Health & Economic Burden of Traumatic Brain Injury in the Emergency Department

Terence S. Fu, Rowan Jing, Steven R. McFaull, Michael D. Cusimano

ABSTRACT: ***Objective:*** To evaluate epidemiological patterns and lifetime costs of traumatic brain injury (TBI) identified in the emergency department (ED) within a publicly insured population in Ontario, Canada, in 2009. ***Methods:*** A nationally representative, population-based database was used to identify TBI cases presenting to Ontario EDs between April 2009 and March 2010. We calculated unit costs for medical treatment and productivity loss, and multiplied these by corresponding incidence estimates to determine the lifetime costs of identified TBI cases across age group, sex, and mechanism of injury. ***Results:*** In 2009, there were more than 133,000 ED visits for TBI in Ontario, resulting in a conservative estimate of $945 million in lifetime costs. Lifetime cost estimates ranged from $279 million to $1.22 billion depending on the diagnostic criteria used to define TBI. Peak rates of TBI occurred among young children (ages 0-4 year) and the elderly (ages 85+ years). Males experienced a 53% greater rate of TBI and incurred two-fold higher costs compared with females. Falls, sports/bicyclist-related injuries, and motor vehicle crashes represented 47%, 12%, and 10% of TBI presenting to ED, respectively, and accounted for a significant proportion of costs. ***Conclusions:*** This study revealed an enormous health and economic burden associated with TBI identified in the ED setting. Our findings underscore the importance of ongoing surveillance and prevention efforts targeted to vulnerable populations. More research is needed to fully appreciate the burden of TBI across a variety of health care settings.

RÉSUMÉ: Fardeau économique et fardeau de santé de lésions cérébrales traumatiques identifiées au service des urgences. ***Objectif:*** Le but de cette étude était d'évaluer le tableau épidémiologique et les coûts pendant la durée de vie de lésions cérébrales traumatiques (LCT) identifiées au service des urgences (SU) dans une population assurée par un régime publique en Ontario, au Canada, en 2009. ***Méthode:*** Une base de données populationnelles représentatives au niveau national a été utilisée pour identifier les cas de LCT s'étant présentés au SU en Ontario entre avril 2009 et mars 2010. Nous avons calculé les coûts unitaires du traitement médical et de la perte de productivité et nous avons multiplié ces coûts par les estimés correspondants d'incidence afin de déterminer les coûts à vie des cas de LCT identifiés selon les groupes d'âge, le sexe et le mécanisme de la lésion. ***Résultats:*** En 2009, il y a eu plus de 133,000 visites au SU pour des LCT en Ontario. Ainsi, on peut estimer de façon conservatrice des coûts afférents à vie de 945 millions de dollars. Les estimés des coûts à vie allaient de 279 millions de dollars à 1,22 billion, selon les critères diagnostiques utilisés pour définir la LCT. Les jeunes enfants entre 0 et 4 ans et les vieillards de 85 ans et plus avaient les taux les plus élevés de LCT. Le taux de LCT chez les hommes était de 53% plus élevé que celui des femmes et les coûts encourus étaient deux fois plus élevés que ceux des femmes. Les chutes, les traumatismes chez les sportifs et les cyclistes ainsi que les accidents de la route étaient respectivement la cause de 47%, 12% et 10% des cas de LCT se présentant au SU et représentaient une proportion importante des coûts. ***Conclusion:*** Cette étude a démontré que le fardeau de santé et le fardeau économique en lien aux LCT identifiées au SU sont énormes. Nos observations soulignent l'importance des mesures de surveillance et de prévention ciblant les populations vulnérables. De plus amples recherches sont nécessaires pour évaluer plus précisément le fardeau que constituent les LCT dans différents établissements de santé.

Keywords: Concussion, cost of illness, epidemiology, prevention, traumatic brain injury

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Traumatic brain injury (TBI) is the leading cause of death and disability globally, and it is involved in nearly one-half of all trauma deaths.[1] An estimated 1.7 million TBIs occur in the United States annually, resulting in 1.3 million emergency department (ED) visits and 52,000 deaths.[2] Lifetime costs of medical treatment for severe TBI range from $600,000 to $1.8 million per case, with the value of lost productivity ten-fold higher.[3,4] Additionally, survivors of TBI face long-term neuropsychiatric sequelae and their treatment requires significant health care expenditures.[3,5-10] Efforts to determine the health and economic burden are important for informing public health policy, guiding appropriate allocation of resources, and targeting and evaluating prevention measures.

Examining the epidemiology of TBI treated in EDs is of particular importance, as 80% to 92% of TBIs present to the ED,[11,12] and recent studies show a surge in these visits.[2,13,14] Yet, there are few studies examining the health care burden of TBI treated in the ED setting, and none that has calculated the costs

From the Division of Neurosurgery, Department of Surgery, St. Michael's Hospital, Toronto, Ontario, Canada, Injury Prevention Research Office, Li Ka Shing Knowledge Institute, Keenan Research Centre, University of Toronto, Toronto, Ontario, Canada (TSF, RJ, MDC); Public Health Agency of Canada, Toronto, Ontario, Canada (SRM); Dalla Lana School of Public Health, University of Toronto, Toronto, Ontario, Canada (MDC).

