Epidemiology of traumatic brain injuries in Europe: a cross-sectional analysis

Marek Majdan, Dominika Plancikova, Alexandra Brazinova, Martin Rusnak, Daan Nieboer, Valery Feigin, Andrew Maas

Summary

Introduction Traumatic brain injuries (TBI) are a major medical and socioeconomic problem. We aimed to estimate the hospital-based incidence, population-wide mortality, and the contribution of TBI to injury-related mortalities in European countries, and to provide European summary estimates for these indicators.

Methods For this cross-sectional analysis, we obtained population data from Eurostat for hospital discharges and causes of death in European countries in 2012. Outcomes of interest were TBIs that required hospital admission or were fatal. We calculated age-adjusted hospital discharge rates and mortality rates and extrapolated data to 28 European Union countries and all 48 states in Europe. We present between-country comparisons, pooled age-adjusted rates, and comparisons with all-injury rates.

Findings In 2012, 1 375 974 hospital discharges (data from 24 countries) and 33 415 deaths (25 countries) related to TBI were identified. The pooled age-adjusted hospital discharge rate was 287·2 per 100 000 (95% CI 232·9–341·5) and the pooled age-adjusted mortality rate was 11·7 per 100 000 (9·9–13·6). TBI caused 37% (95% CI 36–38) of all injury-related deaths in the analysed countries. Extrapolating our results, we estimate 56 946 (95% CI 47 286–66 099) TBI-related deaths and 1 445 526 (1 172 996–1 717 039) hospital discharges occurred in 2012 in the European Union (population 508·5 million) and about 82 000 deaths and about 2·1 million hospital discharges in the whole of Europe (population 737 million). We noted substantial between-country differences.

Interpretation TBI is an important cause of death and hospital admissions in Europe. The substantial between-country differences observed warrant further study and suggest that the true burden of TBI in Europe has not yet been captured. Rigorous epidemiological studies are needed to fully quantify the effect of TBI on society. Despite a great degree of consistency in data reporting across countries already being achieved, further efforts in this respect could improve the validity of between-country comparisons.

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Department of Public Health, Faculty of Health Sciences and Social Work, Trnava University, Trnava, Slovakia (M Majdan PhD, D Plancikova MSc, A Brazinova PhD, Prof M Rusnak PhD); **Department of Public Health, Erasmus MC, Rotterdam, Netherlands** (D Nieboer MSc); **National Institute for Stroke & Applied Neurosciences, Faculty of Health and Environmental Sciences, Auckland University of Technology, Auckland, New Zealand** (Prof V Feigin MD); **and Department of Neurosurgery, Antwerp University Hospital, University of Antwerp, Edegem, Belgium** (Prof A Maas MD)

Correspondence to: Dr Marek Majdan, Department of Public Health, Faculty of Health Sciences and Social Work, Trnava University, 23 Hornopotocna, Trnava 91843, Slovakia **mmajdan@truni.sk**

Introduction

Traumatic brain injuries (TBI) are an important medical, public health, and societal problem worldwide.[1–4] TBI are a major cause of mortality and morbidity in young people,[5–7] and their incidence is increasing in people aged 65 years and older—especially in high-income countries.[8,9] TBI represent a major cause of long-term disabilities among survivors,[10–12] influencing the lives of those affected and their relatives.[13] TBI are associated with increased mortality[10] and decreased life expectancy[14] compared with the general population and people with TBI incur substantial direct (health care) and indirect (loss of productivity and care-giver related) costs.[12,15,16]

Detailed epidemiological data are needed to guide improvements in the clinical, public health, and societal context. Several studies[17–19] that describe the epidemiological aspects of TBI in Europe have been published, but these studies were not population-based, used a single-centre or multicentre design, and were based on data from selected hospitals.

Some of the limitations of hospital-based studies can be overcome by using population-wide analyses, which also include cases not admitted to hospitals.[20] The estimated incidences are substantially higher in population-wide analyses[21] than in hospital-based studies or registry-based studies,[17–19] and the true scope of the disease can be better captured. Population-wide studies also have limitations that stem from their labour-intensive character. Alternative approaches based on routinely collected data (hospital discharge databases or mortality registries)[22] could provide insight into population-wide patterns. Such studies usually have country-wide coverage and deal with all TBI cases that are admitted to hospitals, or are fatal, or both; the main disadvantage is that researchers do not have access to individual patient data and rely on case ascertainment and definitions provided by the statistical service.

