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ORIGINAL PAPER

Long-Term Trends in the Epidemiology of Major Traumatic Brain Injury

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Abstract

Traumatic brain injury (TBI) is a leading cause of death and disability among adults. Falls and motor vehicle collisions (MVCs) are the most common causes of TBI hospitalizations in Canada. The purpose of this study was to determine whether, at the provincial level, there have been significant changes in the injury rate and causes of major TBI. This was a retrospective cohort study of all patients in Nova Scotia who presented with major TBI (Abbreviated Injury Scale Head score ≥ 3) between 2002 and 2018. Prospectively entered data were collected from the Nova Scotia Trauma Registry. Annual injury rates were calculated based on 100,000 population (all ages) using population estimates from Statistics Canada. Linear regression was performed to analyze annual trends of major TBI within the province. There were 5590 major TBI patients in Nova Scotia during the 16-year study period. The overall annual rate of major TBI was 37 per 100,000 population. There was a 39% increase in the rate of major TBI over the study period ($r = -0.72$, $R2 = 0.51$, $p < 0.002$). Patients had a mean age of 51 ± 25 years; 72% were male. The proportion of TBIs in males decreased significantly from 76% in 2002 to 69% in 2017 ($p < 0.001$). Mechanisms of injury were predominantly falls (45%) and MVCs (29%); the proportion of violent injuries was 11.5%. The rate of fall-related TBIs more than doubled between 2002 and 2017, increasing from 9.1 to 20.5 injuries per 100,000 ($p < 0.001$). Our findings demonstrate an increasing incidence of major TBI over a 16-year period with a greater than two-fold increase in the rate of fall-related TBI. These results are important for targeting TBI prevention efforts in reducing falls, especially in older adults.

Keywords Traumatic brain injury · Epidemiology · Falls · Motor vehicle collisions

Introduction

With an estimated 69 million cases worldwide each year, traumatic brain injury (TBI) accounts for more death and disability than any other type of trauma [1]. Globally, the incidence of TBI for individuals of all ages is 349 (95% CI 96.2–1266) per 100,000 person-years [2]. Evidence suggests the incidence of TBI is rising, due in part to increases in population density, population aging, and the use of motor vehicles, motorcycles and bicycles [3].The immense burden of TBI poses a significant concern for health care systems and has enormous economic consequences [4]; it is estimated that TBI costs the international economy upwards of US$400 billion annually [5].

TBI is a major cause of mortality in Canada, contributing to approximately 23% of all injury-related deaths. The burden on the health care system is predictably substantial; in 2017, the age standardized head injury-related emergency department (ED) visit and hospitalization rates were 376.9/100,000 and 84/100,000, respectively [6]. A study of

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nationwide trends of TBI-related hospitalizations and in-hospital mortality between 2006 and 2011 revealed that TBIs caused by falls increased by 24% in Canada, while MVC-related hospitalization rates decreased by 18% [7]. Several epidemiological studies of TBI have been conducted within Canadian provinces. Fu et al. examined the trends of TBI patients treated in Ontario EDs and found trends towards increasing age, comorbidity level, length of stay, and ambulatory transport use [2]. Zygun et al. found that severe TBI was especially common among male and elderly residents of the Calgary Health Region and was associated with a high mortality rate [8]. A head injury rate of 87/100,000 in British Columbia over a 10-year period was reported by Phillips et al. [9].

To date, no studies have systematically measured the long-term trends in major TBI for all ages, both sexes, and from all causes of injury in Canada. To our knowledge, this is the first study to report the long-term trends of TBI by age, sex, and mechanism in a Canadian province using provincial trauma registry data. In addition to evaluating the changing trends in TBI incidence over a 16-year period, predictors of in-hospital mortality following TBI-related hospitalization were assessed.

