Traumatic brain injuries caused by traffic accidents in five European countries: outcome and public health consequences

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Background: Road traffic accidents (RTAs) have been identified by public health organizations as being of major global concern. Traumatic brain injuries (TBIs) are among the most severe injuries and are in a large part caused by RTA. The objective of this article is to analyse the severity and outcome of TBI caused by RTA in different types of road users in five European countries. Methods: The demographic, severity and outcome measures of 683 individuals with RTA-related TBI from Austria, Slovakia, Bosnia, Croatia and Macedonia were analysed. Five types of road users (car drivers, car passengers, motorcyclists, bicyclists and pedestrians) were compared using univariate and multivariate statistical methods. Short-term outcome [intensive care unit (ICU) survival] and long-term outcome of patients were analysed. Results: In our data set, 44% of TBI were traffic related. The median age of patients was 32.5 years, being the lowest (25 years) in car passengers. The most severe and extensive injuries were reported in pedestrians. Pedestrians had the lowest rate of ICU survival (60%) and favourable long-term outcome (46%). Drivers had the highest ICU survival (73%) and car passengers had the best long-term outcome (59% favourable). No differences in the outcome were found between countries with different economy levels. Conclusion: TBI are significantly associated with RTA and thus, tackling them together could be more effective. The population at highest risk of RTA-related TBI are young males (in our sample median age: 32.5 years). Pedestrians have the most severe TBI with the worst outcome. Both groups should be a priority for public health action.

Introduction

Road traffic accidents (RTAs) have been identified by leading public health organizations as a major concern. In its report, the WHO estimated that 1.2 million people are killed in road crashes each year and another 50 million are injured. These figures are projected to increase steeply if no action is taken particularly in developing countries and to discuss some of the public health consequences of this burden.

To our best knowledge, the number of studies dealing with TBI as a consequence of RTA in Europe is limited. The objective of this article is to provide an overview of the severity and outcome of TBI caused by RTAs in different types of road users in five European countries and to discuss some of the public health consequences of this burden.

Methods

Study sample and data collection

A cross-sectional observational study was conducted to collect data for our analysis. Our study sample consisted of 683 patients with severe TBI, where the reported mechanism of injury was traffic related. The data were collected in 25 centres located in Austria, Bosnia, Croatia, Macedonia and Slovakia. The centres included seven University Departments of Neurosurgery, 12 large City Hospitals, 1 Centre for Neurosurgery and Neurology and 5 free-standing Trauma Centres. The data were collected between January 2001 and December 2010. Patients were included if they had ‘severe TBI’ according to the criteria defined by the US National Traumatic Coma Database such as a Glasgow Coma Scale (GCS) score of ≤8 following resuscitation. Only patients who survived at least until admission to the intensive care unit (ICU) were enrolled in this study.
Patients were examined by a physician immediately after admission to the study centre. Using our Internet-based database, basic demographic data of the patient, cause and location of trauma, prehospital status and treatment, mechanism and severity of trauma, results of computed tomography scans, results of laboratory testing and data on surgical procedures and outcomes were recorded. Information on status and location were recorded at 3, 6 and 12 months after injury.

Approaches to analysis

In the course of data collection, the following five subcategories of RTA were recorded: 'motor vehicle accident–driver', 'motor vehicle accident–passenger', 'motorcyclist, bicyclist' and 'pedestrian'. To evaluate the severity of the injury among the five groups, eight indicators were selected. First, the Abbreviated Injury Score (AIS) was used. For the purpose of our article, we coded 'serious', 'severe', 'critical' or 'unsurvivable' injuries as 'severe'. The percentage of patients with 'severe' AIS was then used as a measure of severity. Additionally, the number of body regions with AIS being moderate, serious, severe, critical or unsurvivable, the Injury Severity Score (ISS) and the first available GCS were used to indicate injury severity. Furthermore, pupillary reaction, days spent at the ICU, total days spent at hospital and requirement of cranial surgery were selected as severity measures.

To assess the short-term outcome, the survival rate at the discharge of patients from the ICU was calculated. To assess the long-term outcome of patients, the last available Glasgow Outcome Scale (GOS) assessment was used. The GOS levels were categorized in 'favourable outcome' (which included the original grades of the GOS of 'Good Recovery' and 'Moderate Disability') and in 'unfavourable outcome' (which included the original grades of 'Severe Disability', 'Persistent vegetative state' or 'Death'). A similar approach of long-term outcome analysis was used in other recent studies of TBI outcome. The last available GOS was used to indicate injury severity. Furthermore, pupillary reaction, days spent at the ICU, total days spent at hospital and requirement of cranial surgery were selected as severity measures.

