Epidemiology of hospitalised traumatic brain injury in the state of New South Wales, Australia: a population-based study

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Abstract

Objective: To describe the population-based incidence and epidemiological characteristics of hospitalised traumatic brain injury (TBI) in New South Wales (NSW), Australia.

Methods: One-year statewide hospital admission data from the NSW Department of Health were analysed. TBI cases were identified using a combination of TBI-related diagnostic and external cause codes from the International Classification of Diseases (ICD-10th Revision). Sociodemographics, causes, associated factors, severity and medical details of hospitalisation were examined.

Results: There were 6,827 hospitalised TBI cases that met review criteria. Incidence rate was 99.1/100,000 population. Incidence in persons older than 75 years of age and residents in remote areas was three times higher. Aboriginal and Torres Strait Islander peoples were 1.7 times more likely to sustain a TBI than the general population, and risk was greater for all NSW residents from areas that were remote and disadvantaged-socioeconomically. Older adults and those with severe injuries showed prolonged hospitalisation, higher morbidity and mortality.

Conclusions: Overall TBI incidence in NSW is lower than international estimates. Nevertheless, groups with higher incidence rates and/or poor in-hospital outcomes were identified, highlighting directions for prevention and future research.

Implications for public health: There is a need for identifying risk factors/barriers and assessing the impact of recent policies on these population groups.

Key words: brain injury, epidemiology, incidence

Traumatic brain injury (TBI) is an important cause of preventable mortality and disability across the lifespan. By 2030, brain injuries due to traffic accidents and falls are expected to rise to the 7th and 17th major cause of death, respectively.[1] TBI ranges from mild to extremely severe injury. Recovery levels are similarly variable depending on the severity of the initial injury, from good outcome and resumption of premorbid lifestyles to profound disability affecting physical, cognitive and/or behavioural function. Although it is a critical public health problem worldwide, the actual incidence of TBI is difficult to establish.

The latest systematic review indicates a pooled annual incidence proportion of 295/100,000 (95% CI, 274-317) for all ages.[2] Incidence data, however, still vary widely across countries and among studies,[3] with differences in study methodology contributing most notably to this variability. Injury patterns are also changing, showing that TBI incidence is increasing in low-income countries and more injuries are occurring among older people in high-income countries,[4] which makes it challenging for estimates to be generalised.

The incidence of TBI in Australia is not well established. From the cross-continental comparison, Australasia (including Australia and New Zealand data) yielded the highest incidence proportion of 415/100,000 population.[2] This finding was of particular concern, together with the fact that in Australia only one study[5] met inclusion criteria for meta-analysis, reporting on incidence of TBI in 1988. That study showed much lower rates of 100/100,000 population in a defined New South Wales (NSW) community.[5] Other available Australian data confirmed TBI is less common in Australia than in Europe and North America (228-331/100,000) or New Zealand (790-1750/100,000).[2] These data included findings from the Australian Institute of Health and Welfare study for the period 2004-05 (107/100,000 population)[6] and a Western Australia study for 2003-08 (85.8/100,000 population).[7]

Differences in case identification and study design are the major limitations to current epidemiological research.[8] Evidence strongly suggests population-based studies are the best approach to obtain objective estimates and understand epidemiological patterns of disease.[8] Moreover, while injury patterns in Australian sectors have been previously investigated,[9-12] little is known about characteristics for the whole population. The need for population studies has become even more imperative in developed countries, including Australia, where TBI patterns have changed over the past decades, with

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an ageing population resulting in higher numbers of fall-related injuries.[4]

Well-established characteristics of TBI include some sociodemographic variables (sex, age at injury, socioeconomic status) and injury-related factors (mechanism and circumstances of injury). Yet other reports have identified risk patterns that warrant further investigation. For example, Jamieson et al.[12] found that Aboriginal and Torres Strait Islander peoples are 21 times more likely to incur a TBI due to assault, with other studies indicating a higher risk across all mechanisms of injury.[13] Living in rural and remote areas of the country is another factor commonly associated with higher risk of TBI, but these aspects have only been investigated for sectors of the Australian population (e.g. Aboriginal and Torres Strait Islander peoples[12] and Australian children).[14] Similarly, factors like socioeconomic patterns of TBI in the Australian context and medical details of hospitalisation, such as length of stay (LOS), in-hospital mortality and associated injuries or comorbidities, have been scarcely investigated in previous studies. These factors, together with injury severity, are major determinants of outcome following TBI[15] that could inform healthcare planning and economic impacts of hospital-treated TBI.

This study intended to move the research forward in these areas. The purposes were twofold: estimating the incidence of hospitalised TBI in NSW and describing epidemiological characteristics, with detailed analysis of at-risk groups, causes and factors associated with TBI, as well as severity and medical details of hospitalisation.

