletic Trainers' Association; CI = confidence interval; RR = relative risk.

Table XXI. *Studies of the incidence and risk of second impact syndrome (SIS)*

Study	Source population	Inclusion/exclusion criteria*	Case definitions	Incidence	Risk factors
McCrory & Berkovic, 1998 (130)	Case reports of SIS from Medline, Embase, Sport Discus and personal contact with experts	All published case reports of SIS. Medline was searched from 1966 to 1996 and Sport Discus from 1975 to 1996. Reports of the US National Catastrophic Injury Registry were also considered. Key search terms included concussion, brain injury, head injury, head trauma, brain trauma, sports injury, brain swelling, cerebral oedema, SIS and brain commotion	SIS is diffuse cerebral swelling with delayed catastrophic deterioration (death due to increased intracranial pressure) after a second concussion before symptoms of the first concussion have resolved	Results based on 17 published reports of SIS. No denominator available to calculate incidence rate. Of the 17 reports only 5 satisfied the authors' criteria for probable SIS	Phase I: the 5 probable cases of SIS were males aged 16–19 years. They included 3 boxers, 1 ice-hockey player and 1 American football player. The second impact occurred between 6 hours and 7 days after the first concussion in these cases. All cases developed cerebral oedema

*Additional information obtained directly from author.

limited information on the incidence rate. One study of children aged 0–14 years showed that the incidence of hospital-admitted TBI in Denmark decreased from 430/100,000 in 1979 to 240/100,000 in 1993, and that the majority (88% for boys and 90% for girls) of these injuries were coded as ICD- 850 (concussion) (54). Only 3 of the 11 accepted paediatric studies looked at risk factors for MTBI, and all of these were phase I studies of crude relationships. Two studies showed an elevated risk for boys compared with girls (RR 1.5–2) (47, 56). One study showed an increased risk for older children compared with the very young (51), and another study showed that sports and recreational equipment were the main cause of injury in older children (48). Given the sparse literature on the incidence and risk of paediatric MTBI, there is important and immediate need for more studies (132).

There is little doubt that head injury is an important consequence of many motorcycle collisions. With respect to MTBI, the accepted studies indicate that about 30–40% of hospital-admitted, motorcycle-related TBI is mild (60, 62). We also found strong evidence (phase III studies) that the use of a motorcycle helmet cuts the risk of brain injury by half (63, 65). Furthermore, we accepted 2 studies that convincingly showed that the implementation of legislation for mandatory motorcycle helmet use increased the number of helmeted motorcyclists (65, 67), decreased the number of hospital-treated head injuries (65), decreased the severity of motor-cycle-related TBI (64) and decreased the risk of future impairment from head injury (66). Our task force strongly recommends such legislation for all jurisdictions.

Like motorcyclists, bicyclists are also at risk for head injury. Our task force accepted as evidence 19 studies dealing with this issue (Tables IX–XII). These results are similar to those dealing with motorcycle-related head injury. About 80–90% of hospital-treated, bicycle-related head injuries are mild (25, 69, 72). We accepted 2 studies that showed convincing evidence (phase III) that helmets substantially reduce the risk of bicycle-related TBI (75, 76), and 1 meta-analysis that showed helmets reduce this risk by more than half (77). We also accepted several ecologic studies that suggest that educational interventions can increase bicycle helmet use in children, and this was confirmed by a randomized controlled trial (Table XI). Three accepted studies also showed that mandatory bicycle-helmet legislation increases helmet use and reduces hospital admissions for head injury (Table XII). This task force strongly recommends that both education and mandatory bicycle-helmet legislation be adopted in all jurisdictions.

Recreational and sporting activities can lead to head injury, and our task force accepted studies addressing this issue in rugby, American football, soccer, ice hockey, fighting sports (boxing, karate and taekwondo), Nordic sports (skiing, ski jumping and luge), leisure activities (trampoline jumping, all-terrain vehicle riding and horse-back riding) and several other sports as reported by high-school athletes (basketball, baseball, softball, wrestling, field hockey and volleyball) (Tables XIII–XX). As previously mentioned, many of these studies provided exact denominator information of person-time at risk, which allowed the presentation of incidence density rates (e.g. concussions per 1000 athlete-game-hours or per 1000 athlete-exposures). On the other hand, many of the studies did not have an explicit definition of MTBI or concussion, stating only that the injury was defined as causing cessation of play or was diagnosed by medical or training staff. In addition, the inclusion/exclusion criteria of these studies differed, with different levels of play (practice/games, amateur/professional, male/female, children/adults). In general, the injury rates were lower for practice, in amateurs, in women and in children. Therefore, it is important to stratify the results by these factors.