Table 1 characteristics of severity and outcome of injuries of patients with severe TBI with all recorded mechanisms of injury

<table>
<thead>
<tr>
<th>Accident group</th>
<th>Age, median (IQR)</th>
<th>ISS, median (IQR)</th>
<th>GCS, median (IQR)</th>
<th>ICU outcome n (per cent survived)</th>
<th>Long-term outcome n (per cent survived)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic related</td>
<td>32.5 (20–50)</td>
<td>29 (22–41)</td>
<td>10 (3–14)</td>
<td>431 (66)</td>
<td>344 (53)</td>
<td>683 (44)</td>
</tr>
<tr>
<td>Low-level falls (&lt;3 m)</td>
<td>63.2 (47–75)</td>
<td>18 (16–26)</td>
<td>10 (3–14)</td>
<td>269 (63)</td>
<td>171 (41)</td>
<td>452 (29)</td>
</tr>
<tr>
<td>High-level falls (&gt;3 m)</td>
<td>43 (31–61)</td>
<td>34 (25–47)</td>
<td>9 (3–14)</td>
<td>79 (57)</td>
<td>57 (42)</td>
<td>144 (9)</td>
</tr>
<tr>
<td>Other</td>
<td>47 (31–64)</td>
<td>25 (16–32)</td>
<td>10 (6–15)</td>
<td>74 (71)</td>
<td>45 (79)</td>
<td>64 (4)</td>
</tr>
<tr>
<td>Sports activity related</td>
<td>38 (25–50)</td>
<td>20 (16–26)</td>
<td>10 (5–14)</td>
<td>57 (91)</td>
<td>45 (79)</td>
<td>64 (4)</td>
</tr>
<tr>
<td>Gunshots</td>
<td>40.9 (29–57)</td>
<td>42 (25–44)</td>
<td>3 (3–13)</td>
<td>16 (30)</td>
<td>13 (24)</td>
<td>58 (4)</td>
</tr>
<tr>
<td>Assaults</td>
<td>41.3 (28–51)</td>
<td>21.5 (16–27)</td>
<td>13.5 (9–15)</td>
<td>30 (75)</td>
<td>26 (65)</td>
<td>42 (3)</td>
</tr>
<tr>
<td>Penetration wounds</td>
<td>35 (25.5–43)</td>
<td>34 (27–59)</td>
<td>12 (11–13)</td>
<td>4 (67)</td>
<td>4 (67)</td>
<td>7 (1)</td>
</tr>
<tr>
<td>Total</td>
<td>44.8 (26–64)</td>
<td>26 (17–35)</td>
<td>10 (3–14)</td>
<td>960 (65)</td>
<td>710 (49)</td>
<td>1557</td>
</tr>
</tbody>
</table>

P-value <0.001 <0.001 <0.01 <0.001 <0.001

N = number of cases
The proportion of severe injuries based on AIS classification in the abdominal region was significantly higher in drivers compared with other mechanisms. Severe external injuries and injuries of extremities were significantly more present in drivers compared with other mechanisms. Severe external injuries and injuries of extremities were significantly more present in drivers compared with other mechanisms.

The ISS suggests that the most severe injuries were in the group of drivers and the less severe in bicyclists. The proportion of abnormal pupils was similar in each group ranging from 26% to 38% with no statistically significant differences. The median of the number of days spent at the ICU ranged from 7 in passengers to 10 in drivers and motorcyclists with no significant differences. The total days spent in hospital were significantly higher in drivers and bicyclists compared with others, and the median values ranged from 10 to 19 days. Cranial surgery was necessary in >60% of cases in all groups.

The table also presents the results of our multivariate analysis. In the adjusted analyses, odds ratios were adjusted for age, ISS, number of body regions with AIS of two or more, and number of days at the hospital. The total survival at the ICU discharge (short-term outcome) was 66%, being the highest in the group of drivers (73%) and lowest in cases of pedestrians (60%).

The long-term outcome, presented as a proportion of the patients with favourable last available outcome (Good Recovery or Moderate Disability) was 53% in the whole sample, and ranged from 46% in pedestrians up to 59% in passengers.

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hospital. In case of the ICU outcome, the crude odds ratios suggest significantly higher odds of survival in drivers as compared with pedestrians by a factor of 1.93 (95% confidence interval: 1.21–3.07). The least likely to survive after the ICU as compared with pedestrians were the motorists. The adjusted analysis shows the highest odds of survival after ICU as compared with pedestrians in bicyclists and the lowest in motorists. None of the adjusted odds ratios were statistically significant.