To our knowledge, no study has attempted to estimate the incidence and mortality of TBI using population-wide data for Europe and thus far the best estimates of TBI incidence and mortality in Europe are from three systematic reviews of hospital-based studies or single-country population-based studies.[17–19] Additionally, no studies have estimated the proportion of TBI-related

Research in context

Evidence before this study

We searched PubMed without date restrictions for English language sources on May 15, 2016, with the search terms "traumatic brain injuries", "epidemiology", "incidence", "mortality", and "Europe". The incidence, mortality, and epidemiology of traumatic brain injury (TBI) in European countries have been previously analysed and three systematic reviews were published in 2006, 2015, and 2015; authors identified 23, 28, and 66 reports of TBI epidemiology from 12, 16, and 23 European countries, respectively. In two of these systematic reviews, a summary measure of incidence and mortality for Europe is provided, but the included studies did not apply unified approaches to data acquisition and varied frequently in design, case ascertainment, timeframe (1988–2014), and population outreach.

Added value of this study

Our study analysed data for hospital discharges from 24 European countries and deaths caused by TBI from 25 European countries for a single year (2012) that were centrally aggregated following specific and unified reporting guidelines. Our study estimates the age-adjusted hospital discharge rates and age-adjusted mortality rates for each of the included countries by sex and provides pooled age-adjusted estimates. Unified approaches to calculation of rates, the possibility to perform age-adjustment on raw data, and the broad outreach into countries of Europe make it a valid and comprehensive European epidemiological analysis of hospital-based TBI incidence and TBI mortality. Additionally, to our knowledge, this is the first study that estimates the proportion of age-adjusted TBI-related mortality out of the age-adjusted all-injury mortality in Europe. Our results present a core assessment of the burden of TBI in Europe, which could serve as a solid basis for more detailed analyses of the overall population burden taking into account the level of disabilities caused and potential years of lost life. Although our design produced estimates similar to those produced by systematic reviews, it presents a more valid approach that could be used for continuously updated analyses on a European scale.

Implications of all the available evidence

TBI is confirmed as a major cause of injury-associated deaths and hospital discharges in Europe. Despite the unified approaches, we identified substantial between-country differences in discharge incidence and death rates that require further study. The true population burden of TBI is yet to be determined. We advocate further harmonisation of centrally aggregated administrative data and application of unified epidemiological methods to increase the reliability of estimates for tracking of epidemiological patterns of TBI in European countries and in Europe as a whole. Our results can inform the set-up of a system for continuous assessment of the burden of TBI in Europe to inform public health and policy making.

mortality in relation to all-injury mortality, which hinders the estimation of the overall population burden of TBI.

In this study, we intend to provide a comprehensive overview of TBI in Europe by applying a unified data search and appraisal of official statistics. We aimed to estimate hospital-based incidence rates, population-wide mortality, and the contribution of TBI to overall injury-related mortalities in European countries, and to provide European summary estimates of these indicators.

Methods

Study design and data collection

We did a cross-sectional study of hospital-based incidence from 24 European countries and population mortality from 25 European countries for TBI for 2012. Inclusion of countries in our analyses was based on data availability (table 1).

Data used for all analyses were obtained from Eurostat. A purposely tailored dataset was provided for the most recent year, for which the data aggregation process was complete—2012. Data were aggregated by diagnostic group, into 5 year age groups (presented as 10 years), and by sex. All data were collected on country level and were aggregated by Eurostat. We did an in-depth analysis of the available metadata to explore potential selection bias as a cause of between-country differences. Eurostat performs a validity check on age, sex, cause of death, and number of data in case of cause of death.[23] For hospital discharges, Eurostat does consistency checks over time and between the tables or variables.[24] To our knowledge there are no analyses that would specifically further validate the data collected and aggregated by Eurostat.

The study used administratively collected secondary data and no ethics committee approval was required.

Outcomes and variables

Hospital discharges were defined as the formal release of a patient from a hospital.[24] All patients discharged alive, dead, or transferred to another hospital were included. Transfers within the same institutions and TBI not admitted to a hospital were not included. Patients were differentiated as inpatient (minimum stay 1 night) and day cases (discharged on the same day). Diagnoses for hospital discharges were coded using the International Shortlist for Hospital Morbidity Tabulation (ISHMT).[25] Codes 1901 (intracranial injuries, ICD-10 code S06) and 1902 (other injuries to the head, ICD-10 codes S00–S05 and S07–S09) were used as inclusion criteria.