Method

Design and data sources

This is a population-based study of hospital-treated TBI in NSW. NSW is the most populous state of Australia, located on the east coast of the country, covering a geographical area of almost 810,000 square kilometres. Hospital admission data from 166 public and private hospitals in metropolitan, rural and remote areas were obtained from the NSW Department of Health for the 2007 calendar year. The state's resident population for the study year was 6.8 million[16] and this number was used for the calculation of age- and sex-specific incidence rates. Census data from 2006 were used for comparison of socioeconomic characteristics.[17] Approval to conduct the study was obtained from the NSW Population and Health Services Research Ethics Committee (HREC/08/CIPHS/56).

Study population and case selection

The study population comprised the first admissions of residents of any age who presented with a TBI to a NSW hospital during the calendar year 2007. The International Classification of Diseases (ICD-10th revision) diagnostic codes[18] from hospital admissions were used to identify potential TBI cases. The ICD-10th revision does not contain a specific rubric for TBI, therefore case identification was based on a combination of TBI-related diagnoses and external cause ICD descriptors.[19] A multi-step selection process was adopted. First, admissions were restricted to cases with at least one of the following codes (Figure1): skull fracture, intracranial injury, crushing injury of the head. Second, cases with a reported period of loss of consciousness (LoC) only were matched with external cause of injury (E-Codes) to exclude LoC due to other medical reasons. All ICD descriptors used in this study are provided as supplementary material (Supplementary Table S1). To estimate TBI incidence, only first-time admissions and first-time TBI events during the study year were included in the count. In the analysis of medical details, information from multiple hospital separations relating to the same injury, i.e. inter-hospital and intra-hospital transfers, were incorporated.

Epidemiological characteristics extracted

The following personal and injury-related characteristics were extracted directly from the Department of Health database or derived from the available ICD-codes (Supplementary Table S1).

- **Demographic information** included age at injury, gender, country of birth, postcode and Indigenous status. Participants were stratified based on the following age categories: 0-9, 10-19, 20-39, 40-69, 70+ years. Age-specific incidence was computed for five-year age intervals, with the upper interval being the 75+ years age group to allow comparison with other studies.
- **Socioeconomic and geographical distribution** were derived from residential postcodes. Socioeconomic status was allocated by mapping postcodes to deciles of the Australian Bureau of Statistics Index of Relative Socio-Economic Disadvantage scores.[20] Remoteness was classified according to the Australian Standard Geographical Classification.[21] Statistical comparisons involved the following subgroups: for socioeconomic status, the most disadvantaged (classifications 1-3) versus medium (classifications 4-7) versus least disadvantaged (classifications 8-10);[22] for location, metropolitan (classification 1) versus rural (classifications 2-3) versus remote living location (classification 4-5).
- **Cause of injury** was classified as follows using the ICD external cause (E-Codes): transport accidents, falls, assaults[7] and other mechanisms. Cases with more than one E-Code were described as multiple mechanism TBI group and regarded as a separate group.
- **Associated factors of TBI risk** were ascertained from the diagnosis codes as follows: alcohol consumption, drug use, sports, recreational activities.
- **Severity** was assessed using ICD-code information on post-traumatic amnesia (PTA) and LoC duration. TBI cases were classified as severe (PTA ≥2 weeks and/or LoC >24 hrs); moderate (PTA 24hrs to 2 weeks and/or LoC 30 min to 24 hrs) and mild (PTA <24hrs and/or LoC <30 min).[23]
- **Medical details of hospitalisation:** in-hospital outcomes (LOS, hospital transfers, in-hospital mortality) and morbidity (injuries associated with TBI and comorbidities from ICD codes). *Associated injuries* were categorised as follows: other mechanical trauma, complications or other injuries.[24] *Comorbidities* were identified according to the Charlson Comorbidity Index[25] and grouped into five broad categories: cardiovascular (e.g. ischaemic heart disease, hypertension), neurologic (e.g. stroke, dementia), respiratory (e.g. chronic obstructive pulmonary disease), digestive (e.g. peptic ulcer disease, liver disease) and systemic (e.g. diabetes mellitus, obesity).

Results

Incidence rates, at-risk groups, injury-related characteristics and hospitalisation details were analysed.

Incidence of hospital-treated TBI

A total of 10,175 admissions were initially identified using the ICD-codes selection criteria (Supplementary Figure S1). Of these, 2,435 admissions (23.9%) were subsequently excluded as not meeting study inclusion criteria. These consisted of 1,165 (11.4%) cases with no evidence of TBI, 368 (3.6%) non-residents of NSW, 902 (8.8%) non-acute episodes of care. Three-quarters (7,740) were confirmed TBI cases. A further 913 duplicate cases were excluded from the count: 879 (8.6%) required acute inpatient transfers and 34 (0.33%) sustained a second TBI during the same year, needing multiple admissions. The final study population was thus 6,827 residents of NSW with TBI admitted to a NSW hospital during 2007. The annual incidence of hospitalised TBI in NSW was estimated at 99.1/100,000 population (95%CI 96.8 – 101.5/100,000 population), with a mortality rate of 5.9/100,000 population (95%CI 5.3 – 6.5/100,000 population).

