SEVERITY, CAUSES AND OUTCOMES OF TRAUMATIC BRAIN INJURIES OCCURRING AT DIFFERENT LOCATIONS: IMPLICATIONS FOR PREVENTION AND PUBLIC HEALTH

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SUMMARY

Aim: Traumatic brain injuries (TBI) are a major public health problem. Although they are well studied, information on some aspects, such as the place of occurrence, is limited. The aim of this study was to describe the patterns of severity, causes and outcomes of TBI occurring at different locations and to identify the primary populations at risk of suffering TBI at each of the analysed locations.

Methods: 1,818 patients with TBI admitted to hospitals in Austria, Slovakia, Croatia, Bosnia, and Macedonia were analysed. Primary populations at risk, injury severity and extent along with short/long-term outcomes were analysed for TBI at each location.

Results: The highest mean age (57.9 years, $p<0.001$) was observed in injuries at home. The distribution of injury causes across the group was significantly different ($p<0.001$), with falls (39%) and traffic accidents (30%) being predominant. TBI occurring on roads or highways were the most severe (mean ISS = 32.5, $p<0.001$; mean GCS = 7.8, $p<0.001$). Injuries at home had the worst outcome (50% mortality, $p<0.001$ and 70% unfavourable outcome, $p<0.001$) whereas TBI at sport facilities or outdoors had the best outcome (24% mortality, 44% unfavourable outcome). When adjusted for age and severity, TBI occurring at home had the highest odds of mortality (OR = 3.12, 95% CI = 1.86–5.25) and unfavourable outcome (OR = 2.51, 95% CI = 1.54–4.08), compared to sports facility and outdoors as a reference.

Conclusions: TBI at different locations display distinctive patterns as to causes, severity, outcome and populations at risk. Location is therefore a relevant epidemiological aspect of TBI and we advocate its inclusion in future studies. Definitions of primary populations at risk at different locations could help in targeted public health actions.

Key words: traumatic brain injury, trauma location, injury severity, epidemiology, outcome, prevention

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INTRODUCTION

Traumatic brain injuries (TBI) are a major public health problem with significant socio-economic consequences worldwide. They are major causes of death and disability especially in young adults (1–3). WHO predicts that TBI – surpassing many diseases – will become the third most important cause of global disease burden by 2020 (1). In the US, there are approximately 53,000 TBI related deaths annually (4), and about 5.3 million people live with TBI related disability (5). In Western Europe, the aggregated number of hospital admissions and deaths is about 235/100,000 annually (6). Additionally, the increase in the use of motor vehicles coincides with increase in TBI incidence in low and middle income countries (3).

Although the epidemiological aspects of TBI have been studied in different populations, it is difficult to validly describe and quantify their global patterns owing mainly to the lack of standardized data collection, variability in definitions (7), and geographical and time-related variability in TBI patterns (3, 8). Defining risk factors, protective factors and populations at increased risk is essential for effective public health action (9).

Demographic characteristics of TBI victims, causes and mechanism of injuries as well as outcome are among the aspects of TBI which are relatively well reported in epidemiological studies (6, 10–12). On the other hand, there are aspects with potential relevance to public health that are only marginally studied and reported in the published literature. One of these aspects is the location of TBI which might be of key relevance for designing targeted public health interventions.

The aim of this study was to describe the patterns of severity, causes and outcomes of TBI occurring at different locations and to identify the primary populations at risk of suffering TBI at each of the analysed locations.

MATERIALS AND METHODS

Data

The data analysed in this study were prospectively collected within two observational studies that were implemented by the International Neurotrauma Research Organization (INRO) in

Vienna. Two datasets were merged. The first set of data was collected using the INRO proprietary International Traumatic Coma Projects (ITCP) database (13) within the project 'Effects of the use of guidelines for the treatment of patients with severe TBI'. The study was conducted in 13 centres located in Austria, Bosnia, Croatia, Macedonia, and Slovakia during 2001–2005. A total of 1,172 patients with severe TBI (Glasgow Coma Scale (GCS) (14), score of 8 or less following resuscitation) were enrolled.