In case of long-term outcome, the highest odds for having a favourable outcome compared with pedestrians were in the passenger group. In the adjusted analysis, bicyclists had the highest odds of favourable outcome, and drivers had the lowest, compared with pedestrians. None of the odds ratios of long-term outcome were statistically significant.

### Discussion

#### Road traffic injuries and TBI

This article presents an analysis of 683 patients with severe TBI where the documented mechanism of injury was RTA related. The proportion of such cases was 44% of all 1557 cases in our data set. Tagliaferri et al.,4 in their review of 14 studies found that the proportion of RTA related TBI was up to 60%. Even higher were the proportions reported by Butcher et al.,6 where in the reviewed trials, they ranged from 53% up to >75% of total cases. This presents satisfactory evidence that severe TBI worldwide is in a large part a consequence of RTA.

Studies by other authors from different parts of the world show that head injuries and TBI are among the most prevalent consequences of RTA. A study by Bener et al.,19 from Qatar estimates that >70% of all RTA involved a head injury. The study of Harruff et al.,20 reports a head injury in 73% of cases. A study by Langley et al.,21 from New Zealand shows a head injury in 32% of cases. Collins et al.,22 in their study of bicyclists, found that 60% of them had a head injury. Santamaria-Rubio et al.,23 in their study in Barcelona, found that 78% of RTA victims suffered a TBI. Wong et al.,24 reported a head injury in >86% of cases of RTI in Singapore and Rochette et al.,25 found that 41.3% of the TBI they analysed involved a TBI. These findings lead to a conclusion that TBI can be considered as one of the most common consequences of RTA.

#### Demographic characteristics

Low age at the time of injury is one of the most serious public health aspects of RTA. Murray et al.,26 estimated that by 2020, the disability-adjusted life years of RTA may rank third on the list of diseases with the highest burden if no action is taken. In our analysis, the median age of the whole sample was 32.5 years. The lowest median age was recorded in the passenger and motorcyclist groups (25 and 26.5 years, respectively). The highest age medians were in pedestrians and bicyclists (45.5 and 48.5 years). Most of the cases (more than 67%) of head-injured RTA victims in the study of Bener et al.,19 were in the group of 20–44 years. According to Maas et al.,27 the median age of patients with severe TBI in general is increasing over the decades from approximately 25 years in a late 1980 study to 48 years in an early 2000 study by Rusnak et al.,28 Rochette et al.,25 in their study, found a median age of TBI patients after RTA of 34 years. TBI caused disability in young age, and high rates of premature death confirmed by our study pose a major public health challenge globally.

In their study, Santamaria-Rubio et al.,23 found that 70% of the patients were males, the proportion being higher in motorists and bicyclists (86% combined) as compared with other mechanism groups. These results correspond with our findings; 82% of patients were males in the bicyclists and 83% in motorcyclists. The study of Rochette et al.,25 reports a proportion of 64.9%. Javouhey et al.,29 found a significantly higher incidence of TBI in male RTA victims compared with females. It is clear that the male population is at substantially higher risk of sustaining a TBI as a consequence of RTA compared with females.

#### Severity and outcome

According to the existing studies, the severity and outcome of RTA differs by the type of road users.21,25,29–31 The WHO reports that the most vulnerable groups are bicyclists, motorcyclists and pedestrians. Our analysis of AIS patterns of RTA victims showed no differences in injury severity in the regions of the head, neck, face and thorax between the mechanism groups. This can be explained by the homogeneity of our sample, whereas it only consists of patients with severe TBI where injuries of the head and neck and the neighbouring body regions are present by definition.

Severely injured extremities and external injuries are most common in pedestrians. The abdomen was more often injured in drivers. We found that drivers (20%) and pedestrians (17%) have the highest proportion of more than two body regions injured. Harruff et al.,20 found that 60% of the pedestrians had two body regions injured (head and neck and trunk) and 40% had three regions injured (head and neck, trunk and extremities). We can conclude that pedestrians are the most likely road users to attain severe and extensive injuries.

An important indirect measure of severity of the injury is the length of hospital stay. We conclude that the most severe and demanding injuries (as to length of treatment) are those of drivers. Pedestrians, although they tend to have severe and extensive injuries spend less time in hospital. According to the WHO, only 48% of the vehicles are registered in developing countries; however, 90% of the RTA fatalities occur in these parts of the world. The RTA fatality rate of 21.5 and 19.5/100,000 population in low- and middle-income countries, respectively, are in high contrast with the RTA fatality rate of 10.3/100,000

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**Table 4 Short- and long-term outcome of patients with TBI with different traffic-related injury mechanisms**