At-risk groups and causes of injury

Figure 1 displays age/sex distribution and injury causes of this cohort. Risk of TBI was distinctly higher in the 15-19 years and in the 75+ years age groups, with rates in older people being three times the overall incidence (298/100,000 vs 99.1/100,000; z=9.99, p<0.001). This represents the first standout feature of the study findings. Falls caused most brain injuries in NSW (47.6%), followed by transport accidents (25.9%) and assaults (15.8%). Older people (>70 years) had by far the highest proportion of fall-related injuries (87.3%). Conversely, TBI in teenagers (10-19 years) was more commonly due to motor vehicle crashes (40.5%). Twenty-nine per cent of traffic-related TBI among teenagers were cycling injuries.

Another stand-out feature of the incidence findings was residency. Occurrence of TBI by location of residency, socioeconomic status and indigenous status are described in Table 1. The NSW TBI population was 2.8 times more likely to live in remote areas compared to the NSW general population (1.7% vs 0.6%; χ^2=138.12, df=1, p<0.001), which was higher than the relative proportions living in the most socioeconomic disadvantaged areas (32.3% vs 29.2% respectively, χ^2=31.20, df=1, p<.001). In addition, there was an association between remoteness and socioeconomic disadvantage in the TBI sample (χ^2=1193.54, df=4, p<0.001), and this reflected the NSW general population where there is also a correspondence between remoteness and socioeconomic disadvantage (χ^2=801851.64, df=4, p<0.001) (Supplementary Table S2). Yet, the TBI sample had a higher proportion of both remoteness and disadvantage than the NSW general population (1.4% vs 0.44%, χ^2=140.91, df=1, p<0.001), which was three times higher.

Similar disparities were found in other features of the data (Supplementary Table S3). The NSW group identifying as Aboriginal and Torres Strait Islander residents had a much higher proportion of remoteness and socioeconomic disadvantage (4.5%) compared to the NSW general non-Indigenous population (0.35%), a rate that was 12.8 times higher (χ^2=52450.36, df=1, p<0.001). Even so, at 9.8% the NSW TBI Aboriginal and Torres Strait Islander peoples had the highest proportion of remoteness and socioeconomic disadvantage of all groups, even being twice as high as the general Aboriginal and Torres Strait Islander population in the state. Overall, risk of sustaining a TBI among Aboriginal and Torres Strait Islander peoples was 1.7 times higher compared to the NSW general population (3.8% vs 2.2%, χ^2=81.09, df=1, p<0.001).

Factors associated with TBI risk

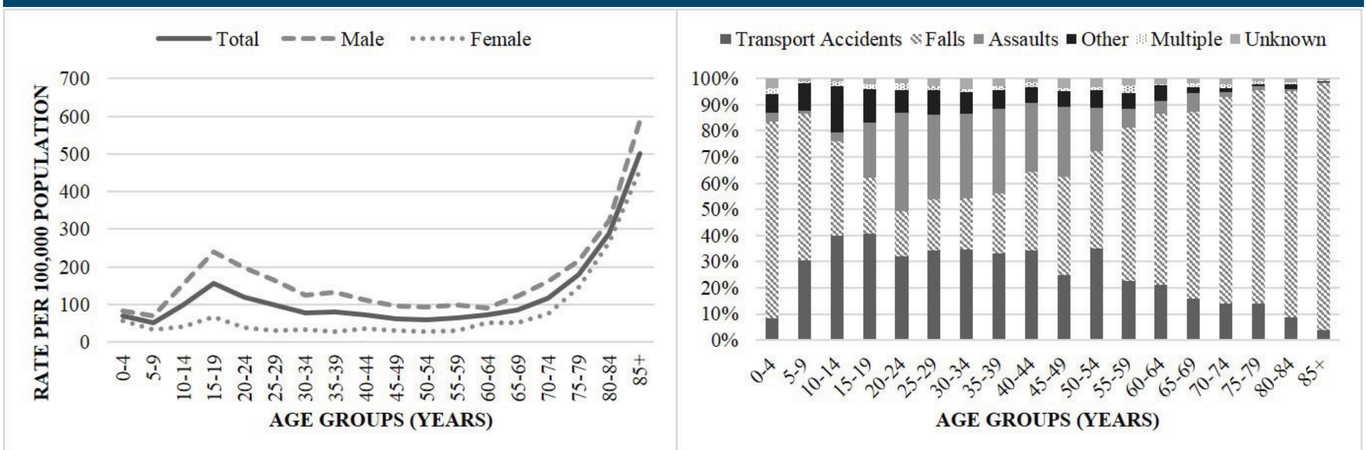
Personal and environmental factors associated with TBI risk varied with severity (Table 1), age and causes (Table 2). At the time of the injury, 14.3% of the overall TBI cohort was involved in sport and leisure activities, with 40% in the 10-19 years age group. About one in five people (18.7%) were under the influence of alcohol or recreational drugs, accounting for 30% of adults between 20 and 69 years of age. Mild injuries were more commonly associated (19.3%) with sport/leisure activities (χ^2=10.17, df=2, p=0.006), while one in three people in the moderate-to-severe group was under the influence of alcohol or drugs (χ^2=16.09, df=2, p<0.001). Substance use was strongly associated with assault-related TBI compared to other causes (41.2%; χ^2=490.42, df=5, p<0.001), as well as with injury occurring during the weekend compared to week days (22.2%; χ^2=59.73, df=1, p<0.001) (Supplementary Table S4).