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Correspondence to: Michael D. Cusimano, Division of Neurosurgery, Department of Surgery, Injury Prevention Research Office, Keenan Research Center, St. Michael's Hospital, 30 Bond St., Toronto, ON, Canada, M5B 1W8. Email: injuryprevention@smh.ca

associated with these visits within a publicly insured population. Previous studies of TBI incidence are outdated, based on non-representative populations[15] or do not describe ED visits in detail.[16,17] Furthermore, to our knowledge, there is only one recent study that described the costs of TBI in a Canadian population. Chen et al[18] calculated the medical costs of hospitalized TBI patients in Ontario across a variety of health care settings up to 3 years postinjury, but did not directly measure incidence or costs in the ED setting.

The present study aims to address this deficiency in the literature. We aim to describe the epidemiological patterns and lifetime costs of TBI presenting to Ontario EDs between April 2009 and March 2010 using a province-wide, population-based database. Furthermore, we identify demographic groups at risk of sustaining a TBI requiring ED treatment who represent populations for targeted injury prevention and surveillance.

Methods

Study Design and Population

Incidence data were obtained from the National Ambulatory Care Resource System (NACRS) database, which collects information on patient identifiers (i.e. unique identification, health card number, postal code) and demographics (sex, birth date, education level), up to ten International Classification of Diseases, Tenth Revision (ICD-10), diagnosis codes, external causes of injury codes, ambulatory transport, and visit disposition. A recent reabstraction study compared NACRS data with the charts for 7500 ED visits at 15 Ontario hospitals in 2004-2005 and found high agreement between NACRS and chart coding.[19]

The study population included all ED visits between April 1, 2009, and March 31, 2010, that contained a TBI code in any diagnosis field. We defined TBI using the ICD-10 codes shown in Table 1. The Centers for Disease Control and Prevention (CDC) includes additional ICD-10 codes in their definition for TBI mortality.[2] We chose a more conservative set of codes to capture TBI morbidity based on previous studies[16,20] and the author's (MC) 30+ years of clinical experience. Patients who registered but left without being seen were excluded from this study. Mechanisms of injury were defined using the CDC's External Cause of Injury Matrix[21] and collapsed into several main categories: falls, struck by/against an object, motor vehicle collisions, sports- and bicyclist-related injuries, and other mechanisms. Fatal injuries occurring during transportation or after arrival to ED were identified using the "discharge disposition" variable. We used admission status as a proxy for injury severity because traditional measures (e.g. Abbreviated Injury Scale, Injury Severity Scale, Glasgow Coma Scale) were either not reported or missing in the majority of cases.

Table 1: ICD-10 codes used to define TBI

Diagnosis	ICD-10 Code	Description
1. Open wound of head	S01.7	Multiple open wound
	S01.8	Other part of head
	S01.9	Unspecified part of head
2. Fracture of skull and facial bones	S02.0	Skull
	S02.1	Base of skull
	S02.7	Multiple fractures involving skull and facial bones
	S02.8	Other skull and facial bones
	S02.9	Skull and facial bones, unspecified part
3. Intracranial injury	S06.0-S06.9	Includes concussion, epidural hemorrhage, traumatic subdural and subarachnoid hemorrhage, and other/unspecified intracranial injuries
4. Crushing injury of head	S07.1	Skull
	S07.8	Other part of head
	S07.9	Unspecified part of head
5. Unspecified injury of head	S09.7	Multiple injuries of head
	S09.8	Other specified injuries of head
	S09.9	Unspecified injury of head
6. Injuries involving head with neck	T02.0	Fractures involving head with neck
	T04.0	Crushing injuries involving head with neck
	T06.0	Injuries of brain and cranial nerves with injuries of nerves and spinal cord at neck level
7. Sequelae of injuries of head	T90.2	Sequelae of fracture of skull and facial bones
	T90.5	Sequelae of intracranial injury
	T90.8	Sequelae of other injury of head
	T90.9	Sequelae of unspecified injury of head

ICD-10 = International Classification of Diseases, Tenth Revision; TBI = traumatic brain injury.

Overview of Costs

This study used a bottom-up approach to calculate lifetime costs from a societal perspective. We computed average unit costs for medical treatment and productivity loss across multiple strata (i.e. age group, sex, mechanism of injury), and multiplied these costs by corresponding incidence estimates to determine total costs. All costs were converted to 2009 Canadian dollars (CAD) using the historical currency conversion rate and Consumer Price Index for health care services in Ontario, unless otherwise noted.[22] All costs were discounted to a present value in 2009 dollars using a 3% discount rate.[23] An overview of the costing approach is shown in Figure 1.

Medical Costs

We computed medical costs separately for fatal and nonfatal injuries. Costs for fatalities included ED facility costs,[24] coroner/medical examiner costs,[25] and ambulatory transport costs[26] (Figure 1). Cases requiring ambulatory transport were identified using the "admit via ambulance" variable. Physician fees were not included in cost estimates for fatal cases because of lack of available data. Fatalities represented only 0.1% of TBI cases; therefore, this likely does not impact cost estimates significantly.

