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Long-term survival and five year hospital resource usage following traumatic brain injury in Scotland from 1997 to 2015: A population-based retrospective cohort study

James J.M. Loan[a,b,*], Neil W. Scott[c], Jan O. Jansen[d]

[a] Centre for Clinical Brain Sciences and Centre for Discovery Brain Sciences, University of Edinburgh, United Kingdom
[b] Department of Clinical Neurosciences, Western General Hospital, Edinburgh, United Kingdom
[c] University of Aberdeen, United Kingdom
[d] Center for Injury Science, University of Alabama at Birmingham and Division of Acute Care Surgery, Department of Surgery, University of Alabama at Birmingham, Birmingham, Alabama, USA

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ABSTRACT

Background: It is unclear if traumatic brain injury (TBI) results in excess mortality compared with head injury without injury to neural structures (HI). Because TBI populations exhibit significant demographic differences from uninjured populations, to determine the effect of TBI on survival, it is essential that a similarly injured control population be used. We aimed to determine if survival and hospital resource usage differ following TBI compared with HI.
Methods: This retrospective population-based cohort study included all 25 319 patients admitted to a Scottish NHS hospital from 1997 to 2015 with TBI. Participants were identified using previously validated ICD-10 based definitions. For comparison, a control group of all 194 049 HI cases was also identified. Our main outcome measures were hazards of all-cause mortality for patients with TBI, compared with those with HI, over the 18-year follow-up period; and odds of mortality at one month post-injury. Number of days spent as inpatients and number of outpatient attendances per surviving month post-injury were used as measures of resource utilisation.
Results: The adjusted odds ratio for mortality in the first month post-injury for TBI, compared with HI, was 7.12 (95% confidence interval [CI] 6.73–7.52; $p < 0.001$). For the remaining 18-year study period, the hazards of morality after TBI were 0.93 (CI 0.90-0.96; $p < 0.001$). During the five-year post-injury period, brain injury was associated with 2.15 (CI 2.10–2.20; $p < 0.001$) more days spent as inpatient and 1.09 times more outpatient attendances (CI 1.07–1.11; $p < 0.001$) compared with HI.
Conclusions: Although initial mortality following TBI is high, survivors of the first month post-injury can achieve comparable long-term survival to HI. However, this is associated with, and may require, increased utilisation of hospital services in the TBI group.

Background

Traumatic brain injury (TBI) is a common reason for admission to hospital, and the principal cause of death in children and young adults in high-income countries, including the UK, as well as some low-middle income countries [1–4]. Many survivors suffer from long-term disability and psychosocial impairment, and have higher risk of both short- and long-term non-neurological morbidity and mortality compared with healthy controls [1,5–15]. The long-term burden of neurodisability has been hypothesised to account for the increased risk of post-injury mortality from non-neurological disease, particularly from respiratory disease, following TBI, compared with uninjured controls, observed in some studies [12,13]. Risk factors for long-term mortality including male gender, and socioeconomic deprivation are over represented in injured populations, and so limited conclusions regarding the specific effect of neurological injury can be drawn studies using uninjured control populations. Furthermore, there is a paucity of population level data, with long-term follow-up [13,16,17]. It is therefore unclear whether TBI, which has been associated with both reduced self-reported access and increased costs of healthcare, results in reduced utilisation of hospital resources or excess long-term mortality

* Corresponding author. Current address: ECAT Clinical Lecturer in Neurosurgery, Centre for Clinical Brain Sciences, Chancellor's Building, 49 Little France Crescent, Edinburgh, EH16 4SB, United Kingdom.
E-mail addresses: James.loan@ed.ac.uk (J.J.M. Loan), n.w.scott@abdn.ac.uk (N.W. Scott), jjansen@uabmc.edu (J.O. Jansen).

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compared with injuries without neurologic injury [8,18,19]. Understanding the long-term impact of TBI on survival and hospital resource usage is important for optimising outcomes, and to ensure the appropriate allocation of resources.