The second set of data was collected using the INRO pre-hospital database (INRO–PH) during the years 2009–2012 in 16 participating Austrian centres within a project focusing on the pre-hospital care of patients with TBI. In this study a total of 778 patients were enrolled with moderate and severe TBI with a GCS score <12 within 48 hours after the accident and/or the Abbreviated Injury Scale (AIS) (15) score of the head injury >2.

The two datasets were merged and patients with missing information on location were excluded. This left a dataset of 1,818 patients which were used in our study.

Injury Location Definition

In both databases used for data collection, the injury location was coded identically which enabled consistent categorization of patients. A total of 5 categories of trauma location were used: home; street, public place; road, highway; outdoors, sports; and workplace.

Approach to Analysis

The main line of analysis in this study was to compare demographic characteristics of the patients (age and sex), injury cause, injury severity and outcomes between the five possible trauma locations. The Injury Severity Score (ISS) (16), GCS and AIS were used as indicators of injury severity and mortality at hospital discharge and outcome six months after injury were used to describe outcomes. Six month outcome was coded favourable when the Glasgow Outcome Scale (GOS) (17) score was 'good recovery' or 'moderate disability' and was coded unfavourable when the GOS score was 'death', 'persistent vegetative state' or 'severe disability'.

Univariate comparisons were performed using the selected sets of indicators in the first step. Multivariate adjusted analysis was used to quantify the effect of TBI location on the outcome of patients while controlling for the effects of additional demographic and injury severity factors.

Statistical Analysis

Medians with interquartile ranges (IQR) and means with 95% confidence intervals were used as central measures of continuous variables and percentages were used as frequency measures in case of categorical variables. The Kruskal-Wallis test was used to compare medians, one-way ANOVA was used to compare means and the Chi-Squared test was used to compare percentages across the location groups. Binomial logistic regression was used in the multivariate analysis and odds ratios with 95% confidence intervals were calculated. $P<0.05$ was considered statistically significant.

RESULTS

A total of 1,818 patients were included in the study. Most patients were enrolled in Austria (N = 1,116, 61%), followed by Macedonia (N = 268, 15%), Croatia (N = 189, 10%) and 7% were enrolled in both Bosnia (N = 126) and Slovakia (N = 119). Although the distributions differed slightly between countries, home and road/highway were the predominant locations of injury in all countries (accounting together for over 45% of cases in each country). In total, road or highway was the most common (N = 572, 32% of all cases), whereas workplace was the least common place of injury (N = 133, 7% of cases).

Age, sex and injury cause patterns are shown in Table 1. Patients injured at home were the oldest with mean age of 57.9 years ($p<0.001$) whereas victims in the workplace and road/highway group were the youngest (mean age 40.5 and 42.1 years, respectively). Figure 1 presents the detailed sex specific age distribution

Table 1. *Demographic factors of patients and cause of TBI by trauma location*

Location group	Road/highway	Home	Street/ public place	Outdoor/ sport facility	Workplace	Total	p-value
N, total (%)	575 (32%)	471 (26%)	387 (21%)	252 (14%)	133 (7%)	1,818	–
Age (mean, 95% CI)	42.1 (40.3–43.8)	57.9 (55.9–59.8)	45.6 (43.5–47.8)	43.4 (40.9–45.9)	40.5 (37.7–43.3)	47.0 (46.0–48.0)	<0.001
Male gender (N, %)	430 (75%)	306 (65%)	297 (77%)	204 (81%)	133 (100%)	1,368 (75%)	<0.001
Cause (N, %)							
Fall <3 m	64 (11%)	271 (58%)	118 (30%)	46 (18%)	23 (17%)	522 (29%)	<0.001
Fall >3 m	16 (3%)	63 (13%)	37 (10%)	27 (11%)	38 (29%)	181 (10%)	
Traffic-related	381 (66%)	20 (4%)	101 (26%)	29 (12%)	13 (10%)	544 (30%)	
Sports-related	5 (1%)	3 (1%)	6 (2%)	77 (31%)	0	91 (5%)	
Work-related	0	1 (0%)	1 (0%)	10 (4%)	21 (16%)	33 (2%)	
Assault/gunshot	10 (2%)	37 (8%)	20 (5%)	19 (8%)	6 (5%)	92 (5%)	
Other	20 (3%)	19 (4%)	24 (6%)	24 (10%)	12 (9%)	99 (5%)	
Unknown	79 (14%)	57 (12%)	80 (21%)	20 (8%)	20 (15%)	256 (14%)	