Injury severity and medical details of hospitalisation

Specific injury severity data were available for 2,925 (43%) cases (Table 1). A total of 122 TBI cases (4%) were classified as severe, 223 (8%) as moderate and 2,580 (88%) as mild (Table 1). More than half of moderate-to-severe injuries occurred over the age of 40 (χ^2=23.52, df=8, p<0.01). By contrast, people younger than 19 years of age had the highest rates (92-94%) of mild TBI. Variation among severity and mechanism of injury was statistically significant (χ^2=52.72, df=10, p<0.001). Falls were the leading cause of minor-to-moderate injuries (42-47%), while severe injuries were mostly (42.6%) due to motor vehicle crashes. People living in areas of high socioeconomic disadvantage were more likely to sustain severe injuries compared to the general population (41.2% vs 29.2%, χ^2=8.49, df=1, p=0.003).

Table 1 also provides medical details of hospitalisation for the whole sample and severity spectrum. Average LOS was 6.4 days (SD=13.1), with inter-hospital transfers occurring in 9.2% of cases. Forty per cent of

Figure 1: Age/sex-specific incidence rates per 100,000 and proportion of injury cause by age in NSW, 2007 (n=6,827).



people sustained other mechanical trauma due to the accident, with one-in-two people having some injury or complications in addition to TBI. One-in-four people had pre-existing or simultaneously sustained comorbidities.

Overall, fatalities occurred in 5.3% of the sample. Those who died were generally older than 70 years of age (63.6%; χ^2=372.95, *df*=4, p<0.001) or sustained the most severe injuries (44.8%; χ^2=400.15, *df*=2, p<0.001). The median age at death was 62.9 years. The majority of fatalities resulted from fall-related TBI (67.9%; χ^2=93.61, *df*=5, p<0.001) compared to other causes.

Not surprisingly, severe TBI, in comparison with the less severe injuries, resulted in longer LOS of about one month (M=28 days; *F*=301.08, *df*=2, p<0.001), higher number of inter-hospital transfers (more than one facility in 21.4% of cases), and the highest fatality rates at 32%. A larger number of associated injuries (64.8%; χ^2=22.1, *df*=2, p<0.001)

Table 1: At-risk groups, associated factors and medical details of first-time hospitalised TBI in NSW (n=6,827) and in a subsample with severity data (n=2,925).