Cause of death for this study was the underlying cause that is the disease or injury that initiated the train of morbid events leading directly to death, or the circumstances of the incident that produced the fatal

	Causes of death	Hospital discharges*
Austria	Yes	Yes
Belgium	Yes	Yes
Croatia	Yes	Yes
Cyprus	Yes	Yes
Czech Republic	Yes	Yes
Denmark	Yes	Not available
Estonia	Yes	Not available
Finland	Yes	Yes
France	Not available	Yes
Germany	Yes	Yes
Hungary	Not available	Yes
Ireland	Yes	Yes
Italy	Yes	Yes
Latvia	Yes	Yes
Lithuania	Yes	Yes
Luxembourg	Yes	Yes
Malta	Yes	Yes
Netherlands	Yes	Yes
Norway	Not available	Yes
Poland	Not available	Yes
Portugal	Yes	Yes
Romania	Yes	Yes
Serbia	Yes	Not available
Slovakia	Yes	Not available
Slovenia	Yes	Yes
Spain	Not available	Yes
Sweden	Yes	Yes
Switzerland	Yes	Not available
Turkey	Yes	Not available
UK	Yes	Yes

*Data for hospital discharges from Sweden and Norway were not available for 2012 and were supplemented by data for 2013.

Table 1: **Countries for which data for causes of death and hospital discharges pertaining to injuries were available**

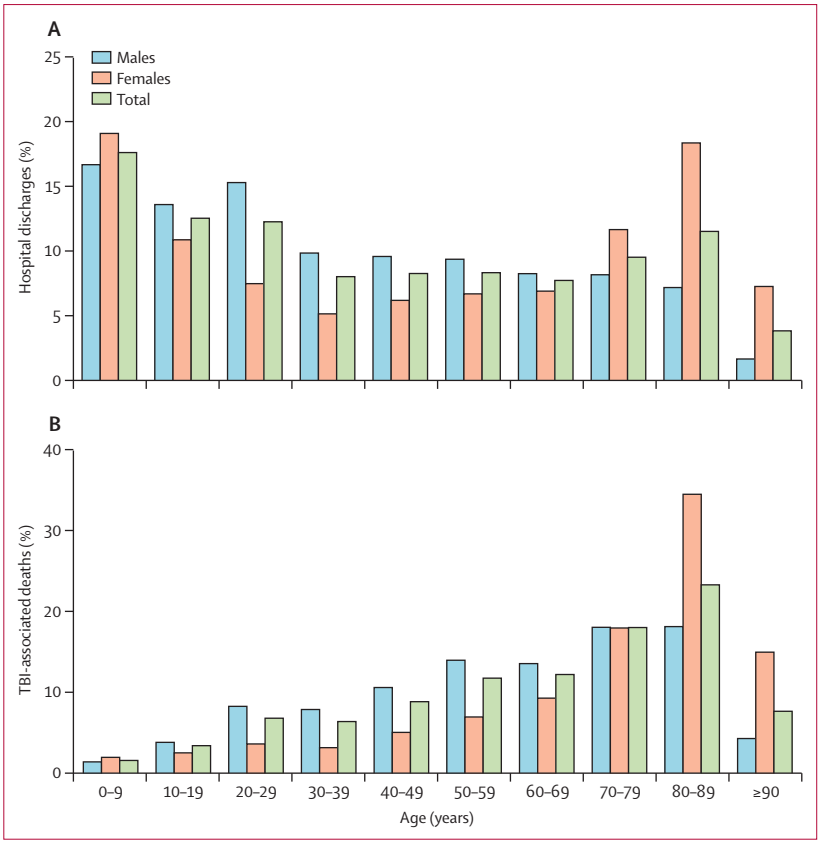


Figure 1: **Hospital discharges and deaths due to TBI by age**
Distribution of (A) hospital discharges due to TBI and (B) TBI-associated deaths. All countries combined.

injury, as defined by WHO.[23,26] Data for mortality for our analyses were based on information from death certificates. The ICD-10 classification was used to code the causes of death (codes S00–S09 and T90 were included). External causes of injury were defined as traffic-related injuries (V01–V99), falls (W00–W19), suicide (X60–X84), violence (X85–Y09), and other (W20–X59, Y10–Y98).

Statistical analysis

Results are presented as crude and age-adjusted hospital discharge rates and mortality rates per 100 000 people stratified by country, sex, and external cause (in case of cause of death). Additionally, pooled age-adjusted rates with 95% CI are presented.

We used annual mid-year populations obtained from Eurostat to calculate crude rates and to extrapolate our results to the population of the 28 member states of the EU (EU-28)[27] and the whole of Europe (48 states).[28] Rates were age-adjusted using the direct method with the European standard population (based on EU-27 plus European Free Trade Association countries [EFTA]).[29] We calculated proportions of TBI-related mortality rates out of overall injury-related mortality rates to evaluate their relative importance as a cause of injury-related death. In doing so, cases with unspecific codes (eg, "other and unspecified effects of external causes"), deaths caused by exposure to heat, frost, intoxications (T15–T65), and cases with other generalised causes (T66–T78, T80–T88) were excluded from injury-related deaths (defined instead by codes S00–S99, T00–T14, T79, and T90–T98).