For nonfatal injuries, we considered costs for ambulatory transport and medical treatment. Transport costs were assigned as

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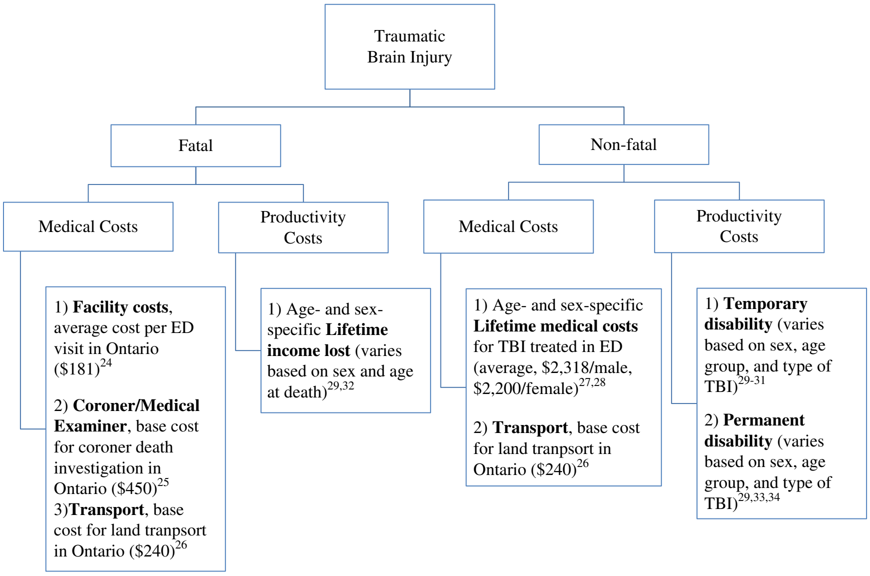

Figure 1: *Overview of costing approach used to calculate medical and productivity costs for traumatic brain injury treated in Ontario emergency departments. All costs reported in 2009 Canadian dollars.*

previously described. Per-patient lifetime medical costs were obtained from the CDC's Web-based Injury Statistics Query and Reporting System,[27] which used nationally representative US data to calculate average cost estimates that include facility costs, physician fees, pharmacy costs, and long-term follow-up costs. We obtained average per-patient lifetime medical costs for TBI by age, sex, and nature of injury, and mapped ICD-10 codes to the corresponding nature of injury using the CDC's Injury Mortality Diagnosis Matrix.[28] All costs were converted to 2009 CAD using the average quarterly currency conversion rate in 2005 and Consumer Price Index for health care services in Canada. Average lifetime costs of TBI treated in the ED were $2,318 CAD for males (range, $1677-$2865) and $2200 CAD (range, $1618-$3141) for females.

Lost Productivity

Productivity loss represents the value of lost potential income as a result of morbidity or death (Figure 1). We quantified productivity loss from temporary disability for the working age population (ages 15-64) by multiplying the following factors: (1) age- and sex-specific average daily income, obtained from Statistics Canada,[29] (2) average workday loss from TBI, and (3) the probability that a TBI resulted in lost workdays.[30] Average workday loss was obtained from a study[31] that examined 1,006 TBI claims to the Workplace Safety and Insurance Board of Ontario in 2004. This study reported an average workday loss of 51.7 days and 38.1 days for male and female workers, respectively.

For fatalities, we quantified productivity loss as the net present value of lost income accrued throughout the remaining lifetime of each individual, assuming a 1% productivity growth rate and 3% discount rate.[23,32] Annual income and survival data were obtained from Statistics Canada.[29,33] For nonfatal cases, we calculated the cost of total permanent disability by multiplying the probability of permanent total disability by the age- and sex-specific lifetime earnings. For partial permanent disability, we multiplied lifetime earnings by the probability of partial permanent disability and an additional factor identifying the reduced earning power resulting from partial permanent disability.[32,34,35]

Statistical Analysis

All calculations and statistical analyses were performed using SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). Rates of TBI were calculated using population data from Statistics Canada, and reported with 95% confidence intervals (CIs). A chi-square test was used to compare the incidence rate of TBI between age groups, sexes, and mechanisms of injury; Cochran's chi-squared test was used to compare the age-standardized rate between sexes. Sensitivity analysis was also used to explore the effects of modifying key study parameters, including: (1) using a more restrictive ICD-10 definition of TBI found in a previous Canadian study,[16] which excluded open wounds of the head [S01(0.7-.0.9)]; (2) adopting the CDC's more inclusive ICD-10 definition of TBI mortality,[2] which included ICD-10 codes corresponding to injuries of optic nerve and pathways (S04.0), open wounds involving head with neck (T01.0), and other injuries involving multiple body regions, not elsewhere classified (T06.0); (3) reducing the number of diagnosis fields examined from ten to three fields (main problem plus two other fields); and (4) varying the discount rate used to estimate productivity loss.

Results

In 2009, there were 133,952 TBI-related visits to Ontario EDs, with an overall incidence rate of 1030.6 per 100,000 (95% CI, 1025.1-1036.1). The rate of TBI was 1250.3 per 100,000 males (95% CI, 1241.7-1258.9) and 818.1 TBI per 100,000 females (95% CI, 811.3-825.0). Fatalities represented only 0.1% of ED visits for TBI. Our conservative costing approach yielded annual lifetime costs of approximately $945 million, comprising $292 million (31%) in medical treatment costs and $653 million (69%) in productivity costs.