	NSW 2006 Census Person/years	Hospitalised TBI	Deceased TBI	TBI subsample with severity data[a]			
	Total (n= 6,817,182)	Total (n=6,827)	Total (n=365)	Mild (n=2,580)	Moderate (n=223)	Severe (n=122)	Total (n=2,925)
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Sociodemographic							
M:F (ratio)	0.99:1	2.4:1	1.5:1	2.9:1	2.7:1	2.9:1	2.9:1
Male gender	3,411,349 (50)	4793 (70.2)	218 (59.7)	1,926 (74.7)	163 (73.1)	91 (74.6)	2,180 (74.5)
Age, years (mean-SD)	38.7 (-)	43.1 (27.1)	69.2 (22.8)	38.9 (23.8)	44.3 (23.3)	43.7 (22.3)	39.5 (23.8)
0-9	876,967 (12.9)	536 (7.9)	6 (1.6)	120 (4.7)	6 (2.7)	2 (1.6)	128 (4.4)
10-19	913,136 (13.4)	1,172 (17.2)	15 (4.1)	584 (22.6)	31 (13.9)	19 (15.6)	634 (21.7)
20-39	1,930,938 (28.3)	1,819 (26.6)	28 (7.7)	801 (31)	67 (30)	36 (29.5)	904 (30.9)
40-69	2,438,428 (35.8)	1,695 (24.8)	84 (23)	685 (26.6)	74 (33.2)	43 (35.2)	802 (27.4)
70+	657,713 (9.6)	1,605 (23.5)	232 (63.6)	390 (15.1)	45 (20.2)	22 (18)	457 (15.6)
Born in Australia	4,703,855 (69)	5,251 (76.9)	243 (71.9)	2,041 (79.1)	158 (70.9)	91 (74.6)	2,290 (80.5)
Indigenous status	152,685 (2.2)	260 (3.8)	6 (1.8)	100 (4.0)	7 (3.2)	6 (5.2)	113 (4)
Socio-economic status*							
Low disadvantaged	2,141,608 (33.1)	1,936 (28.8)	126 (35.5)	747 (29.4)	72 (32.7)	26 (21.8)	845 (29.4)
Medium disadvantaged	2,437,292 (37.7)	2,613 (38.9)	118 (33.2)	994 (39.2)	84 (38.2)	44 (37)	1,122 (39)
High disadvantaged	1,884,400 (29.2)	2,171 (32.3)	111 (31.3)	798 (31.4)	64 (29.1)	49 (41.2)	911 (31.7)
Location of residency**							
Metro	4,948,309 (72.6)	4,482 (66.7)	267 (75.2)	1,651 (65)	160 (72.7)	78 (65.6)	1,889 (65.6)
Rural	1,831,085 (26.8)	2,124 (31.6)	85 (23.9)	850 (33.5)	54 (24.5)	38 (31.9)	942 (32.7)
Remote	37,788 (0.6)	116 (1.7)	3 (0.8)	39 (1.5)	6 (2.7)	3 (2.5)	48 (1.7)
Injury cause							
Transport accident	-	1,768 (25.9)	76 (20.8)	765 (29.7)	70 (31.4)	52 (42.6)	887 (30.3)
Fall	-	3,247 (47.6)	248 (67.9)	1,104 (42.8)	106 (47.5)	38 (31.1)	1,248 (42.7)
Assault	-	1,080 (15.8)	14 (3.8)	452 (17.5)	37 (16.6)	15 (12.3)	504 (17.2)
Other	-	485 (7.1)	6 (1.6)	200 (7.8)	7 (3.1)	5 (4.1)	212 (7.2)
2E-codes	-	102(1.5)	9 (2.5)	46 (1.6)	3 (1.3)	7 (5.7)	52 (1.8)
No E-code	-	145 (2.1)	12 (3.3)	17 (0.7)	0	5 (4.1)	22 (0.8)
Associated factors							
Drug/Alcohol use***	-	1,269 (18.6)	34 (9.3)	520 (20.2)	66 (29.6)	36 (29.5)	622 (21.3)
Sport/Recreation***	-	976 (14.3)	9 (2.5)	497 (19.3)	27 (12.1)	15 (12.3)	539 (18.4)
Medical details							
LoS, days (mean -SD)	-	6.4 (13.1)	6.8 (12.1)	3.5 (7.5)	7.9 (12.7)	28.4 (38.6)	4.91 (12.2)
2 or more facilities	-	632 (9.2)	34 (9.3)	195 (7.5)	35 (15.6)	26 (21.4)	256 (8.7)
Deceased	-	365 (5.3)	-	31 (1.2)	17 (7.6)	39 (32)	87 (3)
Associated injuries***	-						
Other mechanical trauma	-	2,351 (34.4)	124 (34)	1,038 (40.2)	87 (39)	46 (37.7)	1,171 (40)
Complications	-	43 (0.4)	4 (1.1)	6 (0.2)	2 (0.9)	6 (4.9)	14 (0.5)
Other injuries	-	72 (1.1)	8 (2.2)	24 (0.9)	2 (0.9)	5 (4.1)	31 (1.1)
2 or more injuries	-	219 (3.2)	24 (6.6)	50 (1.9)	13 (5.8)	22 (18)	85 (2.9)
None	-	4,142 (60.7)	205 (56.2)	1,462 (56.7)	119 (53.4)	43 (35.2)	1,624 (55.5)
Co-morbidities***	-	1,607 (23.5)	248 (67.9)	397 (15.4)	46 (20.6)	57 (46.7)	500 (17.1)

Notes:
a: Subsample based on Post-Traumatic Amnesia and Loss of Consciousness codes.
**Subsample based on available residential postcodes and ABS scores (2006 Census population, n=6463300; TBI sample: n=6720).*
***Subsample based on available residential postcodes and ABS scores (2006 Census population, n=6817182; TBI sample, n=6722).*
****Percentages of valid case.*
The data contains occasional missing data values, which are assumed to be random.

and co-morbidities (46.7%; χ^2=82.83, *df*=2, *p*<0.001) was also found.

Medical details of hospitalisation varied significantly by age and cause of injury (Table 2). Compared to the other age groups, older people (70-and-older age group) had the longest LOS (M=10.7 days; *F*=87.06, *df*=4, *p*<0.001), and the highest fatality rates (14.5%; χ^2=372.95, *df*=4, *p*<0.001). This group also accounted for the largest number (62.8%) of comorbidities (χ^2=2070.96, *df*=4, *p*<0.001). Of these, cardiovascular and neurological diseases were the most frequent, with 30% of older people affected by multiple disorders. By contrast, comorbidities and mortality rates were very low in those <40 years (1-2%).

