Epidemiology of Global Pediatric Traumatic Brain Injury: Qualitative Review

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Key words
- Epidemiology
- Global
- Pediatric
- Traumatic brain injury
- Worldwide

Abbreviations and Acronyms
CT: Computed tomography
ED: Emergency department
GCS: Glasgow Coma Scale
MVC: Motor vehicle collision
TBI: Traumatic brain injury

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BACKGROUND: **Traumatic brain injury (TBI) is a common condition affecting children all over the world, and it represents a global public health concern. It is unclear how geopolitical, societal, and ethnic differences may influence the nature of TBI among children.**

METHODS: **A comprehensive literature search was conducted incorporating studies with hospital-, regional-, or country-specific pediatric TBI epidemiology data published between 1995 and 2015. Incidence, age, severity, mechanism of injury, and other relevant injury characteristics were extracted and compared across diverse geographic regions.**

RESULTS: **Thirty articles met inclusion criteria, incorporating TBI data from more than 165,000 children on 5 continents. The worldwide incidence of pediatric TBI ranges broadly and varies greatly by country, with most reporting a range between 47 and 280 per 100,000 children. After the age of 3, male children suffered higher rates of TBI than females. A bimodal age distribution is often described, with very young children (0–2 years) and adolescents (15–18) more commonly injured. Mild TBI (Glasgow Coma Scale ≥13) constitutes more than 80% of injuries, and up to 90% of all injuries are associated with negative imaging. Only a small fraction (<10%) requires surgical intervention. Independent of country or region of origin, the vast majority of children suffering TBI achieve a good clinical outcome. Hospital admission rates vary widely, with U.S. patients more commonly admitted than those from other countries. Falls and motor vehicle collisions (MVCs) represent the majority of injury mechanisms. In Africa and Asia, pedestrians were most commonly injured in MVCs, while vehicle occupants were more likely involved among Australian, European, and U.S. populations. For children, nonaccidental trauma was prevalent in developing and developed nations alike.**

CONCLUSIONS: **TBI is a relatively common entity stretching across traditional geographic and demographic boundaries and affecting pediatric populations worldwide. Continued civil infrastructure development and public health policy reforms may help to reduce the societal burden of pediatric TBI.**

INTRODUCTION

Traumatic brain injury (TBI) is a broad and inclusive term designating a wide range of pathology that results from an external force to the cranium and underlying brain. TBI poses a significant health care concern from the time of initial insult until many years later when long-term sequelae may manifest. In the United States alone, an estimated 475,000 children aged 0–14 suffer a TBI each year.[1] TBI results in more than 7000 deaths, 60,000 hospitalizations, and 600,000 emergency department (ED) visits annually among American children.[1] Similarly, TBI affects the pediatric population worldwide. Studies have shown that TBI contributes to more than half of pediatric injuries in Iran, around 20% of trauma ED admissions in India, and around 30% of pediatric injuries in Korea.[2-4] Furthermore, TBI affects more than 486 adolescents per 100,000 people per year in Australia and approximately 280 children out of 100,000 people in the United Kingdom.[5,6] Compared with their adult counterparts, children suffering head injury warrant particular concern given the developmental consequences of early brain damage. Summing domestic data, Schneier et al.[7] identified TBI as the leading cause of child death and long-term disability and among the most frequent causes of interruption to normal child development.

Hundreds of reports from dozens of countries exist describing head injury in children, yet a general epidemiologic overview of the condition as it relates to the global population is lacking. In this review, we sought to synthesize the available data from around the world into a single, broad-reaching manuscript. Here, we report the largest and most comprehensive qualitative review of pediatric TBI to date.

METHODS

Our review was conducted in accordance with the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[8]

Since the study was an epidemiologic review, we did not test an a priori hypothesis nor were clinically significant treatment parameters or outcome differences sought from within target articles.

A comprehensive literature search was conducted using MEDLINE, EMBASE, and the Cochrane Database of Systematic reviews in August 2015. The search terms included the Medical Subject Heading (MeSH) terms "traumatic brain injury," "traumatic head injury," "pediatric," "children," "child," and "adolescent." Case reports, case-control studies, commentaries, and historical articles were excluded. Observational studies, comparative studies, and reviews were included. Two independent reviewers applied the following inclusion criteria: reports containing 40 or more patients aged 18 years or younger and containing epidemiologic data that included at least 2 of the following: TBI incidence, TBI age distribution, gender ratio of TBI, TBI severity across a study population, TBI mortality across a population, and TBI mechanism distribution. Two reviewers (M.D., N.M.) independently extracted data and discussed disagreements before including/excluding manuscripts. Discrepancies between data extraction were resolved by an arbiter (C.B.) before final tables were constructed. Additionally, the methodology of each included study was scrutinized and assigned an evidence level (**Table 1**). Descriptive statistics are reported as proportions of a population and as medians where appropriate (interquartile range). Incidences are described as per 100,000 individuals annually.

RESULTS

The initial literature word-search yielded 9342 results, 8089 of which were removed after filtering for study type. Two reviewers then independently reviewed titles and abstracts of the remaining articles and applied the inclusion criteria stated earlier. Fifty-one articles resulted from this review, and their contents were fully examined and reference sections evaluated for possible relevant additions. Twenty-one articles were removed for 1 or more of the following 3 reasons: inclusion of adults without separate extractable pediatric data (7), inclusion of non-TBI injury without separate TBI-only data (7), and a lack of sufficient original data for epidemiologic data extraction (8). A total of 30 full-text articles or detailed abstracts were included for this qualitative review.