With respect to rugby, studies of Australian men's league play yield fairly consistent estimates of concussions within the range of 1.6–3/1000 athlete-game-hours (86, 89). Other rugby studies from the UK yield highly variable rates from 0.6 to 8/1000 athlete-game-hours (91, 94). For American college and high-school males playing American football, concussion rates varied from 1.3 to 3.3/1000 athlete-game-exposures (99, 103). For soccer, 1 US study gave a rate of 1.3 concussions/1000 athlete-game-hours for males aged 12 to over 25 years of age (104). The concussion rate for young males playing Canadian college ice hockey was reported at 1.5/1000 athlete-game-hours (109), but was much higher in the Swedish elite league for men at 6.5/1000 athlete-game-hours (111). For fighting sports, the rate of concussion for senior men competing in taekwondo championships varied from 7 to 15.5/1000 athlete-exposures (120, 121) and was 2.5–9/1000 athlete-exposures for women (120, 121). These findings suggest that rates for rugby, American football, soccer and hockey are similar, and that taekwondo has the highest risk of concussion among these sports. However, there is a lack of studies of the rate of concussion from professional soccer, American professional football, and professional hockey. Our task force was surprised by this lack of published information, since concussions in American professional football and hockey have been the topic of much media attention and speculation in North America. Furthermore, there is also a surprising lack of published information on the risk of concussion during professional boxing. Our task force recommends that studies of the incidence of concussions in these sports be undertaken as soon as possible, given the potential health risks to participants (132).

With respect to high-school sports, the risk of concussion per athlete-game-exposure in boys is 2.8 for American football, 0.6 for soccer, 0.5 for wrestling, 0.3 for basketball and 0.1 for baseball. For girls, the risk of concussion per athlete-game-exposure is 0.7 for soccer, 0.4 for basketball, 0.3 for field hockey, 0.1 for softball and 0.01 for volleyball. These rates are based on 1 high-quality study (98) and we recommend more studies to corroborate these findings.

There have been several case reports of athletes dying due to rapid development of increased intracranial pressure after a second concussive impact that occurs before an athlete has recovered from an initial concussion. Our task force considered this issue, also known as second impact syndrome (SIS). Most of these cases have been reported in young males playing American football and hockey, or during boxing. All of them are from North America, and these reports prompted the Centers for Disease Control to publish guidelines, developed by the American Academy of Neurology, on the management of concussions in sports to try to prevent SIS (133). Our task force reviewed these cases and accepted 1 study that systematically reviewed this issue and the published cases (130). Based on this evidence, we agree with McCrory & Berkovic (130) that the evidence that a second concussion increases the risk for diffuse cerebral swelling and death is not well established. However, death from diffuse cerebral swelling does occur in rare cases of MTBI, and the risk of repeated concussion can be elevated in some individuals, whether due to position played (i.e. quarterback in American football) or other unknown factors. Therefore, we recommend continued surveillance to document cases and further studies of risk factors for death after MTBI or concussion.

CONCLUSION

The literature on the incidence, risk and prevention of MTBI is very heterogeneous, which limits our ability to draw consistent conclusions. Variations in the definition of MTBI, difficulties defining the population at risk in the studies and variable inclusion/exclusion criteria are all significant problems in summarizing the study results. Given these limitations, we estimate that MTBI represents between 70% and 90% of all treated TBI, and that the rate of hospital-treatment in adults with MTBI ranges from about 100 to 300/100,000. We also accept that that a large number of MTBI cases are not treated at hospitals and that the actual rate of all MTBI is probably in excess of 600/100,000. We also accept that men have about twice the risk of women for MTBI and that the risk is greatest in teenagers and young adults. The data also suggests that motor-vehicle collisions and falls are the main causes of MTBI. We also accept that motorcycle and bicycle helmets can prevent some MTBI, and that mandatory helmet legislation and educational strategies on helmet use are important for prevention. Finally, there is evidence that MTBI or concussion is a concern in some sporting activities, especially in competition taekwondo. However, there is a striking lack of studies of the incidence of MTBI in American profession football, hockey and boxing. The reason for this is not clear, given the media attention and reports of concussions ending the careers of professional athletes in these sports. There is an obvious need for studies of the incidence of concussion in these sports.