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Table 2: Incidence rates (per 100,000) and lifetime costs of traumatic brain injury treated in Ontario EDs in 2009 by age group and gender

	Fatal		Total		Cost (thousands)		
	Incidence	Rate*,†	Incidence	Rate ‡,§,‖	Medical costs ($)	Productivity loss ($)	Total costs ($)
Total	134	1.0	133,952	1030.6	291,975	653,110	945,085
0-4	2	0.3	24,664	3494.0	41,512	55,916	97,429
5-14	6	0.4	24,048	1585.0	41,377	76,521	117,898
15-24	19	1.1	25,385	1427.0	56,146	126,871	183,016
25-34	10	0.6	12,533	728.5	31,733	88,223	119,956
35-44	9	0.5	10,509	554.4	25,871	81,290	107,161
45-54	12	0.6	10,678	516.7	25,933	80,169	106,102
55-64	10	0.7	7,475	487.4	19,985	48,931	68,916
65-74	11	1.2	5,718	604.8	15,336	29,563	44,899
75-84	30	4.9	7,495	1227.0	19,654	42,355	62,009
85+	25	11.2	5,447	2431.0	14,429	23,271	37,700
Male	87	1.4	79,891	1250.3	175,134	466,255	641,388
0-4	2	0.6	14,544	4021.0	24,952	37,925	62,877
5-14	1	0.1	16,036	2058.0	27,431	52,576	80,008
15-24	15	1.7	17,023	1888.0	37,680	96,416	134,096
25-34	8	0.9	8,256	978.3	21,612	66,849	88,462
35-44	8	0.8	6,458	685.8	16,772	61,661	78,433
45-54	12	1.2	6,113	592.1	16,068	60,209	76,276
55-64	9	1.2	3,957	528.2	10,482	36,232	46,714
65-74	7	1.6	2,679	600.0	7,127	18,816	25,943
75-84	17	6.5	3,092	1178.0	8,310	25,558	33,868
85+	8	11.2	1,733	2428.0	4,699	10,013	14,712
Female	47	0.7	54,061	818.1	116,841	186,855	303,696
0-4	0	0.0	10,120	2941.0	16,561	17,991	34,552
5-14	5	0.7	8,012	1086.0	13,946	23,945	37,890
15-24	4	0.5	8,362	953.6	18,466	30,455	48,920
25-34	2	0.2	4,277	488.0	10,120	21,374	31,494
35-44	1	0.1	4,051	424.8	9,099	19,629	28,728
45-54	0	0.0	4,565	441.4	9,865	19,960	29,825
55-64	1	0.1	3,518	448.4	9,503	12,699	22,202
65-74	4	0.8	3,039	609.2	8,209	10,747	18,956
75-84	13	3.7	4,403	1263.0	11,343	16,797	28,140
85+	17	11.1	3,714	2433.0	9,729	13,258	22,987

ED = emergency department; TBI = traumatic brain injury.
*The age-standardized rates of fatal TBI for males and females were 1.5 and 0.67 per 100 000, respectively.
†There was a significant difference in the rate of fatal TBI between genders (Cochran's chi-square $\chi^2 = 22.350$, $p < 0.001$).
‡The age-standardized rates of TBI for males and females were 1243.7 and 812.2 per 100 000, respectively.
§There was a significant difference in rate of total TBI between genders (Cochran's chi-square $\chi^2 = 6005.516$, $p < 0.001$).
‖Significant differences were observed in the rate of TBI between genders across all age groups, except among those ages 65- to 75 years and 85 and older.

Age- and Sex-Related Incidence Patterns

Table 2 shows the incidence of ED visits for TBI, stratified by age group and sex. Among males, 59% of all TBI occurred in those younger than 25 years of age, with peak incidence (21%) occurring among adolescents and young adults (ages 15-24). The highest rates of TBI for males occurred in young children ages 0 through 4 years (4021.0 per 100,000; 95% CI, 3957.3-4085.6) and those ages 85 and older (2428.0 per 100,000; 95% CI, 2316.1-2543.3). Among females, 49% of all TBI occurred in those younger than 25 years of age, with peak

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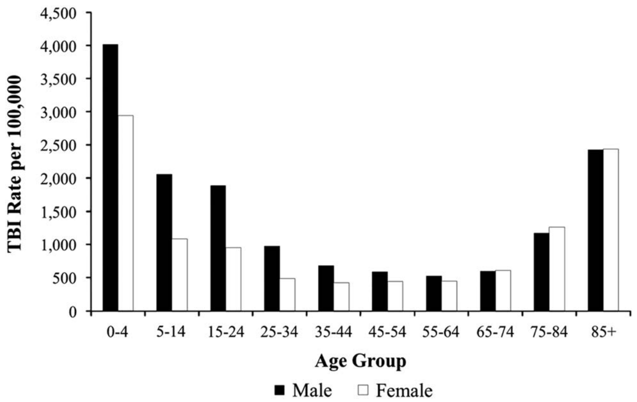

Figure 2: *Age- and sex-specific rates of traumatic brain injury (TBI) presenting to Ontario emergency departments.*

incidence (19%) reported for the 0 to 4 year age group. The peak rates for females also occurred among young children ages 0 to 4 years (2941.0 per 100,000; 95% CI, 2884.7-2997.9) and those ages 85 and older (2433.0 per 100,000; 95% CI, 2356.3-2511.5).