The majority of reports were published after 2000, and half were published within the past 5 years (**Table 1**). The search results yielded studies well representative of the global community with reports from 5 continents including 9 North American, 9 Asian, 5 European, 3 African, and 3 Australian populations. The number of subjects included in individual studies ranged widely (43–71,476), with a median of 914 subjects (interquartile range: 213–3543). Two studies estimated figures from population-based databases; thus exact patient sample sizes were not available.[1,9] Except for 5 prospective studies, most epidemiologic data came from retrospective cohort studies. Article details including individual considerations and relative limitations are outlined further in **Table 1**.

Incidence and Demographics

The worldwide incidence of pediatric TBI ranges broadly from 12 (Sweden[10]) to 486 (Australia[5]) persons per 100,000, depending on individual reports' inclusion criteria (**Table 2**). Three U.S. studies reported incidence between 70 and 75 per 100,000.[7,9,11] Among reports documenting incidence figures, most reported rates between 47 and 280 per 100,000,[6,7,9,11-13] with the highest rates from Australia and the lowest from northern European countries.[5,10,14,15]

Male children were affected more commonly by TBI than their female counterparts in all but 1 report.[16] The gender gap was greatest in Australia with males injured nearly 3 times more often than females.[5,17] The lowest gender difference (1.05:1) was reported in a Nigerian study,[18] while most reported a ratio around 1.8:1 (M:F).[6,7,10,14,19-24]

The mean age of children ranged from 3.2 to 10.4 years (median 6.8), though many reports identified multiple peak ages of injury. A bimodal distribution with the greatest injury occurrence in very young (0–3) and older (15–18) children was described by several authors.[7,17,19,25] A Chinese study identified 63% of injuries occurring in patients aged 0–2 years.[26] Two other studies from East Asia found more than half of pediatric TBI occurred in patients aged 4 years or younger.[2,22] In contrast, in most U.S. populations and in the single Iranian series, older patients (>14 years) constituted the largest subgroup suffering from TBI.[4,7,9,11,25] In a U.S. study of more than 25,000 subjects, multivariate analysis found that older age independently predicted a longer hospital stay and higher total health care costs.[7]

Overall, the role of race and socioeconomic status in determining the likelihood for TBI in pediatric populations is unclear due to limited data being reported on these topics. Racial and ethnic distribution of injury was reported in a minority of series, and none reported figures corrected for baseline racial distributions within the study populations themselves.[1,7,13,16] A single U.S. study found that African American children involved in traffic accidents were more likely than Caucasians to require hospitalization and suffer death.[1] Studies from the United States and United Kingdom found that children from a lower socioeconomic background experienced higher rates of TBI.[11,15] Further available race and socioeconomic details of childhood TBI are recorded in **Table 2**.

Traumatic Brain Injury Details

The majority of studies distinguished TBI severity on a 3-tier scale (mild, moderate, severe), though not all described using a valid and accepted designation scheme. Nonetheless, among studies incorporating all severities, mild TBI (Glasgow Coma Scale [GCS] $\geq$13) represented >80% of subjects in the majority of reports (**Table 3**).

Occasionally, authors using other methods of severity designation (e.g., Abbreviated Injury Score) or excluding cases of mild injury resulted in a skewing of figures toward higher severities.[10,11,20,25] Severe TBI (GCS $\leq$8) accounted for 3%–7% of subjects in most populations.[6,12,14,19,24,27-30] Udoh et al.[18] identified severe TBI in 40% of Nigerian patients, though their population included only patients who were referred for neurosurgical evaluation. Mortality rates ranged from 1%–7% in most study samples[6,7,12,21,23-;25,28-30] or between 2.8 and 3.75 per 100,000 children annually.[5,9]