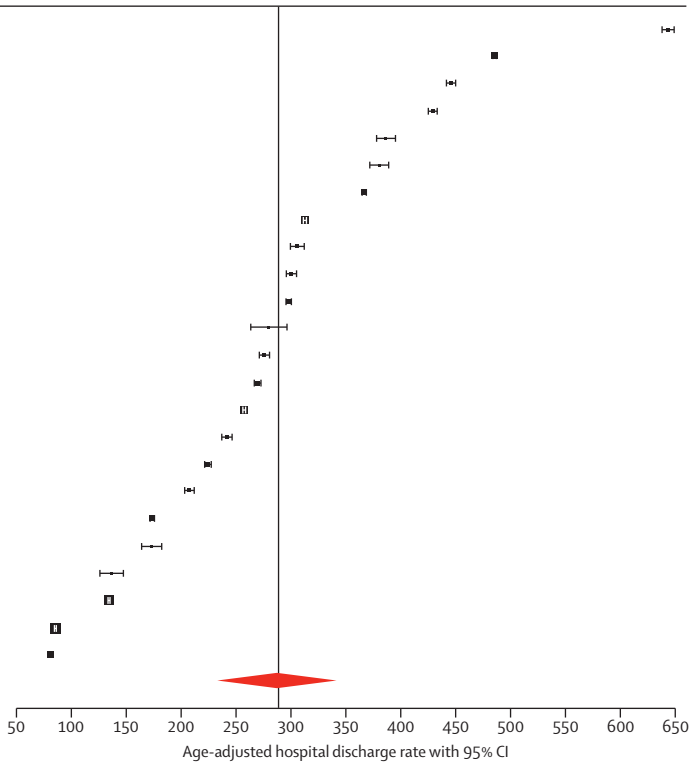
We did pooled analyses to estimate summary age-adjusted hospital discharge rates and mortality rates; we used the random-effects model[30] by the DerSimonian and Laird method, following a previous study,[31] to model possible heterogeneity of rates in the different countries. We used meta-regression, 95% prediction intervals, and I^2 to assess the heterogeneity of pooled estimations. We used R statistical software version 3.1.2 for all analyses.

Role of the funding source

The primary data collection was done with the assistance of Eurostat, which is an agency of the European

A

	Rate (crude)	Rate (adjusted)	95% CI (adjusted)
Austria	627·4	643·5	(638·0–649·0)
Germany	468·2	485·5	(484·0–487·1)
Sweden	451·5	445·8	(441·6–450·0)
Czech Republic	424·6	429·1	(425·1–433·2)
Latvia	388·8	386·5	(378·0–395·2)
Slovenia	372·1	380·3	(371·8–389·0)
Poland	370·9	366·7	(364·8–368·7)
UK	309·7	312·7	(311·3–314·1)
Lithuania	307·3	305·7	(299·5–312·1)
Finland	294·8	300·4	(295·8–305·1)
Romania	296·7	297·9	(295·5–300·4)
Malta	270·8	279·5	(263·4–296·4)
Norway	269·6	275·8	(271·2–280·5)
Belgium	270·5	269·6	(266·6–272·7)
France	256·9	257·5	(256·2–258·7)
Ireland	248·7	241·7	(237·0–246·4)
Hungary	217·3	224·4	(221·4–227·4)
Croatia	205·7	207·5	(203·2–211·9)
Netherlands	171·1	173·7	(171·7–175·7)
Cyprus	174·1	173·0	(164·0–182·3)
Luxembourg	127·7	136·4	(126·0–147·4)
Italy	134·3	134·3	(133·4–135·2)
Spain	82·9	85·4	(84·6–86·3)
Portugal	80·6	81·0	(79·3–82·8)
Pooled	**284·3**	**287·2**	**(232·9–341·5)**



B

Switzerland	20·3	21·8	(20·7–22·9)
Lithuania	20·8	20·9	(19·3–22·7)
Slovakia	15·8	18·2	(17·0–19·5)
Finland	17·3	17·8	(16·7–19·0)
Luxembourg	14·7	17·5	(13·8–21·9)
Latvia	17·3	17·2	(15·5–19·1)
Estonia	15·5	15·6	(13·5–17·9)
Czech Republic	13·1	13·7	(13·0–14·4)
Croatia	13·1	13·4	(12·3–14·6)
Austria	12·1	12·6	(11·8–13·4)
Belgium	11·7	12·4	(11·7–13·1)
Serbia	12·1	12·3	(11·5–13·1)
Romania	10·6	11·0	(10·5–11·5)
Slovenia	10·1	10·8	(9·4–12·4)
Sweden	9·0	9·2	(8·6–9·9)
Netherlands	8·1	8·9	(8·4–9·4)
Germany	8·7	8·3	(8·1–8·5)
Portugal	8·3	8·3	(7·8–8·9)
Italy	8·0	7·6	(7·4–7·8)
Denmark	8·7	7·3	(6·6–8·1)
Cyprus	6·6	7·3	(5·4–9·6)
Ireland	5·6	7·0	(6·1–7·9)
UK	5·4	5·9	(5·7–6·1)
Malta	5·0	5·1	(3·1–7·9)
Turkey	2·8	3·6	(3·4–3·8)
Pooled	**11·2**	**11·7**	**(9·9–13·6)**