The rate of TBI-related ED visits was higher for males than females across all age groups younger than 65 years of age (Figure 2). This sex difference was particularly evident within the 15 to 24 and 25 to 34 age categories, in which males were twice as likely as females to present to ED with TBI. Fatal injuries exhibited a similar sex difference because males were nearly twice as likely as females to suffer an ED visit for TBI resulting in death (Table 2). For both sexes, those ages 75 and older were most likely to suffer a fatal TBI. The 75+ age group represented 7% of the overall population, yet accounted for 41% of all fatalities resulting from TBI.

Incidence Patterns by Age and Mechanism of Injury

Table 3 shows the incidence of ED visits for TBI, stratified by sex and mechanism of injury. Falls were the most common mechanism of TBI (47% of all injuries) and resulted in the highest rate of fatal injury (Figure 3). The highest rate of falls

Table 3: Incidence rates (per 100,000) and lifetime costs of TBI treated in Ontario E in 2009 by gender and mechanism of injury*

	Fatal		Total		Cost (in thousands)		
	Incidence†	Rate	Incidence‡	Rate	Medical costs ($)	Productivity loss ($)	Total costs ($)
Total	134	1.0	133,952	1030.6	291,975	653,110	945,085
Fall	70	0.5	63,225	486.4	137,483	269,724	407,208
Struck by/against	5	0.0	48,974	376.8	104,599	205,112	309,712
Motor vehicle	48	0.4	13,512	104.0	31,187	130,154	161,342
Firearm	6	0.0	93	0.7	224	6,985	7,209
Other	5	0.0	8,148	62.7	18,481	41,134	59,615
Sports	2	0.0	12,638	97.2	25,647	56,281	81,928
Bicyclist	4	0.0	4,106	31.6	8,761	22,394	31,155
Male	87	1.4	79,891	1250.3	175,134	466,255	641,388
Fall	3	0.0	33,723	259.5	73,095	156,187	229,282
Struck by/against	38	0.3	32,488	250.0	70,021	172,686	242,707
Motor vehicle	37	0.3	8,134	62.6	19,030	99,568	118,599
Firearm	5	0.0	83	0.6	202	5,633	5,835
Other	4	0.0	5,463	42.0	12,785	32,181	44,965
Sports	1	0.0	9,262	71.3	18,907	44,152	63,060
Bicyclist	3	0.0	3,053	23.5	6,579	17,910	24,489
Female	47	0.7	54,061	818.1	116,841	186,855	303,696
Fall	32	0.2	30,737	236.5	67,462	97,038	164,501
Struck by/against	2	0.0	15,251	117.3	31,504	48,925	80,429
Motor vehicle	11	0.1	5,378	41.4	12,157	30,586	42,743
Firearm	1	0.0	10	0.1	21	1,352	1,373
Other	1	0.0	2,685	20.7	5,697	8,953	14,650
Sports	1	0.0	3,376	26.0	6,740	12,129	18,869
Bicyclist	1	0.0	1,053	8.1	2,182	4,484	6,666

CDC = Centers for Disease Control and Prevention; ED = emergency department; TBI = traumatic brain injury.
*Mechanisms of injury were defined using the CDC's External Cause of Injury Matrix.
†Fall, struck by/against, motor vehicle, firearm, and "other" mechanisms of injury add to 100% of incidence counts.
‡A significant difference was observed in the distribution of injury mechanisms between genders (chi-square $\chi^2 = 3740.6129$, $p < 0.0001$).

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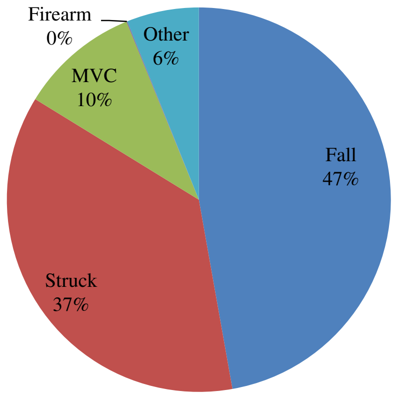

Figure 3: *Incidence of traumatic brain injury identified in the emergency department by mechanism of injury.*