Table 1. Manuscript Details

Author	Year	Country	Number	Age Range	Study Duration	Evidence Level	Type	Limitations/Considerations
Greene et al.[25]	2014	USA	71,476	0—19	2001, 2004, 2007, 2010	III	Retrospective	Only 25/50 U.S. states sampled; TBI severity/cause not indicated
Majdan et al.[17]	2014	Austria	5319	0—19	1980—2012	III	Retrospective	Used ICD coding; only studied deceased
Amaranath et al.[19]	2014	Australia	1489	0—16	2006—2011	III	Retrospective	Hospital-based study
Zhu et al.[26]	2014	China	455	0—14	2012	III	Retrospective	Single center; mild TBI; survey-based outcomes
Schrieff et al.[20]	2013	S. Africa	137	0—15	2006—2011	III	Retrospective	Single center; severe TBI only
Robertson et al.[21]	2013	US	39,384	0—18	2006—2010	III	Retrospective	Used ICD coding
Udoh et al.[18]	2013	Nigeria	127	0—17	2006—2011	II	Prospective	Single center; small sample size
Shao et al.[22]	2012	China	4230	0—17	2002—2011	III	Retrospective	Single center; used ICD coding
Ferreros et al.[27]	2012	Spain	5504	0—19	2002—2009	III	Retrospective	Used ICD coding; population-based estimates
Chabok et al.[4]	2012	Iran	668	0—18	2009—2010	III	Retrospective	Single center
Hassen et al.[28]	2012	Tunisia	298	Pediatric	2007	III	Retrospective	Single center
Kim et al.[2]	2012	Korea	2856	0—18	2008—2009	III	Prospective	Used ICD coding
Koepsell et al.[23]	2011	USA	405	0—17	2007—2008	III	Retrospective	Population estimates from single county sample
Rollins et al.[31]	2011	USA	235	0—14	2003—2008	III	Retrospective	Skull fractures only; heterogenous inclusion criteria
Isik et al.[24]	2011	Turkey	851	0—14	2003—2008	III	Retrospective	Single center
Crowe et al.[14]	2009	Australia	1115	0—16	2004	III	Retrospective	Single center; injury timing details questionable
Bowman et al.[9]	2008	USA	Pop.-based	0—19	1991—2005	III	Retrospective	Used discharge data from national registry
Agrawal et al.[29]	2008	Nepal	43	0—16	2005—2006	III	Retrospective	Single center; small sample size
Schneier et al.[7]	2006	USA	25783	0—17	2000	III	Retrospective	External causes and severity of TBI not indicated
Mitra et al.[5]	2006	Australia	328	12—19	2001—2004	III	Retrospective	Significant TBI only; Sample age: 12—19 years
Tabish et al.[3]	2006	India	1500	0—14	2003	II	Prospective	Single center; TBI severity not indicated
Parslow et al.[15]	2005	UK	644	0—14	2001—2003	II	Prospective	Sparse data reporting; only ICU patients
Sills et al.[13]	2005	USA	1333	0—3	1992—2002	III	Retrospective	Used ICD coding; Sample age: 0—3 years
Chan et al.[16]	2005	Malaysia	265	2—18	1998—2001	III	Prospective	Ambiguous methodology; minor TBI only
Langlois et al.[1]	2005	USA	Pop.-based	0—14	1995—2001	III	Retrospective	Used ICD coding; TBI severity not indicated
Tsai et al.[30]	2004	Taiwan	5349	0—14	1993—2001	III	Retrospective	Used ICD coding
Hawley et al.[6]	2003	UK	1553	0—15	1992—1998	III	Retrospective	Only single region in UK
Reid et al.[11]	2001	USA	977	0—19	1993	III	Retrospective	Only single state in USA
Emanuelson et al.[10]	1997	Sweden	210	0—17	1987—1991	III	Retrospective	Used ICD coding
Kraus et al.[12]	1986	USA	709	0—14	1981	III	Retrospective	Only single county

TBI, traumatic brain injury; ICD, International Classification of Disease; ICU, intensive care unit; UK, United Kingdom.

Table 2. Traumatic Brain Injury Incidence and Patient Characteristics

Author, Year	Country	Incidence Metrics	TBI Rate (M:F)	TBI Rate (Age)	Age (Mean), Years	Race	Income/SES
Greene et al., 2014[25]	USA		2.08:1	25.1% (0–4); 12.2% (5–9); 18.3% (10–14); 44.4% (15–19)			34.3% (Gov. Insurance); 57.6% (Private); 8.1% (Uninsured)
Majdan et al., 2014[17]	Austria		3.00:1	Second highest % (0–2); Highest % (15–19)			
Amaranath et al., 2014[19]	Australia		1.86:1	Bimodal peaks: <2 years, >13 years	7		
Zhu et al., 2014[26]	China		2.25:1	63.3% (0–2); 31.9% (3–9); 4.8% (10–14)	3.2		
Schrieff et al., 2013[20]	S. Africa		1.85:1	Peaks: 4, 6, 7, & 10 years			
Robertson et al., 2013[21]	USA		1.78:1		6.28		41% (Gov. Insurance); 30% (Private); 12% (not listed)
Udoh et al., 2013[18]	Nigeria	Study sample represents 13% of all hospital TBI during study duration	1.05:1	28.3% (0–3); 17.3% (4–6); 26.8% (7–10); 27.6% (11–17)	7.4		
Shao et al., 2012[22]	China		1.87:1	50.1% (0–2); 34.5% (3–6); 14.2% (7–12); 1.3% (13–18)			
Ferreros et al., 2012[27]	Spain	Incidence rate decreased from 2002–2009 for all TBI severities and for both genders					
Chabok et al., 2012[4]	Iran	Study sample represents 81% of pediatric injuries at the study site	2.66:1	25% (0–5); 20% (6–9); ∼17% (10–13); ∼40% (14–18)	10.4		
Hassen et al., 2012[28]	Tunisia		2.00:1		5.9		
Kim et al., 2012[2]	Korea	Study sample represents 32.7% of pediatric injuries at the study site	2.3:1	55.5% (0–4); 24.9% (5–9); 18.9% (10–14); 9.5% (15–18)	5.6		
Koepsell et al., 2011[23]	USA	304/100k child-years Admission rate: 5% of TBI evaluated in ED	1.85:1	38.8% (0–4); 19.1% (5–9); 23.8% (10–14); 18.35% (15–18)			
Rollins et al., 2011[31]	USA	Admission rate: 75% of TBI evaluated in ED					
Isik et al., 2011[24]	Turkey		1.86:1				
Crowe et al., 2009[14]	Australia	2008/100k children presenting to ED Admission rate: 32% of TBI evaluated in ED	1.73:1	16.5% (<1); 49.1% (≤ 3)			