Methods

Data Source

Study data were collected from the Nova Scotia Trauma Registry (NSTR). The NSTR is a provincial population-based registry under the Nova Scotia Department of Health and Wellness and contains data on all major trauma patients with an Injury Severity Score (ISS) ≥ 12 and an appropriate International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Canada (ICD-10-CA) code. The NSTR includes penetrating traumas with an ISS ≥ 9, all trauma team activations (TTAs) regardless of ISS, and traumas resulting in death prior to hospital arrival or in the ED. Cases of major trauma for inclusion in the NSTR, are identified by Trauma Nova Scotia (TNS) staff through a review of facility generated reports of all trauma cases with specific ICD-10-CA External Cause of Injury Codes, ED admissions, facility transfers, and deaths. In Nova Scotia, all adult neurosurgical services are centralized at the Queen Elizabeth II Health Sciences Centre (QEII HSC) in Halifax. This center services a population of 938,183 within 55,000 km^2 and receives all major neurotrauma cases from within the province.

Study Population

This was a retrospective cohort study of all major TBI patients captured in the NSTR between January 1 2002 and March 31, 2018. Consistent with the literature, major TBI was defined using a maximal Abbreviated Injury Scale (AIS) Head score ≥ 3 and an ICD-10-CA diagnosis code consistent with blunt or penetrating trauma.

Data Elements

Data elements collected from the NSTR included age, sex, postal code of injury, injury type, injury mechanism, date and time of incident, max AIS Head score, ISS, Glasgow Coma Scale (GCS) score, TTA, ICD-10-CA codes (primary and secondary diagnosis), and discharge status. Provincial criteria for TTA is explained in detail here: http://www.cdha.nshealth.ca/system/files/sites/139/documents/trauma-team-activation-criteria.pdf.

Age was analyzed as a continuous variable and also categorized to examine older adults ≥ 65 years. The International Statistical Classification of Diseases and Related Health Problems, Tenth Revision, Clinical Modification E codes were used to define the mechanism of injury. Variables that indicated MVCs (including motorcycles, public roadway collisions, and off-road vehicle injuries), falls, violence and other injuries or causes were created. Assaults, handgun, rifle, shotgun, other guns, and knives were grouped together as mechanisms of violence.

Statistical analysis

The outcomes of interest were the rates of injury and the annual trends of major TBI by mechanism and provincial geography. Injury rates were calculated based on 100,000 population (all ages) using population estimates from Statistics Canada. Estimates of population by census division, sex and age group for July 1, based on the Standard Geographical Classification (SGC) 2011 were obtained from CANSIM, a national database of selected demographic and social data including population estimates and vital statistics. The rate of injuries within each division was calculated using the population of both sexes and all ages as the denominator. Results for injury rates are reported for years 2002–2017 (full calendar years). Age-specific rates were calculated using population data from Statistics Canada. The Cochran-Armitage test for trends was used to evaluate trends over time for categorical data. The null hypothesis for each of the Cochran-Armitage tests is that the linear trend parameter is 0, so a significant p-value for the test is consistent with the presence of a trend. Linear regression analysis was performed to analyze annual trends of major

Table 1 Characteristics of patients with major traumatic brain injury in Nova Scotia, 2002–2018

Characteristic	N = 5590
Age, mean ± SD	52 ± 25
Male sex, n (%)	3995 (71)
Injury type, n (%)	
Blunt	5182 (93)
Penetrating	395 (7)
Mechanism of injury, n (%)	
Falls	2531 (45)
MVC	1597 (29)
Violence	642 (12)
Other	820 (14)
GCS on ED arrival*, mean ± SD	12.48 ± 4.0
Max AIS Head, mean ± SD	4.23 ± 0.76
ISS, mean ± SD	26.71 ± 14.03
Trauma Team Activation, n (%)	1192 (21)
BAC testing performed, n (%)	2404 (43)
BAC level, n (%)	
Negative (0–1.9 mmol/L)	1315 (26)
Low (2–17.3 mmol/L)	180 (3)
High (> 17.3 mmol/L)	909 (16)
Mortality, n (%)	
In-hospital	1997 (36)
Pre-hospital	1067(19)

MVC motor vehicle collision, *GCS* Glasgow Coma Scale *(reported in 35.3% of patients), *AIS* Abbreviated Injury Score, *ISS* Injury Severity Score, *BAC* blood alcohol concentration, *SD* standard deviation

TBI; this is reported as the correlation coefficient (r) and the coefficient of determination (R^2). Descriptive statistics including means, standard deviations and proportions were used to characterize the patient population. Logistic regression was used to model in-hospital mortality as a function of predictor variables, including age group, sex, mechanism of injury, ISS, and AIS Head. A p-value < 0.05 was considered statistically significant. Data analyses were performed using SPSS software (version 25; SPSS Inc., Chicago).