The Information Services Division (ISD) of the National Health Service (NHS) in Scotland has collected administrative data for all hospital admissions and outpatient hospital attendances in Scotland since 1981. These data can be linked to the Scottish General Register of deaths. In addition to a process of regular validation and accreditation, the diagnostic accuracy of these records has been externally validated in cross-sectional audit of all patients admitted to a neurosurgical services [20]. Sensitivity as well as accuracy have been confirmed in a separate neurological disease population [21–23]. The majority of patients in Scotland, and virtually all patients presenting as emergencies, are treated in NHS hospitals [24]. Consequently, NHS administrative databases hold details of almost all hospital admissions due to head or brain injury in Scotland. The availability of these data presents an opportunity for the conduct of large, long-term, population-based studies of survival with minimal dropout [25].

The first aim of this study was to conduct a population-based analysis of long-term, all-cause mortality following TBI. We used patients who suffered head injuries, without evidence of brain injury (HI), as a comparison cohort. The use of an anatomical distinction between HI and TBI is pragmatic and clinically relevant as it can usually be determined on the basis of clinical assessment and readily available radiological assessment by computed tomography. On the basis of previous studies that demonstrated poorer short- and long-term survival following TBI, compared with healthy populations or mixed healthy and injured populations, we hypothesised that patients with TBI would have higher long-term mortality compared with patients who suffered HI. The second aim was to compare hospital resource usage between patients with TBI and those with HI. We hypothesised that patients with TBI would utilise more inpatient and outpatient health care resources.

Methods

Study design and setting

Population-based retrospective cohort study, conducted in Scotland, which has a population of 5.2 million.

Data sources

The ISD maintains Scottish Morbidity Records (SMR) by use of a unique national "community health index" (CHI) number, which allows patients to be tracked over time and location within Scotland [26]. For each admission, a primary diagnosis, and up to five subsidiary diagnoses are recorded and coded using the World Health Organisation's International Classification of Diseases. Until 1997, ICD-9 was used. Since then, ICD-10 has been employed. Death records in Scotland utilise ICD-10 diagnostic coding and are maintained by the National Records of Scotland.

Case definitions

All patients admitted to a Scottish hospital with "TBI" – defined using ICD-10 codes, as described by Chen and Kristman – were identified [27,28]. Patients meeting these criteria were classified as having TBI, and were assigned to the "TBI" group, regardless of any other injuries sustained. All patients who had been admitted with any other ICD-10 code relating to injuries to the head, and none of the TBI codes, were classed as having a head injury (HI). The case definitions and their ICD-10 codes are summarised in Supplementary Table 1.

Inclusion and exclusion criteria

We included all patients meeting criteria for TBI or HI, who were admitted to an NHS hospital in Scotland between 1 April 1997 and 1 September 2015. The dataset was closed on 1 September 2015. A lookback was conducted to identify and exclude patients with previous head injury or TBI, between 1 Jan 1981 and 31 March 1997 (Supplementary Table 1). For the resource utilisation analysis, a subgroup of patients admitted between 1 April 1997 and 1 September 2010 were used.

Variables

The index admission was the first admission with HI or TBI. For each episode, the following data were extracted: month and year of birth and death; gender; date of admission; date of outpatient attendance; main condition on admission and other recorded conditions; cause of death; use of intensive care unit (ICU); a marker of continuous inpatient stay, to indicate where multiple admissions to different services occurred during a single admission; and Carstairs and Morris 2001 census deprivation index quintile for patient's home postcode at index admission [29]. Follow-up was from date of index admission until death or closure of the dataset. Age categories were created as per the US Centres for Disease Control (CDC) National Centre for injury prevention and control classification of TBI [30]. Death registry data were linked to the index admission.

Table 1
Baseline characteristics. † Chi-Squared; ‡ Mann-Whitney U; IQR interquartile range.

		HI Group		TBI Group		p
		n	(%/IQR)	n	(%/IQR)	
Number of patients		194049		25319		
Length of follow up to death or study closure, median, months (interquartile range)		33	(11–71)	13	(13–60)	<0.001‡
Number of deaths during study period		54631	(28.6)	8089	(31.9)	
Number of deaths during first month		3495	(1.8)	2653	(10.5)	
Univariable analysis	Male	122580	(63.2)	17,434	(68.9)	<0.001†
	Age (years)					0.013‡
	<25	42577	(21.9)	4871	(19.2)	
	25-44	50506	(26.0)	6713	(26.5)	
	45-64	37067	(19.1)	5719	(22.6)	
	>64	63899	(32.9)	8016	(31.7)	
	Age of death in years (IQR)	82	(69–89)	76	(61–85)	<0.001‡
	Most deprived quintile	50773	(26.5)	6426	(25.8)	0.047†
	Injury below head	34246	(17.6)	4982	(19.7)	<0.001†
	Intensive Care Unit admission	1091	(0.6)	2434	(9.6)	<0.001†

Outcomes

The primary outcome was all-cause mortality. Secondary outcomes for our subgroup analysis of five-year hospital resource usage were the number of days spent as a hospital inpatient divided by number of surviving months post-injury (inpatient days per surviving month), number of outpatient attendances divided by number of surviving months post-injury (outpatient attendances per surviving month), and whether the patient was admitted to an ICU.