Finally, incidence studies are an important source of information. The incidence rate gives us information on the frequency of MTBI and allows the determination of risk factors that can guide prevention strategies for those at risk. When incident cases are followed over time, information on prognosis can also be determined, which also guides treatment and health-care resource allocations. This paper summarizes the MTBI literature on incidence, risk and prevention, draws conclusions about MTBI based on this literature and highlights some strengths and weakness in this information. It provides a baseline of knowledge on these topics, which can guide future research endeavours (132).

ACKNOWLEDGEMENTS

We acknowledge Dr Richard W. Sattin of the National Center for Injury Prevention and Control at the Centers for Disease Control and Prevention in Atlanta, Georgia, for his thoughtful review of this paper.

This work was supported by a grant from Saskatchewan Government Insurance, Canada; the Insurance Corporation of British Columbia, Canada; La Société de l'assurance automobile du Québec, Canada; AFA Insurance, Sweden; Folksam Insurance, Sweden; the Volvo Car Company, Sweden; and Trygg-Hansa, Sweden. Drs Cassidy and Carroll are supported by Health Scholar Awards from the Alberta Heritage Foundation for Medical Research.

REFERENCES

1. Thurman DJ, Alverson C, Dunn KA, Guerrero J, Sniezek JE. Traumatic brain injury in the United States: a public health perspective. J Head Trauma Rehabil 1999; 14: 602–615.
2. Kraus JF. Epidemiology of head injury. In: Cooper PR, ed. Head injury. 3rd edn. Baltimore: Williams & Wilkins; 1993, p. 1–25.
3. Slavin RE. Best evidence synthesis: an alternative to meta-analytic and traditional reviews. Educational Researcher 1986; 15: 5–11.
4. Slavin RE. Best evidence synthesis: an intelligent alternative to meta-analysis. J Clin Epidemiol 1995; 48: 9–18.
5. Carroll LJ, Cassidy JD, Peloso PM, Garritty C, Giles-Smith L. Systematic search and review procedures: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004; (suppl 43): 11–14.
6. von Holst H, Cassidy JD. Mandate of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004; (suppl 43): 8–10.
7. Côté P, Cassidy JD, Carroll LJ, Frank JW, Bombardier C. A systematic review of the prognosis of acute whiplash and a new conceptual framework to synthesize the literature. Spine 2001; 26: E445–E458.
8. Spitzer WO, Skovron ML, Salmi LR, Cassidy JD, Duranceau J, Suissa S, et al. Scientific monograh of the Quebec Task Force on Whiplash-Associated Disorders: redefining "whiplash" and its management [erratum appears in Spine 1995 Nov 1; 20: 2372]. Spine 1995; 20(suppl 8): 1 S–73S.
9. Altman DG. Methodological challenges in the evaluation of prognostic factors in breast cancer. Breast Cancer Res Treat 1998; 52: 289–303.
10. Carroll LJ, Cassidy JD, Peloso PM, Borg J, von Holst H, Holm L, et al. Prognosis for mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004(suppl 43): 84–105.
11. Kraus JF, Fife D, Ramstein K, Conroy C, Cox P. The relationship of family income to the incidence, external causes, and outcomes of serious brain injury, San Diego County, California. Am J Public Health 1986; 76: 1345–1347.
12. Stata/SE [computer program]. Version 8. College Station (TX): Stata Corporation; 2003.
13. Cassidy JD, Carroll LJ, Côté P, Holm L, Nygren Å. Mild traumatic brain injury after traffic collisions: a population-based cohort study. J Rehabil Med 2004; (suppl 43): 15–21.
14. Peloso PM, von Holst H, Borg J. Mild traumatic brain injuries presenting to hospitals in Sweden during the years 1987 to 2000. J Rehabil Med 2004; (suppl 43): 22–27.