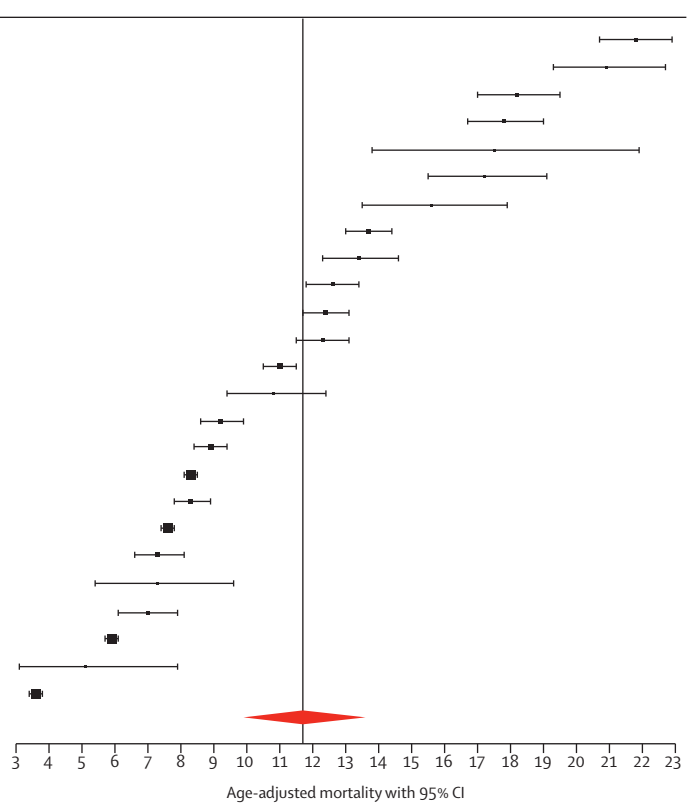


***Figure 2*: Hospital discharge and mortality rates due to TBI by country**

(A) Crude and age-adjusted hospital discharge rates due to TBI by country with pooled age-adjusted estimates of overall hospital discharge rate for 24 European countries. I^2=99·9%. 95% prediction interval: 0·0–593·5 (pooled age-adjusted rate). (B) Crude and age-adjusted mortality rates due to TBI by country with pooled age-adjusted estimates of mortality rate for 25 European countries. I^2=100%. 95% prediction interval: 1·2 to 15 (pooled age-adjusted rate). TBI=traumatic brain injury.

Commission that funded this study. The funding source (European Comission) had no role in the writing, or interpretation of the manuscript and the decision to submit it for publication. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

1 375 974 TBI-related hospital discharges were identified, 841 927 (61%) were men and 534 047 (39%) were female individuals. 751 558 (55%) of patients were 0–44 years old, and 395 158 (29%) were 65 years or older. The proportion of female patients 65 years and older was higher (218 833 [41%] of 534 047) than male patients (176 325 [21%] of 841 927; figure 1).

The pooled age-adjusted hospital discharge rate was estimated to be 287·2 per 100 000 people (95% CI 232·9–341·5; figure 2). Relatively large differences were observed; the highest overall hospital discharge rate was in Austria (643·5, 638·0–649·0) and the lowest was in Portugal (81·0, 79·3–82·8). Hospital discharge rates were higher in male individuals than in female individuals in all countries: the pooled age-adjusted hospital discharge rate was 372·2 (300·0–444·4) for men, and 205·1 (165·8–244·3) for women. Male–female rate ratio was 1·7 (95% CI 1·6–1·7; appendix).

33 415 deaths resulting from TBI were identified in the 25 countries, of which 22 886 (68%) were male individuals (table 2). Many deaths in the included countries occurred in patients 65 years or older: 7599 (72%) of deaths occurred in this age group in female patients, 10 646 (47%) in male patients, and accounting for 18 245 (55%) deaths in both sexes (figure 1). Male–female rate ratios ranged from 1·6 in Luxembourg, Malta, the Netherlands, and Switzerland, to 4·7 (95% CI 3·6–6·1) in Latvia, with a mean of 2·2 (2·2 to 2·3; appendix).