Bowman et al., 2008[9]	USA	74.9/100k children hospitalized	M > F	72.8/100k children (0–4); 43.2/100k children (5–9); 55.4/100k children (10–14); 126.2/100k children (15–19)			
Agrawal et al., 2008[29]	Nepal		1.53:1	27.9% (0–4); 32.6% (5–8); 18.6% (9–12); 20.9% (13–16)	5		
Schneier et al., 2006[7]	USA	70/100k children hospitalized 50,658 total TBI-related pediatric hospitalizations in 2000	1.88:1	29% (0–4); 18.4% (5–9); 22.5% (10–14); 30.1% (15–17)		63% (White); 13% (Black)	26% (Medicaid); 63% (Private); 7% (self-pay)
Mitra et al., 2006[5]	Australia	>486/100k per year	2.64:1				
Tabish et al., 2006[3]	India	21% of trauma admissions from ED	1.50:1	23% (1–5); 46% (6–10); 31% (11–15)			
Parslow et al., 2005[15]	UK	ICU admission rate: 5.6/100k	2.02:1	28.7% (0–4); 28.5% (5–9); 42.7% (10–14)			Less affluent more likely to be admitted for TBI
Sills et al., 2005[13]	USA	Intentional: 16.1/100k Unintentional: 47/100k	1.43:1			53% (White); 6% (Black); 26% (Hispanic)	22.7% (Medicaid); 42.3% (Commercial); 8.7% (Uninsured)
Chan et al., 2005[16]	Malaysia		.48:1		10.2	72.5% (Malay); 11.7% (Chinese); 15% (Indian)	
Langlois et al., 2005[1]	USA	475,000 per annum		45.5% (0–4); 28% (5–9); 6.3% (10–14)		MVC death and hospitalization rates for ages 0–9: blacks > whites	
Tsai et al., 2004[30]	Taiwan		1.69:1	35.5% (0–4); 28.5% (5–9); 36% (10–14)			
Hawley et al., 2003[6]	UK	280/100k	1.8:1	36.9% (0–4); 30.6% (5–9); 32.4% (10–15)	6.76		
Reid et al., 2001[11]	USA	73.5/100k	M > F	21.4% (0–4); 18.7% (5–9); 19.8% (10–14); 40.1% (15–19)			TBI rate inversely correlated with median income and % of high school graduates
Emanuelson et al., 1997[10]	Sweden	12/100k	1.8:1		9.44		
Kraus et al., 1986[12]	USA	185/100k	M > F				

TBI, traumatic brain injury; SES, socioeconomic status; Gov, government; ED, emergency department; MVC, motor vehicle collision; UK, United Kingdom.

Table 3. Traumatic Brain Injury Details

Author, Year	Severity	Mortality Rate	Structural Details	Treatment/Surgery	Recovery Details
Greene et al., 2014[25]	9.9% (Mild); 38.1% (Moderate); 52% (Severe)	3.6%			90.7% discharged from hospital
Majdan et al., 2014[17]		100%			Fatality an inclusion criterion
Amaranath et al., 2014[19]	93% (Mild); 1.5% (Moderate); 5.5% (Severe)	.87%	Imaging obtained in 62% → unremarkable in 25%.	Surgical intervention in 6.5%: EVD/ICPM (30%), craniotomy (48%), fracture elevation (22%)	98.7%: good recovery
Zhu et al., 2014[26]	100% (Mild)		Imaging obtained in 98% → unremarkable (64.7%) skull fracture (45%), EDH (19%), SDH (11.8%), SAH (3.9%), contusion (11.8%), multiple injuries (8.5%)		99.3%: observation & discharge.
Schrieff et al., 2013[20]	100% (Severe)	14.6%			
Robertson et al., 2013[21]		3%			92% discharged home
Udoh et al., 2013[18]	29.1% (Mild); 30.7% (Moderate); 40% (Severe)	8.7%	Imaging obtained in 100% → unremarkable (3%) skull fracture (31%), EDH (11.8%), SDH (4.7%), ICH (37%), SAH (4%), DAI (9%)	Surgical intervention in 21%	91% survived
Shao et al., 2012[22]		.3%	Imaging rate unreported; Intracranial damage (39.5%), open laceration (31%), skull fracture (11.6%)		72.2%:full recovery 25%: partial recovery
Ferreros et al., 2012[27]	92.9% (Mild); 7.1% (Moderate—severe)	.6% (Mild) 15.7% (Moderate—severe)			
Chabok et al., 2012[4]	Majority mild		Unremarkable imaging: 90%.		
Hassen et al., 2012[28]	92.6% (Mild); 5.4% (Severe)	2.1%	Imaging obtained in 89.9% → unremarkable (40%)		97.2%: good recovery
Kim et al., 2012[2]	99% (Mild); .6% (Moderate); .4% (Severe)		Imaging obtained in 22.2% → unremarkable (7.7%), skull fractures (3.4%), EDH (.9%), SDH (.8%), SAH (.7%), edema (.4%).	Surgical intervention in 1.3%	93.9% discharged from ED
Koepsell et al., 2011[23]	97.5% (Mild) 2.5% (Moderate—severe)	1.2%			94% discharged from ED
Rollins et al., 2011[31]	100% (Mild)		46.8% (Parietal); 30.6% (Occipital); 11.9% (Frontal); 4.25% (Temporal); 6.38% (Multiple)		
Isik et al., 2011[24]	74% (Mild); 22% (Moderate); 4% (Severe)	3.8%		Surgical intervention in 10.5%	