15. Fife D. Head injury with and without hospital admission: comparisons of incidence and short-term disability. Am J Public Health 1987; 77: 810–812.
16. Jager TE, Weiss HB, Coben JH, Pepe PE. Traumatic brain injuries evaluated in U.S. emergency departments, 1992–1994. Acad Emerg Med 2000; 7: 134–140.
17. Kalsbeek WD, McLaurin RL, Harris BS, Miller JD. The National Head and Spinal Cord Injury Survey: major findings. J Neurosurg 1980; (suppl S19–S31).
18. Sosin DM, Sniezek JE, Thurman DJ. Incidence of mild and moderate brain injury in the United States, 1991. Brain Inj 1996; 10: 47–54.
19. Thurman D, Guerrero J. Trends in hospitalization associated with traumatic brain injury. JAMA 1999; 282: 954–957.
20. MacKenzie EJ, Edelstein SL, Flynn JP. Hospitalized head-injured patients in Maryland: incidence and severity of injuries. Md Med J 1989; 38: 725–732.
21. Thurman DJ, Jeppson L, Burnett CL, Beaudoin DE, Rheinberger MM, Sniezek JE. Surveillance of traumatic brain injuries in Utah. West J Med 1996; 165: 192–196.
22. Annegers JF, Grabow JD, Kurland LT, Laws ER, Jr. The incidence, causes, and secular trends of head trauma in Olmsted County, Minnesota, 1935–1974. Neurology 1980; 30: 912–919.
23. Kraus JF, Black MA, Hessol N, Ley P, Rokaw W, Sullivan C, et al. The incidence of acute brain injury and serious impairment in a defined population. Am J Epidemiol 1984; 119: 186–201.
24. Kraus JF, Fife D. Incidence, external causes, and outcomes of work-related brain injuries in males. J Occup Med 1985; 27: 757–760.
25. Kraus JF, Fife D, Conroy C. Incidence, severity, and outcomes of brain injuries involving bicycles. Am J Public Health 1987; 77: 76–8.
26. Kraus JF, Nourjah P. The epidemiology of mild, uncomplicated brain injury. J Trauma 1988; 28: 1637–1643.
27. Kraus JF, Morgenstern H, Fife D, Conroy C, Nourjah P. Blood alcohol tests, prevalence of involvement, and outcomes following brain injury. Am J Public Health 1989; 79: 294–99.
28. Whitman S, Coonley HR, Desai BT. Comparative head trauma experiences in two socioeconomically different Chicago-area communities: a population study. Am J Epidemiol 1984; 119: 570–580.
29. McCarroll JE, Zych KA. Descriptive epidemiologic survey of head injury in the Army: 1983 hospitalized cases. Neuroepidemiology 1989; 8: 48–52.
30. McCarroll JE, Gunderson C. 5-year study of incidence rates of hospitalized cases of head injuries in the US Army. Neuroepidemiology 1990; 9: 296–305.
31. Ommaya AK, Dannenberg AL, Salazar AM. Causation, incidence, and costs of traumatic brain injury in the U.S. military medical system. J Trauma 1996; 40: 211–217.
32. Boström L. Injury panorama and medical consequences for 1158 persons assaulted in the central part of Stockholm, Sweden. Arch Orthop Trauma Surg 1997; 116: 315–320.
33. Bring G, Björnstig U, Westman G. Gender patterns in minor head and neck injuries: an analysis of casualty register data. Accid Anal Prev 1996; 28: 359–369.
34. Johansson E, Rönnkvist M, Fugl-Meyer AR. Traumatic brain injury in northern Sweden. Incidence and prevalence of long-standing impairments and disabilities. Scand J Rehabil Med 1991; 23: 179–185.
35. Britton M, Borg J, Colliander M, Ericson A, af Geijerstam J-L, Marké L-Å, et al. Concussion; observation at hospital or computer tomography and discharged home? The Swedish Council on Technology Assessment in Health Care (SBU) 2000; Report no. 153.
36. Nestvold K, Lundar T, Blikra G, Lonnum A. Head injuries during one year in a central hospital in Norway: a prospective study. Epidemiologic features. Neuroepidemiology 1988; 7: 134–144.
37. Ingebrigtsen T, Mortensen K, Romner B. The epidemiology of hospital-referred head injury in northern Norway. Neuroepidemiology 1998; 17: 139–146.