95% CI = 95% Confidence Interval

of patients in the five compared groups. In both sexes there is a sharp increase of home TBI starting at around 50 years of age, road/highway injuries peak in ages 16–25 years. Female outdoor/sports injuries peak in the middle age range whereas in the male groups these injuries are more evenly distributed across the age spectrum. The distribution of injury causes across the groups was significantly different ($p < 0.001$). TBI that happened on roads/highways (N = 575, 32% of cases) were in most cases caused by traffic accidents (66% of cases); in home injuries (N = 471, 26%), low level falls accounted for 58% of all cases; TBI occurring on the street or in public place (N = 387, 21% of cases) were predominantly caused by same level falls or falls from 3 meters or higher (accounting together for 40% of cases); sports was the primary cause (31% of cases) of TBI occurring outdoors or in sport facilities (N = 252, 14% of cases), and in case of workplace injuries, high level falls were the most common (29%).

Although in all groups male was the predominant sex (over 65% in all groups, $p < 0.001$), the proportion of females is apparently the highest in home injuries (35% of cases). On the other hand, TBI at the workplace happened solely to men.

Severity and extent of the injuries along with outcomes are compared in Table 2. The total GCS score which reflects the neurological status after the injury suggests that road/highway injuries are associated significantly with the most severe changes in consciousness (mean GCS 7.4, 95% CI = 7–7.8; $p > 0.01$). The ISS summarizing the severity and extent of all injuries to the body indicates that road/highway (mean ISS of 32.5, 95% CI = 31.1–33.9) and workplace injuries (mean ISS 32.4, 95% CI = 29.6–35.3) were the most severe ones ($p < 0.01$). The injuries in the road/highway and workplace categories also had significantly the highest number of additional body regions with severe injury ($p < 0.001$; median of 2 additional severe injuries, IQR: 1–3 in both groups). In general, additional injuries to the face and thorax regions were most common.

The outcomes are presented in Table 3. The worst outcome was observed in case of injuries occurring at home: these patients had the highest mortality at hospital discharge (50%, $p < 0.001$) and had the highest rate of six months unfavourable outcome (70%, $p < 0.001$). On the other hand, the lowest rates of hospital mortality (24%) and unfavourable outcome at six months post injury (44%) were present in the group of outdoor/sports injuries. These patterns also remained when the sample was broken down by sex ($p < 0.001$) in both sex groups for hospital mortality and six months unfavourable outcome). Injuries occurring at workplace required the longest time of hospitalization (mean of 22.5 days, 95% CI = 10.5–45.1, $p < 0.001$).

The multivariable analysis presented in Table 4 indicates that after controlling for age, GCS, ISS and injury cause, home injuries had the highest odds of hospital mortality (OR = 3.12, 95% CI = 1.86–5.25) and of six month unfavourable outcome (OR = 2.51, 95% CI = 1.54–4.08) as compared to outdoor/sports injuries as a reference group.

DISCUSSION

The aim of this study was to compare the demographic, severity and outcome patterns of TBI based on the location where

Table 2. *Severity and patterns of the injuries by trauma location*

Location group	Road/highway	Home	Street/public place	Outdoor/sport facility	Workplace	Total	p-value
N (%)	575 (32%)	471 (26%)	387 (21%)	252 (14%)	133 (7%)	1,818	–
First GCS (mean, 95% CI)	7.4 (7.0–7.8)	7.6 (7.1–8.0)	8.4 (7.9–8.9)	8.4 (7.8–9)	7.8 (6.9–8.6)	7.8 (7.6–8.1)	<0.01
ISS (mean, 95% CI)	32.5 (31.1–33.9)	29.0 (27.2–30.7)	28.7 (27.1–30.4)	29.2 (26.9–31.5)	32.4 (29.6–35.3)	30.3 (29.5–31.2)	<0.01
Additional body regions with AIS > 2 (median, IQR)	2 (1–3)	1 (1–2)	1 (1–2)	1 (1–2)	2 (1–3)	1 (1–2)	<0.001