Discussion

This is the first study to provide population-based estimates of the incidence of hospitalised TBI in the whole of NSW. We also described specific at-risk groups and prevalent causes of injury. Further analysis included factors associated with TBI risk, injury severity and medical details of TBI hospitalisation. Although the overall TBI incidence in NSW is much lower than expected from international comparisons, our data clearly reveal that greater TBI rates exist within specific sectors of the NSW population, together with differences in hospitalisation outcomes that were not highlighted by previous studies.

The incidence of 99/100,000 persons per year matched the current best estimates calculated by Tate et al.[5] in 1988 in a defined NSW subpopulation, suggesting that the rate of hospitalised TBI in NSW has remained unchanged across a 20-year period, notwithstanding methodological differences between the two studies. The present study used broader inclusion criteria, considering all possible signs of TBI in any diagnosis field, as opposed to intracranial injuries[6,26] as principal diagnosis[5,6] used by previous studies. The only study adopting a similar approach provided a slightly lower incidence of 86/100,000 for the same period.[7] This small difference may be explained by Moorin et al.[7] not including cases without a specified external cause of injury, as well as TBI caused by self-harm.

Compared to international studies, NSW had the lowest incidence rate, showing rates two to three times lower than in Europe and the United States, respectively, which are in the range of 200-300/100,000 population per annum.[2] By contrast, there are considerable methodological differences in study design that make it difficult to compare New Zealand estimates with findings of all other countries. Feigin and colleagues[27] reported an annual incidence of 790/100,000 population, using multiple sources for case identification that included hospital admissions, as well as community-based assessment and treatment data. Most other epidemiological studies of TBI, including the present study, are based on hospital data only. Another New Zealand study[28] reported an unusually high incidence (1,750 /100,000 population). That study employed a longitudinal approach that restricted the age range to 0-25 years.

There were disparities in TBI risk among population groups. Although Tate et al.[5] also found a significant increase of TBI incidence in people aged 75+ years in comparison with the preceding three decades (χ^2=5.66, *df*=1, *p*<0.02), in this study the risk of having a TBI among older people was found to be almost three times higher than the overall incidence in both studies. This shift in observed TBI patterns is consistent with findings from other high income countries,[4] where life

Table 2: Associated factors and medical details of first-time hospitalised TBI in NSW (n=6827) by age and mechanism of injury.

	Hospitalised TBI (n=6,827)										
	By age groups					By injury mechanism					
	0-9 (n=536)	10-19 (n=1,172)	20-39 (n=1,819)	40-69 (n=1,695)	+70 (n=1,605)	Transport Accident (n=1,768)	Fall (n=3,247)	Assault (n=1,080)	Other (n=485)	Two E-codes (n=102)	No E-code (n=145)
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Associated factors											
Drug/Alcohol use***	0	119 (10.2)	563 (31)	495 (29.2)	92 (5.7)	207 (11.7)	527 (16.2)	445 (41.2)	29 (6)	22 (21.6)	39 (26.9)
Sport/Recreation***	66 (12.3)	480 (41)	267 (14.7)	129 (7.6)	34 (2.1)	348 (19.7)	321 (9.9)	44 (4.1)	220 (45.4)	18 (17.6)	25 (17.2)
Medical details											
LoS, days (mean -SD)	2.9 (7.8)	2.9 (7.1)	4.9 (11.3)	7.4 (16.9)	10.7 (16.2)	7.2 (15.6)	7.1 (11.7)	3.4 (8.1)	2.9 (8.3)	14.1 (33.6)	8.2 (15.8)
2 or more facilities	72 (13.4)	112 (9.6)	142 (7.8)	149 (8.8)	157 (9.7)	152 (8.6)	299 (9.2)	105 (9.7)	31 (6.4)	38 (37.3)	7 (4.8)
Deceased	6 (1.1)	15 (1.3)	28 (1.5)	84 (5)	232 (14.5)	76 (4.3)	248 (7.6)	14 (1.3)	6 (1.2)	9 (8.8)	12 (8.3)
Associated injuries* **											
Other trauma	66 (12.3)	424 (36.2)	659 (36.2)	666 (39.3)	536 (33.4)	1,094 (61.9)	888 (27.3)	244 (22.6)	67 (13.8)	40 (39.2)	18 (12.4)
Complications	2 (0.4)	2 (0.2)	7 (0.4)	20 (1.2)	12 (0.7)	6 (0.3)	29 (0.9)	4 (0.4)	0	1 (1)	3 (2.1)
Other injuries	6 (1.1)	8 (0.7)	19 (1)	29 (1.7)	10 (0.6)	11 (0.9)	27 (0.8)	13 (1.2)	6 (1.2)	6 (5.9)	9 (6.2)
2 or more	5 (0.9)	20 (1.7)	75 (4.1)	75 (4.4)	44 (2.7)	128 (10.3)	55 (1.7)	15 (1.4)	11 (2.3)	7 (6.9)	3 (9.1)
None	457 (85.3)	718 (61.3)	1,059 (58.2)	905 (53.4)	602 (62.5)	529 (29.9)	2,248 (69.2)	804 (74.4)	401 (82.7)	48 (47.1)	112 (77.2)
Co-morbidities* **											
Cardiovascular	2 (0.4)	7 (0.6)	43 (2.4)	130 (7.7)	273 (17)	80 (4.5)	322 (9.9)	27 (2.5)	7 (1.4)	6 (5.9)	13 (9)
Neurologic	11 (2.1)	15 (1.3)	31 (1.7)	54 (3.2)	172 (10.7)	32 (1.8)	211 (6.5)	20 (1.9)	8 (1.6)	3 (2.9)	9 (6.2)
Respiratory	3 (0.6)	6 (0.5)	12 (0.7)	12 (0.7)	12 (0.7)	9 (0.5)	22(0.7)	10 (0.9)	1 (0.2)	1 (1)	2 (1.4)
Digestive	0	1 (0.1)	7 (0.4)	18 (1.1)	1 (0.1)	5 (0.3)	16 (0.5)	3 (0.3)	1 (0.2)	2 (2)	0
Systemic	1 (0.2)	6 (0.5)	8 (0.4)	78 (4.6)	88 (5.5)	16 (0.9)	145 (4.5)	10 (0.9)	6 (1.2)	3 (2.9)	1 (0.7)
2 or more	1 (0.2)	3 (0.3)	12 (0.7)	138 (8.1)	462 (28.8)	65 (3.7)	508 (15.6)	16 (1.5)	8 (1.6)	7 (6.9)	12 (8.3)
None	518 (96.6)	1,134 (96.8)	1,706 (93.8)	1265 (74.6)	597 (37.2)	1,561 (88.3)	2,023 (62.3)	994 (92)	454 (93.6)	80 (78.4)	108 (74.5)