Results

Overall, 5590 major TBI patients were seen during the 16-year study period, of which 5520 injuries occurred during full calendar years between 2002 and 2017 (Table 1). The provincial major TBI rate was lowest at 28 per 100,000 in 2002 and peaked at 45 per 100,000 in 2012, with an overall injury rate of 37 per 100,000 (Fig. 1). There was a 39% increase in the overall major TBI rate during the study period with a significant increasing trend ($r = -0.72$, $R^2 = 0.51$, $p < 0.002$).

Age and Sex-Related Trends

The mean age of TBI patients was 52 ± 25 years in the total sample, and the proportion of males was 71% (Table 1). Mean age was lowest in 2002 (44 ± 24 years) and gradually increased until peaking during 2014 (59 ± 24 years), showing a significant increasing trend ($p < 0.001$). Older adults (≥ 65 years) formed 36% of the study sample and the injuries in this age group increased from 24% in 2002 to 52% in 2017. The age-specific increase in TBI for older adults over the study period is shown in Fig. 2; the rate per 100,000 population more than doubled from

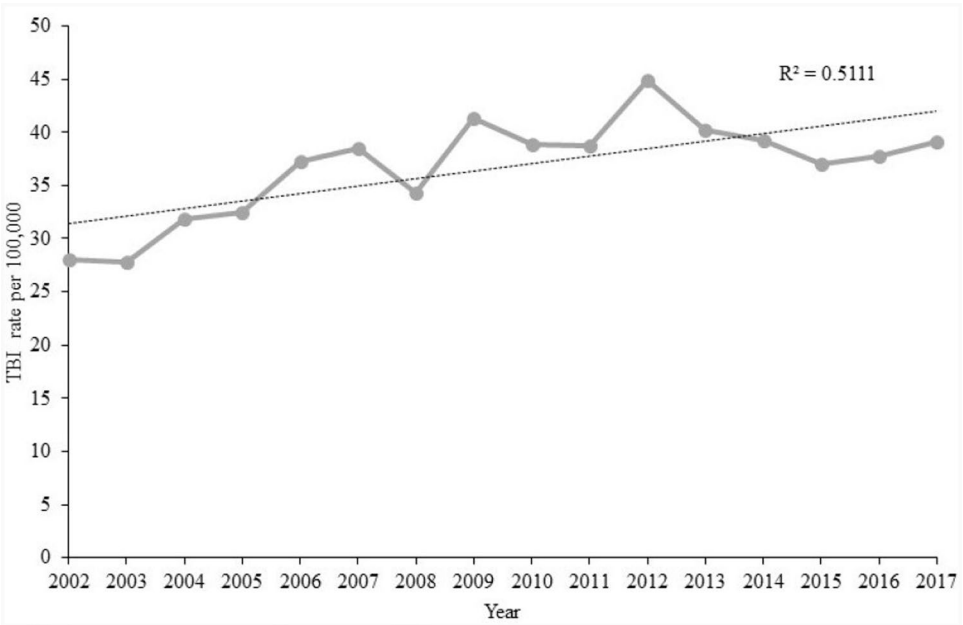

Fig. 1 Major TBI rate in Nova Scotia 2002–2017

47 injuries in 2002 to 101 injuries in 2017 ($r = -0.72$, $R^2 = 0.53$, $p < 0.001$). During this time, the population of those aged ≥ 65 years increased significantly from 129,014 to 189,017 ($r = 0.98$, $R^2 = 0.96$, $p < 0.00$, Fig. 3). The proportion of TBIs in males decreased significantly from 76% in 2002 to 69% in 2017 ($p < 0.001$).