Statistical methods

Data analysis was conducted using SPSS Statistics for Windows v22.0 (IBM Corp, Armonk, New York, 2013). Univariate analysis was conducted using the Mann-Whitney U test and the χ^2 statistic for non-normally-distributed continuous and categorical data, respectively.

Survival analysis

Survival was calculated in months, rounded up to the nearest integer. We described cumulative, censored survival using Kaplan-Meier curves. These demonstrated that the highest death rate occurred over the first month post-injury in all groups. One-month mortality was greater in the TBI group than in the HI group. Following this, the curves indicated similar and constant rates of mortality. Cox regression analysis of survival for the whole period including the first month would therefore violate the assumption of proportional hazards, and separate multivariable analyses were conducted to model survival for the first month post injury, and survival for the rest of the study period after surviving the first month. Binomial logistic regression and Cox proportional hazards models were developed for the first month post-injury, and the remainder of the study period from month two onwards, respectively. These models were adjusted for gender, Carstairs and Morris index of deprivation (most deprived quintile versus other), the presence of other injuries (below the neck) at index admission, and age at index admission [30], which are established risk factors for mortality, independent of injury status. We also included an interaction between gender and deprivation, which have been suggested to play a role in healthcare inequality [31]. Two sensitivity analyses were conducted. The first utilised the same regression model as described above but with exclusion of all patients with extracranial injuries identified on index admission. The second again utilised the same regression model but with patients with concussion – defined as ICD-10 code S06.0 – excluded, or where a further diagnostic code for TBI or HI was identified on index admission, reassignment to the relevant group. For both survival analyses, exclusion criteria were applied equally to both HI and TBI groups.

Resource utilisation

For each patient, the total number days spent as inpatient and the total number of outpatient attendances was calculated during the five years post-injury. We selected a five year follow-up period for all patients in this analysis, rather than variable follow-up from injury until study closure as in the survival analysis. This is because resource utilisation requires analysis of multiple, yet varying in number, time-dependent events. This sort of data is not suitable for modelling by Cox regression. Conversely, multiple events occurring during a fixed period can be subject to linear regression. For each patient, these figures were divided by the total number of surviving months to yield number of days as an inpatient per surviving month and number of outpatient attendances per surviving month. These outcomes were skewed and so the natural logarithm of each was calculated, yielding a normal distribution of residuals. These outcomes were modelled using linear regression with adjustment for age, gender, deprivation and the presence of injury below the head. For interpretation of these analyses, the natural exponent of β [exp(B)] was calculated and is presented. This geometric mean represents the relative difference in number of inpatient days or relative difference in number of outpatient attendances per surviving month associated with each independent variable. ICU admission during the five years post-injury were analysed using binary logistic regression modelling. Sensitivity analysis with exclusion/reassignment of patients from both groups with concussion was conducted as described in our survival analysis.

Permissions and registration

This study's protocol was approved by the NHS National Services Scotland (registration number: XRB14179) Patient Advisory Committee proportionate governance review board, which determined that ethical approval was not required and that the potential benefits of sharing these anonymised data with the research team via secure NHS SafeHaven without obtaining direct patient consent outweighs the low risk of potential harms.

Results

Baseline characteristics

We identified 25 319 patients with TBI and 194 049 with HI. Deprivation data were not available for 2693 patients (1.4%) and gender was not recorded in two cases. Patients with missing data were dropped from regression models. The baseline characteristics are summarised in Table 1. Notably, the proportion of men was greater in the group who had suffered TBI (68.9%) than HI (63.2%, $p < 0.001$) and more patients in the TBI required admission to ICU (9.6% vs 0.6%, $p < 0.001$). The most common primary diagnoses for each group are detailed in Table 2 and Supplementary Table 2.