38. Nell V, Brown DS. Epidemiology of traumatic brain injury in Johannesburg–II. Morbidity, mortality and etiology. Soc Sci Med 1991; 33: 289–296.
39. Servadei F, Ciucci G, Piazza G, Bianchedi G, Rebucci G, Gaist G, et al. A prospective clinical and epidemiological study of head injuries in northern Italy: the Comune of Ravenna. Ital J Neurol Sci 1988; 9: 449–457.
40. Vázquez-Barquero A, Vázquez-Barquero JL, Austin O, Pascual J, Gaite L, Herrera S. The epidemiology of head injury in Cantabria. Eur J Epidemiol 1992; 8: 832–837.
41. Tiret L, Hausherr E, Thicoipe M, Garros B, Maurette P, Castel JP, et al. The epidemiology of head trauma in Aquitaine (France), 1986: a community-based study of hospital admissions and deaths. Int J Epidemiol 1990; 19: 133–140.
42. Wrightson P, Gronwall D. Mild head injury in New Zealand: incidence of injury and persisting symptoms. N Z Med J 1998; 111: 99–101.
43. Tate RL, McDonald S, Lulham JM. Incidence of hospital-treated traumatic brain injury in an Australian community. Aust N Z J Public Health 1998; 22: 419–423.
44. Chiu WT, Yeh KH, Li YC, Gan YH, Chen HY, Hung CC. Traumatic brain injury registry in Taiwan. Neurol Res 1997; 19: 261–264.
45. Centers for Disease Control and Prevention. Playground-related injuries in preschool-aged children–United States, 1983–1987. Morb Mortal Wkly Rep 1988; 37: 629–632.
46. Briss PA, Sacks JJ, Addiss DG, Kresnow M, O'Neil J. A nationwide study of the risk of injury associated with day care center attendance. Pediatrics 1994; 93: 364–368.
47. Rivara FP, Bergman AB, LoGerfo JP, Weiss NS. Epidemiology of childhood injuries: II. Sex differences in injury rates. Am J Dis Child 1982; 136: 502–506.
48. Rivara FP. Childhood injuries. III: epidemiology of non-motor vehicle head trauma. Dev Med Child Neurol 1984; 26: 81–87.
49. Kraus JF, Fife D, Cox P, Ramstein K, Conroy C. Incidence, severity, and external causes of pediatric brain injury. Am J Dis Child 1986; 140: 687–693.
50. Kraus JF, Fife D, Conroy C. Pediatric brain injuries: the nature, clinical course, and early outcomes in a defined United States' population. Pediatrics 1987; 79: 501–507.
51. Durkin MS, Olsen S, Barlow B, Virella A, Connolly ES, Jr. The epidemiology of urban pediatric neurological trauma: evaluation of, and implications for, injury prevention programs. Neurosurgery 1998; 42: 300–310.
52. Osberg JS, Di Scala C. Morbidity among pediatric motor vehicle crash victims: the effectiveness of seat belts. Am J Public Health 1992; 82: 422–425.
53. Langley JD, Silva PA. Injuries in the eighth and ninth years of life. Aust Paediatr J 1985; 21: 51–55.
54. Engberg A, Teasdale TW. Traumatic brain injury in children in Denmark: a national 15-year study. Eur J Epidemiol 1998; 14: 165–173.
55. Levi L, Guilburd JN, Linn S, Feinsod M. The association between skull fracture, intracranial pathology and outcome in pediatric head injury. Br J Neurosurg 1991; 5: 617–625.
56. Arnarson EÖ, Halldórsson JG. Head trauma among children in Reykjavik. Acta Paediatr 1995; 84: 96–99.
57. Goh KY, Poon WS. Children's head injuries in the Vietnamese refugee population in Hong Kong. Injury 1995; 26: 533–536.
58. Adesunkanmi AR, Oginni LM, Oyelami OA, Badru OS. Road traffic accidents to African children: assessment of severity using the injury severity score (ISS). Injury 2000; 31: 225–228.
59. Kelly P, Sanson T, Strange G, Orsay E. A prospective study of the impact of helmet usage on motorcycle trauma. Ann Emerg Med 1991; 20: 852–856.
60. Orsay E, Holden JA, Williams J, Lumpkin JR. Motorcycle trauma in the state of Illinois: analysis of the Illinois Department of Public Health Trauma Registry. Ann Emerg Med 1995; 26: 455–460.
61. Braddock M, Schwartz R, Lapidus G, Banco L, Jacobs L. A population-based study of motorcycle injury and costs. Ann Emerg Med 1992; 21: 273–278.
62. Mätzsch T, Karlsson B. Moped and motorcycle accidents – similarities and discrepancies. J Trauma 1986; 26: 538–543.