Mechanism of Injury Trends

The vast majority of injuries were the result of blunt trauma (93%), with relatively few major TBIs resulting from penetrating trauma (7%). Falls were the most common mechanism of injury (45.3%), followed by MVCs (28.6%) and violence (11.5%). Trends in major TBI due to falls, MVCs, and violence are shown in Fig. 4. TBIs from falls significantly increased between 2002 and 2017 from 9.1 injuries per 100,000 to 20.5 injuries per 100,000 ($r = 0.85$, $R^2 = 0.72$, $p < 0.001$). In contrast, injuries from violent mechanisms remained stable with 3.8 per 100,000 in 2002 and 4.1 in 2017 ($r = -0.30$ $R^2 = 0.09$, $p = 0.25$). The MVC injury rate decreased from 11.3 per 100,000 in 2002 to 8.4 in 2017; this decline was not statistically significant ($r = -0.36$, $R^2 = 0.13$, $p = 0.16$).

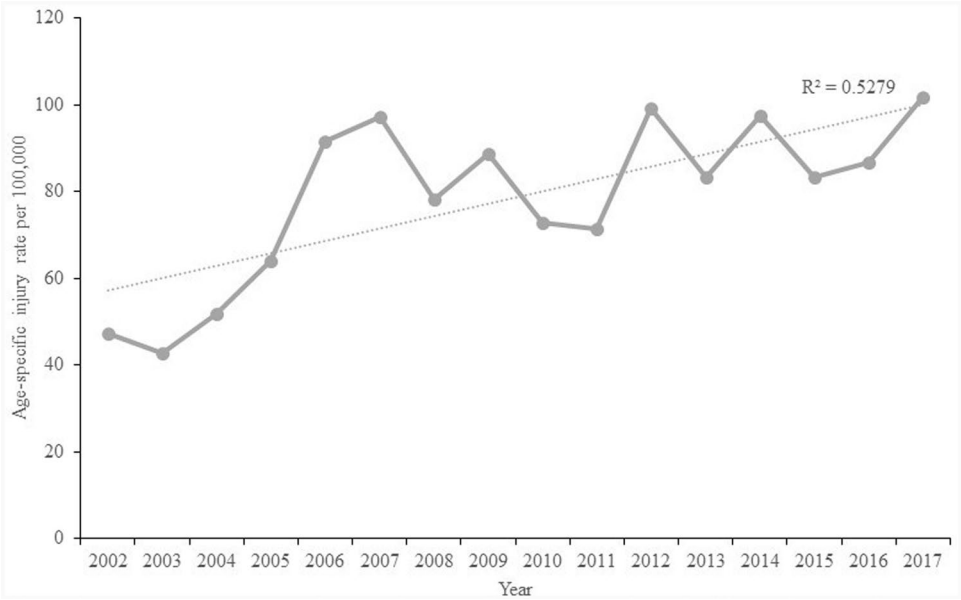

Fig. 2 Major TBI rate in patients age ≥ 65 years

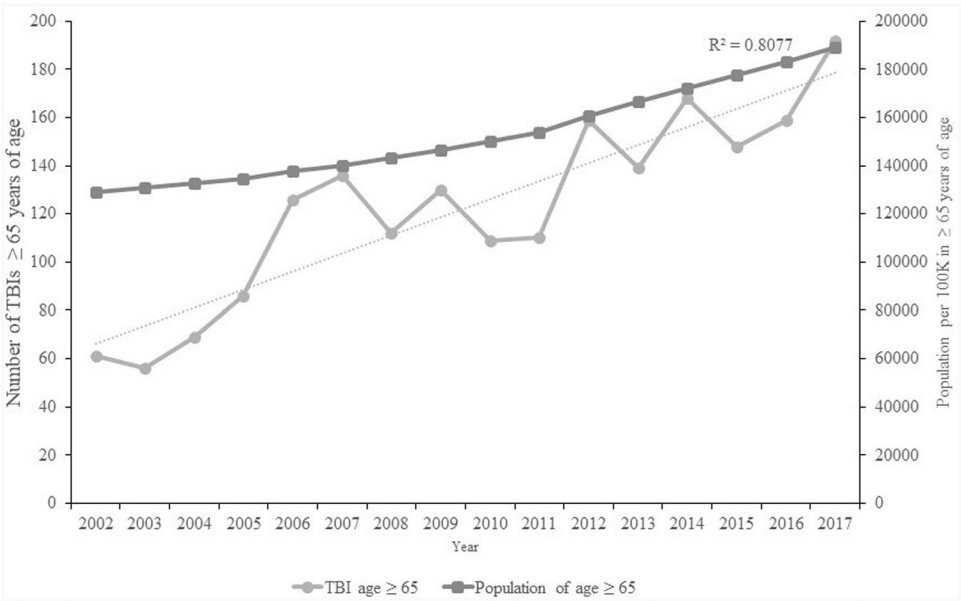

Fig. 3 Major TBI rate by population growth in patients age ≥ 65 years

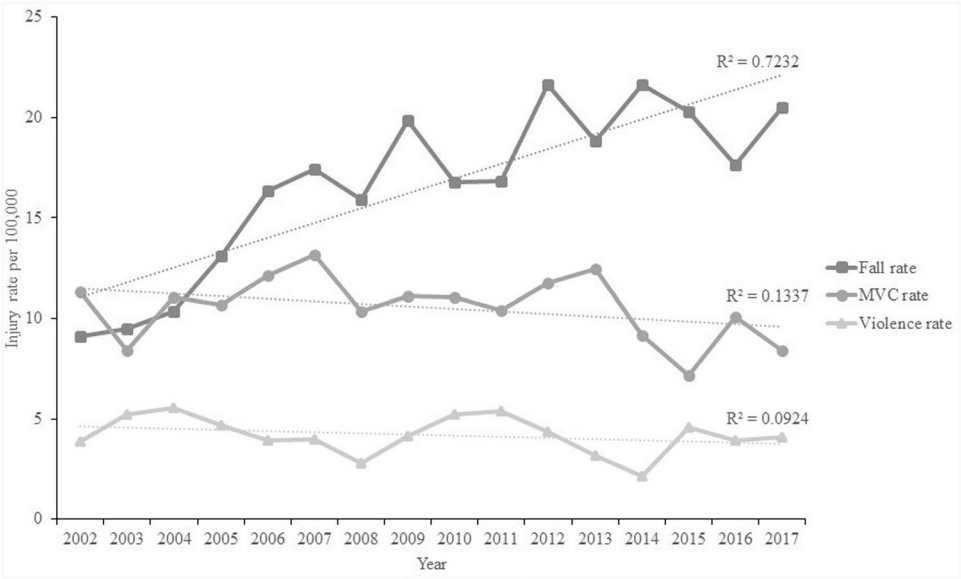

Fig. 4 Major TBI rate by mechanism of injury

Mortality Trends

There were 1056 (19%) deaths in the pre-hospital phase over the course of the study period. Pre-hospital deaths decreased from 26.7% in 2002 to 14.2% in 2017 ($p < 0.001$). The majority of pre-hospital deaths were due to MVCs (48.6%), followed by violence (28.7%) and falls (14%). In-hospital mortality remained stable between 2002 and 2017 (22.5% to 20.1%, $p = 0.39$). The most common cause of TBI for in-hospital mortality was falls (61.2%), followed by MVCs (23.1%) and violence (3.5%).

There was a large decrease in major TBI-related deaths attributable to motor vehicle crashes (30.2% in 2002 to 12.5% in 2017). From 2002 to 2017, major TBI-related deaths attributable to falls and violence increased (from 51.2 to 68.8% and from 2.3 to 4.7%, respectively).

TBIs from falls were almost three times more likely to die than TBIs from violent mechanisms (unadjusted OR = 2.93, 95%CI 2.0–4.3, $p < 0.001$) and TBIs from MVCs were twice as likely to die than TBIs from violence (unadjusted OR = 2.28, 95%CI 1.5–3.4, $p < 0.001$).

After controlling for factors on multivariable regression analysis (Table 2), patients who were > 65 years of age were almost three times as likely to die compared with those < 65 years (OR, 2.78; 95% CI 2.29–3.37; $p < 0.01$). Falls (vs. other causes) were independently predictive of increased in-hospital mortality (OR, 1.38; 95%CI 1.06–1.80; $p = 0.018$). Injury severity, as measured by maximum AIS Head and ISS, were important predictors of in-hospital mortality. The odds of in-hospital death increased by 57% for each additional increase in AIS Head and by 6% for every unit increase in ISS.