Survival analysis: TBI vs. head injury

Overall, 62 720 deaths were recorded; 8089 in the TBI group (68.1% survival) and 54 631 in the HI group (71.4% survival). 6148 deaths occurred in the first month post-injury; 2653 in the TBI group and 3495 in the HI group. The most common primary causes of death for each group are listed in Table 2 and Supplementary Table 2.

Cumulative survival was poorer in TBI than HI across the entire study period (Fig. 1A). However, comparison from month two onwards was similar (Fig. 1B). Analysis of one-month post-injury survival demonstrated statistically significantly increased odds of mortality in the TBI group compared with the HI group (OR 7.12; 95% confidence interval [CI] 6.73–7.52; $p < 0.001$), and for patients with additional injuries below the head and in older age groups (Table 3). A statistically significant interaction between gender and deprivation was detected, indicating lower odds of mortality for males in the most deprived quintile.

We next modelled survival over the 18-year follow-up period for those patients who survived the first month (Table 3). This analysis demonstrated that, for patients who did not die in the first month, TBI was associated with reduced hazards of mortality (HR 0.93; 95% CI 0.90-0.96; $p < 0.001$). Similarly, the presence of additional injures below the head, and male gender, were also associated with reduced hazards of mortality. A statistically significant interaction between gender and deprivation indicated that males from deprived backgrounds were at increased long-term hazards of mortality. Deprivation and older age were associated with increased long-term mortality.

Table 2
Principal diagnosis on admission and primary cause of death excluding cases where death occurred <1 month.

	HI Group			TBI Group		
		n	(%/IQR)		n	(%/IQR)
Number of patients		194049			25319	
Length of follow up to death or study closure, months (interquartile range)		33	(11–71)		13	(13–60)
Main condition on index admission	Unspecified injury of face, ear or nose	67456	(34.8)	Traumatic subdural haemorrhage	4503	(17.6)
	Superficial injury of head, unspecified	16554	(8.5)	Concussion	2791	(11.0)
	Open wound of other parts of head	14375	(7.4)	Fracture of base of skull	2404	(9.6)
	Fracture of nasal bones	13523	(7.0)	Diffuse brain injury	1912	(7.5)
	Open wound of scalp	12127	(6.2)	Intracranial injury, unspecified	1766	(7.2)
Primary cause of death	Acute myocardial infarction, unspecified	3586	(7.0)	Acute myocardial infarction, unspecified	347	(6.4)
	Unspecified Dementia	2584	(5.1)	Malignant neoplasm of bronchus/lung, unspecified	229	(4.2)
	Chronic ischaemic heart disease, unspecified	2226	(4.4)	Unspecified Dementia	223	(4.1)
	Stroke, not specified as haemorrhage or infarction	1997	(3.9)	Stroke, not specified as haemorrhage or infarction	201	(3.7)
	Malignant neoplasm of bronchus/lung, unspecified	1852	(3.6)	Chronic ischaemic heart disease, unspecified	192	(3.5)

Sensitivity analyses

As extracranial injuries were unexpectedly associated with increased long-term survival in the long-term model of survival in our initial analysis of all included patients (Table 3), we conducted a sensitivity analysis by excluding patients with these injuries, resulting in a change in the magnitude of some of the results, but not the direction of effect (Supplementary Fig. 1A and B; Supplementary Table 3.

11% of the TBI group comprised patients with concussion. This potentially represented a different pathology, with better outcomes and less resource use, from the other common causes for admission in the TBI group. We therefore conducted a further sensitivity analysis by excluding patients with isolated concussion from analysis and reassigning those with concussion and other head or brain injury to their relevant groups (Supplementary Fig. 2A and B; Supplementary Table 4). The odds ratio for mortality in the TBI group rose from 7.12 to 8.11 (CI 7.67–8.58; $p < 0.001$) in the first month and from 0.93 to 0.97 (CI 0.94-0.997; $p = 0.031$) thereafter. The risks of mortality associated with the other covariates at one month and at all time points thereafter changed minimally.

Resource utilisation

To ensure full five-year follow-up for our resource utilisation analysis, patients admitted after September 2010 were excluded from this analysis. The remaining subgroup for resource utilisation analysis included 144 751 patients in the HI group and 18 332 in the TBI group. The baseline demographic data for both groups are comparable to the survival analysis (Table 4). In the univariate analysis, TBI was associated with increased length of stay during the index admission, as well during subsequent admissions, and an increased proportion of patients requiring admission to an ICU during the five-year period (Table 4).