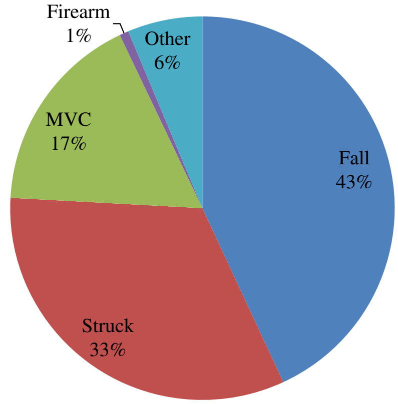

Figure 5: *Lifetime costs of traumatic brain injury treated in the emergency department by mechanism of injury.*

occurred among young children (ages 0-4 years) and the elderly (age 75+ years), who together were six-fold more likely to sustain a fall-related TBI compared with other age groups. Other common causes of TBI were struck by/against injuries (37%), motor vehicle crashes (MVCs, 10%), and sports- and bicyclist-related injuries (combined 12%) (Figure 3). Young children (ages 0-4 years) were most likely to sustain TBI resulting from struck by/against injuries, whereas adolescents and young adults (ages 15-24 years) suffered the highest rate of motor vehicle injuries (results not shown). In addition, a disproportionate number of bicyclist and sports-related TBI occurred among 5 to 24 year olds. This age group was four times more likely to sustain a bicyclist-related TBI and eight times more likely to sustain a sports-related TBI compared with other age groups.

Lifetime Costs of TBI

Total lifetime costs for TBI presenting to Ontario EDs in 2009 amounted to $945 million; medical costs were $292 million (31% of total costs) and productivity costs were $653 million (69%; Table 3). Costs were greater for males than females across nearly all age groups, with males incurring two-fold higher costs overall (Figure 4). This finding is consistent with the fact that males suffer

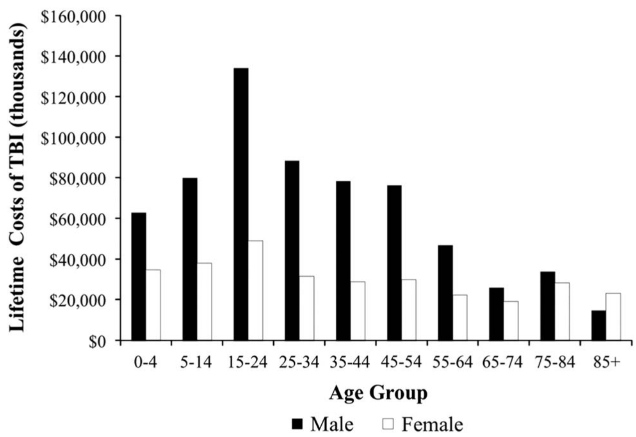

Figure 4: *Estimates of lifetime costs of traumatic brain injury (TBI) treated in Ontario emergency departments by age and sex.*

a higher rate of fatal injury and earn a higher income on average, compared with females. One exception was the 85+ year age category, in which costs were 56% higher for females than males. This cost disparity likely arises from the fact that females tend to live longer than males and accrue higher costs during elderly age. Together, falls ($407 million; 43%), struck by/against ($309 million; 33%), and motor vehicle injuries ($161 million; 17%) represented 93% of lifetime costs associated with TBI (Figure 5). We noted a link between admission status (a proxy for injury severity) and lifetime costs, with admitted patients incurring 11.2% of total costs ($106.3 million) despite accounting for only 4.6% of TBI patients presenting to ED.

Sensitivity Analysis

Modifying key parameters had varying effects on TBI incidence and costs (Table 4). Adopting a more restrictive ICD-10 definition for TBI resulted in a significant decrease in the overall rate (177.6 per 100,000) and total lifetime costs ($279 million). In contrast, using the CDC's more inclusive ICD-10 definition, the rate of TBI increased to 1416.5 per 100,000 and lifetime costs rose to $1.22 billion. Reducing the number of diagnosis fields from ten to three fields resulted in a slight decrease in the rate of TBI (1023.1 per 100,000) and lifetime costs ($930 million). Productivity costs were very sensitive to changes in the discount rate, ranging from $771 million to $1.38 billion using 5% and 1% discount rates, respectively.

Discussion

Canada is among other developed countries facing the challenge of containing rising health care costs. Health care expenditures in Canada exceeded $200 billion in 2011, and they are projected to continue to grow.[36] Increasingly, policymakers have used cost-of-illness studies to guide optimal allocation of resources and identify opportunities for improving health care sustainability.[4,37] The present study is the first to describe epidemiological patterns and costs of TBI presenting to the ED within a publicly insured population. We report a substantial health and economic burden associated with TBI in EDs in Ontario, Canada, and identify demographic groups at risk of sustaining TBI requiring ED treatment.

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Table 4: Results of sensitivity analysis assessing the effects of modifying key parameters on incidence and cost estimates

	Fatal		Total		Costs (in thousands)		
Key parameters	Incidence	Rate	Incidence	Rate	Medical costs ($)	Productivity loss ($)	Total costs ($)
Baseline*	134	1.03	133,952	1,030.6	291,975	653,110	945,085
Restrictive ICD-10 definition of TBI†	79	0.61	23,087	177.6	52,180	226,324	278,504
CDC's ICD-10 definition of TBI mortality‡	143	1.10	184,112	1,416.5	402,956	815,536	1,218,492
Three diagnosis fields§	128	0.98	132,978	1,023.1	289,575	640,061	929,636
1% Discount Raterate	134	1.03	133,952	1,030.6	291,975	1,091,926	1,383,901
5% Discount Raterate	134	1.03	133,952	1,030.6	$291,975	478,593	770,568

CDC = Centers for Disease Control and Prevention; ED = emergency department; ICD-10 = International Classification of Diseases, Tenth Revision; TBI = traumatic brain injury.