Table 2 Predictors of in-hospital mortality following TBI

Characteristic	Adjusted OR	95% CI	Adjusted p value
Age ≥ 65 years	2.78	2.29–3.37	< 0.001*
Male	0.98	0.83–1.16	0.808
Mechanism of injury			
Other	Referent		
Falls	1.38	1.06–1.80	0.018*
MVC	1.23	0.92–1.65	0.156
Violence	0.95	0.61–1.50	0.848
Max AIS head	1.57	1.36–1.79	< 0.001*
ISS	1.06	1.05–1.07	< 0.001*

Discussion

Overall Trends in Major TBI

Reports of the worldwide incidence of severe TBI vary in the literature. For example, the global incidence of severe TBI is estimated at 73 cases per 100,000 people across WHO regions and World Bank income groups [1], whereas a recent comprehensive systematic review and meta-analysis of the worldwide incidence of TBI described the pooled annual incidence proportion of severe TBI as 13 per 100,000 [10]. Among European countries, a range of incidence for severe TBI from 4.1 per 100,000 population in Norway [11] to 17.3 per 100,000 population in Aquitaine, France [12] has been described.

This study reports a rate of 37 per 100,000 for major TBI in Nova Scotia with a significant increasing trend in the number of major TBI patients over the 16-year study period. This increasing trend is consistent with international

and Canadian literature that have examined TBI more generally. For example, a population-based descriptive epidemiological study of TBI visits to EDs in the United States from 2006 through 2010 demonstrated an eightfold increase in TBI visits [13]. Similarly, in Canada, there was a significant increase in the incidence of nonfatal injuries of all types, and in TBIs between 2005 and 2014 using data from the annual cycles of the Canadian Community Health Survey [14]. This increasing trend of TBI in NS requires dedicated responsive trauma services.

Increasing Major TBI in the Elderly

There was an increasing age trend in severe TBI patients over the 16-year study period, specifically in those ≥ 65 years. This increase in the elderly corresponds to the increasing trend of elderly in the provincial population over the same period (Fig. 3). As of July 1, 2018, 20.4% Nova Scotians were 65 and older, which illustrates a 33% increase in the ageing trend for the province since 2008. However, we not only observed a significant increase in the age-specific fall injury rate in the elderly but also a doubling of the age-adjusted fall injury rate (Fig. 4). In North America, falls are the leading cause of TBI in both the United States and Canada, whereas MVC-related TBIs are the most common cause in developing countries. Multivariable analysis showed that the elderly segment of the population was most at risk of death following a fall-related TBI. This finding is in contrast to the report by Fu et al. [7], who found that falls and MVCs decreased the odds of in-hospital mortality, although the oldest segment of the population was more vulnerable to death. Consistent with our findings, patients over the age of 75 have the highest rates of both TBI-related hospitalization and death [15]. This is a significant public health concern as the nation's elderly population continues to increase; older age individuals should remain key targets for focused injury prevention and surveillance.

Limitations

There are several limitations to this study. The retrospective study design is subject to the known limitations of retrospective data analysis and limits our conclusions. Although data were collected from a prospective population-based registry, information was unknown or incomplete in some cases. This study was focused on a major TBI population treated at a single center; thus, our results may not be generalizable to other patient populations: the small numbers of penetrating head injuries/gunshot wounds seen in our patient population would be an example of this. Trauma centers vary in terms of the percentage of patients with measured blood alcohol levels. Only 36% of the patients with major TBI in the NSTR had an assessment of BAC; however, more recently in TTA major TBIs, BAC testing is seen in over 80%. Despite these limitations, the study represents the largest epidemiological analysis of major TBI and contributes to the epidemiological literature by providing results over a 16-year period.

Conclusion

This study describes long-term trends in major TBI hospitalization, pre-hospital deaths, and in-hospital mortality during a 16-year period. Our findings demonstrate an increasing incidence in major TBI with a greater than two-fold increase in fall-related TBI. These results highlight the elderly as a vulnerable demographic group and will inform policymakers for ongoing surveillance, prevention, and trauma care.

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Author Contributions NK and ME participated in the study design, data collection, data analysis, interpretation, writing, and critical revision. GTH participated in the study design, data collection, data analysis. LF participated in the study design, data collection, writing, and critical revision. DBC and RSG participated in the study design, interpretation, and critical revision.

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Availability of data and material Data used in this research was made available by the Nova Scotia Department of Health and Wellness.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval This study was approved by the Nova Scotia Health Research Ethics Board.

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