95% CI = 95% Confidence Interval; ISS = Injury Severity Score; IQR = Interquartile Range; AIS = Abbreviated Injury Scale

Table 3. *Outcomes at hospital discharge and at six months after injury by trauma location*

Location group	Road/highway	Home	Street/public place	Outdoor/sport facility	Workplace	Total	p-value
N (%)	575 (32%)	471 (26%)	387 (21%)	252 (14%)	133 (7%)	1,818	–
Total days in hospital (median, IQR)	20.6 (8.2–27.8)	13.9 (3.8–30.4)	20.4 (6.7–40.9)	13.4 (6.2–24.3)	22.5 (10.5–45.1)	18.0 (6.1–34.3)	<0.001
Hospital mortality (N, %)	140 (26%)	230 (50%)	128 (35%)	58 (24%)	40 (31%)	596 (34%)	<0.001
Male (N, %)	106 (26%)	149 (5%)	95 (34%)	46 (24%)	40 (32%)	436 (33%)	<0.001
Female (N, %)	34 (25%)	81 (50%)	33 (38%)	12 (26%)	–	160 (37%)	<0.001
Six month unfavourable outcome (N, %)	223 (46%)	293 (70%)	162 (46%)	86 (44%)	58 (52%)	822 (53%)	<0.001
Male (N, %)	169 (46%)	195 (70%)	122 (45%)	69 (44%)	58 (53%)	613 (52%)	<0.001
Female (N, %)	54 (45%)	98 (70%)	40 (49%)	17 (43%)	–	209 (55%)	<0.001

IQR = Interquartile Range

Table 4. *Adjusted analysis of outcomes*

Factor	Hospital mortality (death = 1)		Six months outcome (unfavourable = 1)	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Trauma location				
Outdoor/sport facility	1	–	1	–
Road/highway	0.76 (0.45–1.26)	0.287	1.00 (0.64–1.59)	0.976
Workplace	1.19 (0.60–2.33)	0.618	1.40 (0.74–2.64)	0.301
Street/public place	1.80 (1.10–3.1)	0.026	1.01 (0.62–1.65)	0.940
Home	3.12 (1.86–5.25)	< 0.001	2.51 (1.54–4.08)	< 0.001
Age	1.03 (1.02–1.04)	< 0.001	1.04 (1.03–1.05)	< 0.001
GCS	0.74 (0.70–0.77)	< 0.001	0.76 (0.72–7.78)	< 0.001
ISS	1.06 (1.05–1.07)	< 0.001	1.04 (1.03–1.05)	< 0.001

95% CI = 95% Confidence Interval; GCS = Glasgow Coma Scale; ISS = Injury Severity Score; OR = Odds Ratio

they happened in a total of 1,818 patients admitted to hospitals in five European countries in 2001–2012. The epidemiology of TBI has been previously extensively studied mostly focusing on demographic characteristics of patients, injury cause, injury severity, extent, and outcome (6, 7, 10). However, location of injury as an epidemiological characteristic is in most studies omitted or not available for analysis and if reported then usually only marginally, without detailed analysis (18–20). To our knowledge, this study is the first one that considers the location of injury as the primary aspect and brings side by side comparisons of TBI characteristics at different locations. We identified a number of distinctive patterns to TBI at different locations that provide valuable information especially in the context of public health. The following paragraphs summarize our key findings, compare them to other studies and discuss the public health implications.