Abbreviations: ICD-10, International Classification of Diseases, Tenth Revision. TBI, traumatic brain injury.

*We searched all ten diagnosis fields for a TBI diagnosis, defined using the following ICD-10 codes: S01(.7-.9), S02 (.0, .1, .7-.9), S06.0-S06.9, S07 (.1, .8, .9), S09(.7-.9), T02.0, T04.0, and T90(.2, .5, .8, .9).

†We defined TBI using a more restrictive ICD-10 definition of TBI found in a previous Canadian study: S02(.0, .1, .3, .7-.9), S04.0, S06.0-S06.9, S07 (.0-.9), T02.0, and T90(.1-.9).

‡We defined TBI using the CDC's inclusion criteria for TBI mortality: S01.0-S01.9, S02(.0, .1, .3, .7-.9), S04.0, S06.0-S06.9, S07(.0, .1, .8, .9), S09(.7-.9), T01.0, T02.0, T04.0, T06.0, and T90(.1, .2, .4, .5, .8, .9).

§We searched for a TBI diagnosis in three diagnosis fields (i.e. main diagnosis plus two other diagnosis fields).

Health and Economic Burden of TBI: Comparison to the Literature

The TBI rates reported in the present study are significantly higher than those described in previous Canadian[15,16] and US studies.[13,38,39] Greater rates could indicate an increase in injuries over time; one US study found that ED visits for TBI increased at an eight-fold higher rate compared with total ED visits from 2006 to 2010.[13] Discrepancies could also be explained by differences in data sources, methods of data collection, geographical location, and ICD-code inclusion criteria. For instance, on sensitivity analysis, adopting ICD-10 definitions of varying inclusiveness resulted in a wide range of estimates for TBI rates (177.6-1416.5 per 100,000) and lifetime costs ($279 million to $1.22 billion). The true health and economic burden of TBI likely falls within these ranges. Our study highlights the need for a standardized ICD-10 definition of TBI morbidity as well as studies based on more recent data to generate meaningful comparisons across studies.[2,15-17,38,39]

Our study also shows that TBIs treated in the ED setting represent a larger economic burden than suggested by previous Canadian studies. Chen et al[18] estimated the 3-year medical costs for hospitalized TBI patients in Ontario across a continuum of health care services, including ED care, acute inpatient care, inpatient rehabilitation, and complex continuing care. They calculated that medical costs for TBI treated in various health care settings (including the ED) were $446 million (2009 CAD) in the first 3 years postinjury. In contrast, the present study estimated annual medical costs of $292 million for TBI treated in the ED alone. This discrepancy in cost estimates can be explained by differences in study period, data sources, TBI inclusion criteria, and costing methodology. For instance, Chen et al[18] underestimated ED costs by assuming a single ED visit per TBI inpatient valued at only $187 CAD. In addition, Chen et al[18] did not examine the lifetime costs of TBI, which have been shown to be substantial.[3,4,27]

In a different report, the Canadian Institute of Health Information (CIHI) found that the direct costs of head injury in Canada including all hospital, physician, and drug costs were $183 million (2009 CAD) in 2000.[17] As a crude comparison, we applied age- and sex-specific incidence-to-population ratios to our provincial estimates to obtain national costs of medical treatment of $754 million—more than four-fold greater than the CIHI estimate. Discrepancies can be explained by the same previously mentioned differences in study design and that CIHI estimate did not consider long-term costs. Additionally, higher medical costs could indicate an increase in the rate and/or severity of TBI over the past decade, a well-reported trend in the literature.[2,13,14,40] Studies have also demonstrated a clear link between TBI severity and costs.[7,8,10] In our study, we used admission status as a proxy for injury severity and found that admitted patients incurred a disproportionate amount of total costs compared with non-admitted patients.

Vulnerable TBI Populations and Policy Implications

Our study highlighted the importance of fall prevention efforts targeted to the youngest and oldest segments of the population (ages 0-4 and 75+), who remain at greatest risk of suffering a fall-related TBI.[2,17,38,39] Fall prevention strategies targeting young children include improved helmet laws and child safety equipment, safer sports practices, and increased TBI awareness.[41] In addition, multifaceted programs incorporating patient education, environmental safety modification, drug regimen reviews, and other interventions have been shown to be effective in reducing falls among the elderly.[42,43]

This study also found a high incidence of TBIs caused by MVCs. In our study, peak rates of MVCs occurred among adolescents and young adults (ages 15-24), a finding that is well-supported in the literature.[2,13,44-46] Furthermore, although MVCs accounted for only 10% of TBIs, they encompassed more

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than 17% of total lifetime costs. This disproportionately large cost reflects the long-term debilitating sequelae of MVCs and the tendency to afflict younger age groups, resulting in substantial lifetime medical and productivity costs.[4] Our findings emphasize the need for prevention efforts targeted to these vulnerable groups. In Ontario, a graduated driver licensing program was introduced in 1994 requiring new drivers to advance through two stages of licensing. Additional young driver restrictions have been added over time, including a recent 2009 law mandating a zero blood alcohol concentration for drivers younger than age 22 years. Previous studies have demonstrated the effectiveness of graduated driver licensing programs and impaired driving laws at reducing MVC rates, particularly among young adults.[45,46]