Notes:
****Percentages of valid cases.*
The data contains occasional missing data values, which are assumed to be random.

expectancy is increasing and falls have become the leading cause of sustaining a TBI. Even so, compared to some other studies that reported rates of 361/100,000[26] and 380,000/100,000,[29] the rate of TBI among the 85+ year group in the NSW population was much higher, reaching a peak of 499/100,000 population.

People living in the most remote areas of NSW represent another group at high TBI risk. While place of residence had previously been found to be associated with a higher risk of sustaining a TBI in specific sectors of the population,[12,14] data across all population sectors were not available. This group was shown to have a similarly high risk as the 75+ age group, being nearly three times higher compared to the general population. Lower socioeconomic status was also found to be associated with occurrence and severity of TBI in this study.

In addition, the occurrence of TBI in NSW residents identifying as Aboriginal and Torres Strait Islander was 1.7 times the rate of the general population. This finding, supporting known ethnicity-related disparities in TBI risk,[30] allows for a more accurate estimate of the magnitude of risk among Aboriginal and Torres Strait Islander peoples. There are only two studies providing data in this regard but these are limited to small, selected Australian cohorts, such as assault-related TBI[12] and incarcerated young people.[31]

The interrelation among Indigenous status, remoteness and socioeconomic disadvantage has not been previously reported. All three groups separately have a higher risk of TBI than the general population. Although there were associations between remoteness and socioeconomic disadvantage that reflect the general population distribution, TBI risk was higher among all NSW residents living in areas that are both remote and highly disadvantaged. Among these, Aboriginal and Torres Strait Islander people had the highest proportion of remoteness and socioeconomic disadvantage, being twice as likely to sustain a TBI compared to the general Aboriginal and Torres Strait Islander population.

Our analysis of factors associated with TBI risk demonstrated that overall, at 19%, there was a lower incidence of people under the influence of substances at the time of their injury compared to previous estimates of 30-50%.[32,33] Previous research has pointed to alcohol as an important factor associated with all TBI causes,[34] and Wagner et al.[35] linked the use of drugs and alcohol more specifically to violence-related TBIs. In our study, substance use, especially weekend consumption, was also greatly associated with risk of sustaining a brain injury from assault, and the occurrence of assault-related TBI (15.8%) nearly doubled compared to Tate et al.[5] By contrast, substance use in traffic-related TBI was not as high as previously documented,[36] being in line with our overall finding of decreased traffic-related TBI rates.[5]

The exploration of medical details highlighted that not only were brain injuries in older people common, but they had relatively long LOS and high in-hospital mortality (14.5%). While complex care needs and difficulties in discharge planning may have contributed to prolonged LOS in older patients, greater mortality rates confirm this group having a much worse prognosis than younger people, which is likely due to physiological differences[37] that impact on recovery from TBI. Several factors other than injury severity may be linked to the risk of dying after a TBI in the older population, such as a higher number of comorbidities.[38] In population-based studies, the use of the Charlson Comorbidity Index does not allow distinction between pre-existing and co-occurring comorbidities, yet these are both believed to have a negative impact on recovery from injury.[39] Three in four older people had other diseases in addition to TBI. Cardiovascular diseases were the most common, at about 17%, reinforcing previous hypotheses that cardiovascular morbidity[26,40] may further complicate recovery from TBI.