TBI at Home

In total, TBI at home accounted for 26% of all TBI in our study. In an observational study similar to ours conducted in the Netherlands, Andriessen et al. (18) found the same proportion of home TBI. The study of Jager et al. (20) evaluating TBI at emergency departments in the US found that home injuries were the most frequent, and Baldo et al. (19) in their analysis of hospitalized TBI patients in Northern Italy found 11.4/100,000 home TBI cases in 2000 which was significantly lower than motor vehicle accidents or other injuries. In our study, the population at the highest risk of acquiring TBI at home were older adults (mean age of 57.9 years). In the majority of cases (58%) home TBI was caused by the same level fall, which is consistent with results of studies focusing on the elderly population (21, 22). Males in general are at significantly higher risk of suffering TBI (3, 4, 6, 10) and this was confirmed in the case of home TBI. However, in this group we found the highest proportion of females (35%) with a peak shifted by a decade to 76–85 years when compared to men (Fig. 1). This finding may reflect the generally higher life expectancy of women and thus higher proportion of women in higher age groups. The shift of TBI to higher age driven by the same level falls occurring mainly at home has been described previously (4, 21, 22); our findings confirm that this aspect of TBI becomes a medical and public health priority. Despite a relatively low overall injury severity, this group of injuries showed the poorest outcome of all groups. This fact could be partly explained by generally poorer outcomes in elderly TBI patients (22, 23).

TBI on Streets and Public Places

The proportion of these injuries in the total was 21%. Andriessen et al. (18) using a slightly different categorization found an aggregated 67% of injuries happening in public places and roads. Combining these two categories in our study we observed about half of the cases, which is comparable. A key finding is that the largest part of injuries in this group is caused by the same level falls (30%) which suggests that fall prevention should be considered at these locations as well (besides home or workplace). An additional 18% of these injuries are results of traffic accidents where the victim is involved as a pedestrian or cyclist. This is understandable presuming the urban character of these accidents. Other characteristics of these injuries are high degree of severity and second poorest outcome after home injuries.

TBI on Roads and Highways

These injuries were the most common in our sample accounting for 32% of cases and traffic accidents (accounting for 66% of cases in our study) were the most common cause. Street and highway were identified as the second most common location of injury in the study of Jager et al. (20) (after home TBI). In cross-comparison, we found that motor vehicle accidents caused 19% of street/public place injuries and 65% of road/highway injuries and this ratio was 24% vs. 30% in the case of pedestrian bicycle injuries. Thus, whereas the risk of motor vehicle accidents is significantly higher on roads and highways, the risk of pedestrian and bicycle injuries is similar at both locations. We can conclude that motor vehicle users are at risk of TBI primarily outside urbanized areas. Our findings confirm that young motor-vehicle users represent the primary population at risk of TBI in these locations (3, 7, 24). An important aspect regarding this group of TBI is the relatively young age of the victims (peaking at 16–25 years, see Fig. 1). This suggests high numbers of years of potential life lost (PYLL) and high numbers of years lived with disability, as shown by other studies (25, 26) and warrants for further preventive measures.

TBI Outdoors and in Sport Facilities

Sports related causes are reported in 29% of cases in this group, followed by the same and high level falls. Additional analysis revealed that sports are the major cause especially in men (69% of cases vs. 34% in women) and that falls are more prevalent as a cause in women (34% vs. 11% in men). In general, sport related injuries have the best outcome and tend to be less severe. According to the review of Sahler et al. (27), about 10% of all TBI in the US are due to sports or recreational activities and the number of ED admissions is rising. Additionally, besides immediate effects, there is growing evidence of sequelae even after minor TBI and this underlines the importance of public health action (27). Based on our findings, adults between 30–60 years, especially males (Fig. 1) are the population at highest risk of TBI in this location. Other studies suggest that the mean age in sport related injuries is lower: 22.7 years (28) or between 10–19 years (27). However, most of the cases in these studies were mild TBI and thus are not fully comparable to our findings.

TBI at the Workplace

TBI at the workplace contributed 7% to the total number of TBI in our study. A relatively low number of cases at this location (4%) were also indicated by Andriessen et al. (18). Baldo et al. (19) and Jager et al. (20) confirm that the workplace is one of the least frequent locations of TBI. However, the devastating nature of these injuries (high frequencies of major extra-cranial injuries) and poor outcomes indicate a major public health issue. Most cases in our study were caused by falls (mainly high level, 29%). The study of Tiesman et al. (29) reports that 29% of occupational fatalities in the US in 2003–2008 were caused by falls, the highest ratio being in construction jobs (57%). Colantonio et al. (30) studied construction site TBI and found that trades helpers and labourers are at the highest risk (31% of cases). Based on these findings we can assume that a large part of TBI in this group happened at construction sites and that is where the prevention should be targeted primarily. The population at risk is almost solely men.