63. Tsai YJ, Wang JD, Huang WF. Case-control study of the effectiveness of different types of helmets for the prevention of head injuries among motorcycle riders in Taipei, Taiwan. Am J Epidemiol 1995; 142: 974–981.
64. Kraus JF, Peek C, McArthur DL, Williams A. The effect of the 1992 California motorcycle helmet use law on motorcycle crash fatalities and injuries. JAMA 1994; 272: 1506–1511.
65. Kraus JF, Peek C. The impact of two related prevention strategies on head injury reduction among nonfatally injured motorcycle riders, California, 1991–1993. J Neurotrauma 1995; 12: 873–881.
66. Peek-Asa C, Kraus JF. Estimates of injury impairment after acute traumatic injury in motorcycle crashes before and after passage of a mandatory helmet use law. Ann Emerg Med 1997; 29: 630–636.
67. Chiu WT, Kuo CY, Hung CC, Chen M. The effect of the Taiwan motorcycle helmet use law on head injuries. Am J Public Health 2000; 90: 793–796.
68. Björnstig U, Ostrom M, Eriksson A, Sonntag OE. Head and face injuries in bicyclists – with special reference to possible effects of helmet use. J Trauma 1992; 33: 887–893.
69. Belongia E, Weiss H, Bowman M, Rattanassiri P. Severity and types of head trauma among adult bicycle riders. Wis Med J 1988; 87: 11–14.
70. Li G, Baker SP, Fowler C, DiScala C. Factors related to the presence of head injury in bicycle-related pediatric trauma patients. J Trauma 1995; 38: 871–875.
71. Sacks JJ, Holmgreen P, Smith SM, Sosin DM. Bicycle-associated head injuries and deaths in the United States from 1984 through 1988. How many are preventable? JAMA 1991; 266: 3016–3018.
72. O'Rourke NA, Costello F, Yelland JD, Stuart GG. Head injuries to children riding bicycles. Med J Aust 1987; 146: 619–621.
73. Linn S, Smith D, Sheps S. Epidemiology of bicycle injury, head injury, and helmet use among children in British Columbia: a five year descriptive study. Canadian Hospitals Injury, Reporting and Prevention Program (CHIRPP). Inj Prev 1998; 4: 122–125.
74. McDermott FT, Lane JC, Brazenor GA, Debney EA. The effectiveness of bicyclist helmets: a study of 1710 casualties. J Trauma 1993; 34: 834–844.
75. Thomas S, Acton C, Nixon J, Battistutta D, Pitt WR, Clark R. Effectiveness of bicycle helmets in preventing head injury in children: case-control study. BMJ 1994; 308: 173–176.
76. Thompson RS, Rivara FP, Thompson DC. A case-control study of the effectiveness of bicycle safety helmets. N Engl J Med 1989; 320: 1361–1367.
77. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. Accid Anal Prev 2001; 33: 345–352.
78. DiGuiseppi CG, Rivara FP, Koepsell TD, Polissar L. Bicycle helmet use by children. Evaluation of a community-wide helmet campaign. JAMA 1989; 262: 2256–2261.
79. Parkin PC, Spence LJ, Hu X, Kranz KE, Shortt LG, Wesson DE. Evaluation of a promotional strategy to increase bicycle helmet use by children. Pediatrics 1993; 91: 772–777.
80. Weiss BD. Trends in bicycle helmet use by children: 1985 to 1990. Pediatrics 1992; 89: 78–80.
81. Hendrickson SG, Becker H. Impact of a theory-based intervention to increase bicycle helmet use in low income children. Inj Prev 1998; 4: 126–131.
82. Shafi S, Gilbert JC, Loghmanee F, Allen JE, Caty MG, Glick PL, et al. Impact of bicycle helmet safety legislation on children admitted to a regional pediatric trauma center. J Pediatr Surg 1998; 33: 317–321.
83. Macpherson AK, To TM, Macarthur C, Chipman ML, Wright JG, Parkin PC. Impact of mandatory helmet legislation on bicycle-related head injuries in children: a population-based study. Pediatrics 2002; 110: 60.
84. Dannenberg AL, Gielen AC, Beilenson PL, Wilson MH, Joffe A. Bicycle helmet laws and educational campaigns: an evaluation of strategies to increase children's helmet use. Am J Public Health 1993; 83: 667–674.
85. Dicker G, McColl D, Sali A. The incidence and nature of Australian Rules football injuries. Aust Fam Physician 1986; 15: 455–459.
86. Gibbs N. Injuries in professional rugby league. A three-year prospective study of the South Sydney Professional Rugby League Football Club. Am J Sports Med 1993; 21: 696–700.