Estimated pooled age-adjusted mortality was 11·7 per 100 000 (95% CI 9·9–13·6), ranging from 3·6 (3·4–3·8) in Turkey to 21·8 (20·7–22·9) in Switzerland (figure 2). TBI resulting from falls and traffic incidents were most prevalent, but their relative contribution to mortality varied across countries (figure 3). TBI-related mortality was substantially higher in men (18·2, 15·0–21·4) than in women (6·3, 5·3–7·3) (appendix). On average, the TBI-related age-adjusted mortality accounted for 37% (95% CI 36–38) of the all-injury age-adjusted mortality overall, 42% (41–44) in men, and 29% (28–29) in women.

Data collection and aggregation coordinated by Eurostat ensured the best possible degree of homogeneity and between-country comparability under the conditions, and allowed for age-adjustment. Despite these similar approaches to data acquisition and unified approaches to analysis, we found substantial between-country differences (I^2 for all meta-analyses was >99%).

To estimate the impact of TBI in the broader territory of Europe, we extrapolated the pooled crude hospital discharge rates (284·3 per 100 000, 95% CI 230·7–337·7) and pooled crude mortality rate (11·2 per 100 0000, 95% CI 9·3–13·0) to the population of the EU-28 (508 450 856 people) and to the population of Europe as defined by the UN (48 states, population 737 021 812) as of 2012. Using this approach, in 2012, an estimated 1 445 526 (95% CI 1 172 996–1 717 039) TBI-related hospital discharges and 56 946 (47 286–66 099) TBI-related deaths occurred in the EU-28, compared with 2 095 353 (1 700 309–2 488 923) TBI-related hospital discharges and 82 546 (68 543–95 812) TBI-related deaths in the whole of Europe (table 3).

In addition to the age-adjustment using the European standard (based on EU-27 plus EFTA countries) population, we age-adjusted our main findings using the WHO World population[32] to allow for easier global comparisons (appendix).

19% (266 241) of all 1 375 974 patients in the Eurostat database were treated as day-cases—ranging from

	TBI		All injuries		TBI MR/all injury MR† (95% CI)
	Number of deaths	Age-adjusted rate (95% CI)	Number of deaths	Age-adjusted rate (95% CI)	
Switzerland	1620	21·8 (20·7–22·9)	4058	55·0 (53·3–56·7)	40 (39–40)
Lithuania	621	20·9 (19·3–22·7)	1242	41·8 (39·5–44·2)	50 (49–51)
Slovakia	856	18·2 (17·0–19·5)	2072	45·4 (43·4–47·5)	40 (39–41)
Finland	935	17·8 (16·7–19·0)	1919	36·6 (35·0–38·3)	49 (48–50)
Luxembourg	78	17·5 (13·8–21·9)	171	39·0 (33·3–45·4)	45 (41–48)
Latvia	351	17·2 (15·5–19·1)	755	37·0 (34·4–39·8)	46 (45–48)
Estonia	205	15·6 (13·5–17·9)	384	29·4 (26·5–32·5)	53 (51–55)
Czech Republic	1377	13·7 (13·0–14·4)	3538	35·9 (34·8–37·2)	38 (37–39)
Croatia	561	13·4 (12·3–14·6)	2033	49·5 (47·4–51·7)	27 (26–28)
Austria	1018	12·6 (11·8–13·4)	3181	39·2 (37·9–40·6)	32 (31–33)
Belgium	1300	12·4 (11·7–13·1)	3558	34·1 (33·0–35·2)	36 (35–37)
Serbia	870	12·3 (11·5–13·1)	1790	25·2 (24·0–26·4)	49 (48–50)
Romania	2124	11·0 (10·5–11·5)	4987	25·6 (24·9–26·4)	43 (42–44)
Slovenia	207	10·8 (9·4–12·4)	793	41·8 (38·9–44·8)	26 (24–28)
Sweden	858	9·2 (8·6–9·9)	2658	28·6 (27·5–29·7)	32 (31–33)
Netherlands	1357	8·9 (8·4–9·4)	4612	30·9 (30·0–31·8)	29 (28–30)
Germany	7160	8·3 (8·1–8·5)	21 229	24·7 (24·4–25·1)	34 (33–34)
Portugal	876	8·3 (7·8–8·9)	2635	24·9 (24·0–25·9)	33 (33–34)
Italy	4743	7·6 (7·4–7·8)	18 922	30·1 (29·7–30·5)	25 (25–26)
Denmark	389	7·3 (6·6–8·1)	1143	21·9 (20·7–23·2)	33 (32–35)
Cyprus	57	7·6 (5·4–9·6)	222	30·7 (26·6–35·2)	24 (20–27)
Ireland	259	7·0 (6·1–7·9)	592	16·8 (15·4–18·2)	42 (40–43)
UK	3447	5·9 (5·7–6·1)	10 653	18·3 (18·0–18·7)	32 (32–33)
Malta	21	5·1 (3·1–7·9)	53	13·4 (10·0–17·6)	38 (31–45)
Turkey	2125	3·6 (3·4–3·8)	11 096	21·9 (21·5–22·4)	16 (16–17)
Overall‡	33 415	11·7 (9·9–13·6)	104 296	31·9 (27·8–36·0)	37 (36–38)