Crowe et al., 2009[14]	89% (Mild); 8% (Moderate); 3% (Severe)		Imaging obtained in 21% → unremarkable (92%), skull fracture (18.6%), SDH (6.2%), contusion (1.5%), EDH (1.1%)	Surgical intervention in 2.7%: EVD (19.2%), craniotomy for hematoma (38.5%), fracture elevation (23.1%), plastic surgery (.4%)	
Bowman et al., 2008[9]	23.8/100k (Mild); 24.8/100k (Moderate); 13.9/100k (Severe)	2.8/100k			
Agrawal et al., 2008[29]	65% (Mild); 27.9% (Moderate); 6.9% (Severe)	7%	Imaging obtained in 58% → unremarkable (8%), contusions (25%), EDH (14%), SDH (5%), skull fracture (28%)	Surgical intervention in 14%	86%: good recovery; 7%: moderate disability.
Schneier et al., 2006[7]		3.8%			
Mitra et al., 2006[5]		3.75/100k	Imaging rate unreported; skull fracture (∼35%), EDH (∼9%), SDH (∼13%), contusion (∼15%), SAH (∼12%), DAI (∼4%), edema (∼7%)	Surgical intervention in 63%: EVD/ICPM (∼47%), craniectomy (∼17%), craniotomy for hematoma (∼20%), fracture elevation (∼13%)	∼45% discharged home ∼45% discharged to rehab facility ∼10% mortality
Tabish et al., 2006[3]					90% discharged within 24 hours
Parslow et al., 2005[15]		23% (MVC-occupant) 12% (Pedestrian) 3% (Falls)			
Sills et al., 2005[13]		12.2%			87.8%: discharged from hospital
Chan et al., 2005[16]	100% (Mild)		Imaging rate unreported; unremarkable (58%), linear skull fracture (31%), depressed skull fracture (7%), skull base fracture (3%)	Surgical intervention in 6%	
Langlois et al., 2005[1]		.6%			
Tsai et al., 2004[30]	83.1% (Mild); 9.8% (Moderate); 7% (Severe)	2.8%			89.7%: good recovery 3.2%: moderate disability 3.9%: severe disability.
Hawley et al., 2003[6]	83% (Mild); 9% (Moderate); 6% (Severe)	1%			
Reid et al., 2001[11]	63.5% (Mild—moderate) 36.5% (Severe)	12.3%			53%: good recovery 8%: moderate disability 3%: severe disability 1%: vegetative state

EVD, external ventricular drain; ICPM, intracranial pressure monitor; ED, emergency department; EDH, epidural hematoma; SDH, subdural hematoma; SAH, subarachnoid hemorrhage; ICH, intracerebral hematoma; DAI, diffuse axonal injury.

Continues

Table 3. Continued

Author, Year	Severity	Mortality Rate	Structural Details	Treatment/Surgery	Recovery Details
Emanuelson et al., 1997[10]	29% (Mild); 19% (Moderate); 52% (Severe)	21%	Imaging obtained in 82% → unremarkable (10.5%), hemorrhage or contusion (61%) edema (12%), miscellaneous intracranial injury (16%)		49%: full recovery 52%: functional impairment
Kraus et al., 1986[12]	88% (Mild); 7% (Moderate); 5% (Severe)	5.6%			

EVD, external ventricular drain; ICPM, intracranial pressure monitor; ED, emergency department; EDH, epidural hematoma; SDH, subdural hematoma; SAH, subarachnoid hemorrhage; ICH, intracerebral hematoma; DAI, diffuse axonal injury.

Specific geographic predilections for mortality were not apparent, with higher mortality rates (>10%) reported in South African, Spanish, Swedish, and American populations.[10,11,13,20,27]

The rate at which radiographic studies were performed ranged widely by study, and findings were documented variably. Generally, unremarkable computed tomography (CT) findings were discovered in the majority of patients (58%–92%) in studies that included mostly mild TBI.[14,16,26] Among patients with positive imaging findings, skull fractures (19%–45%) and contusions (15%–61%) were the most common abnormality.[5,10,14,16,18,26,29] Extra-axial collections were reported in many series and included subdural hematoma in 1%–12% and epidural hematoma in 1%–19% of pediatric TBI.[2,14,18,26,29]

The majority of pediatric TBI (>90% in most studies) was managed nonoperatively.[2,14,16,19,24] Expectedly, reports including only severe head injury reported higher rates of surgery for TBI (21%–63%).[5,18] Among surgical interventions, placement of external ventricular drain (19%–47%) and craniotomy/craniectomy for hematoma evacuation (37%–48%) were most frequently performed, followed by fracture elevation (13%–23%).[5,14,19]

Recovery from TBI was good in more than 90% of patients in reports that included >90% mild TBI,[2,19,23,26,28] a pattern that remained independent of country or region. However, in studies from the United States and Sweden with more than 35% severe TBI, the proportion of patients with a "good" or "full" recovery fell to approximately 50%.[10,11] In 2 East Asian reports including only mild TBI, more than 90% of patients were discharged after a short period of observation in the ED. Most U.S. studies reported higher rates of admission, though the majority of patients were discharged from the hospital in good condition without undergoing surgical intervention[13,23,25] (Table 3).