87. McCrory PR, Ariens T, Berkovic SF. The nature and duration of acute concussive symptoms in Australian football. Clin J Sport Med 2000; 10: 235–238.
88. McMahon KA, Nolan T, Bennett CM, Carlin JB. Australian Rules football injuries in children and adolescents. Med J Aust 1993; 159: 301–306.
89. Myers PT. Injuries presenting from rugby union football. Med J Aust 1980; 2: 17–20.
90. Seward H, Orchard J, Hazard H, Collinson D. Football injuries in Australia at the elite level. Med J Aust 1993; 159: 298–301.
91. Garraway M, Macleod D. Epidemiology of rugby football injuries. Lancet 1995; 345: 1485–1487.
92. Gissane C, Jennings DC, Cumine AJ, Stephenson SE, White JA. Differences in the incidence of injury between rugby league forwards and backs. Aust J Sci Med Sport 1997; 29: 91–94.
93. Lee AJ, Garraway WM. Epidemiological comparison of injuries in school and senior club rugby. Br J Sports Med 1996; 30: 213–217.
94. Stephenson S, Gissane C, Jennings D. Injury in rugby league: a four year prospective survey. Br J Sports Med 1996; 30: 331–334.
95. Bird YN, Waller AE, Marshall SW, Alsop JC, Chalmers DJ, Gerrard DF. The New Zealand rugby injury and performance project: V. Epidemiology of a season of rugby injury. Br J Sports Med 1998; 32: 319–325.
96. DeLee JC, Farney WC. Incidence of injury in Texas high school football. Am J Sports Med 1992; 20: 575–580.
97. Gerberich SG, Priest JD, Boen JR, Straub CP, Maxwell RE. Concussion incidences and severity in secondary school varsity football players. Am J Public Health 1983; 73: 1370–1375.
98. Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. JAMA 1999; 282: 958–963.
99. Buckley WE. Concussion injury in college football: an eight-year overview. Athl Training 1986; 21: 207–211.
100. Buckley WE. Concussions in college football. A multivariate analysis. Am J Sports Med 1988; 16: 51–56.
101. Meeuwisse WH, Hagel BE, Mohtadi NGH, Butterwick DJ, Fick GH. The distribution of injuries in men's Canada West university football: a 5-year analysis. Am J Sports Med 2000; 28: 516–523.
102. Zemper ED. Analysis of cerebral concussion frequency with the most commonly used models of football helmets. J Athl Train 1994; 29: 44–50.
103. Guskiewicz KM, Weaver NL, Padua DA, Garrett WE, Jr. Epidemiology of concussion in collegiate and high school football players. Am J Sports Med 2000; 28: 643–650.
104. Lindenfeld TN, Schmitt DJ, Hendy MP, Mangine RE, Noyes FR. Incidence of injury in indoor soccer. Am J Sports Med 1994; 22: 364–371.
105. Barnes BC, Cooper L, Kirkendall DT, McDermott TP, Jordan BD, Garrett WE, Jr. Concussion history in elite male and female soccer players. Am J Sports Med 1998; 26: 433–438.
106. Boden BP, Kirkendall DT, Garrett WE, Jr. Concussion incidence in elite college soccer players. Am J Sports Med 1998; 26: 238–241.
107. Benson BW, Mohtadi NG, Rose MS, Meeuwisse WH. Head and neck injuries among ice hockey players wearing full face shields vs half face shields. JAMA 1999; 282: 2328–2332.
108. Benson BW, Rose MS, Meeuwisse WH. The impact of face shield use on concussions in ice hockey: a multivariate analysis. Br J Sports Med 2002; 36: 27–32.
109. Pelletier RL, Montelpare WJ, Stark RM. Intercollegiate ice hockey injuries: a case for uniform definitions and reports. Am J Sports Med 1993; 21: 78–81.
110. Jørgensen U, Schmidt-Olsen S. The epidemiology of ice hockey injuries. Br J Sports Med 1986; 20: 7–9.