Multivariable analysis of this subgroup demonstrated that, with adjustment for age, gender, deprivation and the presence of injuries below the head, patients with TBI utilised 2.15 times more inpatient days per surviving month (CI 2.10–2.20; $p < 0.001$), 1.09 times more outpatient attendances (CI 1.07–1.11; $p < 0.001$) and had 5.22 times greater odds of subsequent ICU admission (CI 4.95–5.51; $p < 0.001$), relative to patients with head injury (Table 5). High deprivation was associated with increased inpatient days and outpatient attendances

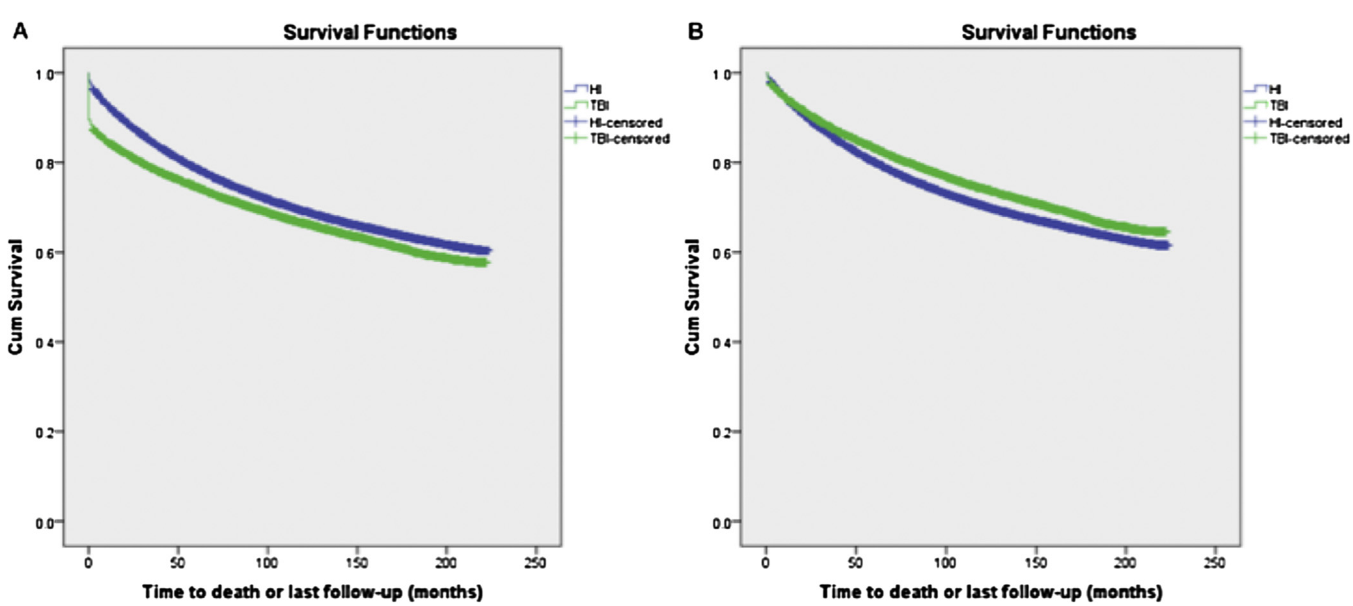

Fig. 1. Cumulative survival in the HI and TBI groups. Censoring occurred when follow-up was incomplete at closure of dataset. A: Survival including first month post-injury. B: Survival excluding first month post-injury.

Table 3
Regression analysis of mortality at one month and Cox regression for those surviving the first month. Odds ratio (OR) and Hazard ratio (HR) are for mortality and associated with independent variable compared with comparator variable (listed).