Injury Mechanisms

Mechanism of pediatric TBI ranged broadly across populations and age groups. Generally, motor vehicle collisions (MVCs) (6%–80%) and falls (5%–87%) accounted for the majority of injuries, followed by abuse and other forms of nonaccidental trauma (2%–12%) and sports-related injury (<1%–29%) (Table 4).

Across 4 studies from Africa, Asia, and India, pedestrians were the victims in more than half of MVCs.[3,18,20,26] Shao et al.[22] found that 43% of MVCs in China involved a bicycle being struck by a motorized vehicle. Vehicle occupants, on the other hand, were more likely injured in several reports from Australia, Europe, and the United States.[5,10,15,17,19,21]

Falls accounted for more than 50% of pediatric TBI in Chinese populations, as well as in reports from Nepal, Turkey, and India.[3,22,24,26,29] In most of these studies, young children (<4 years) made up the largest age subgroup. Excluding one U.S. series of isolated skull fractures,[31] among Western populations, falls accounted for less TBI (range 8%–45%) than in Asian and African populations.[6,10,12,13,17,21] Nonaccidental trauma in the form of assault or child abuse was responsible for <10% of pediatric TBI with the highest rates coming from a population in Nigeria (10%) and another in Malaysia (9%).[16,18,20] Rates of nonaccidental trauma in the United States ranged from 1%–8% (median 4%), though this included both child abuse and adolescent assault.[6,12,15,21,31] Sports-related TBI was far more common in the United States and Australia (2%–29%)[6,12,19,21] than in Asian countries (0.7%–2%).[22,26,30]

Injured patients were more likely to present to the ED during warmer months: from May to September in the Northern Hemisphere[3,14,17,23] and in December in the Southern Hemisphere.[14] Uniformly across populations, TBI occurred more commonly on Saturdays and Sundays and in the afternoon/evening hours[2,3,12,14,15,17,23] (see Table 4). Among studies reporting population cluster characteristics, injuries were more likely to occur in urban areas (47–79) than in rural areas (21%–52%), particularly among industrialized countries.[4,21,22,32]

DISCUSSION

Herein, we report the largest and most comprehensive qualitative review of global pediatric TBI to date. More than 1200 titles and abstracts were filtered to ultimately yield 30 series of TBI over 3 decades, representing more than 165,000 children

Table 4. Injury Mechanisms

Author, Year	MVC (Total)	MVC (Pedestrian)	Bicycle/ Motorcycle	Falls	Sports	NAT/Abuse	Miscellaneous	Time	Location
Greene et al., 2014[25]									
Majdan et al., 2014[17]	78%			8%		12%: 9% (Suicide) 3% (Assault)	3% (Machine accidents)	Male predominance from April-Oct.	
Amaranath et al., 2014[19]	51%			24%	16%	8% (Assault)			
Zhu et al., 2014[26]	14%	45% of MVC		62%	.7%	4% (Abuse)	19% (high-energy blows to head)		51.2% (Home); 15% (Street/ road); 12% (School); 13% (Other)
Schrieff et al., 2013[20]	80%	55%		5%		8%: ∼3% (NAT); ∼3% (Gun); ∼1% (Stab); ∼1% (Assault)	4%: ∼1% (Struck by/ against); ∼2% (Crush injury)	Majority on Sat. or Sun.; MC between 12:00 and 20:00	
Robertson et al., 2013[21]	16%			29%	3%	8% (Assault/Abuse)	5% (Struck by/ against)		79% (Urban); 9% (Large town); 5% (Small town)
Udoh et al., 2013[18]	68%	50%		15%		10%: ∼7% (Assault); ∼2% (Gun); ∼2% (Stab)	5% (Total) ∼3% (Falls) ∼2% (Misc.)		
Shao et al., 2012[22]	14%	3% of MVC	43% of MVC	52%	.7%	4% (Assault/Abuse)	25.3% (Struck by/ against)		67% (Urban); 29% (Rural)
Ferreros et al., 2012[27]									
Chabok et al., 2012[4]	65%	13%		25%		3% (Fighting)			47% (Urban); 52% (Rural)
Hassen et al., 2012[28]	28%								64% (Home)
Kim et al., 2012[2]	9%			39%			6.5% (Sharp objects)	MC on Fri. or Sat. MC between 16:00—24:00	51% (Home); 16% (Street); 12% (Playground); 8% (School)
Koepsell et al., 2011[23]	118/100k child-years		64/100k child-years	683/100k child-years			337/100k (Struck by/against)	MC in warmer months (April-Sept.). MC on Fri. or Sat.	

MVC, motor vehicle collision; NAT, nonaccidental trauma; MC, most common; TBI, traumatic brain injury.