111. Tegner Y, Lorentzon R. Concussion among Swedish elite ice hockey players. Br J Sports Med 1996; 30: 251–255.
112. Roberts WO, Brust JD, Leonard B. Youth ice hockey tournament injuries: rates and patterns compared to season play. Med Sci Sports Exerc 1999; 31: 46–51.
113. Jordan BD, Campbell EA. Acute injuries among professional boxers in New York State: a two-year survey. Physician Sports Med 1988; 16: 87–91.
114. Porter M, O'Brien M. Incidence and severity of injuries resulting from amateur boxing in Ireland. Clin J Sport Med 1996; 6: 97–101.
115. Welch MJ, Sitler M, Kroeten H. Boxing injuries from an instructional program. Physician Sports Med 1986; 14: 81–89.
116. Critchley GR, Mannion S, Meredith C. Injury rates in Shotokan karate. Br J Sports Med 1999; 33: 174–177.
117. Stricevic MV, Patel MR, Okazaki T, Swain BK. Karate: historical perspective and injuries sustained in national and international tournament competitions. Am J Sports Med 1983; 11: 320–324.
118. Koh JO, de Freitas T, Watkinson EJ. Injuries at the 14th World Taekwondo Championships in 1999. Int J Appl Sports Sci 2001; 13: 33–48.
119. Pieter W, Lufting R. Injuries at the 1991 taekwondo World Championships. J Sports Traumatol Rel Res 1994; 16: 49–57.
120. Pieter W, van Ryssegem G, Lufting R. Injury situation and injury mechanism at the 1993 European Taekwondo Cup. J Hum Movement Stud 1995; 28: 1–24.
121. Pieter W, Zemper ED. Incidence of reported cerebral concussion in adult taekwondo athletes. J R Soc Health 1998; 118: 272–279.
122. Pieter W, Zemper ED. Head and neck injuries in young taekwondo athletes. J Sports Med Phys Fitness 1999; 39: 147–153.
123. Wright JR, Jr, Hixson EG, Rand JJ. Injury patterns in nordic ski jumpers. A retrospective analysis of injuries occurring at the Intervale Ski Jump Complex from 1980 to 1985. Am J Sports Med 1986; 14: 393–397.
124. Cummings RS, Jr, Shurland AT, Prodoehl JA, Moody K, Sherk HH. Injuries in the sport of luge. Epidemiology and analysis. Am J Sports Med 1997; 25: 508–513.
125. Sahlin Y. Alpine skiing injuries. Br J Sports Med 1989; 23: 241–244.
126. Chalmers DJ, Hume PA, Wilson BD. Trampolines in New Zealand: a decade of injuries. Br J Sports Med 1994; 28: 234–238.
127. Cardoso ER, Pyper A. Pediatric head injury caused by off-road vehicle accidents. Can J Neurol Sci 1989; 16: 336–339.
128. Smith SM, Middaugh JP. Injuries associated with three-wheeled, all-terrain vehicles, Alaska, 1983 and 1984. JAMA 1986; 255: 2454–2458.
129. McGhee CN, Gullan RW, Miller JD. Horse riding and head injury: admissions to a regional head injury unit. Br J Neurosurg 1987; 1: 131–135.
130. McCrory PR, Berkovic SF. Second impact syndrome. Neurology 1998; 50: 677–683.
131. Deb S. ICD-10 codes detect only a proportion of all head injury admissions. Brain Inj 1999; 13: 369–373.
132. Carroll LJ, Cassidy JD, Holm L, Kraus J, Coronado V. Methodological issues and research recommendations for mild traumatic brain injury: the WHO Collaborating Task Force on Mild Traumatic Brain Injury. J Rehabil Med 2004; (suppl 43): 113–125.
133. Centers for Disease Control and Prevention. Sports-related recurrent brain injuries–United States. Morb Mortal Wkly Rep 1997; 46: 224–227.
134. Nelson WE, Jane JA, Gieck JH. Minor head injury in sports: a new system of classification and management. Physician Sports Med 1984; 12: 103–107.