	Odds ratio (OR) for mortality at 1 month			Hazard ratio (HR) for mortality at >1 month		
	OR	95% CI	p	HR	95% CI	p
HI	Reference					
TBI	7.12	(6.73–7.52)	<0.001	0.93	(0.90- 0.96)	<0.001
Female	Reference					
Male	1.10	(1.03–1.17)	0.003	0.98	(0.96-0.998)	0.035
Not most deprived						
Most Deprived	1.00	(0.92–1.10)	0.933	1.09	(1.06–1.12)	<0.001
Age (years) <25	Reference					
25-44	1.30	(1.10–1.54)	0.002	3.06	(2.87–3.26)	<0.001
45-64	3.63	(3.12–4.21)	<0.001	11.67	(10.98–12.39)	<0.001
>64	15.56	(13.57–17.84)	<0.001	56.29	(53.10–59.67)	<0.001
Injury below the head absent	Reference					
Injury below the head present	1.20	(1.13–1.28)	<0.001	0.90	(0.88-0.92)	<0.001
Most Deprived & male gender interacting variable	0.83	(0.73-0.95)	0.005	1.07	(1.03–1.11)	0.001

Table 4
Baseline data and univariate analysis of resource utilisation subgroup. † Chi-Squared; ‡ Mann-Whitney U; IQR interquartile range.

			HI Group		TBI Group		p
			n	(%)	n	(%)	
Number of patients			144751		18332		
Demographics	Male gender		94144	(65.0)	12,984	(70.8)	<0.001†
	Age (years) <25		34275	(23.7)	3865	(21.1)	<0.001‡
	25-44		40660	(28.1)	5358	(29.2)	
	45-64		27665	(19.1)	4168	(22.7)	
	>64		42151	(29.1)	4941	(27.0)	
	Most deprived quintile		39046	(27.0)	4966	(27.1)	0.780†
	Injury below head		25465	(17.6)	3447	(18.8)	<0.001†
Univariable analysis of resource utilisation and deaths			n	(%/IQR)			
	Total number of hospital admissions		**554470**		**72205**		
	Median number of admissions per patient during study period	Median (IQR)	2.0	(1–4)	2.0	(1–3)	<0.001‡
	Median length of index admission (days)	Median (IQR)	2	(1–3)	4	(2–13)	<0.001‡
	Median length of stay for all admissions during study period (days)	Median (IQR)	3	(1–11)	5	(2–20)	<0.001‡
	Total number of Intensive Care Unit admissions		**4888**		**2996**		
	≥1 Intensive Care Unit admission during study period	n (%)	4164	(2.9)	2532	(13.8)	<0.001†
	Median number of admissions to Intensive Care Unit over study period per patient	Median (range)	0	(0–41)	0	(0–6)	<0.001‡
	Total number of outpatient attendances		**761312**		**98800**		
	Median number of outpatient attendances per patient	Median (IQR)	3	(1–7)	3	(0–7)	0.050‡
	Total number of deaths	n (%)	**45,978**	**(31.8)**	**6405**	**(34.9)**	
	Median age at death (years)	Median (IQR)	81	(67–88)	75	(59–84)	<0.001‡

Table 5
Multivariable analyses of resource utilisation in 5 years post-injury. Exp(B): geometric mean of relative difference in number of inpatient days or outpatient attendances during the 5-year post-injury period compared with comparator group. OR: odds ratio for intensive care unit admission during the 5-years post-injury. Independent variables and comparator variables listed.

	Relative difference in inpatient days per surviving month (geometric mean)			Relative difference in outpatient attendances per surviving month (geometric mean)			Odds ratio of ≥1 intensive care unit admission during 5 year post-injury period		
	Exp(B)	95% CI	p	Exp(B)	95% CI	p	Exp(B)	95% CI	p
HI	Reference								
TBI	2.15	(2.10–2.20)	<0.001	1.09	(1.07–1.11)	<0.001	5.22	(4.95–5.51)	<0.001
Female	Reference								
Male	0.83	(0.82-0.85)	<0.001	0.85	(0.84-0.86)	<0.001	1.28	(1.21–1.36)	<0.001
Not most deprived	Reference								
Most Deprived	1.15	(1.13–1.16)	<0.001	1.10	(1.08–1.11)	<0.001	0.90	(0.85-0.96)	<0.001
Age (years)									
<25	Reference								
25-44	1.37	(1.34–1.40)	<0.001	1.20	(1.19–1.22)	<0.001	1.28	(1.18–1.38)	<0.001
45-64	2.89	(2.83–2.96)	<0.001	1.47	(1.44–1.49)	<0.001	1.95	(1.81–2.11)	<0.001
>64	16.38	(16.04–16.71)	<0.001	1.76	(1.73–1.79)	<0.001	1.13	(1.05–1.23)	0.002
Injury below the head absent	Reference								
Injury below the head present	1.06	(1.04–1.08)	<0.001	0.90	(0.89-0.92)	<0.001	1.38	(1.29–1.48)	<0.001

but a smaller chance of ICU admission. Patients with additional injuries below the head utilised more inpatient days and were more likely to be admitted to an ICU, but attended fewer outpatient clinics than those with isolated TBI or HI.