Continues

Table 4. Continued

Author, Year	MVC (Total)	MVC (Pedestrian)	Bicycle/ Motorcycle	Falls	Sports	NAT/Abuse	Miscellaneous	Time	Location
Rollins et al., 2011[31]		.4%	5%	87%	2%	Total 2% ~1% (Assault) ~1% (Abuse)	3% (Struck by/ against)		
Isik et al., 2011[24]				70%					
Crowe et al., 2009[14]				MC ages 0–5	MC age >5			MC in March, Dec. (holidays). MC on Sat. or Sun., and after 15:00	57% (Home); 13% (Street); 9% (School); 8% (Sporting venues); 6% (Playground)
Bowman et al., 2008[9]	20.9/100k	4.2/100k	5.6/100k	17.7/100k		.8/100k (Firearms)	6.6/100k (Struck by/ against)		
Agrawal et al., 2008[29]	26%			65%		5% (Assault)			
Schneier et al., 2006[7]									
Mitra et al., 2006[5]	69%	~15%		~8%			~10% (Struck by/ against)		70% (streets —adolescents). 38% (home —children)
Tabish et al., 2006[3]	26%	58% of MVC		68%		3% (Assault)	2% (airborne objects)	More common from May-Aug. 80% between 09:00 and 17:00	
Parslow et al., 2005[15]	45%		10%	24%		6% (Assault)		MC in summer months ages 0–9; MC Fri., Sat.; Peak in mid-late afternoon	
Sills et al., 2005[13]	18%			43%					
Chan et al., 2005[16]	62%	14%		28%		9% (Assault)			
Langlois et al., 2005[1]									
Tsai et al., 2004[30]	47%	27% of MVCs		40%	2%	3% (Assault)			
Hawley et al., 2003[6]	21%	13%		45%	3%	4% (Assault)		MC May, July, Aug., Oct. (holidays)	

Reid et al., 2001[11]	MC ages 15–19	MC ages 0–14							Higher rates of MVC-related TBI/ mortality among rural patients
Emanuelson et al., 1997[10]	60%			22%	7%	2%	3% (Struck by object)		
Kraus et al., 1986[12]	24%	8%	8%	35%	29%	4%		MC from July-Sept.; MC in late afternoon/evening	

MVC, motor vehicle collision; NAT, nonaccidental trauma; MC, most common; TBI, traumatic brain injury.

across 5 continents. Heterogeneity existed across studies with regard to population size, sampling method used, incidence figures reported, and injury details documented. Nonetheless, numerous patterns appeared throughout the literature and several important observations can be highlighted.

Pediatric TBI is a significant public health concern that affects nearly every population and every demographic regardless of location or socioeconomic status. Using the most conservative incidence estimates of 50 per 100,000 persons, TBI affects more than 3 million children worldwide every year. In comparison, there are approximately 2 million new cases of HIV and 500,000 new cases of meningitis every year.[33,34] Overall, male children are more commonly affected by TBI than females. At younger ages (<3 years) the gender distribution is split evenly, though with increasing age, males incur nearly twice the injury rate. This difference could be explained in part by the higher participation rate by males in organized sport, or perhaps by the more physical nature of childhood play among boys relative to girls. Across most populations there is a relative nadir in pediatric incidence between the ages of 5 and 13, while the very young (<2 years) and old (15–18) present with TBI most commonly.

The vast majority of pediatric TBI can be classified as mild (GCS $\geq$ 13) with negative imaging findings. It is commonplace in many countries to manage such patients with a short period of observation only. Among more severe cases of TBI, skull fractures and contusions are the most frequently encountered structural pathologies. Neurosurgical intervention was rarely necessary—a feature that appeared to be independent of geographic region. As expected, series that included more severe cases of TBI reported lower rates of discharge to home and a lower proportion of patients with a good recovery.

Some geographic differences in etiology of TBI were appreciated. MVCs were responsible for a larger proportion of injuries in high-income countries, with vehicle occupants almost always the only victims. On the other hand, low- and middle-income countries experienced lower rates of MVC-related TBI, and injured children were more likely to be roadside pedestrians. Asian populations suffered higher rates of injury secondary to falls, particularly among younger age groups. This population, however, including China and Taiwan, suffered lower rates of sports-related injury compared with the United States and Australia. This fact may have been a result of the relative popularity of lower-impact sports such as soccer and cricket, in contrast to American football and rugby among English-speaking populations.

The seasonal variation of pediatric TBI—more common in warmer months—may reflect school patterns as they relate to the summer holiday in some countries. Additionally, it is not surprising that injuries occur primarily in the evenings and on weekends when children are likely to be out of the classroom.

The results from this study have provided some useful avenues to effectively reduce the burden of TBI worldwide by applying both worldwide and region-specific intervention. MVCs are reported to be the most common etiology for pediatric TBI in most of the reports studied. Therefore increasing enforced legislation involving the legal driving age and speed limit may see worldwide benefit, particularly in countries with less developed enforcement policies. Since MVCs primarily affect vehicle occupants in high-income countries, innovation toward greater protection within the vehicle via airbags, seat belts, and other safety measures is a natural risk-reducing strategy under constant evolution. On the other hand, MVCs in lower-income countries usually result in injury to the pedestrian. Thus improving roads, building sidewalks, and increasing traffic lights may substantially reduce TBIs in these areas of the world. As this decade ushers in technology supporting self-driving vehicles, there will be plenty of opportunities for safety innovation for roads and vehicles alike.[35]

Our results show that the second most common cause of pediatric TBIs is falling, which predominantly affects children 0–4 years of age. Counseling by pediatricians and obstetricians might increase the awareness of parents of this common problem. Numerous studies have demonstrated a benefit to the use of checklists by physicians and surgeons.[36,37] Accordingly, a formal checklist of items including vaccinations, protection from falls, and proper sleeping positions for physicians to counsel parents may facilitate a reduction of not only pediatric TBI but also other injuries and death.[38] Lastly, sports-related TBI injuries seem to predominate in countries such as the United States and Australia, which have more contact-driven sports. Hence better protective gear such as helmets could help the pediatric population in these countries.