In addition, we reported a significant incidence of sports- and bicyclist-related injuries (12% of TBI) affecting primarily children and young adults (ages 5-24), a finding supported in the literature.[41,43,47] Other studies report that sports-related injures compose up to 19% to 20% of TBI, and recent reports show that rates have been increasing over time, particularly among this age group.[41,47,48] The significant and rising rate of sports-related TBI warrants the need for enhanced surveillance and targeted prevention efforts among these age groups. Previous research has highlighted several successful interventions, including education and awareness campaigns, reorganization sports sponsorship and governance, enforcement of sports safety rules and return-to-play guidelines, and development of resources to assist clinicians in the diagnosis and management of TBI.[43,49,50]

Study Limitations and Future Directions

The present study is subject to certain limitations. Incidence is based on the NACRS database, which does not account for those treated in physician offices or fatalities occurring outside of the ED. Incidence data are also subject to potential miscoding, particularly given the large number of ED visits (47% of identified cases) coded as unspecified head injuries (S09.9), which may include visits for other TBI or non-TBI diagnoses. Additionally, this database does not capture TBI patients who did not seek ED treatment. TBI has been described as the “silent epidemic” because neuropsychiatric sequelae such as cognitive dysfunction, depression, and anxiety are not immediately apparent. Our study likely underestimates the true incidence of TBI, because reports show that up to 39% of these injuries remain undiagnosed.[51] Furthermore, TBI is likely underdiagnosed in the ED setting, because observed signs of neurologic and neuropsychiatric sequelae cannot be used to make the diagnosis of TBI in the absence of loss of consciousness (LOC) or altered consciousness.[6] However, studies have shown that LOC is an unreliable predictor of TBI diagnosis, with the presence of LOC and TBI diagnosis coexisting at varying frequencies ranging from 32% to 50%.[6,51,52]

Our approach for estimating costs also requires additional caveats. There is no single source that exists for estimating costs; consequently, we used the best available data taken from a myriad of sources, recognizing that each is subject to limitations. Because of the paucity of Canadian literature and data on the costs of TBI treated in ED, lifetime medical costs were adapted from large nationally representative US data under the assumption that the epidemiology and treatment patterns for TBI are relatively uniform in North America. However, differences in health care delivery, access, and reimbursement could limit the applicability of these data. The cost estimates reported in this study should be interpreted in the context of these limitations. Future studies with better data will improve upon the precision of our cost estimates. In addition, although we used admission status as a proxy for injury severity, we were unable to stratify costs by common measures of injury severity due to underreporting and lack of these data. More work is needed to elucidate the link between costs and injury severity in the publicly insured ED setting.

This study used a conservative approach to define TBI and designate unit costs. We did not assess quality of life loss, productivity losses borne by family members, or intangible costs of disease such as grief and pain. These costs, although difficult to quantify, are likely to be substantial, with one study reporting annual quality of life costs of $129 billion for TBI.[9] Furthermore, we did not include costs associated with other well-known consequences of TBI, including suicide, alcohol and drug abuse, and mental health issues.[4] Therefore, we believe that the costs presented in this study significantly underestimate the true economic burden of TBI in Ontario.

Despite these limitations, our study provides the best available estimates of TBI incidence and costs in the ED setting within a publicly insured population, and presents unequivocal evidence of the substantial health and economic burden associated with these injuries. Future research should focus on the direct measurement of per-patient ED costs using primary or secondary data from a publicly insured population. Additionally, cost analysis could be extended to examine the relative impact of factors influencing TBI incidence and costs, such as comorbidities, ICD-10 diagnosis, or markers of TBI severity. Finally, studies could expand the geographical scope of this study and extend cost estimates to include more diverse health care settings such as hospitals and physician offices.

Conclusions

This study reported a substantial health and economic burden associated with TBI in the ED setting. We conducted our analyses using a nationally representative, population-based database which is mandatory for all EDs in Ontario. In 2009, there were more than 133,000 TBI-related ED visits in Ontario, resulting in total lifetime costs of $945 million. Lifetime costs were sensitive to changes in the ICD-10 definition for TBI, with estimates ranging from $279 million to 1.22 billion using definitions of varying inclusiveness. We identified several high-risk populations that would benefit from targeted injury prevention measures, with an emphasis on fall prevention among the elderly, MVC prevention among young adults, and sports-/bicyclist-related TBI prevention among youth. Efforts to evaluate the economic burden of TBI are important because of its prevalence and potential for long-term disability. This study can serve as an initial evaluation and case report to guide the assessment of economic burden in other similar publicly insured populations.

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Statement of Authorship

All authors contributed extensively to the work presented in this paper. TSF, RJ, and MDC jointly conceived the study design; SRM and RJ collected and analyzed the data; TSF interpreted the results and prepared the manuscript under supervision from MDC; RJ and SRM provided technical support and conceptual advice; and all authors discussed the results and implications and edited the manuscript.

Disclosures

The authors have nothing to disclose.

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