Sensitivity analysis with exclusion of concussion codes resulted in an increase in the relative use of hospital resources associated with TBI compared with HI but minimal change in the magnitude of the associations of the other covariates (Supplementary Table 5).

Discussion

Principal findings

This population-based study, which reports on more than 25 000 patients with TBI, is – to our knowledge – the largest published study of survival and resource utilisation following TBI to date. We used patients with HI as a comparator group. This is important as previous studies have compared post-TBI survival against healthy [8,12,14,17] or mixed healthy and injured populations [13]. Extracranial injury itself is a risk factor for long and short-term mortality and frequently complicates TBI [32]. Furthermore, young male patients of low socioeconomic status are over represented in HI and TBI, compared with healthy populations [32,33]. These factors influence long-term survival and therefore, to determine the independent effect of brain injury on survival, it is necessary that a similarly injured comparator group be used. Our analysis demonstrates that, as expected, the odds of one-month mortality were greater following TBI than HI. However, following this, based on a long period of follow-up, survival of the two groups was similar. Indeed, survival was slightly better for survivors of the first month following TBI. The most common causes of deaths following the immediate post-injury period did not appear to be causally related to the injury and were similarly distributed to the causes of death for the overall Scottish population [34]. Our study further shows that TBI was associated with increased use of hospital services in the first five years post-injury, compared with head injury. Of note, patients with TBI were particularly reliant on inpatient and critical care services, spending more than twice as many days in hospital, and being over five times more likely to require an ICU admission than their head injured counterparts.

Interpretation and implications for clinicians and policymakers

These findings are in line with those of smaller studies, which have demonstrated that the additional risk of mortality associated with TBI is greatest in the first months following injury, and that the hazards of mortality fall with time post-injury [13,16,17]. Being population-based, our study is highly generalisable. As the risk of non-neurological morbidity is persistently elevated beyond the early post-brain injury period, compared with the general population [12,35], it is interesting that excess long-term mortality was not observed in our TBI cohort compared with our HI cohort. One explanation for our findings is that TBI, which resulted in more early deaths, selected for a physiologically fitter cohort who went on to suffer less subsequent illness. The high mortality associated with acute TBI might trigger intensive initial management and follow-up, consuming greater hospital resources and resulting in rapid detection and treatment of comorbidities. This “healthy survivor” effect could account for the observed small long-term survival benefit associated with TBI [36]. An alternative explanation is that patients with head injury without overt neurological injury received less intensive initial management and/or follow-up. This could account for the lower level of resource utilisation in this group, as well as the observed lack of anticipated survival advantage in the HI group, compared with TBI.

It is important that clinicians making treatment decisions for patients with TBI recognise that survivors of the first month following TBI can achieve equivalent long-term survival to non-neurologically head-injured patients. However, our results suggest that these outcomes may be contingent on comprehensive hospital follow-up, and a readiness to admit to inpatient and critical care services when required. Patients who have survived beyond one-month following TBI should therefore not be denied access to services on the basis of concerns regarding poor long-term survival. Policymakers and local authorities should take steps to ensure that barriers to access to unscheduled care for brain-injured patients are minimized [18] and that comprehensive regular long-term community follow-up is available to detect and prevent disease at an early stage [37]. It is important to note that, as several previous studies have previously described, patients who have sustained TBI or HI are vulnerable to subsequent illnesses and have higher mortality compared with uninjured populations [8,12,14,17]. Our findings are in line with these and emphasise the importance of careful follow-up of all victims of injury, particularly during the early phase of TBI. Conversely, our study also facilitates the counselling of patients and their families of the high risk of death in the first month following a TBI and treatment decisions may be tailored appropriately.

Unanswered questions

It is uncertain why men from highly deprived areas have lower risk of early death in our analysis. One explanation is that males from deprived backgrounds are more likely to present following relatively minor injuries. This has been previously described in Scottish head-injured populations and is supported by our resource utilisation analysis which demonstrated more hospital attendances but fewer ICU admissions in patients from deprived backgrounds [33]. The presence of injury below the head was associated with lower odds of long-term mortality. As with TBI, injury below the head may generate a selection pressure such that survivors of the initial injury are more resilient to ill health [36]. Conversely, it is possible that for some cases, the injury below the head was the most significant injury and the head or brain injury secondary, although this explanation is not supported by our sensitivity analysis.