TBI=traumatic brain injury. *We only included those cases where the cause of death has been defined by a specific ICD diagnostic code; cases where the cause was defined as "other and unspecified effects of external causes" or any of the ICD codes of T15–T78 and T80–T88 were excluded. †Percentage of age-adjusted TBI-related mortality rate out of age-adjusted all injury-related mortality rate. ‡Pooled age-adjusted mortality rates estimated using the random-effects model.

Table 2: **Deaths* and age-adjusted mortality rates due to all injuries and TBI**

See Online for appendix

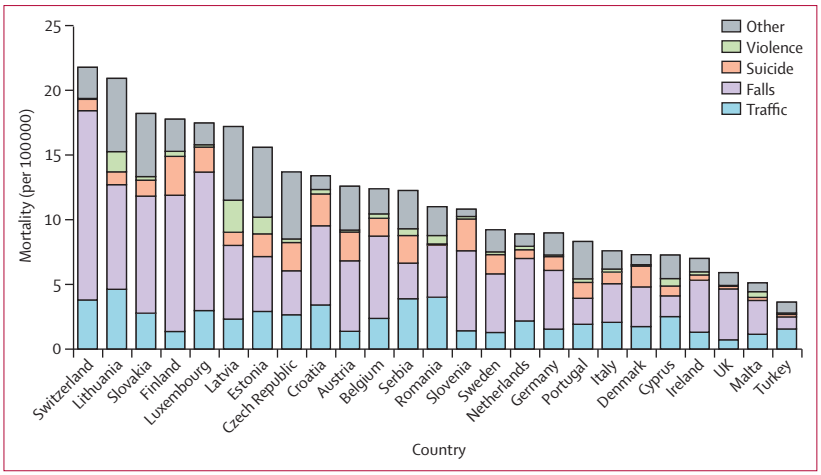


Figure 3: **Age-adjusted mortality rates due to traumatic brain injury in 25 European countries in 2012, by cause of injury**

	Population count	Pooled crude rate (95% CI)	Estimated number of cases (95% CI)
Deaths due to TBI			
EU-28[27]	508 450 856	11·2 (9·3–13·0)	56 946 (47 286–66 099)
Europe[30]*	737 021 812	11·2 (9·3–13·0)	82 546 (68 543–95 812)
Hospital discharges due to TBI			
EU-28	508 450 856	284·3 (230·7–337·7)	1 445 526 (1 172 996–1 717 039)
Europe	737 021 812	284·3 (230·7–337·7)	2 095 353 (1 700 309–2 488 923)

TBI=traumatic brain injury. *Europe as defined by the UN population division including 48 countries.

Table 3: **Estimated numbers of deaths and hospital discharges in Europe based on extrapolation of pooled crude hospital discharge and mortality rates**

63 cases (0·3%) of 21 560 cases in Hungary, to 87 632 (44%) of 197 277 cases in the UK. Proportions of day-cases were similar for both sexes; 172 416 (20%) were men and 93 825 (18%) were women. Day-case hospital discharge rates of the UK and Poland both rank above all other countries (appendix).

Among the inpatient cases, 617 657 (56%) were coded as intracranial injuries compared with 28% of day-cases. The average length of stay was 7·9 days (95% CI 6·1–9·7) among inpatients for intracranial injuries, and 3·7 days (3·3–4·0) for other head injuries (appendix).

Discussion

We found a pooled age-adjusted hospital discharge rate due to TBI of almost 300 per 100 000 people and a pooled age-adjusted mortality rate due to TBI of about 12 per 100 000 people in the analysed countries. TBI contributed about 37% overall to the all-injury mortality rate—42% in men and 29% in women. We found substantial between country differences in reported hospital discharge and mortality rates. On the basis of our results, about 57 000 TBI-related deaths and 1·5 million hospital discharges are estimated to have occurred in 2012 in the EU (population 508·5 million) and about 82 000 deaths and 2·1 million hospital discharges in the whole of Europe (population 737 million).