Another group with less favorable in-hospital outcome includes people with severe TBI. Although data were only available for 43% of the sample, severity rates were in line with previous studies (mild, 88%; moderate 8%; severe 4%)[27]. Severe TBI compared to less severe injuries had the longest LOS and the highest fatality rates and proportion of inter-hospital transfers. Beside injury severity, differences between these groups may be partially explained by the high number of complications and systemic injuries associated with severe TBI.

The inclusion of data relating only to hospitalised TBI cases may be a limitation of this study. Death before hospital admission and mild injury for which hospital care was not sought were not included. Furthermore, ICD codes are known to not be specific for identification of hospitalised mild TBI. A strength of this study was the analysis of medical details of TBI hospitalisation, which are rarely available from epidemiological studies, although crucial to inform resource planning and secondary prevention measures. This is an overview incidence study, drawing upon retrospective administrative data. Had specific data been available for a control population, we would have been able to conduct regression analyses to identify potential predictors/moderators of TBI. Nevertheless, there was a high chance that potentially important predictors/moderators were not contained in this data set, thus weakening any conclusions drawn from such an analysis. This will be a fruitful avenue for future research.

Implications

Public health strategies should be employed to reduce TBI incidence, increase awareness of and meet the healthcare demands for TBI-related services among identified high-risk groups. Effort is needed to establish whether modifiable risk factors exist in these population sectors. For instance, TBI risk among older people may be reduced by targeting anticoagulation,[26,40] matching the success of decreased fall-related hip fracture rates in this age group.[41]

Consideration should be given to prevention efforts and making TBI-related services available in remote and socioeconomically disadvantaged areas. The high representation of Aboriginal and Torres Strait Islander peoples in these areas requires culturally aware health service provision to reduce barriers to health care access and ensure optimal care beyond the issue of medical service availability. In addition, the impact of recent health policy initiatives (e.g. the 'Close the Gap: National Indigenous Reform Agreement' in 2012 and the National Aboriginal and Torres Strait Islander Health Plan 2013–2023) on health outcomes in this group should be assessed.

Education about substance use may contribute to reducing assault-related TBI and injury vulnerability during weekends. In fact, there are indirect indications that traffic-related TBI rates and associated substance use may have fallen as a result of targeted prevention campaigns by the Australian government.

Further research is needed to elicit the human and economic impact of in-hospital mortality and prolonged hospitalisation of older people and people with severe TBI. It may be valuable to explore the influence on these population groups of the latest health and disability policy reforms. Among these, there is the introduction of the NSW

Lifetime Care and Support Scheme in 2006 (first participant entered in January 2007) to provide care services to all severe traffic-related TBI, together with the transition to the National Disability Insurance Scheme in 2016 to support recovery of all Australians with permanent and substantial disability below the age of 65. By contrast, hospital outcomes and costs of people over 65 years of age may benefit from significant changes in home and community care services as a result of the Australian aged care reforms starting from July 2013.

Conclusion

We have comprehensively investigated the incidence and epidemiological characteristics of TBI hospitalisations in NSW. These data demonstrate that TBI is much less common than in the rest of the world, but substantial differences exist in the incidence and in-hospital outcomes among population groups, calling for public health preventive strategy and actions. High TBI rates in older people, remote and socioeconomically disadvantaged residents, and Aboriginal and Torres Strait Islander peoples make these groups a public health priority. Further, TBI had a substantially negative impact on hospitalisation course in older people and people with severe injuries.

These findings highlight various challenges and areas for future research. Rigorous multivariate analysis is needed to examine specific contributors to injury vulnerability and the complex interrelationship among at-risk groups and the whole population. Prospective and community-based research is also warranted for more comprehensive estimates of TBI incidence, in particular, mild injuries, as well as clarifying disability and cost implications to the disparity in incidence and outcome between population groups.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Supplementary Table 1: International Classification of Diseases, 10th Revision diagnosis codes used in selection of traumatic brain injury events and description of injury-related characteristics from NSW Department of Health hospitalisation data.

Supplementary Table 2: Associations between remoteness and socio-economic disadvantage in the NSW general population – 2006 Census (n= 6,463,300) and TBI sample (n=6,720).

Supplementary Table 3: Associations between remoteness and socio-economic disadvantage in the NSW Aboriginal and Torres Strait Islander population – 2006 Census (n= 135,299) and TBI Aboriginal and Torres Strait Islander subsample (n=255).

Supplementary Table 4: Substance use by seasonality in first-time hospitalised TBI in NSW (n=6,827).

Supplementary Figure 1: Flowchart of study population from NSW hospitalisations during calendar year 2007.