<table>
<thead>
<tr>
<th>Mechanism group</th>
<th>ICU outcome (alive = 1)</th>
<th>Long-term outcome (favourable = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alive, N (%)</td>
<td>Crude OR (95% CI)</td>
</tr>
<tr>
<td>Pedestrian (N = 158)</td>
<td>88 (60)</td>
<td>Reference (1.0)</td>
</tr>
<tr>
<td>Bicycle (N = 72)</td>
<td>47 (70)</td>
<td>1.58 (0.85–2.92)</td>
</tr>
<tr>
<td>Motorcycle (N = 130)</td>
<td>79 (62)</td>
<td>1.1 (0.68–1.8)</td>
</tr>
<tr>
<td>Passenger (N = 118)</td>
<td>76 (66)</td>
<td>1.27 (0.77–2.11)</td>
</tr>
<tr>
<td>Driver (N = 205)</td>
<td>141 (73)</td>
<td>1.93* (1.21–3.07)</td>
</tr>
<tr>
<td>Total (N = 683)</td>
<td>431 (66)</td>
<td>–</td>
</tr>
</tbody>
</table>

*P < 0.01; 'OR adjusted for age, ISS, Number of body regions with severe AIS and number of days at the hospital.

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population in high-income countries. However, RTA remains a significant public health concern there as well.

From the public health and societal point of view, the long-term outcome of TBI victims is of a higher relevance. In our sample, pedestrians had the worst long-term outcome in countries of all economy levels included in our article, and passengers tended to have a high proportion of favourable outcome in all countries. However, we are not able to generalize these findings because the differences were not statistically significant.

**Public health consequences**

The WHO, as a leading public health body, states that data on how RTA occur and on their severity and type are important for the planning and implementation of effective interventions. Our study contributes such information and our findings document that TBI, as a consequence of RTA for different types of road users, has severe short- and long-term consequences. The population most at-risk based on our findings are young males (median age in our sample was 32.5 years). When targeting interventions to reduce RTA-related TBI, this population should be a priority.

Based on our findings and confirmed by other studies, a large proportion of RTA victims sustain a TBI. In contrast, looking at the whole range of TBI victims, our data in accordance with studies of other authors confirm that the main mechanisms of injury in TBI are RTA. This creates a clear overlap between RTA and TBI, both being of high public health relevance. Prevention and tackling of both problems might therefore be more effective when they are considered together as highly related. Based on the fact that TBI is in large part related to RTA, we can conclude that tackling RTA will lower the overall incidence of TBI. Out of all type of road users in our database, pedestrians had the most severe TBI and also had the worse outcome and should be considered a priority group for public health interventions.

**External validity and study limitations**

The data for this article were obtained from an observational study which did not allow for random sampling. Thus, our results should be generalized with caution. The study was conducted in 25 centres, with different levels of care in five European countries. However, the analysis of data from five countries could not be considered sufficient to allow generalizing for the whole European region. The data were collected using an online database interface and were entered by local research fellows. Data quality and completeness was assessed by the study managers (A.B. and M.R.). Incomplete or missing data was reported back to the centres, and were then provided by the local research fellows. Study monitors (A.B. and I.W.) double-checked 20% of the collected data using the original hospital records for comparison. The rate of errors was less than 3% of entered data. Thus, we are reasonably sure that the data entered into the database are valid. As with all observational studies, there could be some errors but these are unlikely to be of relevance.

Although we did not find significantly different severity of TBI between the different types of centres, we cannot rule out the possibility that in higher level centres such as university hospitals or specialized trauma centres, patients with more severe TBI were admitted in higher rates compared with city hospitals or general hospitals, both as direct admissions or transfers. This is a possible bias and a population-based study with randomized sampling, and inclusion of all levels of institutions is a more appropriate design to increase the external validity of the findings.

As a consequence of the primary focus of the study (TBI), the sample used in this study only represents those RTA where the victims sustained a TBI. Therefore, any findings stated in this article only apply to this specific group of RTA.

Our findings on the severity and outcome of TBI in different types of road users were not statistically significant and thus they lack external validity and should not be generalized to the whole population. It should be seen as a contribution to the debate on RTA from a specific viewpoint of TBI as a major and severe consequence. Despite its limitations, we believe that it presents useful and valuable information for the scientific and public health debate on this topic.

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**Conflicts of interest**: None declared.

**Key points**

- TBI and RTA are closely related; their prevention and the tackling of them could be more effective when considered together.
- TBI is one of the most severe and fatal type of injury in general and thus becomes one of the most severe and fatal type of injury associated with RTA.
- RTA-related TBI are especially of concern in young age groups and in an overwhelming ratio in the male population; young males should be a priority population for public health action.
- Tackling RTIs could significantly lower the incidence of TBI in both developing and developed countries.

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