The substantial between-country differences in hospital discharges might be attributed in part to variations in data coding and collection procedures. We identified factors (ie, differences in dealing with transfers within the same institution; dealing with newborn patients or dealing with non-residents) that might introduce selection bias and extreme outliers (appendix). To a certain extent, these factors are leveraged by the relatively broad outreach of our study (24 European countries). We recalculated the pooled age-adjusted hospital discharge rates after excluding extremes (Austria and Portugal) and the rate was 280·5 per 100 000 (95% CI 234·3–326·7). The similarity to the original pooled rate points towards the robustness of our method and suggests generalisability to the population of Europe. By further exploratory analysis we have revealed possible contribution of per-capita GDP (lowest pooled rates were observed in countries with highest GDP, appendix). Differences were also revealed by geographical location (appendix).

The difference between the highest and lowest age-adjusted mortality was about six times. Compared with hospital discharge rates, data for cause of death could be considered more homogeneous because they are collected on the basis of an EU regulation.[23] Factors that could bias between-country comparisons might include national differences in interpretation and use of International Classification of Diseases rules, not applying recommended WHO updates, differences in coverage of residents dying abroad or non-residents dying in the reporting country, or national certification and coding procedures.[23] Some of the variation might be attributable to varying proportions of TBI-related deaths masked under multiple injuries, unknown, or other causes. For example, the low mortality rate in Turkey (3·6) could be partly due to a relatively low proportion of cases in which the cause of death was stated as TBI (16% in Turkey *vs* 37% on average elsewhere), which in turn could be attributable to a high proportion of deaths coded as multiple injuries (49% in Turkey *vs* 21% on average elsewhere). Differences were observed between countries grouped by per-capita GDP—the highest mortality was observed in countries with the highest GDP, compared with countries with lower GDP (appendix). Fitting of a meta-regression model using this categorisation revealed no significant effect.

The large differences between hospital discharge rates and mortality rates suggest that a substantial number of people in Europe annually survive a TBI and are presumably living with the consequences of the injury. Novel approaches such as those used in the Global Burden of Disease study take these into account through indicators such as number of years lived with disability (YLDs) or years of life lost (YLL)[33] and could be used to capture the full burden of TBI. To date, TBI has not

been analysed in such a manner on the European level, owing in part to non-availability of valid epidemiological data. Our study creates grounds for such an endeavour.

To date, three systematic reviews[17–19] have been published that estimated the epidemiological patterns of TBI in Europe. Our pooled age-adjusted hospital discharge rates for Europe are best comparable with the pooled incidence reported by Peeters and colleagues:[18] our hospital discharge rate was 287·2 (95% CI 232·9–341·5) compared with their reported incidence of 261·9 (198·5–325·2) (appendix).

Despite yielding similar results, the method applied in our study (and thus our findings) could be considered more valid, because our method tackles the general limitations of the presented systematic reviews—significant heterogeneity of the methods, study populations, and time range of the included studies. We believe that our novel approach could be used for regularly updated epidemiological overview of TBI epidemiology in Europe.

Our study has limitations. The substantial between-country differences imply methodological inconsistencies, which might lead to overestimation or underestimation of incidence rates in some countries. For example, the higher hospital discharge rates of Austria could be partly explained by failing to exclude transfers of patients within the same institution as separate discharges (as acknowledged in the hospital discharge dataset metadata).[24] For mortality rates, the relatively high proportion of general codes could cause mortality rates to appear lower than they are in reality. Although we did not have sufficient evidence to present a more detailed analysis of such influences, these aspects should be considered when interpreting our findings. The substantial between-country differences also warrant caution when extrapolating the pooled estimates towards other European countries, which is reflected in the wide prediction intervals of the pooled rates. Although we did capture population-wide mortality rates, we did not aim for full-capture of population-wide incidence of TBI (including milder injuries not seen in hospital, or only in the emergency room), but focused instead on hospital discharge rates. We did not address direct and indirect costs generated because of TBI. As a consequence, our study might not fully account for the overall burden of TBI in the population.

TBI is an important cause of injury-related deaths and hospital admissions in Europe and should be considered a serious public health problem. In this Article, we present the most comprehensive analysis of TBI epidemiology in Europe to date. The substantial between-country differences observed, despite a unified approach to data acquisition and analysis, warrant further study and indicate that the true burden of TBI in Europe has not yet been captured. Rigorous epidemiological studies are needed to quantify the full spectrum of the impact of TBI on society. Despite a great degree of consistency in data reporting across countries already achieved, further efforts in this respect might further improve the validity of between-country comparisons.

Contributors

MM conceived and designed the study, acquired and analysed the data, interpreted the results, wrote the first draft of the manuscript, and revised it on the basis of comments of other authors and reviewers; AM and VF contributed equally to the conception and design of the work, the analysis and interpretation of the data; DP, MR, AB, and DN contributed substantially to the data acquisition, data analysis, and interpretation. All authors revised the draft manuscript for important intellectual content and approved the final version.

Declaration of interests

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