Limitations and Future Directions

These observations should be interpreted in light of several study limitations. By design, this was a retrospective evaluation, incorporating a diverse collection of large pediatric series. Thus differences between individual study findings may reflect the study methodology and inclusion/exclusion criteria as much as they may represent true population differences. Furthermore, both sampling and publication biases likely limit generalization of these results to a broad and inclusive global population. Maintaining relatively strict inclusion criteria resulted in nonrepresentation of certain large population subgroups, such as those in Latin America. Timing of injury was not reported in a uniform fashion across studies. Care should thus be taken when interpreting time of injury, as these figures may have been mislabeled by source studies that instead measured time of admission. Lastly, while important during a time in which global reforms are shaping health care delivery, this study was unable to draw any meaningful conclusions regarding the socioeconomic impact of pediatric TBI worldwide. Although this analysis begins to quantify the scope of the problem, further studies are necessary to objectively measure the economic consequences of pediatric TBI and identify region-specific methods to prevent its occurrence and reduce its global impact.

CONCLUSIONS

TBI is a relatively frequent and important public health concern that reaches beyond traditional demographic and societal boundaries and affects more than 3 million children annually. Males suffer injury more commonly than females, especially at older ages. While traffic-related accidents and falls account for the majority of pediatric TBI depending on geographic region, most cases are mild and can be treated with observation alone. Identification of region-specific causes, risk factors, and shortcomings may help facilitate measures toward head injury avoidance. Future studies to determine the global economic burden of and universal preventive measure for pediatric TBI are warranted.

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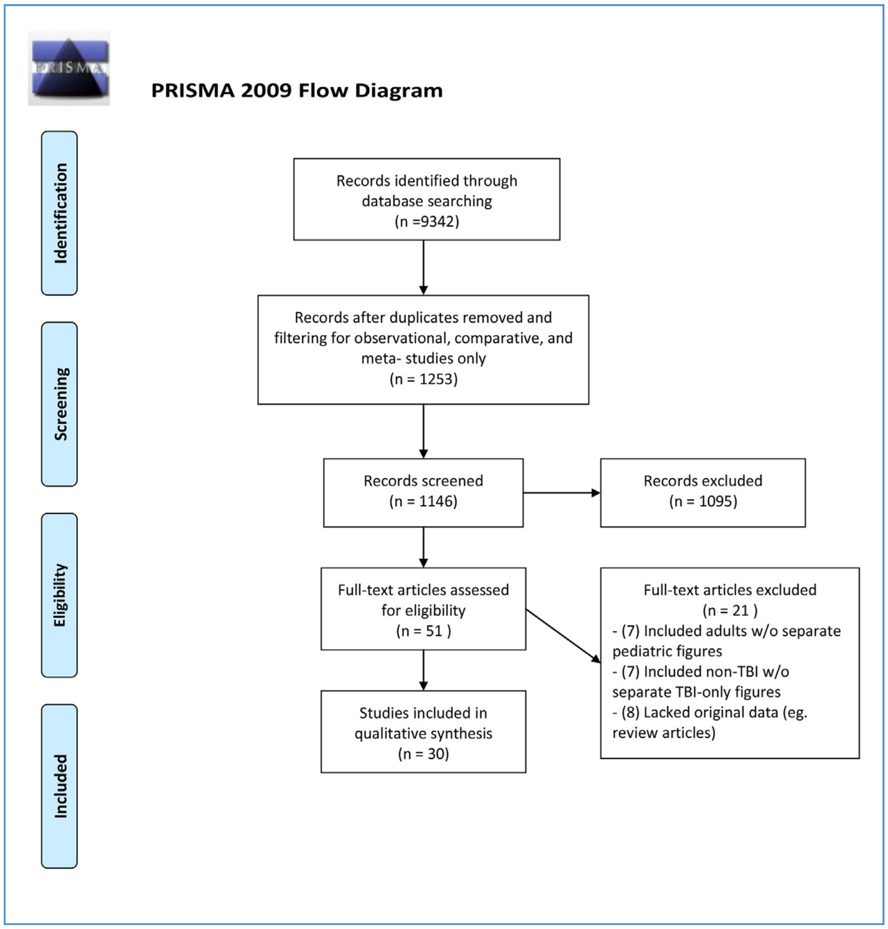
APPENDIX


PRISMA 2009 Flow Diagram
Identification
Screening
Eligibility
Included
Records identified through database searching (n =9342)
Records after duplicates removed and filtering for observational, comparative, and meta- studies only (n = 1253)
Records screened (n = 1146)
Records excluded (n = 1095)
Full-text articles assessed for eligibility (n = 51)
Full-text articles excluded (n = 21)
- (7) Included adults w/o separate pediatric figures
- (7) Included non-TBI w/o separate TBI-only figures
- (8) Lacked original data (eg. review articles)
Studies included in qualitative synthesis (n = 30)