Limitations

Case acquisition utilised a sensitive definition of TBI [27,38]. However, specificity has not yet been demonstrated and consequently it is likely that some cases of head injury with no, or minimal, neurological injury have been included in our TBI group. Although assignment of diagnostic codes is applied independently, using standardises processes, by NHS National Services clinical coding staff and is subject to internal and external validation, it is not possible to rule out that trends in documentation of diagnoses by front line clinical staff could have resulted in misassignment of patients to HI or TBI groups [20–24]. In particular, brain injury without radiological evidence of structural injury, “minor” brain injury and concussion are clinically ill-defined and diagnostic strategy varies widely [39]. This could reduce the observed effect of brain injury on survival and partly account for the lack of long-term excess mortality observed in the TBI group. However, use of a sensitive definition of TBI ensures that few cases of neurological injury would be wrongly assigned to the HI group. Furthermore, our sensitivity analysis with exclusion of concussion did not demonstrate any reversal of direction of our findings, thus providing evidence of our findings’ resilience to misassignment of patients with “minor” brain injury.

Over an 18-year follow-up period, and particularly in older patients, age-associated risk of mortality is dependent on time since injury, irrespective of injury site. We therefore considered age according to broad age categories as per US CDC convention, in our statistical models [30]. However, by doing so the analysis is limited with regards to detecting association between injury type and old age. For example, we are unable to determine whether survival following TBI compared with HI in patients aged 90 is worse than for those aged 70. The mechanisms and consequent injury patterns change with age and the impact of HI on survival might be relatively greater with increasing age [40]. Conversely, it is possible that patients with a background of age-related cognitive decline exhibit reduced cognitive reserve and consequently relatively worse survival than HI. As the mean age of presentation to hospital with TBI is increasing, the effect of older age on survival and resource usage following HI and TBI should not be overlooked [41]. A dedicated and contemporary analysis of these factors might be of value to clinicians and health economists.

We did not have access to comorbidity data, and the administrative dataset that we used does not include measures of injury severity. The Scottish Trauma Audit Group collects such data. However, in addition to a decade-long period without data collection, several hospitals do not contribute to the audit [42]. Consequently, it was not possible to stratify cases by injury severity, extracranial injury severity, neurological status, or pre-injury comorbidity, which are important determinants of survival and resource utilisation following head and brain injury [1,43–45]. This is therefore a significant limitation to our study. Nonetheless, anatomic descriptions of brain injury – as utilised by the ICD-10 – are frequently used clinically to prognosticate, inform patient selection and determine management strategy, both acutely and in the longer term. The greatest limitation of our study is that it only considers mortality and resource utilisation, rather than functional outcomes and quality of life. Equivalent long-term survival does not equate to normal function, and further analysis of injury severity correlated with long-term functional outcomes and quality of life is warranted.

Conclusions

TBI is associated with greater mortality in the first month following an injury, compared with HI. This increased risk of mortality is not sustained beyond the initial injury. TBI is associated with a two-fold increase in inpatient stay, over a five-fold increase in chance of admission to an ICU and a modest increase in the number of hospital outpatient attendances in the five years post-injury. Survivors of the first month following TBI can achieve equivalent long-term survival but require additional hospital resources compared with patients with HI.

Author contributions

James JM Loan: ECAT Clinical Lecturer in Neurosurgery, Honorary Specialty Registrar in Neurosurgery. Study conception and design, sourcing of funding, submission for PAC approval, data cleaning and preparation, analysis of raw data, production of manuscript and figures.

Neil W Scott: Biomedical Statistician. Study design, statistical analysis, review of manuscript and figures.

Jan O Jansen: Associate Professor of Surgery. Study conception and design, sourcing of funding, submission for PAC approval, statistical analysis, production of manuscript and figures.

Study guarantor

James JM Loan.

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Competing interests

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Declaration

All study authors had access to all of the study data, analyses, statistical reports and tables. All authors take responsibility for the integrity of the data and accuracy of analysis. The lead author affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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Appendix A. Supplementary data

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