Limitations to the Study and Generalizability

The study enrolled only patients admitted to hospitals alive and enrolment criteria further limit those to severe or moderate TBI. Therefore, patients dying prior to hospital admission (on-site fatalities) and mild cases of TBI are not included. Our findings should be viewed as a pioneer effort to provide a detailed description of TBI that occurred at different locations and should be transferred to other populations with caution. However, as the data has been collected in five countries there is a clear international dimension to our results.

Other information such as day, month or season of occurrence are of potential relevance to the aspects covered by this study. However, due to various periods of patient enrolments in the centres participating in the study (e.g. the start and end date of data collection differed) would introduce a potentially significant bias to such analyses. Therefore, these characteristics were not analysed. Furthermore, data on use of preventive measures such as seatbelts or helmets could bring further important insights. However, such information was not available for this analysis.

CONCLUSIONS

TBI that happened at different locations display distinctive patterns of causes, severity, outcomes, and populations at risk. We therefore conclude that location of injury is a relevant epidemiological aspect to TBI and we advocate its inclusion in all epidemiological studies dealing with TBI. Clear definitions of populations at risk at different locations could help in targeted public health actions.

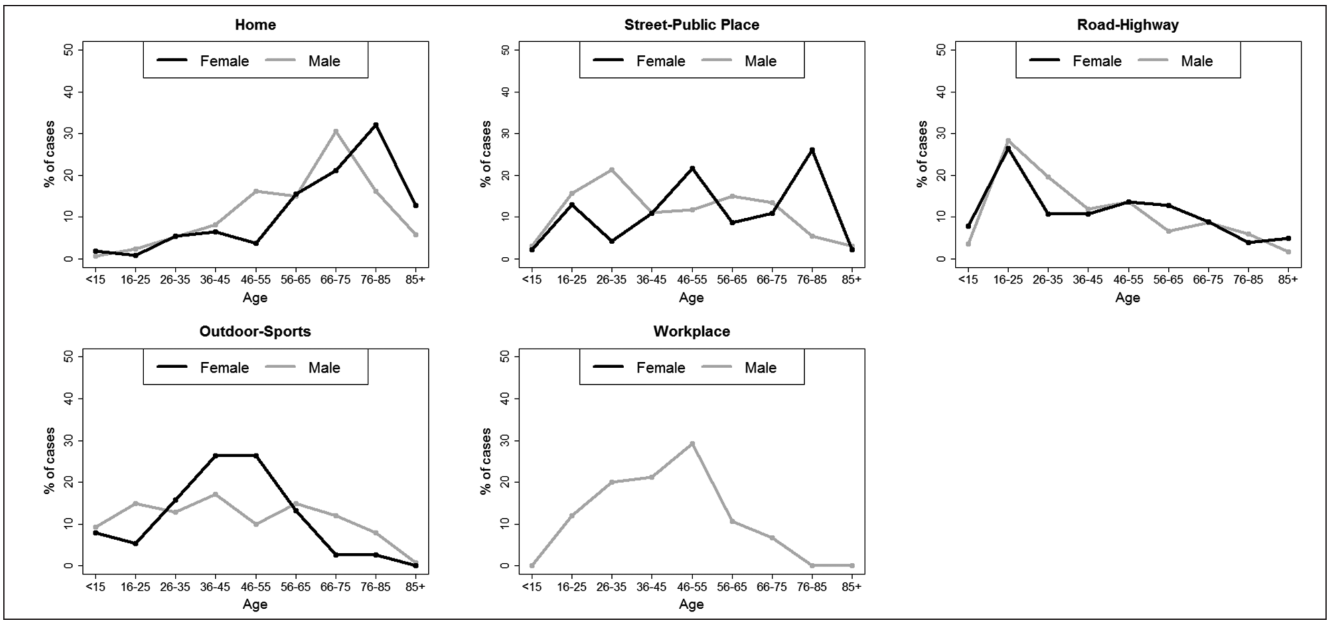

Fig. 1. *Age and sex distribution of patients by location.*

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Conflicts of Interests
None declared

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